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# SIGNIFICANCE OF INDUSTRIAL ROBOTS IN DEVELOPMENT OF AUTOMOBILE INDUSTRY IN EUROPE AND THE WORLD

***Isak Karabegović*[1], *Ermin Husak*,**

**UDC:681.5;681.9**

**Summary**

It is known that human population is increasing year after year, there is also a constant increase of automation and modernization of all production processes as well as the production processes of an automobile industry. This results with increasing production of the new motor vehicles every year in a total number of motor vehicles, and also increasing of the new vehicle models and opening of the new factories of motor vehicles. For such given conclusion of production enlargement of motor vehicles, the new technologies that are responsible are: information technologies, sensor technology, robotic technology and new production technologies. An application of the new technologies looks back in adoption of new products, tool production, speed and accuracy of production. The production processes in automobile industry were amongst the first in which industrial robots were beginning to apply, and were used for automation of process while performing different jobs. The application of industrial robots in production processes of automobile industry is increasing from day to day, and their application for performing those jobs that, until today, could not be carried out with the industrial robot. The development of sensor technology, i.e. the equipped industrial robots, robot's vision enabled to perform these jobs. This paper provides the role of industrial robots in development of automobile industry in Europe and the world.

**Key words:** automobile industry, industrial robot, application, production, new technologies.....

# ZNAČAJ INDUSTRIJSKIH ROBOTA U RAZVOJU AUTOMOBILSKE INDUSTRIJE U EVROPI I SVETU

**UDC: 681.5;681.9**

**Rezime**

Poznato je da je ljudska populacija raste iz godine u godinu, Takođe, postoji konstantan porast automatizacije i modernizacije svih proizvodnih procesa, kao i proizvodnih procesa automobilske industrije. Ovo dovodi do toga da se svake godine povećava proizvodnja novih motornih vozila u ukupnom broju motornih vozila, a takođe se povećava broj novih modela i otvaraju se nove fabrike motornih vozila. Za takav zaključak datog proizvodnog proširenja motornih vozila, nove tehnologije koje su odgovorne su: informacione tehnologije, tehnologija senzora, tehnologija robota i nove proizvodne tehnologije. Primena

[1] *Received March 2014, accepted: June 2014*.

novih tehnologija daje osvrt na: način usvajanja novih proizvoda, proizvodnju alata, brzinu i tačnost proizvodnje. Proizvodni procesi u automobilskoj industriji bili su među prvima u kojoj su industrijski roboti su počeli da se primenjuju. Korišćeni su za automatizaciju procesa prilikom obavljanja različitih poslova. Primena industrijskih robota u procesu proizvodnje u automobilskoj industriji se raste iz dana u dan i njihova primena u obavljanju tih poslova, do danas je nezamisliva bez industrijskih robota. Razvoj tehnologije senzora, tj. usavršavanje industrijskih robota, primenom robota koji „vidi“ omogućeno obezbeđuje se da roboti mogu da obavljaju ove zadatke. U ovom radu prikazana je uloga industrijskih robota u razvoju automobilske industrije u Evropi i svetu.

**Ključne reči:** automobilska industrija, industrijski robot, primena, proizvodnja, nove tehnologije

# SIGNIFICANCE OF INDUSTRIAL ROBOTS IN DEVELOPMENT OF AUTOMOBILE INDUSTRY IN EUROPE AND THE WORLD

***Isak Karabegović[1] PhD, Professor, Ermin Husak, MSc, Assistant***

**UDC:681.5;681.9**

## INTRODUCTION

For vehicle production enlargement of all kinds is responsible the technology development of all kinds. One of the technologies is the new production technologies. The new production technologies, with the process integration as a main goal, production and quality enlargement, are based on a new techniques and short development time. The new technologies are made of the sophisticated knowledge, experiences and information techniques with a goal to approach a customer at a right time.

