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**M**otorna **V**ozila i **M**otori

# POSSIBILITIES OF USING DYNAMIC TORSIONAL VIBRATION DAMPERS WITH SPRINGS IN IC ENGINES FOR ROAD VEHICLES

*Almir Blažević[1], Ivan Filipović, Dževad Bibić, Boran Pikula*

**UDC:621.431;534.013**

**ABSTRACT:** One of the main reasons of fatigue of the IC engine crankshaft, which inevitably leads to its failure, is the occurrence of high amplitudes of twist angle due to torsional vibrations. Amplitudes of twist angle due to torsional vibrations are particularly pronounced in vibration resonant modes of the crankshaft including crank-gear and other associated elements. An objective way to reduce the torsional vibration amplitudes of twist angle is the application of the torsional vibration dampers (TVD).

So far elastic TVD with rubber as elastic element are used for high and medium speed engines for road vehicles. The main reasons are simple construction, reliability and relatively low costs of this type of additional elements. Modern production technologies of crankshaft system elements allow implementation of dynamic TVD with springs for high-speed as well for medium-speed engines for road vehicles (e.g. dual-mass flywheel, a damper in the counterweight etc.).This way, reliability is increased and the costs for TVD are reduced.

A method for selecting characteristics of the dynamic TVD with springs built in the counterweight (torsional rigidity, inertia inertial mass), as well as an analysis of its impact on the critical values of the angular amplitudes of twist angle due to torsional vibrations are presented in this paper. The results of analysis are compared with the corresponding angular amplitudes of twist angle of the crankshaft with an elastic TVD element, and the potential of amplitudes of twist angle reduction by selection realistic dynamic characteristics of the dynamic TVD are shown. The complete analysis is carried out for a specific medium speed truck diesel engine

**KEY WORDS:** torsional vibration damper, dynamic damper with springs, IC engine, road vehicles

# MOGUĆNOSTI PRIMJENE DINAMIČKIH PRIGUŠIVAČA TORZIONIH OSCILACIJA SA OPRUGAMA KOD MOTORA ZA CESTOVNA VOZILA

**REZIME**: Jedan od osnovnih razloga zamora materijala kolenastog vratila motora sus, koje neumitno dovodi do njegovog pucanja, je pojava visokih amplituda uvijanja usled torzionih oscilacija. Amplitude uvijanja usled torzionih oscilacija su posebno izražene u zonama rezonantnih režima oscilovanja kolenastog vratila sa krivajnim mehanizmima i ostalim pripadajućim elementima. Realan put za smanjenje amplituda uvijanja usled torzionog oscilovanja je primena prigušivača torzionih oscilacija (PTO). Kod brzohodnih i srednje brzohodnih motora za cestovna vozila do sada je pretežno korišćen elastični PTO sa gumom kao elastičnim elementom. Razlozi za ovo su uglavnom jednostavna konstrukcija, pouzdanost i cena ovakvog dodatnog elementa. Nove tehnologije izrade elemenata sistema koji se nalaze na kolenastom vratilu omogućavaju uvođenje dinamičkih PTO sa oprugama i kod brzohodnih i srednje brzohodnih motora za cestovna vozila (npr. dvomaseni zamajac, prigušivač u kontrategu, i sl.). Na ovaj način se povećava pouzdanost i smanjuje cena PTO.

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U ovom radu je predstavljen način izbora karakteristika dinamičkog PTO sa oprugama ugrađenog u kontrategu (torziona krutost, moment inercije inercione mase), kao i analiza njegovog uticaja na kritične vrednosti amplituda uglova uvijanja usled torzionog oscilovanja. Dobijeni rezultati analize su upoređivani sa odgovarajućim amplitudama uglova uvijanja kolenastog vratila pri korišćenju elastičnih PTO, te su prikazane mogućnosti redukcije amplituda oscilovanja pri izboru realnih karakteristika dinamičkog PTO. Kompletna analiza je provedena za konkretan srednje brzohodni dizel motor za teretna vozila.

**KLJUČNE REČI:** prigušivač torzionih oscilacija, dinamički prigušivač sa oprugama, motor sus, cestovna vozila

# POSSIBILITIES OF USING DYNAMIC TORSIONAL VIBRATION DAMPERS WITH SPRINGS IN IC ENGINES FOR ROAD VEHICLES

*Almir Blažević[1], Ivan Filipović[2], Dževad Bibić[3], Boran Pikula[4]*

**UDC: 621.431;534.013**

## 1. INTRODUCTION

Internal combustion engines have a changing value of the current torque at the crankshaft within one working cycle (two revolutions of the crankshaft in four-stroke engines for one working cycle) due to their cyclical tape of work and the stochastic nature of the combustion process. Also within the IC engine due specific regulation processes a so called quasi stationary process occurs at constant speed operation [2], which further affects the change of torque at the crankshaft.

In addition to the above described character changes of the crankshaft excitation torque, the crank-gear shave variable moments of inertia of rotating masses and the crankshaft has a variable torsional stiffness by cross-sections [2, 3, 5]. All this results in the presence of significant torsional twisting at some cross-sections of the crankshaft with associated elements around the equilibrium of angular rotation. Occurrence of crankshaft twisting at some engine operating modes, primarily due to torsional vibration, can be of such intensity that can lead to fatigue and fracture of the crankshaft.

When defining the engine operating modes where high value amplitudes of crankshaft twist angle due to torsional vibration are expected, an important role has the machine that is powered by the internal combustion engine (road vehicle, power unit, ship, etc.).

This paper will observe the internal combustion engine without a powered machine, and the possibilities of reducing the amplitudes of twist angle due to torsional vibration at critical operation modes. Any attempt to avoid critical operation modes of the torsional vibration system, shifting the so called resonant crankshaft speeds outside the operation mode by changing the torsional stiffness and/or mass moments of inertia at the current level of development of crankshaft construction is quite unrealistic. The real way is the introduction of devices for forced reduction of critical amplitudes of twist angle due to torsional vibration, so-called torsional vibration dampers.

An overview of torsional vibration dampers which are used in internal combustion engines is best described in [9], from elastic dampers, dynamic absorbers, frictional dampers, hydraulic dampers to centrifugal pendulum which is used in some engines as a torsional vibration damper. Detailed overview of conventional torsional vibration dampers which are

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used for engines for road vehicles, with the basic characteristics of damping elements, is given in [1, 3].

Most commonly used conventional dampers for engines for road vehicles are the so-called viscoelastic dampers (dampers with rubber), who have a number of advantages (efficiency, durability, storage space, etc.). Approach to define the basic characteristics of damping and a way of modeling these dampers is given in [1, 5].

In recent years thanks to new technologies of engine parts manufacturing and new materials, there are also other solutions for torsional vibration damping based on so-called dynamic absorbers. Solutions of these dampers are shown in [4, 6, 8]. The advantages of these dampers are reflected in lower cost, higher reliability and the same or greater efficiency of damping of amplitudes of twist angle due to torsional vibration. Mounting and a way of modelling of the basic features of the new damper designs is described in [4].

In this paper a comparative analysis of amplitudes of twist angle due to torsional vibration with the application of conventional viscoelastic torsional vibration damper and a torsional vibration damper incorporated into the crankshaft counterweight in the form of a dynamic absorber for a same engine taking into account the real dimensions of the crankshaft counterweights is carried out.

## 2. OBJECT OF RESEARCH

For research purposes of applying a dynamic torsional vibration damper a medium speed, turbo-compressor charged, four-stroke, water cooled, six-cylinder diesel engine for road vehicles was considered. The main characteristics of the engine are given in Table 1.

*Table 1 Wheel numeric equations proposed by different researchers*

| | |
|---|---|
| Number of cylinders | 6 |
| Piston diameter | $D_k$= 125 mm |
| Piston stroke | s = 150 mm |
| Power ($P_e$) / speed (n) | 184 kW / 2100 rpm |
| Maximum torque | 890 Nm |
| Firing order | 1-5-3-6-2-4 |
| Moment of inertia of masses according to Figure 5 a) | $\theta_1$ = 0,0277 kgm$^2$, $\theta_2 = \theta_4 = \theta_5 = \theta_7$=0,147 kgm$^2$, $\theta_3 = \theta_6$ = 0,0835 kgm$^2$, $\theta_8$ = 1,87 kgm$^2$ |
| Stiffness according to Figure 5 a) | $c_1 = 4{,}32\cdot10^6$ Nm/rad, $c_2 =...= c_7 = 2{,}81\cdot10^6$ Nm/rad, $c_8 = 4{,}12\cdot10^6$ Nm/rad, |
| External damping coefficient | $\nu_1$=... =$\nu_6$= 7,5 Nms/rad |
| Internal damping coefficient | $\varepsilon_1, \varepsilon_2, ..., \varepsilon_7$, computed according to model in [3] |

In series mass production the engine is equipped with a viscoelastic torsional vibration damper, shown in figure 1.

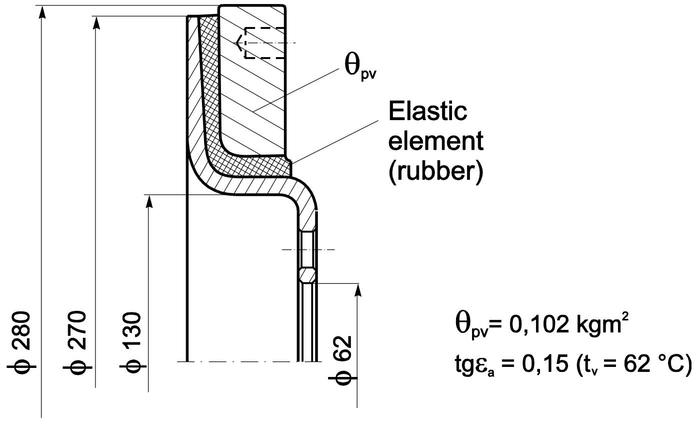


*Figure 1 Scheme of a viscoelastic torsional vibration damper*

The dynamic torsional vibration damper, with whom the research in this paper is carried out, is set within the crankshaft counterweight at the first joint. The inertial mass is attached to the crankshaft base structure with four coil springs and a stop bar. In Figure 2 the layout of the dynamic torsional vibration damper with the most important coil spring characteristics is shown.

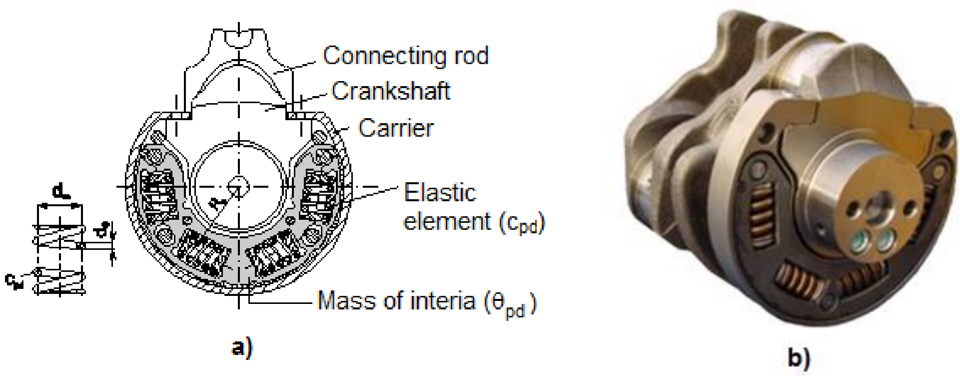


*Figure 2 Scheme of the dynamic torsional vibration damper a) and an actual photo b)*

The assemble position of the torsional vibration dampers from Figures 1 and 2, are schematically shown in Figure 3.

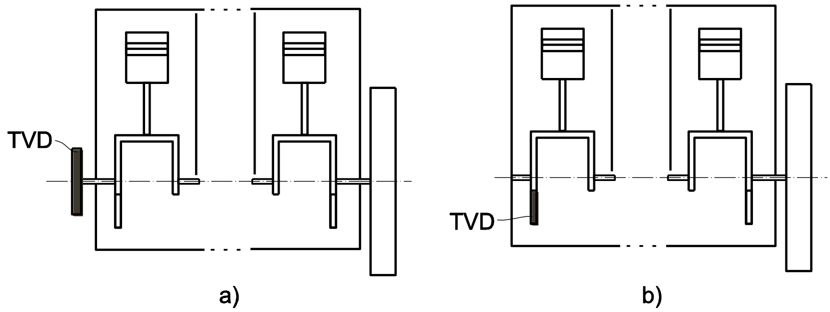


*Figure 3 Assemble positions of the viscoelastic a) and dynamic b) torsional vibrations damper at the IC engine*

## 3. MODELS FOR CALCULATING TWIST ANGLES DUE TO TORSIONAL VIBRATIONS

The analysis of the torsional vibration system was performed using the mass-spring type model [3]. The basic data for the given model, which are partially given in Table 1, are explained in detail in [5]. Since the viscoelastic damper has highly nonlinear damping ($\varepsilon_{pv}$) and stiffness ($c_{pv}$) characteristics, in this work the characteristics of the damper are obtained as a combination of computing and experiments presented in [3, 5] were used.

The values of the dynamic stiffness ($c_{pv}$) and the dynamic internal damping coefficient ($\varepsilon_{pv}$) of the damper in Figure 1 are given in Figure 4, where the surface temperature of the elastic element (rubber) is $t_v$=62 °C. This temperature is an average temperature of the elastic element at the external speed characteristic of the engine at which all experiments were performed. In Figure 4 the amplitude of twist angle of the appropriate masses is marked with ($A_r$).

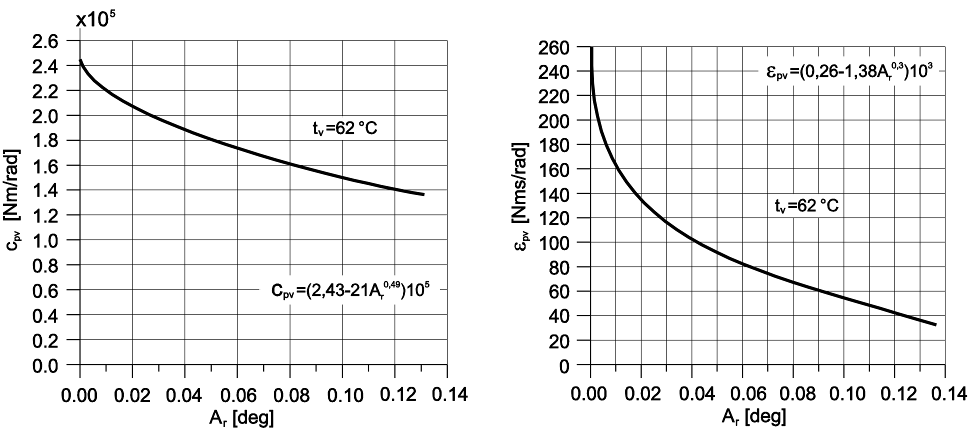


*Figure 4 The diagram of torsional stiffness (cpv) and internal damping coefficient (εpv) transition of the elastic element of the viscoelastic damper (Figure 1) as a function of the relative twist angle amplitudes Ar=Ap-A1*

The physical torsional vibration system model of the engine with the viscoelastic torsional vibration damper is shown in Figure 5 a) and in Figure 5 b) the physical model of the same engine with the dynamic torsional vibration damper incorporated into the crankshaft counterweight is shown.

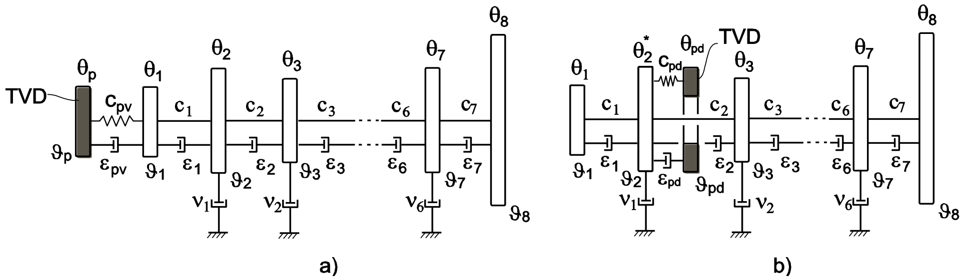


*Figure 5 The physical torsional vibration system model with viscoelastic a) and dynamic b) torsional vibration damper*

For the analysis of the torsional vibration system model given in Figure 5 a) the next mathematical model was used.

$$[I]\{\ddot{\vartheta}\}+[K]\{\dot{\vartheta}\}+[C]\{\vartheta\}=\{T(t)\} \quad (1)$$

where:

$[I]$ – matrix of the moment of inertia of masses (θ),

$[K]$ –internal and external damping matrix (ε,ν),

$[C]$ – stiffness matrix (c),

$\{T(t)\}$ – excitation matrix and

$\{\vartheta\}$, $\{\dot{\vartheta}\}$, $\{\ddot{\vartheta}\}$ – matrix of angular twist, speed and acceleration due to torsional vibration.