Constant outbuilding of the production technologies is enabled with fast development of the information technologies. The new conceptual approaches have incurred in the last fifteen years in an area of the mechanical production engineering, with the main goal to shorten production cycle of a product. Researches indicate that about 80% of production quality is achieved in a development stage and that 70% of product costs are determined in this stage. The other responsible technology for development of automobile industry is the robotic technology, i.e. an application of industrial robots in production processes of automobile industry. At the beginning, the industrial robot applications in production processes are used for performing jobs that were dangerous for an employee health and for performing jobs in difficult conditions of work.

The development of information technology, sensor technology and robotic technology is extending the industrial robot application in production processes of automobile industry, so that any process in automobile industry today is unconceivable without the industrial robot [1, 2, 3]. The industrial robots are used in welding process of the car shell, painting, montage and inspection. The industrial robots are also used in many other applications in automobile industry, like: different forms of mechanical processing in making parts for vehicles, plastic moulding, seal application on an automobile windshield, and taking parts from a transporters and their packing on the palettes for a forklift truck. The application of robot's vision on the industrial robots leads to extending of industrial robot application in vehicle production processes, and also a number of produced motor vehicles of all kinds are increasing year after year.

## 1. INDUSTRIAL ROBOT APPLICATION IN AUTOMOBILE INDUSTRY OF EUROPE AND THE WORLD

An application of industrial robots in Europe and the World is shown in a table 1, and a figure 1. The statistical data that are shown in table 1 and figure 1 are used from the IFR (International Federation of Robotics) [6, 7, 8].

[1] *Isak Karabegović, University of Bihać, Faculty of Technical Engineering, Irfana Ljubijankića bb. 77000 Bihać, Bosnia and Herzegovina, email: isak1910@hotmail.com*

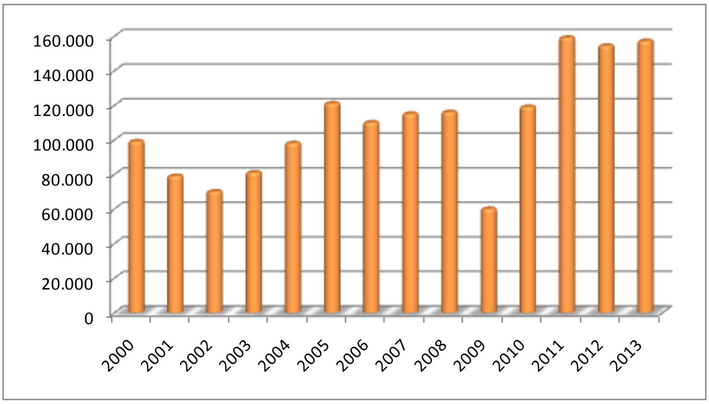
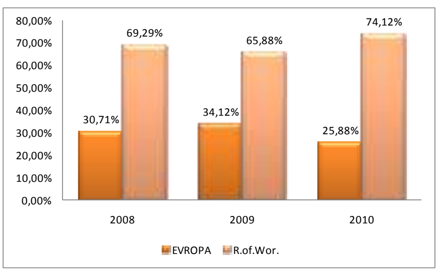



*Figure 1. Trend of annual application of industrial robots in the World,*

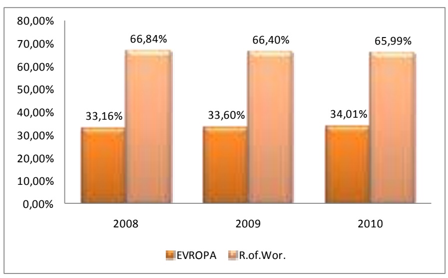
An annual application trend of industrial robots in the World for a period of 2000 - 2013 is shown at figure 1. The annual industrial robot application in this period moved from 60.000 to 120.000 of robot units. According to shown trend it can be concluded: in a period of 2000-2002 the industrial robot application trend is decreasing at annual level, then the increasing trend from 2002-2005. From 2005 - 2013 can be concluded that the robot application at annual level is almost constant and moves about 157.000 units, but in 2009 the application decline has been recorded to 60.000 units. In the last three years 2011 – 2013 industrial robot application is increasing to 155.000. In this period, the minimal industrial robot application has been recorded in 2002 and 2009 due to industrial world crisis, as shows figure 1.