For the physical model shown in Figure 5 b) a corrected version of equation system (1) were used. The correction is reflected in the fact that instead of using one equation for disc ($\theta_2$) and disc ($\theta_{pd}$) of the type.

$$\theta_2\ddot{\vartheta}_2+\nu_1\dot{\vartheta}_2+\varepsilon_1(\dot{\vartheta}_2-\dot{\vartheta}_1)+\varepsilon_2(\dot{\vartheta}_2-\dot{\vartheta}_3)+c_1(\vartheta_2-\vartheta_1)+c_2(\vartheta_2-\vartheta_3)=T_2 \quad (2)$$

two equations were used:

$$\theta_2^*\ddot{\vartheta}_2+\nu_1\dot{\vartheta}_2+\varepsilon_1(\dot{\vartheta}_2-\dot{\vartheta}_1)+\varepsilon_2(\dot{\vartheta}_2-\dot{\vartheta}_3)+\varepsilon_{pd}(\dot{\vartheta}_2-\dot{\vartheta}_{pd})+c_1(\vartheta_2-\vartheta_1)+$$
$$+c_2(\vartheta_2-\vartheta_3)+c_{pd}(\vartheta_2-\vartheta_{pd})=T_2$$
$$(3)$$
$$\theta_{pd}\ddot{\vartheta}_{pd}+\varepsilon_{pd}(\dot{\vartheta}_{pd}-\dot{\vartheta}_2)+c_{pd}(\vartheta_{pd}-\vartheta_2)=0$$

Using the mathematical model described with the differential equation system (1), using inputs for the engine with viscoelastic damper from Table 1 and values for ($c_{pv}$) and

($\varepsilon_{pv}$) from Figure 4, amplitudes of twist angle of the pulley ($A_1$) were obtained through computing. Computing results were compared with corresponding experimental values, as shown in Figure 6.

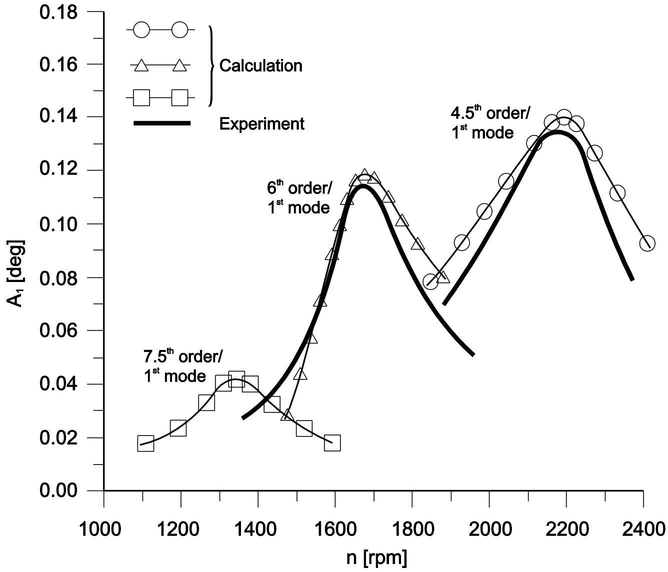


*Figure 6 Comparison of the amplitude of twist angle at the engine pulley with viscoelastic torsional vibration damper obtained computationally and experimentally*

By analysing comparative values of twist angles due to torsional vibrations shown in Figure 6, obtained computationally and experimentally, it can be concluded that the agreement between the results is satisfactory and that for, for further analysis of the influence of the damper on the torsional vibration of the crankshaft can be carried out through computation.

## 4. ANALYSIS OF THE COMPUTATIONAL RESULTS

Dynamic torsional vibration damper, based to Figure 2 b), is designed and incorporated in the first counterweight on the left crankshaft end (on the opposite side of the engine flywheel).Moment of inertia of the first left crank-gear with counterweight without damper is $\theta_2$=0,147 kgm$^2$ (Table 1). Based on the analysis of the technical documentation and computation, the inertial mass of the counterweight, which is located on the first crank-gear from the left is 0,064 kgm$^2$.

Having in mind the shape change of the counterweight (Figure 2), the total inertia moment of the mass of the counterweight is computed and has the value 0,085 kgm$^2$. From the technical documentation 65% to 75% of the total moment of inertia of the mass belongs to the dynamic damper (inertial mass + springs) which in this particular case is $\theta_{pd}$ = 0,055 ÷ 0,065 kgm$^2$. The value of the moment of inertia of mass $\theta_2^*$ (crank gear with a new shape of counterweight without inertial mass) is in the range of 0,104 kgm$^2$ to 0,115 kgm$^2$.

Bearing in mind the design of the four coil springs (Figure 2), where in pare of two springs are acting on the inertial mass ($\theta_{pd}$), realistically the dimensions of the springs can be seated as: wire diameter $D_0$ = 5.5 ÷ 6.3 mm, with a mean diameter of the spring $d_m$ ~ 32 mm. Spring length in the free state is 50 mm. Bearing in mind the dimensions of this springs their individual axial stiffness ranges from 120 N/mm to 160 N/mm.

Taking into account springs in pares in parallel connection, their position relative to the center of rotation of the crankshaft is $R_0$=93÷95 mm, the torsional stiffness of the springs is within the range 1500 Nm/rad to 2700 Nm /rad. Using the above data, self-developed software for the mathematical model given by equations (1) and (3) an analysis of the changes in the maximum vibration amplitude for various values of the characteristics of the dynamic torsional vibration damper is performed.

In these analyses the coefficient of internal damping $\varepsilon_{pd}$=20 Nms/rad is maintained the same and it is the result of friction between the counterweight and elements of the inertial mass.

In order to obtain optimal characteristic values of the dynamic damper, torsional stiffness of the springs ($c_{pd}$) and the moment of inertia ($\theta_{pd}$) of the inertial mass were varied. In the analysis the $6^{th}$ order and I mode of vibration were considered, since the $4.5^{th}$ order fall out of the operating range of the engine ($n_{max}$=2100 $^o$/min). Despite the statements that the $4.5^{th}$ order lies at the border of the operating range of the engine, the same trends can be observed for any of the main excitation orders. The results are shown in Figures 7 and 8. In these figures maximum values of the amplitude of twist angle of the engine pulley ($A_{1max}$), where practically the largest twist due to torsional vibrations occurs, are presented.

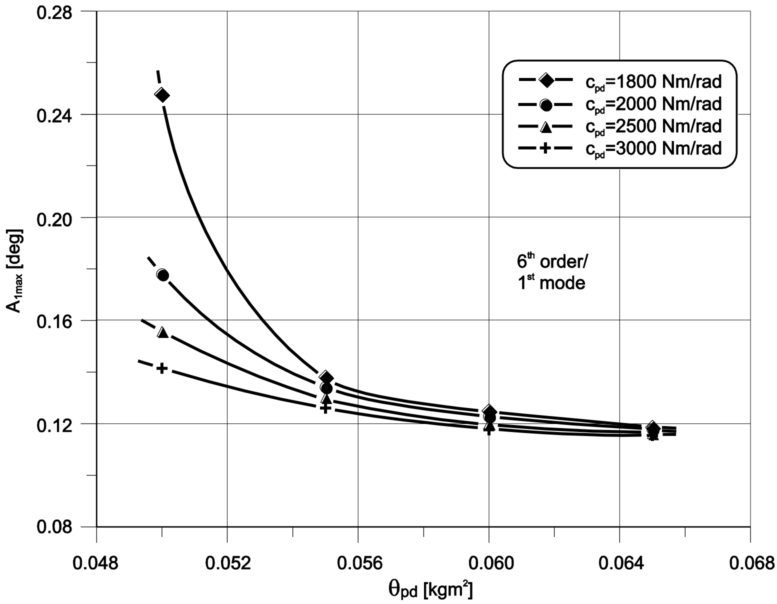


*Figure 7 The diagram of maximum amplitudes of twist angle of the engine pulley as a function of the moment of inertia of the inertial mass and torsional spring stiffness of the damper as a parameter*

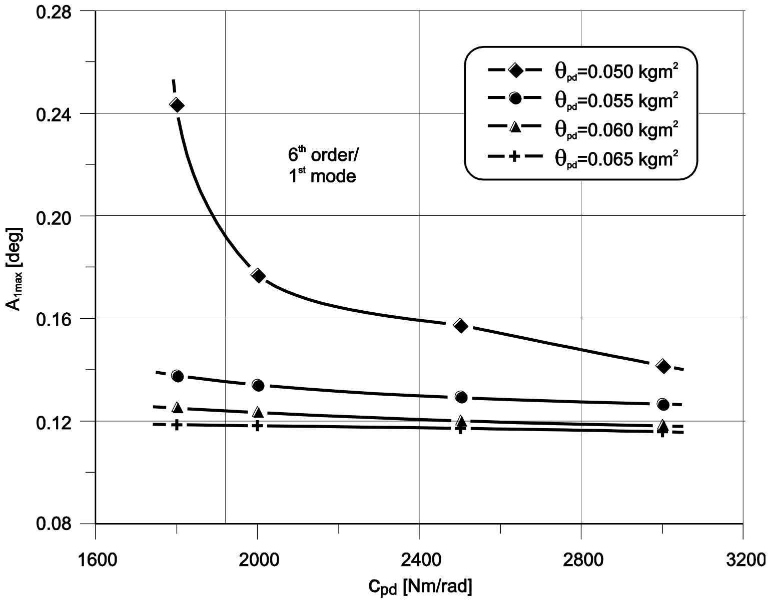


*Figure 8 The diagram of maximum amplitudes of twist angle of the engine pulley as a function of the torsional spring stiffness of the damper and moment of inertia of the inertial mass as a parameter*

Figures 7 and 8 indicate that minimum reasonable values of the maximum amplitude of the twist angle of the engine pulley of the particular engine with a dynamic damper are obtained for moment of inertia of masses ($\theta_{pd}$) greater then 0,055 kgm$^2$ and for torsional stiffness of the springs of the damper (CPD) greater than 2000 Nm/rad. These results show that it is possible to incorporate a dynamic damper into a dimensionally realistic crankshaft counterweight to gain the same or even better effectiveness than using a viscoelastic torsional vibration damper.

A comparison example of values of amplitudes of twist angle of the engine pulley with a viscoelastic and dynamic torsional vibration damper is shown in Figure 9.

In this particular example a dynamic damper with characteristics $\theta_{pd}$=0,060 kgm$^2$ and $c_{pd}$=2500 Nm/rad is taken. At the same diagram (Figure 9) amplitudes of the twist angle of the engine pulley ($A_1$) for the same engine without a torsional vibration damper is given.

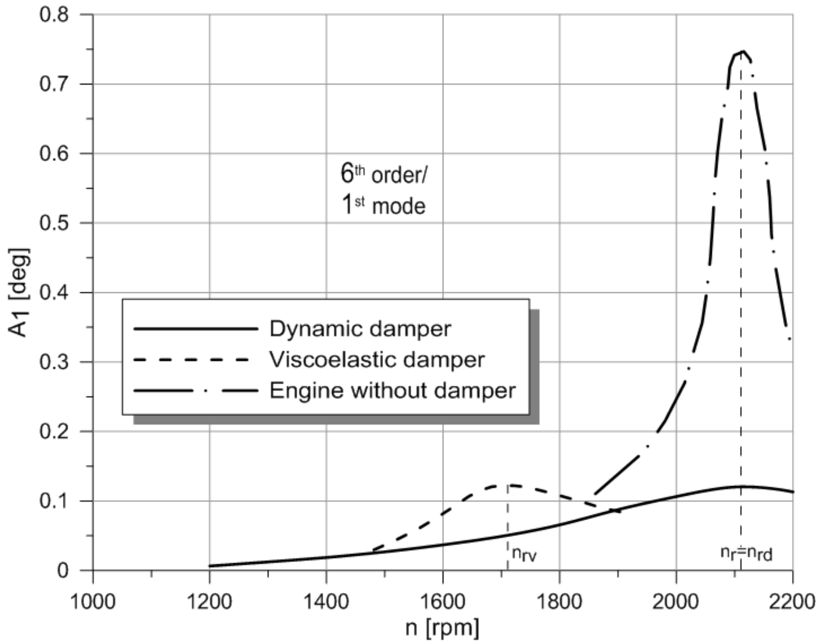


*Figure 9 The comparative diagram of maximum amplitude of twist angle of the engine pulley (A1) for an engine with a viscoelastic and dynamic torsional vibration damper*

Comparative results in Figure 9 show that it is possible to get the same or even less amplitudes of twist angle due to torsional vibrations using a dynamic torsional vibration damper as using a viscoelastic torsional vibration damper. It should also be noted that in addition to a satisfactory level of absolute values of the maximum twist angles due to torsional vibration in the application of both types of dampers, the maximum value of the amplitudes are at different engine speeds. Applying the viscoelastic torsional vibration damper on the engine the resonant vibration mode moves to the lower speeds of the engine ($n_{rv}$~1710 $^o$/min) relative to the resonant vibration mode of the engine without a damper ($n_r$~2120 $^o$/min). Unlike the viscoelastic damper, which significantly shifts the resonant mode, the dynamic damper practically does not affect the engine resonant mode ($n_{rd}$~$n_r$). This analysis is given only for the 6$^{th}$ excitationorder and I mode of vibration, which are assessed as the most important parameters to check the operation safety of the crankshaft of a six-cylinder engine. Similar conclusions are obtained for other major (9$^{th}$; 12$^{th}$; ...) and strong (4.5$^{th}$, 7.5$^{th}$, ...) excitation orders for a six-cylinder engine, noting that in this case the most dangerous 6$^{th}$ order, considering the value of the amplitude of the twist angle of the crankshaft due to torsional vibration, is in the operation range of the engine.

The foregoing discussion and analysis can be done for any engine type, but it should be taken into account the proper definition of the parameters of the dynamic torsional vibration damper, with respect of the major excitation orders according to the number of cylinders of the engine.

## 5. CONCLUSION

Through the analysis of parameters of a torsional vibration system of an IC engine with two different torsional vibration dampers it can be concluded:

- The same or even better damping effects of amplitudes of crankshaft twist angel due to torsional vibration can be obtained with incorporating a dynamic damper in the crankshaft counterweight instead of using so-called conventional viscoelastic dampers.
- The engine resonant mode doesn't change with using the dynamic torsional vibration damper in relation to the resonant mode of the engine without a torsional vibration damper. In addition, conventional viscoelastic torsional vibration dampers significantly reduce the value of the resonant engine speed relative to the resonant mode of the engine without the damper.
- Bearing in mind the real design and dimensions of the crankshaft with counterweights for medium speed engines for road vehicles, there is enough space for incorporating a dynamic torsional vibration damper, with an optimum moment of inertia of the inertial mass and stiffness of the spring damper, into one counterweight. In the case of smaller engines and insufficient space to incorporate the dynamic damper with optimal parameters, two counterweight on the same crankshaft knee can be used.

## REFERENCES

[1] BibićDž., Filipović I., Doleček V.: Contribution to Damping Modellingin IC EngineTorsional Vibration Damper, 5th Int. Scientific Conf. on Production Engineering, RIM 2005, sept. 14-17, Bihać, 2005., p. 415-420.

[2] Filipović I.: Motori s unutarnjim izgaranjem – Dinamika i oscilacije, knjiga, Mašinski fakultet Sarajevo, 2007.

[3] Filipović I.,BibićDž.: Motori s unutrašnjim sagorijevanjem – Torzione oscilacije, knjiga, Mašinski fakultet Sarajevo, 2015.

[4] Filipović I.,BibićDž., Milašinović A., Blažević A., Pecar A.: Preliminary Selection of Basic Parameters of Different Torsional Vibration Dampers Intended for Use in Medium Speed Diesel Engines, Transactions of Famena XXXVI-3 (2012), p. 79-88.

[5] Filipović I., Določek V., BibićDž.: Modeling and the Analysis of Parameters in the Torsional-Oscilatory System Equivalent to the Diesel Engines in Heavy-Duty Vehicles, Jurnal of Mehanical Engineering vol. 51, No 12/15 isuue 488 (2005), p.786-797.

[6] Gerhardt F., Fechler C., Lehmann S., Langeneckert H.: Internal Crankshaft Damper, 7th LuK Symposium, april 2002, p.41÷49.

[7] Hafner K. E., Maass H.: Torsionsschwingungen in der Verbrennungskraftmaschine, SpringerVerlag, 1985.

[8] Kroll J., Kooy A.,Seebacher R.: Torsional Vibration Damping for Future Engines, Schaeffler Symposium, 2010.

[9] Wilson W.K.: Practical Solution of Torsional Vibration Problems, Devices for Controlling Vibration, Volume Four, Chapman Hall, London, 1968.

# CHINA AS A LEADING COUNTRY IN THE WORLD IN AUTOMATION OF AUTOMOTIVE INDUSTRY MANUFACTURING PROCESSES

*Isak Karabegović[1], Ermin Husak*

**UDC:629,1-4;338,312**

**ABSTRACT:** Year after year, installations of industrial robots in manufacturing processes in the world have been increasing, and especially in recent years in continents Asia/Australia. Sales of industrial robots and their application in all industry branches in 2014 have increased compared to 2013 for 29 % so that in 2014 sales and installation of industrial robots reached 229.261 units. Two industrial branches: automotive and electro/electronics are significant for industrial robot applications. Since 2010 demand for industrial robots and their installations in automation of manufacturing processes have significantly accelerated. One of the reasons is innovative technical improvement of the robots. From 2010 to 2014 average increase of industrial robot installation in automation and modernization of manufacturing processes at the annual level was 17 % (CAGR-Compound Annual Growth Rate). China is a world leading country in the last two years in industrial robot installations. Almost 25 % of annual supply of industrial robots in the world belongs to China. Taking into consideration that China in the last several years is leading country in production of motor vehicles, it is easy to conclude that these industrial robot applications are aimed to automation and modernization of manufacturing processes in automotive industry.

**KEY WORDS:** automation, manufacturing process, automotive industry, industrial robots, installation, production

## KINA KAO VODEĆA ZEMLJA U SVETU U AUTOMATIZACIJI PROIZVODNIH PROCESA U AUTOMOBILSKOJ INDUSTRIJI

**REZIME**: Iz godine u godinu dolazi do povećanja primene industrijskih robota u proizvodne procese u svetu, a naročito u zadnjim godinama u Aziji/Australiji. Prodaja industrijskih robota i njihova primena u svim industrijskim granama se povećala u odnosu na 2013.godinu za 29% tako da je u 2014.godini dostigla cifru od 229.261 jedinica. Dve industrije su značajne u primeni industrijskih robota, automobilska i elektro/elektronska industrija. Od 2010.godine potražnja i instaliranje industrijskih robota pri automatizaciji proizvodnih procesa znatno je ubrzana, a jedan od razloga je inovativno tehničko poboljšanje industrijskih robota. Između 2010-2014.godine prosečno povećanje primene industrijskih robota pri automatizaciji i modernizaciji proizvodnih procesa na godišnjem nivo je iznosilo 17% (CAGR-Compound Annual Growth Rate). Kina je u zadnje dve godine vodeća zelja u svetu po primeni industrijskih robota, tako što je u 2014.godini proširila svoju primenu sa učešćem od oko 25% od ukupne primene u svetu. Vodeći računa da je Kina u zadnjim godinama vodeća zemlja u svetu po proizvodnji vozila, lako je doneti zaključak da je primena industrijskih robota usmerena na automatizaciju i modernizaciju proizvodnih procesa automobilske industrije.

**KLJUČNE REČI:** automatizacija, proizvodni proces, automobilska industrija, industrijski robot, primena, proizvodnja

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# CHINA AS A LEADING COUNTRY IN THE WORLD IN AUTOMATION OF AUTOMOTIVE INDUSTRY MANUFACTURING PROCESSES

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**UDC: 629,1-4;338,312**

## 1. INTRODUCTION

In the last twenty years, the rapid development of information technology led to a sudden development and a constant improvement of production technology. Also, all kinds of new technologies appear every day, as well as new production technologies with the aim to reduce the time of product production, and thereby increase productivity as well as the quality of the finished product. Integration of the production process, automation and modernization of production processes, which is impossible to imagine without the introduction of industrial robots into a production process, have led to the increase in product quality and reduced time of the finished product production. When it comes to the automotive industry, it is impossible to imagine the production process in the automotive industry without industrial robots being involved. The use of industrial robots and new technologies leads to a rapid increase in production in the automotive industry, both in terms of number of produced vehicles and the number of different models. When it comes to the automotive industry, the application of industrial robots at the very beginning was related to the performance of activities that affected the health of workers, such as welding and painting. The development of information technology and sensor technology led to the development of industrial robotics, so we have a concurrent connection of several industrial robots in performing identical operations, which leads to a shortening of the processing time [1, 2, 3-11]. The development of sensor technology has a direct impact on the development of different grippers which allow the application of industrial robots in various operations of productive processes of the automotive industry. Industrial robots are used in manufacturing processes of the automotive industry for the following purposes: car parts machining (axles, bearings, motors, etc.), production of plastic parts and carosserie parts, carosserie welding, carosserie painting, control of manufactured car parts, assembly process, as well as in the process of controlling elements embedded during a vehicle assembly [2,10,11,18-21]. It can be concluded in the end that there is no single manufacturing process of the automotive industry in which an industrial robot could not be installed. Steady growth in production in the automotive industry leads to an increased application of industrial robots in manufacturing processes of the automotive industry, which will be discussed in the next chapter.

## 2. TREND OF INDUSTRIAL ROBOTS APPLICATION IN THE WORLD

The trend of annual supply of industrial robots in the world is shown in Figure 1, and statistical data that have been used are obtained from the IFR (International Federation of Robotics) [7, 8, 9].

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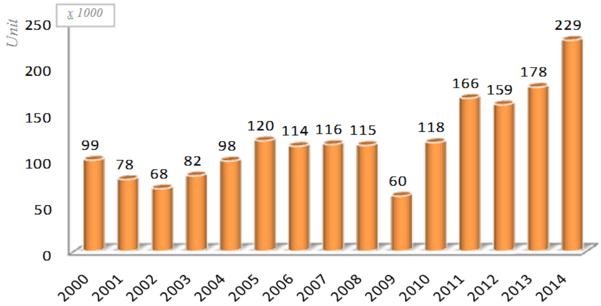
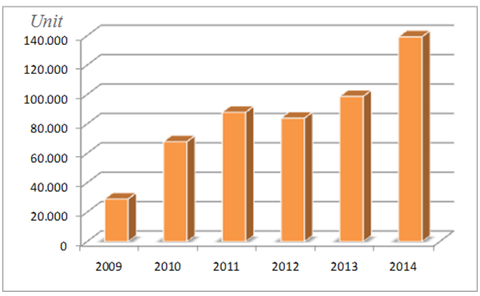


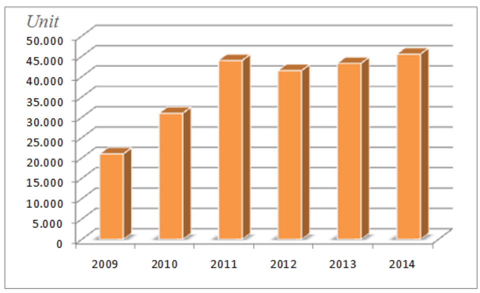

*Figure 1 Annual supply of industrial robots in the world for the period 2000-2014 [7-9]*

Based on Figure 1, it can be concluded that the trend of annual application of industrial robots had a growing tendency from 2002 to 2014, but this trend declined to 60.000 robot units in 2009 due to the economic and industrial crisis. From 2010 to 2014, an average increase of industrial robots accounted for 17% per annum. In comparison to the period of application from 2005-2008 when an average of about 115.000 units was applied, the number increased to about 171.000 units in the period 2010-2014, which represents an increase of 48.7%.

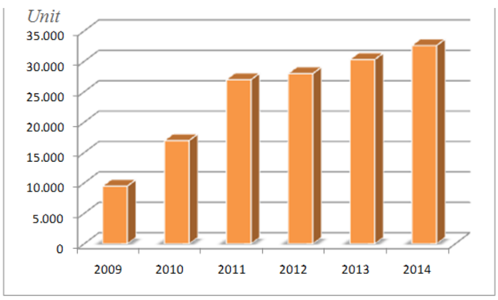
This leads to the conclusion that there has been a significant increase in industrial robots application in the automation of production processes.




*Asia/Australia*




*Europe*




*America*

*Figure 2 Trend of annual application of industrial robots from 2009-2014 in Asia/Australia, Europe and America [1,7-9]*

When it comes to the application of industrial robots in the world shown in Figure 2, the continent number one is Asia/Australia, where around 140.000 units were applied in 2014. The second is Europe with about 46.000 units of industrial robots applied in 2014. The third continent is America, where about 32.000 units were applied in 2014. The analysis of industrial robots application in 2014 yields the conclusion that industrial robots application is around 80.5% bigger in Asia than in Europe and America together, which means that the automotive industry and the automation and modernization of manufacturing processes in the automotive and electrical industry are developing in Asia, because industrial robots are the most used in these two industries. The diagrams in Figure 3 confirm this statement.

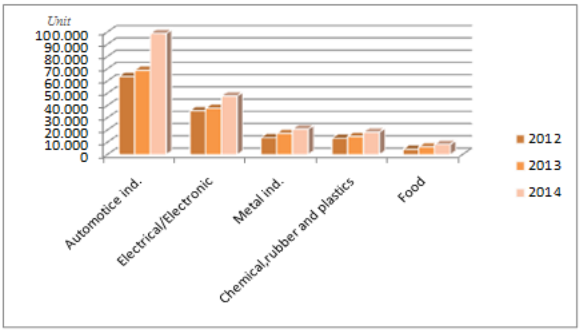
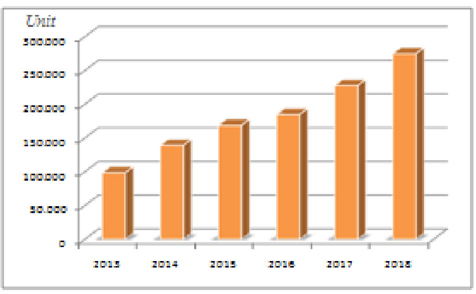



*Figure 3 Industrial robots application from 2012-2014 in industries [7]*

The graphs in Figure 3 show that it holds the first place when it comes to industrial robots application in the automation of production processes in the automotive industry. Then these industries follow: electrical/electronics industry, metal industry, chemical industry (production processes in rubber and plastic industry) and the food production process. It can be concluded that trend of industrial robots application increased in the period from 2012-2014, and the increase is the most evident in the automotive industry, where it reached the worth of about 100.000 units in the world in 2014. Overview of the industrial robots application in the period that follows will be given in Figure 4.

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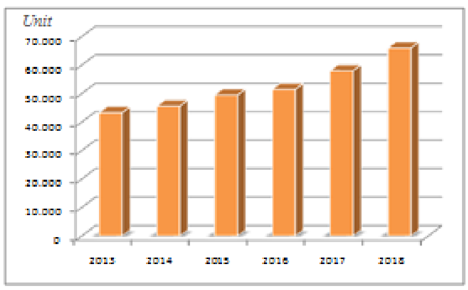


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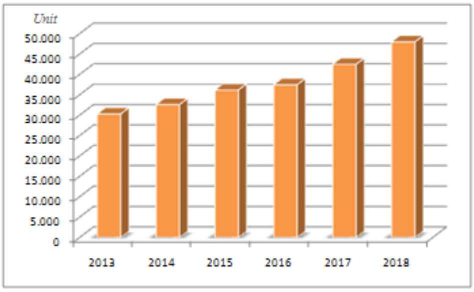


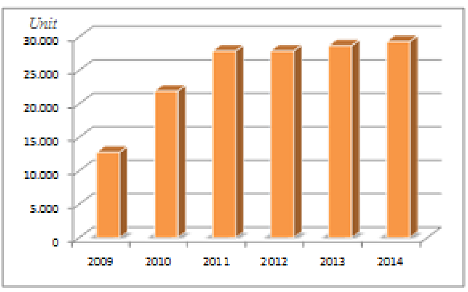

*America*

*Figure 4 Trend of anticipated annual application of industrial robots by 2018 in the Asia/Australia, Europe and America [7]*

When it comes to the application of industrial robots in the future period, the figure 4 shows that the application will have a growing trend in all three continents, but the number one will be Asia/Australia. Predictions are that about 270.000 units of robots will have been applied in 2018 in the automation process in various industrial branches, primarily in the automotive industry. It can be concluded that industrial robots application will be twice as larger on the continent of Asia/Australia than in Europe and America together. This means that there will be a development of the automotive and electrical/electronics industry, as well as automation and modernization of production processes in these industries through the use of new technologies. In order to verify this conclusion, let us analyze the application of industrial robots in five countries in the world that use industrial robots the most.

## 3. CHINA, LEADING COUNTRY IN THE WORLD IN INDUSTRIAL ROBOT APPLICATION

Given that Asia/Australia is the number one continent in application of industrial robots, let us analyse industrial robots application in the following countries: Japan, the Republic of Korea, China, North America (USA, Mexico and Canada) and Germany.

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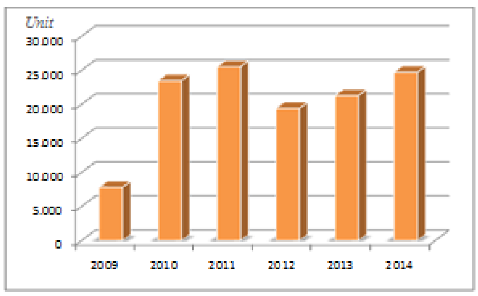
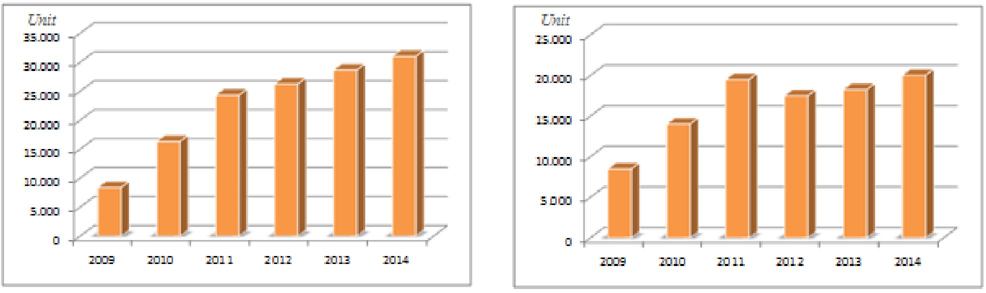



*Republic of Korea*




*North America(USA,Canada,Mexico)* *Germany*

*Figure 5 Industrial robots application in Japan, the Republic of Korea, North America and Germany from za 2009-2014 [1,7,14,15,16,17]*

The Figure 5 indicates that industrial robots application is constantly increasing, so that the application in Japan and North America was between 25.000-30.000 units from 2012-2014, while it was around 20.000 units in the Republic of Korea and between 15.000-20.000 units in Germany in the same period of time. The reason for such a large application of industrial robots in these four countries lies in global competition in the market of the automotive industry (because these four countries are among the first countries in the world in the production of vehicles), which requires continuous modernization and flexible automation of production processes through the continuous improvement in quality by applying sophisticated industrial robots of high technology. Simplifying the use of industrial robots presents an enormous potential in their application in all industrial branches, including the automotive industry. Also, growing demand in the automotive industry requires an expansion of production capacities and a creation of new companies that want a full modernization and a flexible automation of production processes in the automotive industry. One of the countries is China, which has become number one in recent years when it comes to both industrial robots application (shown in Figure 6) and the production of vehicles in the world (Figure 7).

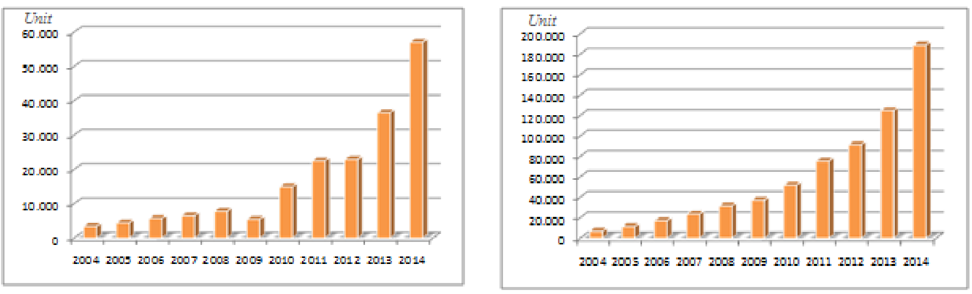



*Figure 6 Annual and overall application of industrial robots in China from 2004-2014 [7,8,9]*

The analysis of the graph in Figure 6 indicates that industrial robots application in China had a growing trend both at the annual and overall levels year after year from 2004-2014, so that in the last three years it is a leading country in the world which applies the most industrial robots. The growing trend of industrial robots application results in a fact that China is the leading country in the world in the production of vehicles, as shown in Figure 7.

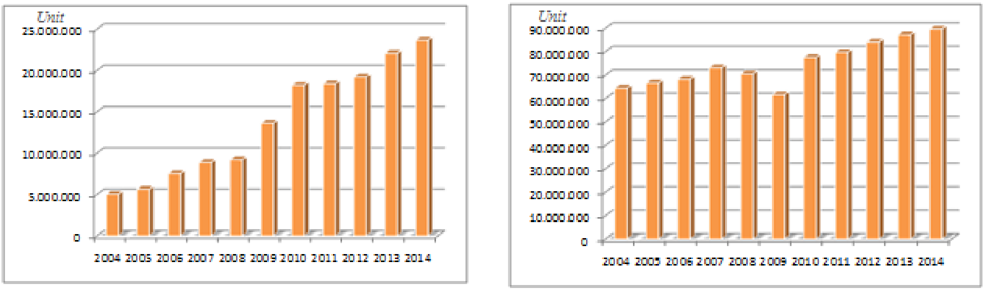
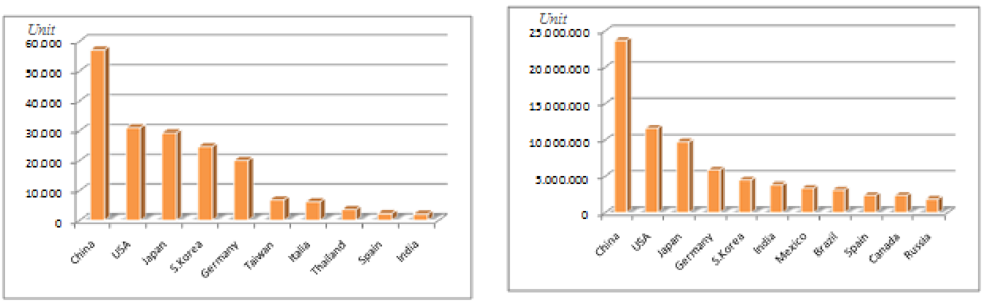



*Figure 7 Vehicle production in China and the World from 2004-2014 [4,5,6,21]*

As seen in Figure 7, China ranks first in the production of vehicles in the world in recent years, with the production of 23.723.000 units of vehicles in 2014. Given that 89.750.000 vehicles were produced in the world in 2014, this figure presents more that the fourth of produced vehicles in the world, i. e. 26.4%. This conclusion is also confirmed by the Figure 8, which shows a graph of industrial robots application and vehicles production in certain countries in the world for 2014.