*Table 1. Application of industrial robots at annual and total level in Europe and World [6, 7, 8]*

| Installation Cont./Yar | Annual application of robots units | | | Total application of robots units | | |
|---|---|---|---|---|---|---|
| | 2008 | 2009 | 2010 | 2008 | 2009 | 2010 |
| EUROPA | 34.695 | 20.480 | 30.630 | 343.329 | 343.661 | 352.031 |
| Rest of the World | 78.277 | 39.538 | 87.707 | 691.972 | 677.070 | 682.985 |
| Total World | 112.972 | 60.018 | 118.337 | 1.035.301 | 1.020.731 | 1.035.016 |




*Annual application of robots units*




*Total application of robots units*

*Figure 2. Percentage of industrial robot application in Europe and World at annual and total level in production processes*

Table 1 and figure 2 are showing the annual and total industrial robot application in Europe and the World at annul and total level in period of 2008 - 2010. If we overlook the application trend of industrial robot in Europe, it is seen that at annual level in this period moves from 20.480 - 34.695 units, i.e. 22,88% - 34,12%, in relation to total annual application in the World. When considering the total industrial robot application, in Europe is applied 343.329 - 352.031 units, i.e. 33, 16% - 34, 01%, in relation to 1.030.000 units of industrial robots in the World. We come to a conclusion that 34% of industrial robots are installed in production processes in Europe, and the rest of 66% is installed on other continents in the World. Let us analyse the industrial robot application in the drives of automobile industry in the World. The trend of robot application in production processes of motors and motor vehicles at annual and total level is shown in figure 3.

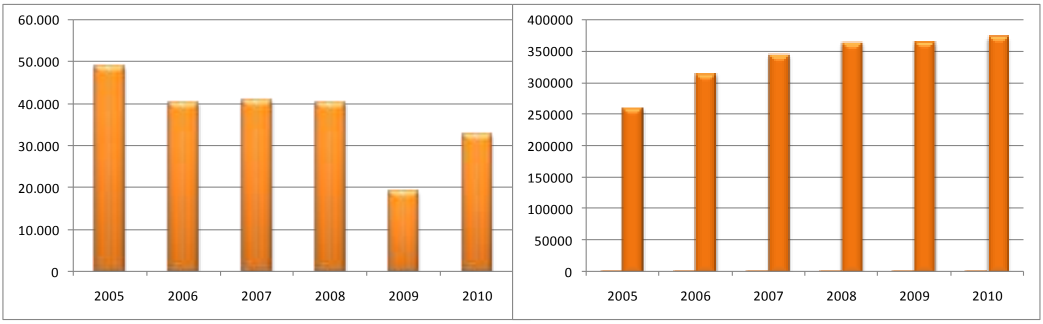


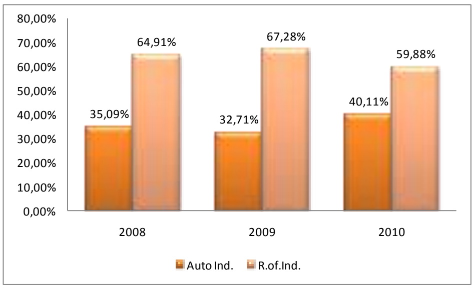

*Figure 3. Application of industrial robots in production processes of motors and motor vehicles at annual and total level in the World*

According to figure 3, the robot application trend at annual level in automobile industry has the decline trend with 50.000 units to 40.000 units from 2006 to 2008, and then the decline to 20.000 units in 2009, while in 2010, the robot application increase to 33.000 units. The smallest application has been recorded in 2009 due to a huge industrial crisis in the World. The trend of robot application in automobile industry at total level is in increase year after year, and has increased from 260.000 units in 2006 to 373.000 in 2010. It happened due to automation and modernization of fabrics that produce vehicles and opening of the new fabrics for vehicle production.