*Industrial robots* *Vehicles*

*Figure 8 Application of industrial robots and vehicle production in 2014 in ten countries [7,21]*

Figure 8 shows the application of industrial robots and production of vehicles in 2014 in ten countries, on the basis of which we can conclude that China is the leading country when it comes to both the industrial robots application and the production of vehicles in the world. It is followed by these countries: the USA, Japan, North Korea and Germany, because these are the five countries with a developed automotive industry. Also, these are the countries that present a competition to each other on the automotive industry market. The obvious reason why the automotive industry is of interest is that the largest number of industrial robots is installed precisely in the automotive industry, as shown by Figure 3.

## 4. CONCLUSIONS

Based on the analysis conducted in this paper and shown argumentative results, it can be said that the car industry is the leading world industry in the application of industrial robots, and it is followed by the electrical/electronics industry. The reason for such a trend of industrial robots application in the automotive industry is global competition on the market of automotive industry, which requires a continuous modernization and a flexible automation of production processes in the automotive industry using industrial robots. The use of industrial robots in the automotive industry improves quality continuously because sophisticated industrial robots with new technologies systems are used. The development of sensor and information technology has particularly led to the improvement of grippers on industrial robots, which found their application in all operations of vehicle production. China is in the leading position in the world when it comes to the application of robots. It is assumed that it will expand its dominance in the application of industrial robots, so it is expected that more than one-third of industrial robots in 2018 will be installed in China. Simplifying the use of industrial robots will create a huge potential in industrial robots application in all industries, including small and medium enterprises.

## REFERENCES

[1] Karabegović I., Husak E.: "Significance of industrial robots in development of automobile industry in Europe and the World", Journal Mobility and Vehicle, Vol.40., No.1., 2014., University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia, ISSN 1450-5304, pp.7-16.(http:/www.mvm.fink.rs).

[2] Doleček V., Karabegović I.: "Roboti u industriji", Tehnički fakultet Bihać, Bihać, 2008.

[3] Doleček V, Karabegović I.:" Robotika", Tehnički fakultet Bihać, Bihać, 2002.

[4] VDA: „AutoJahresbericht 2011“, 2011.

[5] VDA: „AutoJahresbericht 2012“, 2012.

[6] VDV: "AutoJahresbericht 2014", 2014.

[7] World Robotics 2015, United Nations, New York and Geneva, 2015.

[8] World Robotics 2012, United Nations, New York and Geneva, 2012.

[9] World Robotics 2009, United Nations, New York and Geneva, 2009.

[10] Bakšys B., Fedaravičius A.: "Robotu Technika", Kaunas Technologija, Kaunas, 2004.

[11] Rogić M.: "Industrijski roboti", Mašinski fakultet Banjaluka, Banjaluka, 2001.

[12] Karabegović I., Karabegović E., Husak E.: "Application analyses of industrial robot in World automobile industry in 2010", Journal of international scientific publications:Material,Methods & Technologies, Vol.5, No.2, decembar 2011. Sofia,Bulgaria, ISSN 1313-2539, : pp 336-345.

[13] Freund E., Stern O.: "Robotertechnologie I", Institut für Roboterforschung, Dortmund, 1999.

[14] Karabegović I., Karabegović E., Husak E.: "Comparative analysis of the industrial robot application in Europa and Asia", International Journal of Engineering & Technology IJET-IJENS Vol.11, No.01, 2011.

[15] Karabegović E., Karabegović I., Hadžalić E.: "Industrial robots application trend in world metal industry", Journal Engineering Economics,Vol.23, No.4, Lithvania, 2012,: pp.368-378.

[16] Karabegović I., Doleček V., Husak E.: "Analysis of the Industrial Robots in Various Production Processes in the World", International Review of Mechanical Engineering, Vol.5, No.7, 2011., Napoli, Italy, :pp.1272-1277.

[17] Wolka D.W.: "Roboter sisteme", Technishe Universität des Saarlandes im Stadtwald, 1992.

[18] McKerrow P. J.: "Introduction to robotics", Addison-Wesley Publishing Company, Sydney, 1991.

[19] Sciavicco L., Siliciano B.: "Modeling and Control of Robot Manipulators", McGraw-Hill International Editions, 1996.

[20] Shimon Y. N.: "Handbook of Industrial Robotics", 2nd Edition, 1999.

[21] http:/www.worldometers.info7cars/.

# CONTRIBUTION TO THE CONSIDERATION OF SIGNIFICANCE OF HYBRID BUSES IMPLEMENTATION IN CITY TRAFFIC COMPANIES

*Darko Stanojević[1], Nenad Lužanin, Miloš Vasić, Nada Stanojević, Milun Todorović*

**UDC:629.3.038**

**ABSTRACT:** Paper presents analysis of implementation development of hybrid buses as well as interpretation of different experiences which users of hybrid vehicles have in their exploitation. Particular accent of interpretation was placed on the reducing of fuel consumption, which also indicates reducing of exhaust emissions gases, which can be achieved with implementation of hybrid buses in city traffic companies. Regarding to problem of autonomy which is still present in complete electric vehicles, it can be said that hybrid drive is more acceptable. This paper is involved in answer to the question: Does implementation of hybrid buses in city traffic companies is justified?

**KEY WORDS:** hybrid drive, bus, city traffic, fuel consumption

## DOPRINOS SAGLEDAVANJU ZNAČAJA PRIMENE AUTOBUSA SA HIBRIDNIM POGONOM U GRADSKIM SAOBRAĆAJNIM PREDUZEĆIMA

**REZIME**: Rad predstavlja analizu stanja razvoja primene gradskih autobusa sa hibridnim pogonom kao i tumačenje različitih iskustava koje su korisnici hibridnih autobusa imali u njihovoj eksploataciji. Poseban akcenat tumačenja stavljen je na smanjenje potrošnje goriva, što indicira i smanjenje emisije štetnih izduvnih gasova koja se postiže primenom hibridnog pogona. S obzirom na problem autonomnosti koji je još uvek prisutan kod čisto električnog pogona može se reći da se za sada još uvek daje prednost hibridnom pogonu. Rad učestvuje u odgovoru na pitanje: Da li je opravdano uvesti u primenu što veći broj autobusa sa hibridnim pogonom u gradska saobraćajna preduzeća?

**KLJUČNE REČI:** hibridni pogon, autobus, gradski saobraćaj, potrošnja goriva

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# CONTRIBUTION TO THE CONSIDERATION OF SIGNIFICANCE OF HYBRID BUSES IMPLEMENTATION IN CITY TRAFFIC COMPANIES

*Darko Stanojević[1], Nenad Lužanin [2], Miloš Vasić[3], Nada Stanojević [4], Milun Todorović[5]*

**UDC: 629.3.038**

## 1. INTRODUCTION

Today's hybrid buses are important part of the improvement of catalytic vehicle safety [8]. Because of their specific work principle, which allows many benefits such as: reducing of exhaust emissions gases (which satisfy ecological aspect), economy (cost effectiveness regarding to the reducing of fuel consumption) and noise reduction, accent to their presence in urban and suburban traffic is increasing. Because of greenhouse effect which is, between other, consequence of increased exhaust emissions gases, exist continuously efforts to use as much as possible hybrid vehicles, especially in vehicle fleets of city transportation companies. Policy of "green vehicles", regardless to concisely defined and improved positive effects, still it is not fully accept. In accepting of this policy significant role play hybrid vehicles while different factors influence on development of their implementation. Traffic companies still partly are accepting mentioned tendencies and with reserve. This paper briefly presents basic work principle and classification of hybrid buses, interpretation of several experiences regarding to their exploitation and reasons of their accepting or denied. Also paper presents review presence of hybrid buses in Europe as well as one example of comparison analysis of fuel consumption within conventional bus with diesel engine and hybrid bus in aim to participate in answer to the question: Does increasing of hybrid buses implementation in city traffic companies is justified?

## 2. HYBRID DRIVE IN BUSES – WORK PRINCIPLE AND CLASSIFICATION

Hybrid drive in buses is composed of combination of electric motor and smaller than normal conventional internal combustion engine. The main components of hybrid drive are internal combustion engine, generator, a battery pack, and an electric motor. There are three types of hybrid drive systems. One is a parallel hybrid (Figure 1) bus where the combustion engine and the electric motor are connected to the transmission independently and where the power from the electric motor is using for "stop-and-go" traffic conditions, which are the most affected to the increasing of fuel consumption, while the power from the internal combustion engine is using at highway. Second type is hybrid bus with serial configuration, where internal combustion engine is connected to an electric generator which

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converts the energy produced by internal combustion engine into electric power (Figure 2). Thus, the main power for drive produces electric motor [3].

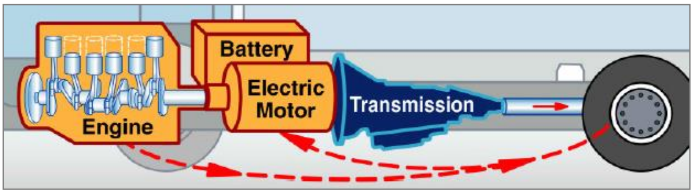


*Figure 1: Parallel hybrid configuration on hybrid buses [3]*

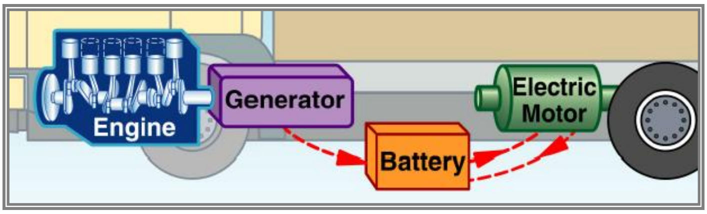


*Figure 2 Serial hybrid configuration on hybrid buses [3]*

The third type is combination of parallel and serial configuration of hybrid drive. In serial configuration, since the ICE is not connected to the wheels; it can operate at an optimum rate and can even be switched off for short periods of time for a temporary all-electric operation of the bus. Buses with parallel configuration in comparison with buses with serial hybrid configuration can provide high percent of fuel consumption efficiency on highway at high constant speeds, while serial configuration is better solution for city traffic environment, which is characterized with “stop-and-go” traffic [3].

## 3. SOME EXPERIENCE IN IMPLEMENTATION OF HYBRID BUSES

Regarding to the configuration of hybrid buses, for city traffic companies, beside mentioned fact (reducing of exhaust emission gases) it is particularly important element which is refers to possibility of reducing fuel consumption. However, uncertainty in their accepting is related to insufficiently improvement of reduced fuel consumption in real exploitation conditions, particularly in city traffic environment.  Experiences in their using in such conditions are different. Beside, insufficiently practical improvement of reducing fuel consumption, problems of their higher participation in city traffic companies, can be dedicate to possible complexity of their maintenance, maintenance costs and cost price of hybrid buses. Complexity of their maintenance is related to the batteries which are using for energy storage for power of electro motors, while other components are suitable for maintenance.  Many maintenance experts in city traffic companies have opinion that with failure of batteries, it can be expected serious downtime of vehicles with hybrid drive, which is regarding to the necessary exploitation frequency of vehicle fleet extremely unwanted. Their experience told that battery in hybrid buses is a component that is non-reparable and that the only way to repair failure and to get hybrid vehicle in fully function is to replace old batteries with new, which price is relative high in comparison with average price of components with similar functional characteristic and purposes. This indicates increasing of maintenance costs. Average price of batteries for hybrid vehicles is about 700 $ and more

[1], while frequency of their failures is high. For example, city traffic in London was equipped with 500 hybrid buses, which are from Irish bus factory “Wright bus”. After relative short period in exploitation, 80 buses worked only in the mode where using diesel internal combustion engine is. Reason for that were failures of batteries. Also 200 buses demands replacing of previous batteries with new [2]. Besides that, significant role in their higher participation in city traffic companies is related to the cost price. Average price of one contemporary hybrid bus is about 250.000-270.000 euros, while price of the conventional contemporary bus with engine emission class 5 and 6 is about 220.000 euros. [5, 6] If the topic is total maintenance costs, estimation of manufacturers is that total maintenance costs for conventional buses is approximately 0.10-0.15 euro cent/km, while total maintenance costs for hybrid buses is approximately 0.12-0.17 euro cent/km [5].

## 4. REVIEW THE PRESENCE OF HYBRID BUSES IN EUROPE

First hybrid buses in Europe were put into operation in year 2006. Period from year 2006-2010 was marked by small number of hybrid buses in exploitation in public transportation. It was the pilot testing a hybrid concept in cities: Paris, Barcelona, Dresden, Strasbourg, Nuremberg, Wallonia and Flanders region in Belgium, Luxemburg. London was exception where from 2006 in regular exploitation included 56 "double-decker’’ Wright-bus, which can be considered the beginning of the "mass" of introducing this kind of buses in Europe [9]. The EU has been in service 178 buses with hybrid drive but the mid-2012, in service is 1191 buses with hybrid drive.

Cities and regions with the highest number of hybrid buses currently in service are: London (260), Manchester (162); Flanders Region-Belgium (136), Dresden (57), Oxford (43); Birmingham (33), Dordrecht (27), Barcelona (25), Region South Holland (24), Luxembourg (21), Hamburg (20), Oslo (18), Bochum (13) [09]. (Figure 3)

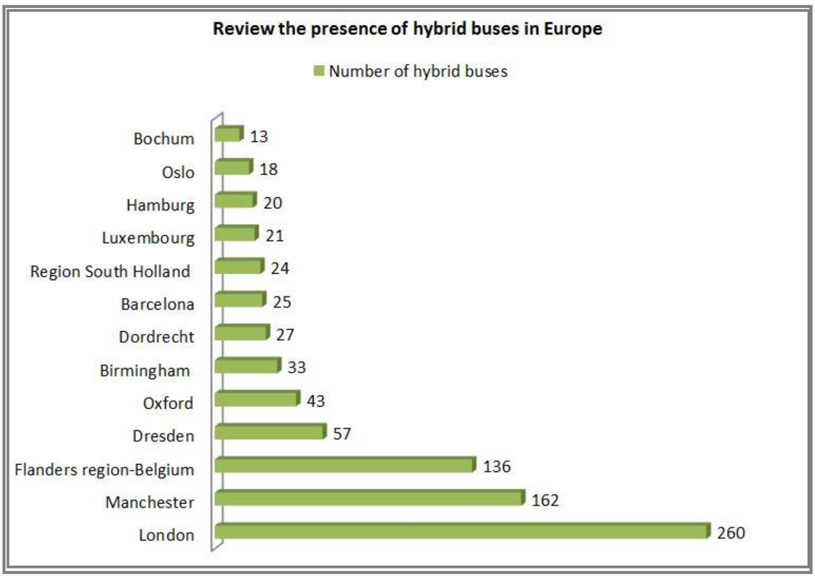


*Figure 3 Presence of hybrid buses in Europe cities*

## 5. COMPARISON OF FUEL CONSUMPTION BETWEEN HYBRID AND BUS WITH CONVENTIONAL DIESEL DRIVE – A CASE STUDY

Beside interpretation and analysis of different actualities regarding to the hybrid buses, in this paper particularly accent was placed to the lower fuel consumption within hybrid buses. [10, 12] In that purposes, it was performed comparison analysis of fuel consumption between hybrid bus and bus with conventional diesel engine. For monitoring of fuel consumption, it was selected two contemporary buses with diesel engine and hybrid drive. Both of them were in the same exploitation conditions. It is the city line, where the buses daily passing in average from 150-320 kilometers. The monitoring of fuel consumption for mentioned buses was performed during the 11 days driving. Both vehicles which were participated in analysis were without functional defects and during the monitoring there was no performing of maintenance. Also failures were not identified. Fuel in vehicles was on the same quality level for all 11 days of monitoring. For both buses tires were checked every day of monitoring, where was identified proper air pressure in tires. Bus drivers were with experience in driving both, buses with conventional diesel engine and hybrid buses, with similar driving behavior. Some of technical characteristic of compared buses, which are significant for the analysis are:

1. Conventional bus with diesel engine [04]:
   - length: 12.000 mm;
   - width: 2.550 mm;
   - height: 3.076 mm, including air condition system;
   - Tire size: 275/70 R 22.5;
   - Fuel tank capacity: 280 l;
   - Gross vehicle weight: 18.000 kg;
   - Engine: diesel 7.700 cm3, power Pmax = 210 KW na 2200 rpm, max. torque Tmax = 1.120 Nm at 1.200-1.600 rpm , emission class Euro 5;
   - Transmission: 6-speed, automatic transmission

2. Hybrid bus [11]:
   - length: 12.000 mm;
   - width: 2.550 mm;
   - height: 3.200 mm;
   - Tire size: 275/70 R 22.5;
   - Gross vehicle weight: 18.600 kg;
   - Hybrid system: Parallel hybrid configuration;
   - Diesel engine: 5.000 cm3, Pmax = 210 KW, Tmax = 800 Nm;
   - Electro motor: Pmax = 210 KW, Tmax = 800 Nm;
   - Power battery: 600 V;
   - Transmission: 12-speed, automatic transmission
   - Fuel efficiency: 35 % more fuel-efficiency than a conventional bus of the same category.

From above listed technical characteristics, it can be concluded that these buses are with very similar performance. This is particularly related to engines that using vehicle which were subject of monitoring of fuel consumption as well as dimensions and transmission. With this it is eliminated potential criticism to the possible structural and functional diversity of vehicles that are subject of monitoring. Measurement of fuel consumption, carried out with a probe (electronic float), which is designed for measuring the level of fuel and other liquids in tanks, pools, etc., which in this case sets in the tanks of vehicles that are subject of monitoring of fuel consumption (Figure 4). Length of probe is adjustable, and all sealing and mounting elements. Fuel level is recorded every 3 seconds. The measurement results are recorded in the independent electronic unit where they are processed, filtered and stored in memory. Measurement accuracy depends on several factors such as the cross-section of the tank, or the height and width, the position in which a measurement is performing etc. During this measurement, it was used probe capacitance-meter, which has a temperature gauge and G-sensor for detection of angles and fluid turbulence, which can guarantee the accuracy of the measurements [7].

*Figure 4 The probe – electronic float [7]*

Monitoring of fuel consumption was performed by Traffic Company “Mariborski potniski promet-Marprom” in year 2015 while comments and conclusions are results of author’s analysis.

Table 1 presents data about fuel consumption in l/100 kilometers for each day and kilometers which conventional bus with diesel engine have passed during that day. Also, in Table 1 is present average fuel consumption for all 11 days.

*Table 1 Fuel consumption for each day of monitoring for conventional bus with diesel engine and average consumption*

| Day | Bus type | Passed km | L/100 km | Average consumption |
|---|---|---|---|---|
| 1st day | Conventional bus with diesel engine | 317 | 24.92114 | 34,16951389 |
| 2nd day | Conventional bus with diesel engine | 325 | 28.30769 | |
| 3rd day | Conventional bus with diesel engine | 315 | 29.84127 | |
| 4th day | Conventional bus with diesel engine | 314 | 36.94268 | |
| 5th day | Conventional bus with diesel engine | 318 | 42.45283 | |
| 6th day | Conventional bus with diesel engine | 300 | 36.66667 | |
| 7th day | Conventional bus with diesel engine | 314 | 35.35032 | |
| 8th day | Conventional bus with diesel engine | 315 | 35.2381 | |
| 9th day | Conventional bus with diesel engine | 314 | 35.35032 | |
| 10th day | Conventional bus with diesel engine | 315 | 35.55556 | |
| 11th day | Conventional bus with diesel engine | 315 | 35.2381 | |

Figure 5 shows graph of fuel consumption of bus with standard diesel engine.

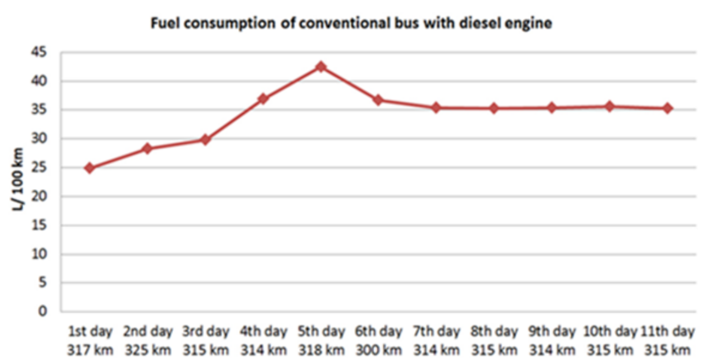


*Figure 5 Graph of fuel consumption of conventional bus with diesel engine*

In monitoring of fuel consumption of conventional bus with diesel engine, it can be notice different varieties. From the Figure 5, it can be seen that the lowest fuel consumption was on the first day of driving, when fuel consumption was 25l/100 km for 317 passed kilometers. The larger fuel consumption was recorded at fourth, fifth and sixth day, with fuel consumption of 37 l/100 km, 43 l/100 km and 36 l/100 km. These large varieties in fuel consumption can be prescribed to different driving regimes in relation to the traffic conditions. Besides that, it can be notice that on seventh, eighth, ninth, tenth and eleventh day fuel consumption was nearly the same. Total average consumption of conventional bus with diesel engine was about 35 l/100 km.

Table 2 presents data about fuel consumption in l/100 kilometers for each day and kilometers which hybrid bus with have passed during that day. Also, in Table 2 is present average fuel consumption for all 11 days.

*Table 2 Fuel consumption for each day of monitoring for hybrid bus and average consumption*

| Day | Bus type | Passed km | L/100 km | Average consumption |
|---|---|---|---|---|
| 1st day | Hybrid bus | 381 | 18.3727 | 29,77267279 |
| 2nd day | Hybrid bus | 242 | 42.56198 | |
| 3rd day | Hybrid bus | 311 | 28.93891 | |
| 4th day | Hybrid bus | 310 | 17.09677 | |
| 5th day | Hybrid bus | 310 | 28.06452 | |
| 6th day | Hybrid bus | 224 | 33.03571 | |
| 7th day | Hybrid bus | 311 | 26.6881 | |
| 8th day | Hybrid bus | 307 | 42.34528 | |
| 9th day | Hybrid bus | 293 | 27.30375 | |
| 10th day | Hybrid bus | 232 | 30.17241 | |
| 11th day | Hybrid bus | 161 | 32.91925 | |

Figure 6 shows graph of fuel consumption of hybrid bus.

In monitoring of fuel consumption of hybrid bus, it can be also notice different varieties. From the Figure 6, it can be seen that the lowest fuel consumption was on the fourth day of driving, when fuel consumption was 17 l/100 km for 310 passed kilometres. The larger fuel consumption was recorded at second, sixth and eighth day, with fuel consumption of 42 l/100 km, 33 l/100 km and 42 l/100 km. These large varieties in fuel consumption can be also prescribed to different driving regimes in relation to the traffic conditions. Besides that, it can be notice that on the other days, unlike bus with diesel engine, there is a significant more variety. Total average consumption of hybrid bus with diesel was about 29 l/100 km.

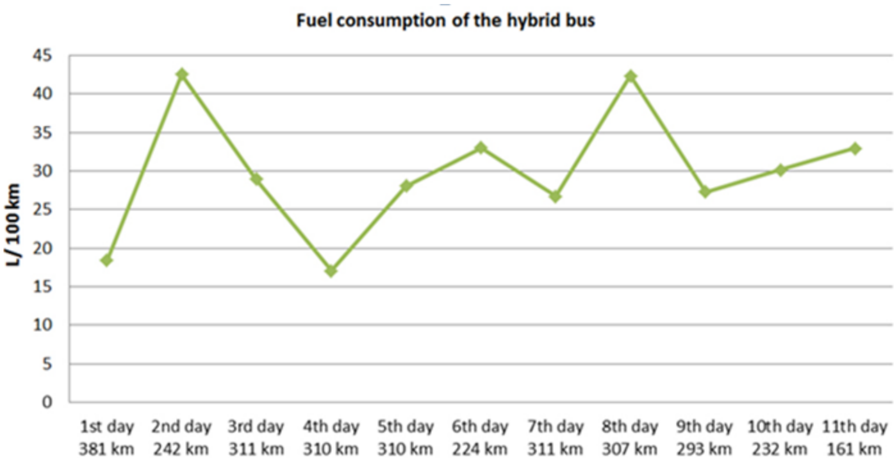


*Figure 6 Graph of fuel consumption of conventional bus with diesel engine*

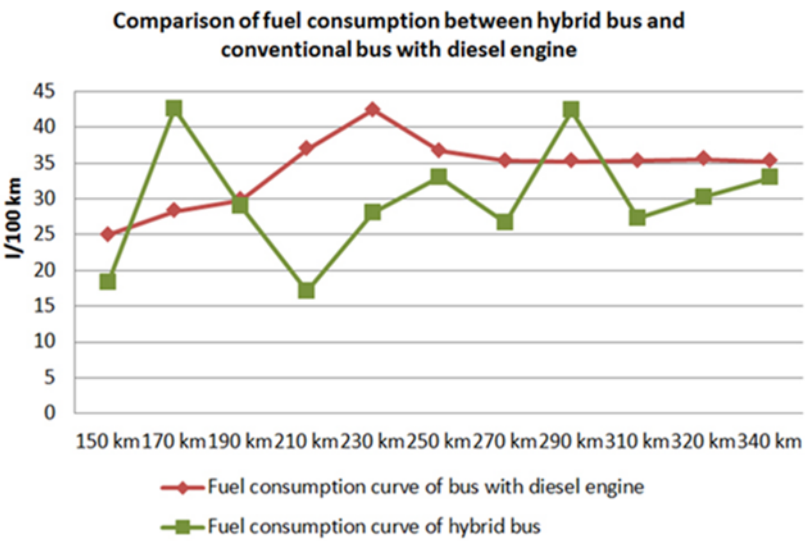


*Figure 7 Comparison of fuel consumption between hybrid and conventional bus with diesel engine*

In direct comparison of fuel consumption graphs of hybrid and bus with diesel engine, it can be seen that hybrid bus has moments with larger fuel consumption versus bus with conventional diesel engine. However, certainly there are more days when hybrid bus has significant lower fuel consumption unlike bus with diesel engine. This particular refers to first, fourth, fifth, sixth, seventh, ninth, tenth and eleventh day. Total average fuel consumption is on the side of the hybrid bus, with average consumption of nearly 29 l/100 km. Thus, hybrid bus made up about 4l/100 km lower fuel consumption versus conventional bus with diesel engine. Manufacturer of hybrid bus which was participating in comparison analysis estimate about 35% more fuel-efficiency than a conventional bus of the same category. Considered obtain results of comparative analysis, it can be concluded that hybrid bus, in the same exploitation conditions was achieved about 13% savings in fuel consumption relative to conventional bus with diesel engine.

## 6. CONCLUSIONS

Hybrid buses should certainly, from the standpoint of reducing exhaust emissions gases and environmental pollution, took an important place in large vehicle fleets, especially in the city traffic companies. However, their higher presence undoubtedly depends of higher level of improvement in lower fuel consumption in comparison with conventional buses with diesel engine. Example of the comparison analysis of monitoring fuel consumption, which is present in this paper, show that fuel consumption efficiency is significant lower than estimation of hybrid buses manufactures. This case show that is 22% lower saving in fuel consumption versus commercial data about fuel consumption efficiency of hybrid bus which was participate in comparison analysis. Besides that, factors such as price of the hybrid buses, maintenance costs, as well as problems related to the powering and failures of batteries for electro motors, also exists. For all this potential problems, better answer gives development countries, which can be seen in preview of presence of hybrid buses in cities in Europe, while in middle and poor countries it cannot be seen larger participation of hybrid vehicles in city transportation companies. Although in this example was identified lower savings in fuel consumption versus commercial data about fuel consumption efficiency of hybrid bus, if fuel savings considered on the level of the whole vehicle fleet, savings in fuel consumption is much larger. Thus, it can be said that implementation of hybrid vehicles in city transportation companies is more than justified, together with reducing of exhaust emissions gases. Further research should be performed through longer time period, with consideration of heterogeneity of test vehicle fleet, from the aspect of vehicle age and diversity of their constructional characteristics.

## REFERENCES

[1] https://www.alibaba.com/product-detail/Free-maintenance-green-energy-rechargeable-lithium_60439964635.html?spm=a2700.7735675.30.2.Kv2Cx4&s=p, date of access: 13.09.2016.

[2] http://www.bestmag.co.uk/content/london%E2%80%99s-hybrid-buses-suffer-li-ion-battery-failures, date of access: 05.09.2016.

[3] http://www.eesi.org/files/eesi_hybrid_bus_032007.pdf, datum pristupa: 09.09.2016. godine.

[4] http://buses.mercedesbenzme.com/media/1503957/2014_08_01_techinfo_conecto_en.pdf, date of access: 10.09.2016.

[5] http://www.intrans.iastate.edu/publications/_documents/t2summaries/hybrid_transit_bus_tech_brief1.pdf, date of access: 07.09.2016.

[6] http://www.civitas.eu/sites/default/files/civitas_policy_note_clean_buses_for_your_city.pdf, date of access: 03.09.2016.

[7] http://www.ais.d-logic.rs/sr/proizvodi-i-usluge/pracenje-vozila/kapacitivni-merac-nivoa-goriva, date of access: 21.07.2016.

[8] M.J. Kellawey (2007): Hybrid buses-What their batteries really need to do, Journal of power sources, 168, pp. 95-98.

[9] Mišanović, S. (2014): Exploitation and environmentally aspects of hybrid buses in European cities, Mobility and Vehicle Mechanics, Vol. 40, pp. 17-31.

[10] S., Hallmark, R., Sperry (2012): Comparison of in-use operating costs of hybrid-electric and conventional school buses, Journal of Transportation Technologies, No.2, pp. 158-164.

[11] http://www.finpro.fi/documents/10304/8ebf0d65-0855-4902-8f6d-1d4c5dc23c27, date of access: 12.09.2016.

[12] Kaplanović, S., Manojlović, A. (2013): „Environmental taxation policy: the case of taxes on motor fuels in the European union", Journal of Applied Engineering Science (Istraživanja i projektovanja za privredu), No. 2, Vol. 11, pp. 57-62.

# A STUDY OF RURAL PUBLIC TRANSPORT SYSTEM – A CASE STUDY OF MYSORE AND CHAMARAJANAGAR DISTRICTS

*N. Ramesh Babu*[1]*, Harish Mahadevappa,*

**UDC: 629.1-49**

**ABSTRACT:** Providing transport facilities to rural people are very important in order to improve the economic lot of the people. In Mysore and Chamarajanagar Districts, transportation is provided by both KSRTC (Public Organisation) and Private Bus Operators. The objective was to study the rural transportation system of these two districts provided by KSRTC and private bus operators and do a comparative analysis and see which organization provides better transportation in the rural areas and also to give some suggestions to improve it. Data were collected by administering questionnaire to the commuters of both public and private bus service.

**KEY WORDS:** KSRTC, comparative analysis, data, public organization

# STUDIJA RURALNOG JAVNOG TRANSPORTNOG SISTEMA-ISTRAZIVANJE SLUČAJA MYSORE I CHAMARAJANAGAR OBLASTI

**REZIME**: Pružanje prevoza do seoskog stanovništva je veoma važno u cilju poboljšanja ekonomije mnogih ljudi. U Mysore and Chamarajanagar okrugu, prevoz je obezbeđen i od strane KSRTC (javna organizacija) i privatnih autobuskih operatera. Cilj je bio da se prouči ruralni prevoz ova dva okruga obezbeđeni od strane KSRTC-a i privatnih operatera i napravi komparativna analiza, i vidi koja organizacija pruža bolji transport u ruralnim područjima, kao i da se daju neke sugestije za poboljšanje. Podaci su prikupljeni primenom upitnika putnika i javnog i privatnog prevoza.

**KLJUČNE REČI:** KSRTC, uporedna analiza, podaci, javne organizacije

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# A STUDY OF RURAL PUBLIC TRANSPORT SYSTEM – A CASE STUDY OF MYSORE AND CHAMARAJANAGAR DISTRICTS

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## 1. INTRODUCTION

In India, nearly 70 percent of the people live in rural areas. In order to improve the economic lot of the rural people a good rural transportation with good connectivity is required. Many rural folks come to the city to sell their agricultural produce and good rural transportation is very much required. The economic level of the rural people has improved a lot in some of the Indian States like Kerala due to good rural public transportation and connectivity. In this study the problems of public transportation in the two districts of Mysore and Chamarajanagar Districts has been studied. In Mysore and Chamarajanagar Districts public transportation is provided by both KSRTC and private sector.

## 2. OBJECTIVE OF THE STUDY

The objective is to study the rural transportation system of two districts of Karnataka i.e., Mysore and Chamarajanagar Districts and come out with suitable suggestions to improve the rural transportation system in these two districts.

## 3. METHODOLOGY OF THE STUDY

The methodology of the study is given below.

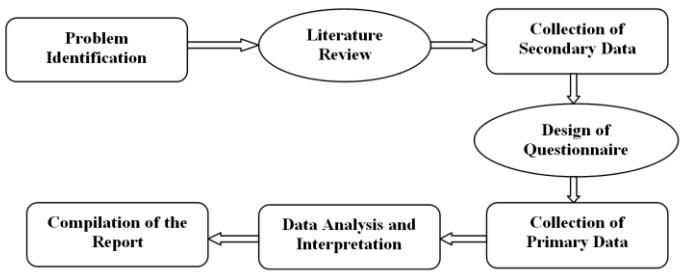


*Figure 1.1 The methodology of the study*

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[2] *Harish Mahadevappa, Transport Planner*

## 4. DATA COLLECTION AND ANALYSIS

Public opinion survey was conducted in Mysore and Chamarajanagar Districts regarding performance of public transportation of Government (KSRTC) and Private Buses. Questionnaire was designed for both KSRTC and private bus commuters and the questionnaire was administered to the commuters in Chamarajanagar and Mysore District. The questionnaire consisted of three sections, General Section consisted of general questions like name, age and gender of respondents, Basic Travel Information Section consisted of origin, destination, frequency of travel, purpose of travel, cost of fare etc., and KSRTC/Private Bus Section consisted of questions like frequency, connectivity, overcrowding, travel comfort, cleanliness, safety etc., Nearly 250 commuters were interviewed regarding the performance of KSRTC and Private Bus.

### *4.1 General Questions*

General Questions involved question regarding gender and age group of respondents.

### *4.2 Gender of Respondents*

The genders of majority of respondents in the opinion survey were male (63%) as shown in Figure 1.2.

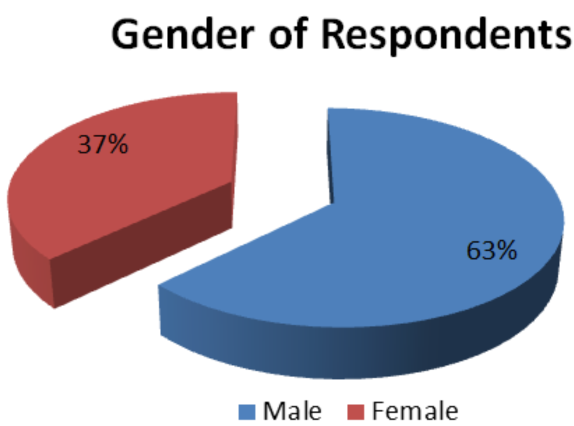


*Figure 1.2 Gender of Respondents*

### *4.3Age Group of Respondents*

The age group of majority of respondents was under 25 years of age as shown in Figure 1.3.

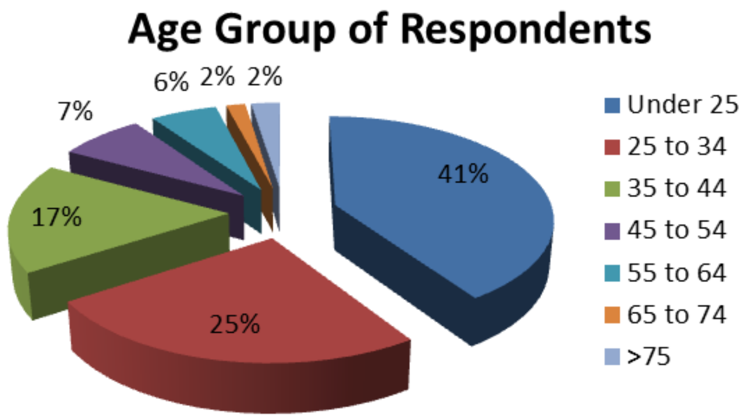


*Figure 1.3 Age group of Respondents*

### *4.4 Basic Travel Information*

The questions of Basic Travel Information involved purpose of travel, frequency of travel, travel by KSRTC or Private buses.

### *4.5 Purpose of Travel*

The purpose of travel of thirty six percent (majority) of respondents was work, twenty four percent was for education, twelve percent was for shopping and the remaining 28 percent were others as shown in Figure 1.4.

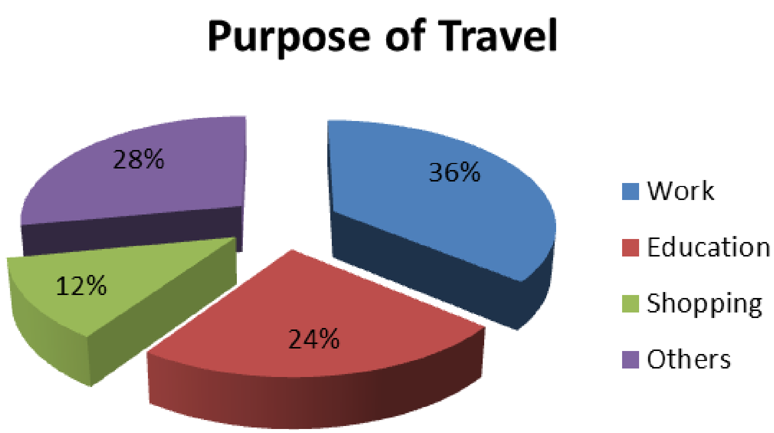


*Figure 1.4 Purpose o Travel*

***4.6 Frequency of Travel***

The frequency of travel of forty two percent (majority) of the respondents was daily, twenty two percent was weekly, nineteen percent was monthly, six percent was fortnightly, five percent was bi-weekly and the balance six percent were others as shown in Figure 1.5.

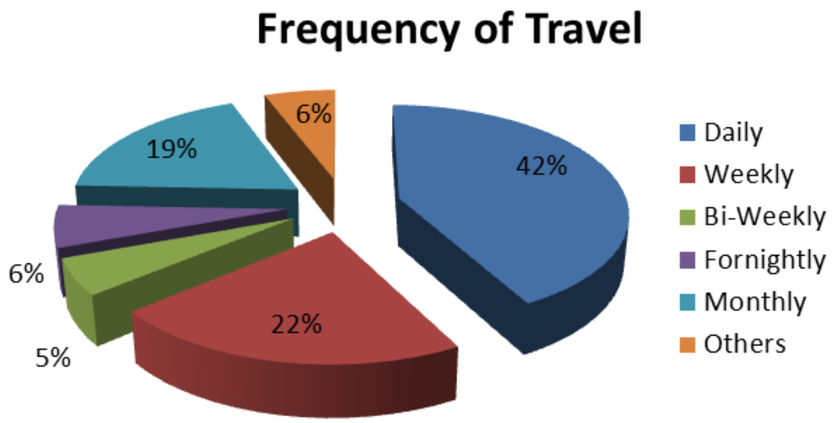


*Figure 1.5 Frequency of Travel*

***4.7 Do you travel by KSRTC or Private Bus?***

As per the survey majority (64 %) of the respondents travelled by KSRTC bus, twenty nine percent travelled by private bus and the balance seven percent travelled by both KSRTC and Private Bus as shown in Figure 1.6.

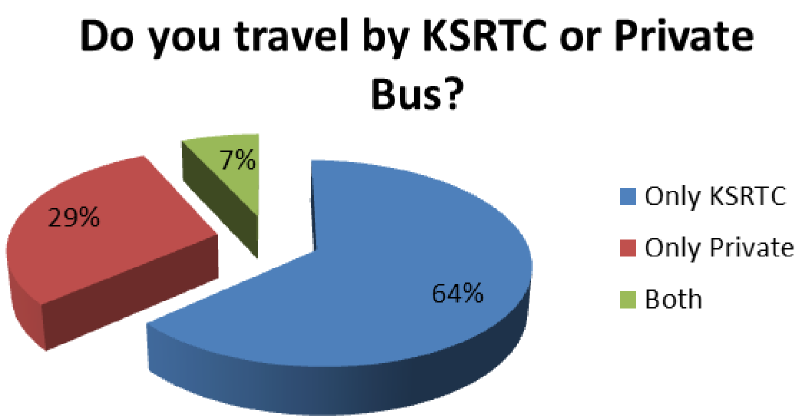


*Figure 1.6 Questionnaire of using transport*

### *4.8 Performance*

The questions pertaining to performance involved frequency of buses, connectivity of buses, stops, arrival on scheduled time, departure on schedule time, overcrowding, safety, etc.

### *4.9 Frequency of Buses*

To the question 'Is the frequency of buses good?'

- 76 percent of KSRTC bus commuters said 'Yes' and 24 percent said 'No'.
- 68 percent of private bus commuters said 'Yes' and 32 percent said 'No'.
- In comparison between KSRTC and Private Buses, KSRTC buses have better frequency when compared to private buses.

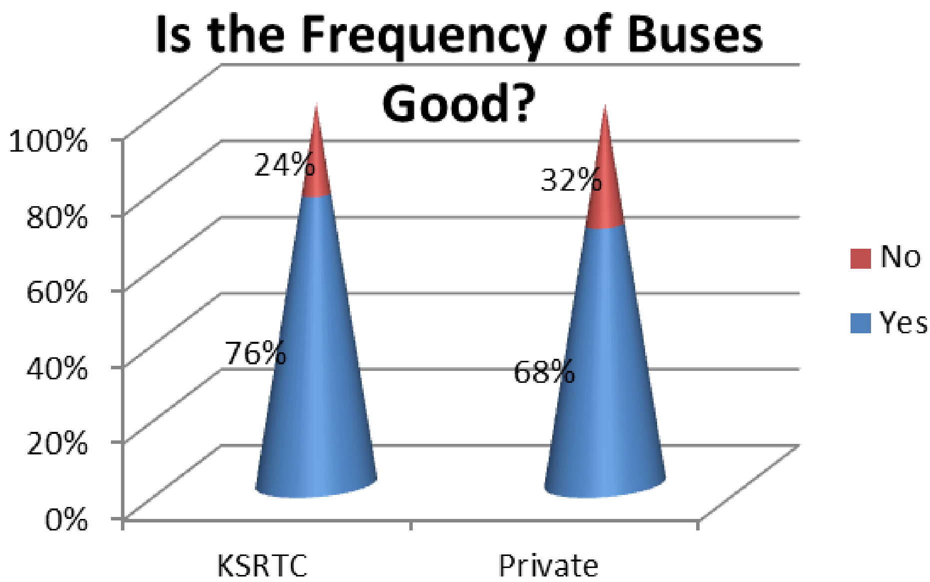


*Figure 1.7 The question 'Is the frequency of buses good?'*

### *4.10 Connectivity of Buses*

To the question 'Is the connectivity of buses good?'

- 73 percent of KSRTC bus commuters said 'Yes' and 27 percent said 'No'.
- 68 percent of private bus commuters said 'Yes' and 32 percent said 'No'.
- In comparison KSRTC buses have better connectivity when compared to private buses.

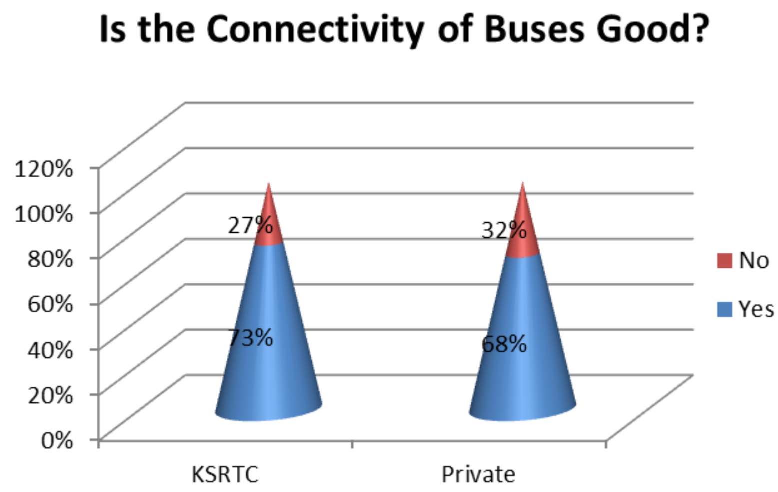


*Figure 1.8 The question 'Is the connectivity of buses good?'*

#### *4.11 Stops*

To the question 'Do the buses give enough stops?'

- 68 percent of the KSRTC bus commuters said 'Yes' and 32 percent said 'No'.
- 76 percent of the Private bus commuters said 'Yes' and 24 percent said 'No'.
- In comparison private buses give more stops than KSRTC buses.

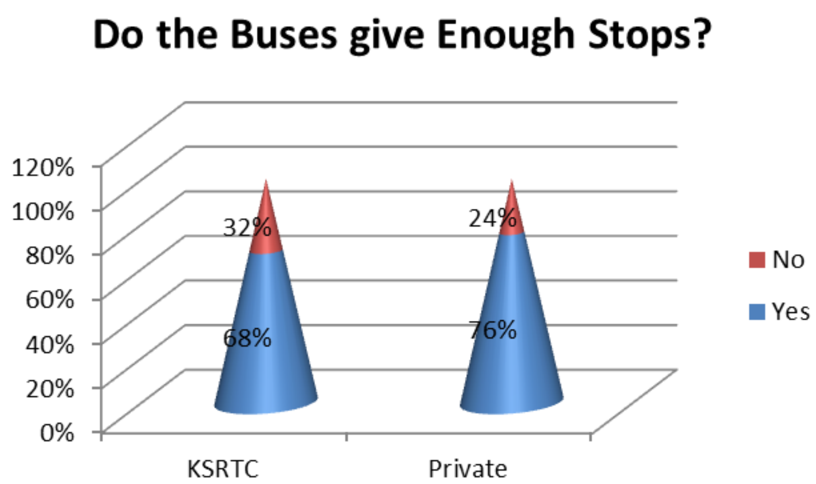


*Figure 1.9 The question 'Do the buses give enough stops?'*

#### *4.12 Arrive on Schedule Time*

To the question 'Do the buses arrive on Schedule Time?'

- 61 percent of the KSRTC bus commuters said 'Yes' and 39 percent said 'No'.
- 64 percent of the Private bus commuters said 'Yes' and

• In comparison private buses arrive on scheduled time when compared to KSRTC buses.36 percent said 'No'.

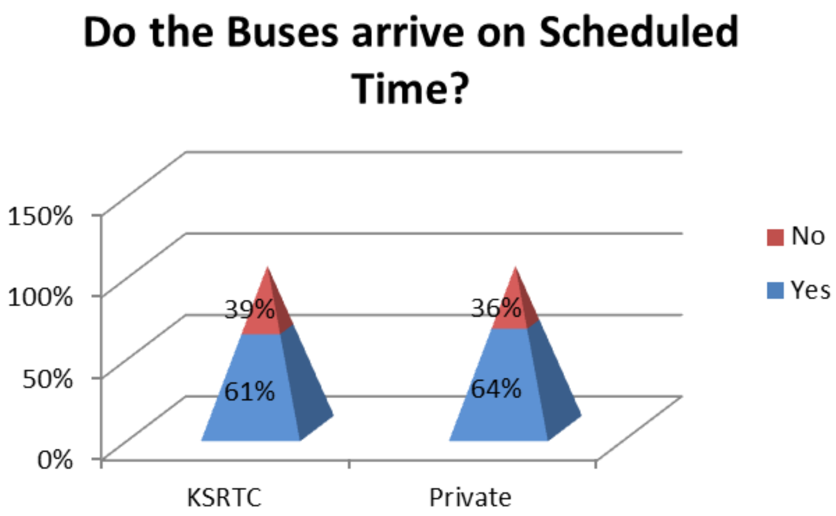


*Figure 1.10 The question 'Do the buses arrive on Schedule Time?'*

### *4.13 Depart on Scheduled Time*

To the question 'Do the buses depart on Schedule Time?'

- 57 percent of the KSRTC bus commuters said 'Yes' and 43 percent said 'No'.
- 57 percent of the Private bus commuters said 'Yes' and 43 percent said 'No'.
- It shows that both the KSRTC buses and Private buses depart on scheduled time.

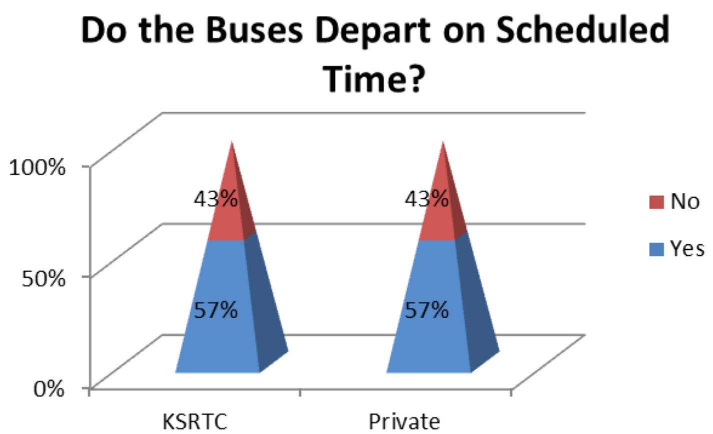


*Figure 1.11 The question 'Do the buses depart on Schedule Time?'*

### *4.14 Buses Overcrowded*

To the question 'Are the buses overcrowded all the time?'
- 49 percent of the KSRTC bus commuters said 'Yes' and 51 percent said 'No'.
- 61 percent of the Private bus commuters said 'Yes' and 39 percent said 'No'.
- It shows that the private buses are overcrowded all the time.

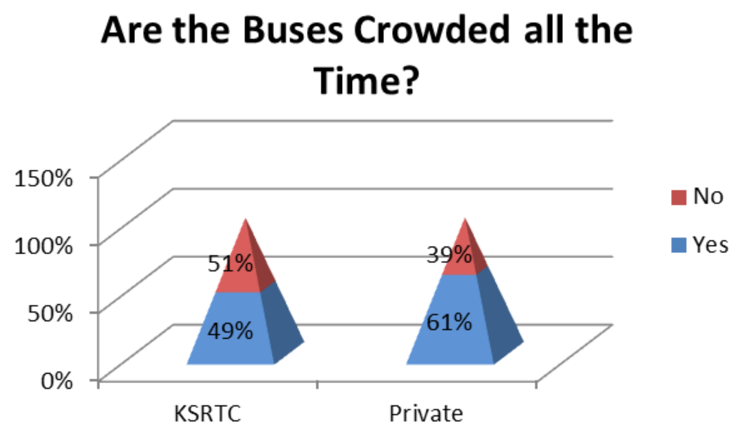


*Figure 1.12 The question 'Are the buses overcrowded all the time?'*

### *4.15 Buses Comfortable to Travel*

To the question 'Are the buses comfortable to travel?'
- 77 percent of the KSRTC bus commuters said 'Yes' and 23 percent said 'No'.
- 66 percent of the Private bus commuters said 'Yes' and 34 percent said 'No'.
- In comparison KSRTC buses is more comfortable to travel when compared to private buses.

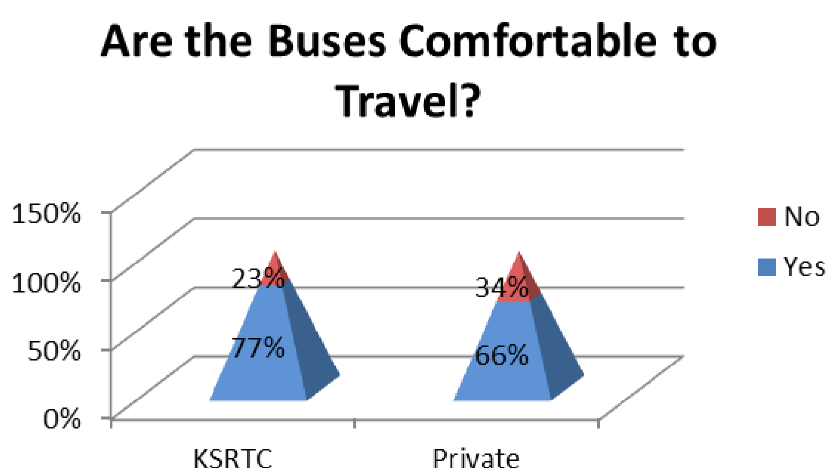


*Figure 1.13 The question 'Are the buses comfortable to travel?'*

### *4.16 Buses are Clean and Well Maintained*

To the question 'Do you think that the buses are clean and well maintained?'

- 53 percent of the KSRTC bus commuters said 'Yes' and 47 percent said 'No'.
- 54 percent of the Private bus commuters said 'Yes' and 46 percent said 'No'.
- It shows that both KSRTC and private buses are clean and well maintained.

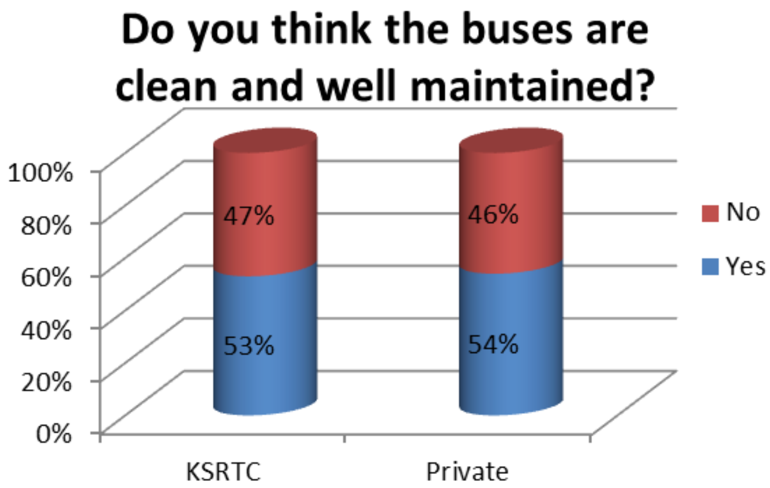


*Figure 1.14 The question 'Do you think that the buses are clean and well maintained?'*

### *4.17 Seats in Buses Comfortable*

To the question 'Are the seats in the bus comfortable?'

- 62 percent of the KSRTC bus commuters said 'Yes' and 48 percent said 'No'.
- 56 percent of the Private bus commuters said 'Yes' and 44 percent said 'No'.
- In comparison the seats in KSRTC buses are more comfortable than private buses.

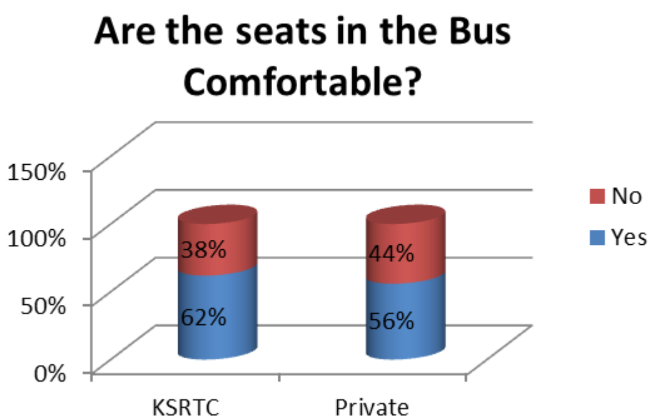


*Figure 1.15 The question 'Are the seats in the bus comfortable?'*

### *4.18 Easy to getin/getoff buses*

To the question 'Are the buses are easy to getin/getoff?'

- 71 percent of the KSRTC bus commuters said 'Yes' and 29 percent said 'No'.
- 58 percent of the Private bus commuters said 'Yes' and 42 percent said 'No'.
- In comparison it is easy to getin/getoff in KSRTC buses when compared to private Buses.

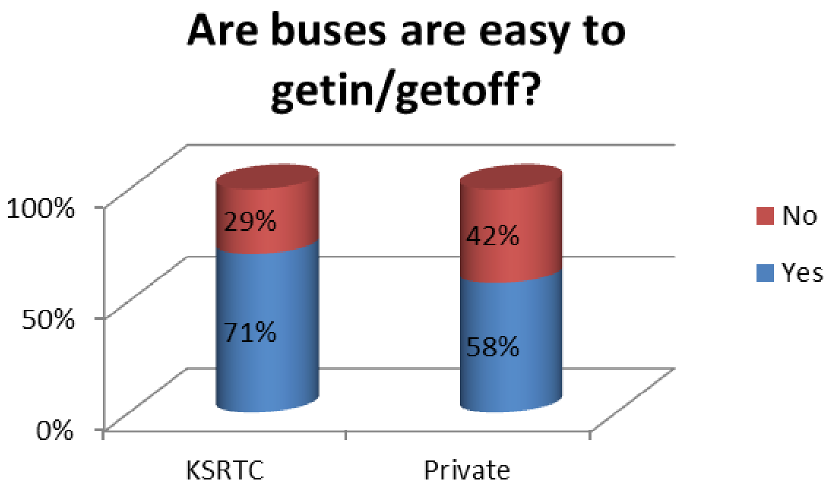


*Figure 1.16 The question 'Are the buses are easy to getin/getoff?'*

### *4.19 Get Seat in the Bus*

To the question 'Do you get seat in the bus?'

- 61 percent of the KSRTC bus commuters said 'Yes' and 39 percent said 'No'.
- 54 percent of the Private bus commuters said 'Yes' and 46 percent said 'No'.
- In comparison it is easy to get seat in KSRTC buses when compared to private buses.

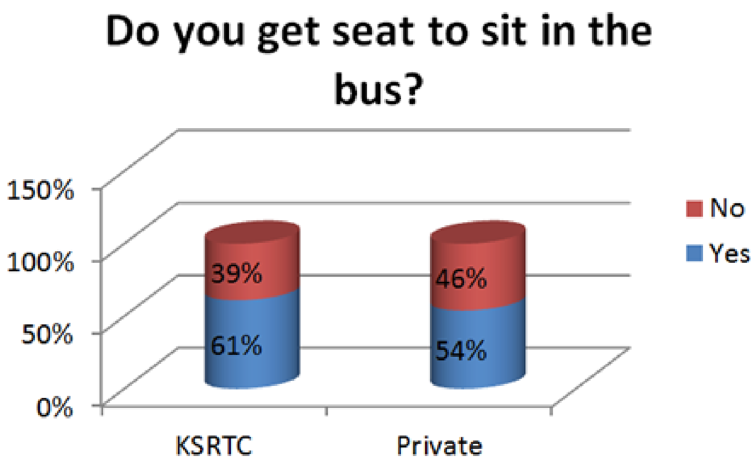


*Figure 1.17 the question 'Do you get seat in the bus?'*

### *4.20 Buses are Safe*

To the question 'Do you think buses are safe?'

- 80 percent of the KSRTC bus commuters said 'Yes' and 20 percent said 'No'.
- 64 percent of the Private bus commuters said 'Yes' and 36 percent said 'No'.
- In comparison the commuters think that the KSRTC buses are safer when compared to private buses.

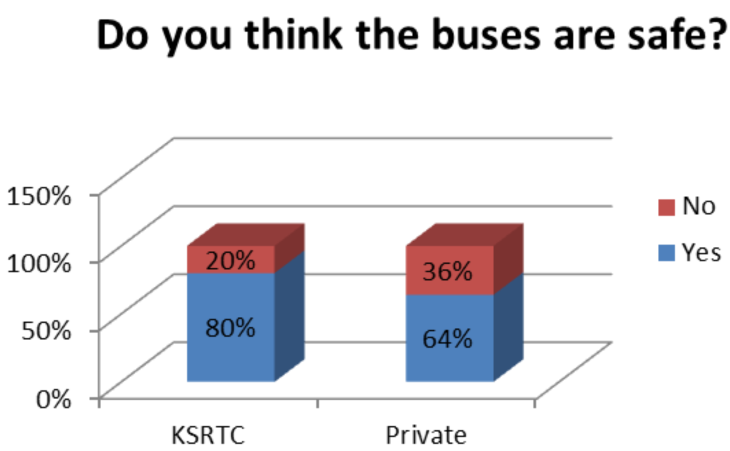


*Figure 1.18 The question 'Do you think buses are safe?'*

### *4.21 Buses Overspeed*

To the question 'Do you think that the buses overspeed?'

- 30 percent of the KSRTC bus commuters said 'Yes' and 70 percent said 'No'.
- 56 percent of the Private bus commuters said 'Yes' and 44 percent said 'No'.
- It shows that the private buses over speed when compared to KSRTC buses.

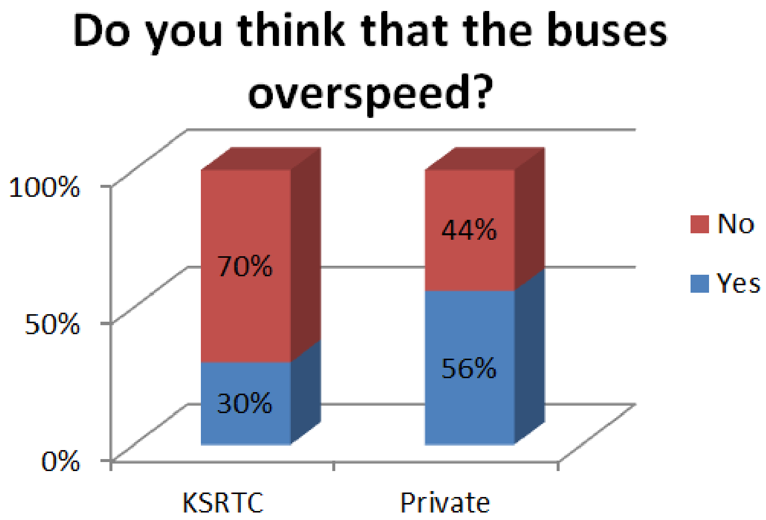


*Figure 1.19 The question 'Do you think that the buses overspeed?'*

#### *4.22 Buses Breakdown Frequently*

To the question 'Do the buses breakdown frequently?'

- 42 percent of the KSRTC bus commuters said 'Yes' and 58 percent said 'No'.
- 51 percent of the Private bus commuters said 'Yes' and 49 percent said 'No'.
- It shows that the private buses breakdown frequently when compared to KSRTC buses.

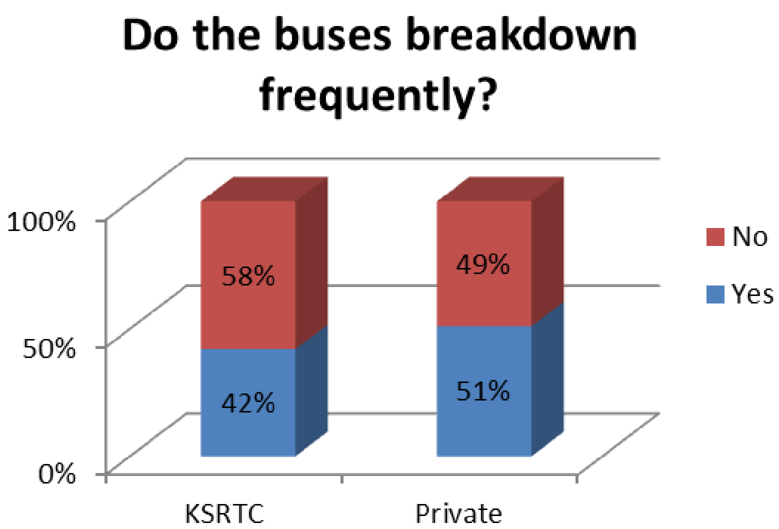


*Figure 1.20 The question 'Do the buses breakdown frequently?'*

### *4.23 Drivers Safe and Competent*

To the question 'Are drivers safe and competent?'

- 79 percent of the KSRTC bus commuters said 'Yes' and 21 percent said 'No'.
- 67 percent of the Private bus commuters said 'Yes' and 33 percent said 'No'.
- In comparison it shows that the drivers of KSRTC buses are more safe and competent when compared to private bus drivers.

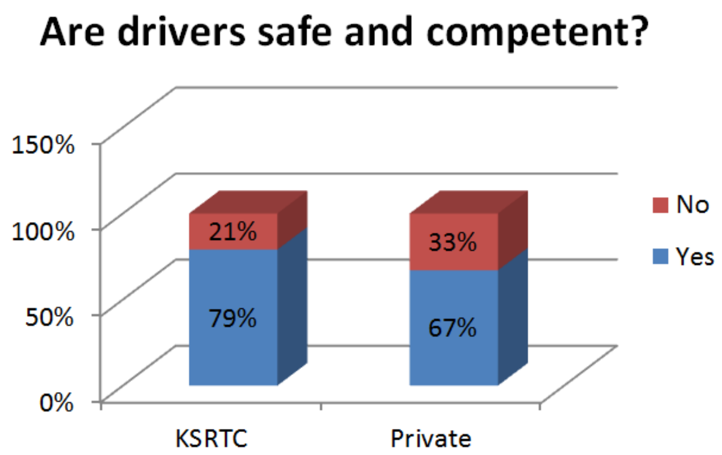


*Figure 1.21 The question 'Are drivers safe and competent?'*

### *4.24 Drivers Respond to Request Stop*

To the question 'Do the bus drivers respond to request stop?'

- 50 percent of the KSRTC bus commuters said 'Yes' and 50 percent said 'No'.
- 63 percent of the Private bus commuters said 'Yes' and 37 percent said 'No'.
- It shows that the drivers of Private Buses respond to request stop better than KSRTC buses.

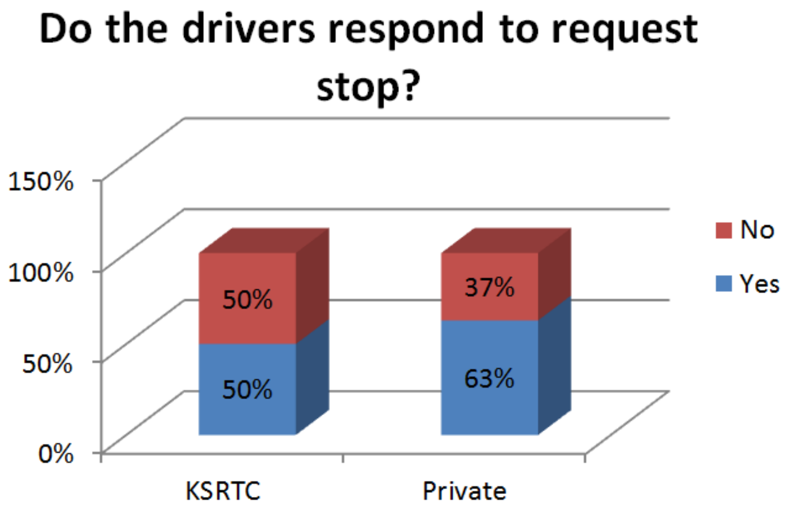


*Figure 1.22 The question 'Do the bus drivers respond to request stop?'*

## 5. CONCLUSIONS

It can be concluded from the study that,

- The purpose of travel of majority of commuters is work and then comes education, others and shopping.
- Most of the commuters travel daily and most of the commuters travel by KSRTC buses.
- KSRTC buses have better frequency when compared to private buses.
- KSRTC buses have better connectivity when compared to private buses.
- Private buses give more stops when compared to KSRTC buses.
- Private buses arrive on scheduled time when compared to KSRTC buses.
- Private buses are overcrowded most of the time.
- KSRTC buses are more comfortable to travel when compared to private buses.
- KSRTC bus seats are more comfortable to sit when compared to private bus seats.
- KSRTC buses are more comfortable to getin/getoff at destinations when compared to private buses.
- It is easy to get a seat in KSRTC buses when compared to private buses.
- KSRTC buses are perceived to be safer than private buses.
- Private buses over speed when compared to KSRTC buses.
- Private buses breakdown more frequently when compared to KSRTC buses.
- KSRTC buses provide alternate buses if there is any breakdown, but private buses do not provide alternate buses if there is any breakdown.
- KSRTC bus drivers are perceived to be more safe drivers when compared with private bus drivers.
- Private buses respond to request stops better than the KSRTC buses.

## RECOMMENDATIONS

The following are the recommendations for the Private Buses and KSRTC Buses.

***Private Buses***

- The private bus operators should be made to run on their original approved routes with strict enforcement from the Government.
- Adulteration of fuel in private buses should be checked periodically with the help of Karnataka State Pollution Control Board (KSPCB).
- The number of passengers who travel in private buses should be restricted and overcrowding should be avoided for the convenience and safety of commuters.
- There should be regular check for emissions for the private vehicles by KSPCB officials with the help of police.
- Private bus operators should also be brought under the speed breakers rule in order to reduce accidents.
- The 15 years old vehicles should be scrapped with permit with immediate effect.

***KSRTC Buses***

- Incentives should be given to KSRTC conductors and drivers who make more collection on their routes or attract more passengers to KSRTC buses.
- New routes have to be planned for revenue generation by connecting to new villages by KSRTC.
- KSRTC should attract commuters by giving additional stops in Hoblis, Gram Panchayats and Towns in the district.
- KSRTC should provide more number of buses during peak hours to district and taluk head quarters.
- More number of buses should be provided where there are educational institutions, offices, industries, next to cities and towns in these two districts.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] Kevin Majkut, ‘Rural Transportation Issues and Strategies’, Queens School of Business, The Monieson Centre-Transforming Business in the Knowledge Economy, March 2011.

[2] Ramaswamy N.S., ‘Rural Transport in India’, Rural Transportation Study, Indian Institute of Management, Bangalore, 1991.

[3] Chapter 13: Transport, Roads, Railways, Ports and Highways.

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# ECOLOGY AND ENERGY ASPECTS OF EXPLOITATION FULLY ELECTRICAL BUSES ON THE NEW LINE IN PUBLIC TRANSPORTATION IN BELGRADE

*Slobodan Mišanović*[1]*, Slaven Tica, Željko Milković, Pavle Krstić, Branko Milovanović*

**UDC:**

**ABSTRACT:** Buses with fully electric drive are present in many cities of Europe, Asia and America. City of Belgrade and JKP GSP ’’Beograd’’ (City Public Transport Company’’ Belgrade’’ ), following the positive experience of the public transport companies which have started the exploitation of buses with electric drive, will plan the beginning of the regular exploitationin in September 2016, with 5 electrical buses on a new line EKO 1 (Vukov spomenik-"Belvil"). It will be the first step in a long-term strategy of using buses with electric drive.

This paper presents the first results and the effects of their use in the public transport in Belgrade in terms of exploitation, ecology and energy efficiency.

**KEY WORDS:** electric bus, public transportation, ecology, energy efficiency

# EKOLOŠKI I ENERGETSKI ASPEKTI EKSPLOATACIJE AUTOBUSA NA ELEKTRIČNI POGON NA NOVOJ LINIJI U JAVNOM PREVOZU BEOGRADA

**REZIME**: Autobusi na čisto električni pogon prisutni su u mnogim gradovima Evrope, Azije i Amerike. Grad Beograd i JKP GSP’'Beograd", sledeći pozitivna iskustva kompanija za javni prevoz koje koriste ovu vrstu autobusa, od 1. Septembra 2016.godine odpočeli su regularnu eksploataciju sa 5 autobusa na čisto električni pogon na novoj liniji EKO 1 (Vukov spomenik-"Belvil"). To je prvi korak u dugoročnoj strategiji korišćenja autobusa na električni pogon. U radu su prikazani prvi rezultati i efekti korišćenja u sistemu javnog prevoza u Beogradu sa aspekta eksploatacije, ekologije i energetske efikasnosti.

**KLJUČNE REČI:** električni autobus, javni prevoz, ekologija, energetska efikasnost

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

# ECOLOGY AND ENERGY ASPECTS OF EXPLOITATION FULLY ELECTRICAL BUSES ON THE NEW LINE IN PUBLIC TRANSPORTATION BELGRADE

*Slobodan Mišanović[1], Slaven Tica[2], Željko Milković[3], Pavle Krstić[4], Branko Milovanović[5]*

**UDC: 629.071**

## 1. INTRODUCTION

JKP GSP "Beograd" is the carrier of function public transport in Belgrade and the largest operator. In their development plans JKP GSP "Beograd" special attention dedicate on the possibilities of application of the concept of E-bus, on the operation on the most endangered traffic corridors in terms of pollution. In the past the emphasis were on monitoring trends in their development, exchange of experience with companies for public transport, bus manufacturers and was carried one pilot test.

Since August 2016, the JKP GSP "Beograd", is began a regular exploitation with 5 solo bus on purely electric drive as a first step in a long-term strategy of using buses with electric drive. These vehicles have a steady trend of development and improvement, which makes them more competitive in comparison with other concepts buses (diesel, CNG). It should be noted a significant improvement in terms of reducing vehicle weight, which is reflected in the increase in the capacity of the vehicle (80-90 passengers), which is approaching the capacity of a standard diesel-powered buses (100-105 passengers). These are significant assumptions allowing their use on the first place on the central lines in the bus subsystem Belgrade.

## 2. FROM IDEA TO REALISATION

Idea of introducing buses on pure electric drive was stemmed from JKP GSP "Belgrade" on the basis of permanent monitoring of development trends the bus subsystem in many cities of Europe and the world, as well as the positive experiences of companies that have buses on electric drive in operation. The idea is that the City of Belgrade to be included in the "green" maps cities that have electric buses in operation, on the way that the E-buses will operate on a completely new line in the city center that will be recognizable in that. Carrier of project is JKP GSP "Belgrade" in cooperation with the Secretariat of Environment and Secretariat of Traffic. The project of introducing buses on electric power

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in Belgrade included the following phases, (Table 1) which lasted from January 2015 to August 2016.

*Table 1 Phases of the E-bus project in Belgrade*

| Activity | Period |
|---|---|
| The idea of introducing E-bus in public transportation system | January 2015 |
| Formation of the working team' | February 2015 |
| Analysis of the most acceptable concept of E-bus | March-September 2015 |
| Analysis of variants of the new line | March-September 2015 |
| The adoption of the concept of E-bus and the route of the new line | September 2015 |
| The decision to purchase 5 E-bus | September 2015 |
| Financing model | September 2015 |
| Preparation of tender documents | September 2015 |
| An invitation to tender for the purchase of 5 E-bus | October 2015 |
| Opening of offer | December 2015 |
| Signing the contract with ''Chariot motors" for purchase of 5 E-bus' 'HIGHER' A6L | January 2016 |
| Production control of 5 E-buses | April 2016 |
| Delivery and exploitation | July /August 2016 |

## 3. THE CHOICE OF LINE: LINE 1E

Introduction of the buses on electric drive is a good way "rehabilitation " of electrical transport system on the left bank of the Sava River, considering that until 1970 were in exploitation 3 trolleybus lines that connected the old part of the city with Zemun and New Belgrade.

In this regard the line 1E (Vukov spomenik - TC "Delta City") fully justifies the use of electrically-powered buses, since that line is passes near the attractive location and transport corridors which in some sections have high levels of aero pollution and noise. (Brankova ulica, boulevard of Kralj Aleksandar) [1].


*Figure 1 Brankova street*

*Figure 2 National Assembly*

*Figure 3 Shoping malles "Usce"*

Line 1E is planned as a diametrical line that would connect Vukov monument, over the Nikola Pasic Square, Branko's Bridge to the New Belgrade (Figure 4). This line would provide the missing direct connection with New Belgrade on the Nikola Pasic Square and King Alexander Boulevard. The route located along of many tourist attractions (National Assembly , St. Mark's Church ...), administrative center of Belgrade, Faculty of Law, Faculty of Engineering, Shoping Malls "Usce" and "Delta City", Kombank arena, Railway station "Novi Beograd ".

The route of the line 1E:

- Direction A: Kraljice Marije, Bulevar kralja Aleksandra, Trg Nikole Pašića, Dečanska, tunel, Brankova ulica, Brankov most, Bulevar Mihajla Pupina, Milentija Popovića, Bulevar Zorana Đinđića, Antifašističke borbe, Bulevar Milutina Milankovića, Đorđa Stanojevića.
- Direction B: (Đorđa Stanojevića, Omladinskih brigada, Antifašističke borbe, Bulevar Zorana Đinđića, Milentija Popovića, bulevar mihajla Pupina, Brankov most, Brankova, Trg Nikole Pašića, Bulevar kralja Aleksandra, Ruzveltova, Kraljice Marije.

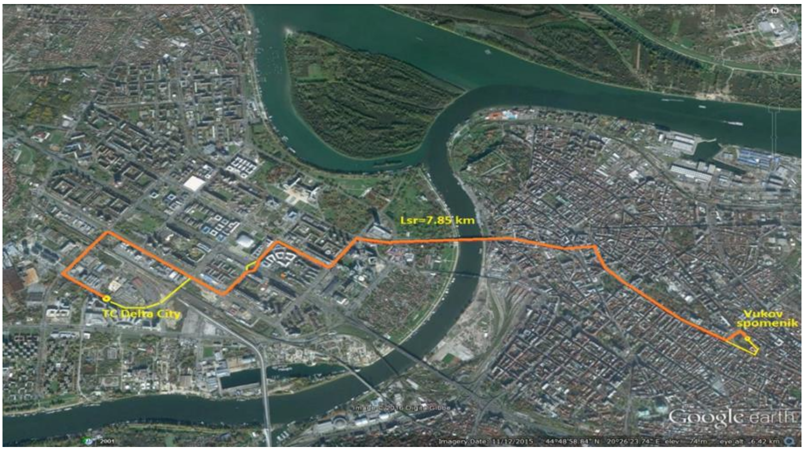


*Figure 4 Route of line 1E (Vukov spomenik – TC "Delta City")*

Mean length of route is 7.68 km stations and distance on the directions are given in Table 2.

*Table 2 Static elements of line 1E*

| Direction A: | **Vukov spomenik - TC ''Delta City''** | |
|---|---|---|
| terminal | station | (m) |
| Vukov spomenik | | 0 |
| | Tehnički fakulteti | 518 |
| | Pravni fakultet | 364 |
| | Park "Tašmajdan" | 344 |
| | Glavna pošta | 204 |
| | Pionirski park | 332 |
| | Zeleni venac | 762 |
| | Brankov most | 415 |
| | Blok 21 | 1548 |
| | Milentija Popovića | 438 |
| | Blok 25 | 560 |
| | Blok 24 | 418 |
| | Milutina Milankovića TC "Vero" | 283 |
| | Depo "Sava" | 830 |
| **TC ''Delta City''** | | 454 |
| | | **7.470** |

| Direction B: | ***TC "Delta City"* - Vukov spomenik** | |
|---|---|---|
| terminal | station | (m) |
| ***TC ''Delta*** '' | | 0 |
| | Airport city | 706 |
| | Omladinskih brigada 1 | 416 |
| | Bulevar umetnosti | 340 |
| | Španskih boraca | 384 |
| | Milutina Milankovića | 469 |
| | Blok 24 | 194 |
| | Blok 25 | 491 |
| | Milentija Popovića | 515 |
| | Blok 21 | 345 |
| | Brankov most | 1560 |
| | Zeleni venac | 337 |
| | Pionirski park | 850 |
| | Resavska | 300 |
| | Pravni fakultet | 237 |
| | Tehnički fakulteti | 323 |
| | Vukov spomenik | 300 |
| VUKOV SPOMENIK | | 128 |
| | | **7.895** |

Dynamic elements on the line 1E, are presented in the following table 3. With five vehicles in operation, interval a vehicle passes amounted to 12-13 minutes. The offered capacity on the line would be 289 places / hour.

*Table 3 Dynamic elements on the line 1E*

| 1E | Vukov spomenik-TC Delta City | | | 5 E-buses in the operation | |
|---|---|---|---|---|---|
| Total length of rute [km] | driving time [min] | charging time[min] | time of turnround [min] | interval [min] | offered capacity (places/hour) |
| 15,36 | 34 | 5-10 | 88 | 17-18 | 273 |

## 4. CHOICE OF CONCEPT BUS ON ELECTRIC DRIVE

Analysis of experience in the exploitation of E-buses by different manufacturers with different concepts of charging and storage of electricity, came to the decision that for conditions of exploitation in Belgrade most acceptable is "pantograph" fast-charging system on the terminals and application systems for electrical energy storage using super capacitors. [4].

Advantages of pantograph charging system [2]

• Acceptable charging time 5-8 minutes
• Possibility to connect the charger to the tram network (DC) or public distribution network (AC)
• E.bus can operate throughout the work day (Especially important in summer conditions when using the air conditioner)

Advantages of storage electricity using supercapacitors [2]

• Principle: Electro Static
• Flexibility for rapid charging and emptying
• High efficiency 92-98%
• Acceptable weight: 900 kg
• Temperature range: -40 to +65 Co.
• Fast charge 5-8 min
• The possibility of accepting the entire electricity in the process of recuperation
• Long life: min. 10 years
• Convenience recycling


*Figure 5 Charging station ''Belvile''*


*Figure 6 Position of supercapacitors*

*Figure 7 Charging station ''Vukov spomenik''*

*Figure 8 Charger*

*Figure 9 E-bus Higer KLQ6125GEV3*

*Figure 10 Interior of the E-bus Higer*

*Table 4 Technical characteristics E-bus Higer [3]*

| | |
|---|---|
| Manufacturer | Higher |
| Type | Electric KLQ6125GFV3 |
| Length/width/height | 12000/2550/3630 mm |
| Curb weight | 12540 kg |
| Passengers | 82+1 |
| Max. speed | 70 km/h |
| Charging the terminus: 660 V DC or 380 V AC, 580 V DC output, 250 A | |
| Charging time at the terminus | 5-8 minutes |
| Storage systems | |
| Electricity | Super capacitors |
| Capacity | 20 kWh |
| Manufacture | Aowei |
| Type | U-CAP (37DT6-03210) |
| Traction motors | 2 |
| Manufacture | Siemens |
| Type | 1PV5135 |
| Power 2x90 kW (peak opt.) | 2x67 kW (nom. Opt.) |
| Torque | 2x430 Nm |
| Inverter | DC / AC |
| Manufacture | Zhonglian |
| Type | IEVD 130-60ZO6GA |
| Working range | 580 V DC / AC 500-650V |
| Converter | DC / DC |
| Manufacture | Zhonglian |
| Type | DY074C |

| | |
|---|---|
| Working range | 12-24-48 V DC |
| Charging systems | |
| Pantograph | Aowei 37DT6-03212 |
| Plug-in | DU OSIDA 37XL2-3709 |
| Auxiliary systems | |
| Air conditioning | Thermoking 81 DT6 |
| Pump control | KVD HDZXB 1416 |
| Compressor | IEM ER 230 |
| UC-Cooler | Aowei 37DT6 |
| Traction control | Siemens 10DT6 |
| External display | NFHS-020 |

## 5. EXPECTATIONS OF THE USE OF E-BUSES (ECOLOGICAL AND ENERGY ASPECTS)

Putting into operation first line with the purely electric buses would start a new chapter in the exploitation of the bus subsystem in Belgrade. Given that this is a completely new drive concept, special attention will be focused on the monitoring of all the techno-exploitation characteristics, in order to give real insight into the advantages and disadvantages of this concept, which was first applied not only in Belgrade but also in the region of South Eastern Europe. During July and August 2016, before the start of the regular exploitation, test-driving was done, which showed satisfactory results, which are expected, when will start regular exploitation (end of August or beginning of September 2016).

Expectations of introducing buses on pure electric drive are:

- Zero emissions by E-bus at the micro location
- Significantly advantageous carbon dioxide emissions at the macro level, from the production electricity from the electrical energy system of the Republic of Serbia in comparison to the $CO_2$ emissions, derived from the combustion of hydrocarbons fuels.
- Lower level emitted noise of 12-17 dB
- High energy efficiency compared to diesel-powered buses. Expected electricity Consumption
- E-bus on the new line is between 1,06 to 1,30 kWh/km, depending on the mode, passengers load, use of air conditioning .
- Profitability of invested assets after 6 years
- E-bus is technology of future.

## 4. CONCLUSION

The introduction of buses with electric drive in regular operation represents a significant development step in the improvement of the system of public transport in Belgrade. E-buses with pantograph system supplementing on the terminus fully meet the requirements for operation in terms of supply of electricity, the daily route and transportation demands of passengers. The proposed route of the first line in staffed by electric buses allow the full effect of the use of this concept in terms of environmental, transport requirements (the arrival interval, the offered capacity) and a high level of attractiveness of the locations they serve.

Monitoring the results of using the buses on electric drive on the line 1E, will serve as the best argument for defining future strategies of public transport in Belgrade as well as in other major cities of the Republic of Serbia (Novi Sad, Niš, Kragujevac ...) when this concept of buses issue and its mass application.

## REFERENCES

[1] ЈКП ГСП"Београд": Елаборат о увођењу прве линије са аутобусима на електрични погон у ЈКП ГСП"Београд", октобар 2015.

[2] M.Milev: The Ultra capacitors electric bus-the future of urban transportation, Elektrobusse-markt der zukunft, Berlin, 23.02.2015.

[3] Higer Electric bus – EC TYPE APPROVAL CERTIFICATE, Idiada automotive technology .A.C, 2016.

[4] Mišanović S.: Mogućnosti korišćenja autobusa sa električnim pogonom u sistemu javnog gradskog prevoza putnika, seminarski rad na doktorskim studijama, Fakultet inženjerskih nauka, Univerzitet u Kragujevcu, 2016.

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