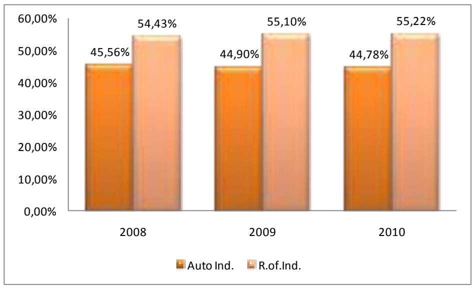
Let us analyze the industrial robot application in automobile industry in Europe, and through an analysis let us cover those countries with the most developed automobile industry. The robot application trend in automobile industry has been given in table 2.

*Table 2. Trend of industrial robot application in automobile industry al annual and total level in Europe [6, 7, 8]*

| Installation Cont./Year | Annual application of robots units | | | Total application of robots units | | |
|---|---|---|---|---|---|---|
| | 2008 | 2009 | 2010 | 2008 | 2009 | 2010 |
| Aut. Ind. of Europe | 12.177 | 6.700 | 12.288 | 156.447 | 154.308 | 157.646 |
| Re. of Indus. | 22.518 | 13.780 | 18.342 | 186.882 | 189.353 | 195.385 |
| Total EVRO. | 34.695 | 20.480 | 30.630 | 343.329 | 343.661 | 352.031 |




*Annual application of robots units*




*Total application of robots units*

*Figure 4. Percentage of industrial robot application in automobile industry in Europe at annual and total level in production processes [14, 15, 16]*

If we analyze the industrial robot application in automobile industry in Europe, table 2 and figure 4, it is obvious that at annual level is applying about 12.000 units, which is about 38% of total robot application at annual level, while 62% of robot units is applying in other production processes. The total industrial robot application trend in automobile industry is somewhat different, and is applied about 190.000 units of total application of 350.000 units. In other words, in automobile industry robots are mostly applied, about 45%, while in other industries are applied about 55% of total industrial robot quantity. We can conclude that in Europe, the production processes are modernizing and are more automated in automobile industry as a result of constant development of the new technologies, information technologies and robotic technology.

## 2. PRODUCTION OF AUTOMOBILE AND LOAD VEHICLES IN THE WORLD

The production trend of automobile and load vehicles in automobile industry is given in a figure 5, according to data from the OECD (*Organization for Economical Co-operation and Development).*

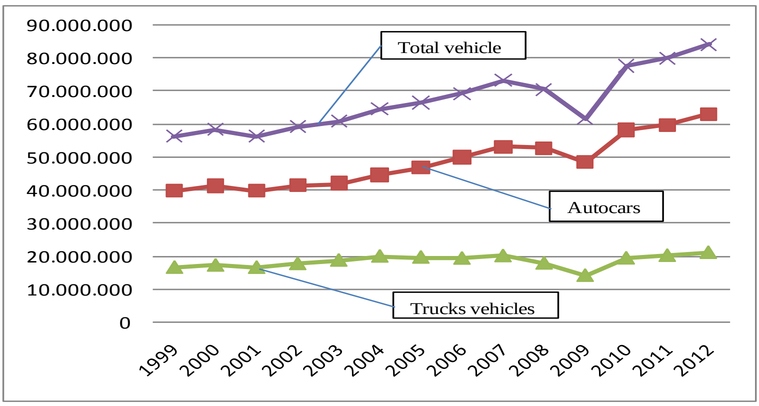



*Figure 5. Annual automobile and trucks vehicles production in period 1999-2012 [4, 5]*

According to figure 5, it is seen that the production trend of automobile and load vehicles is increasing year after year. In 1999 have been produced about 40 million of automobiles and about 16 million of load vehicles which gives the number of 56 million vehicles. In 2012 has been produced about 63 million of automobiles and 21 million of load vehicles, and the total production in 2012 amounts to 84 million of vehicles. It is obvious that in 13 years the production of vehicles increased for 28 million units.

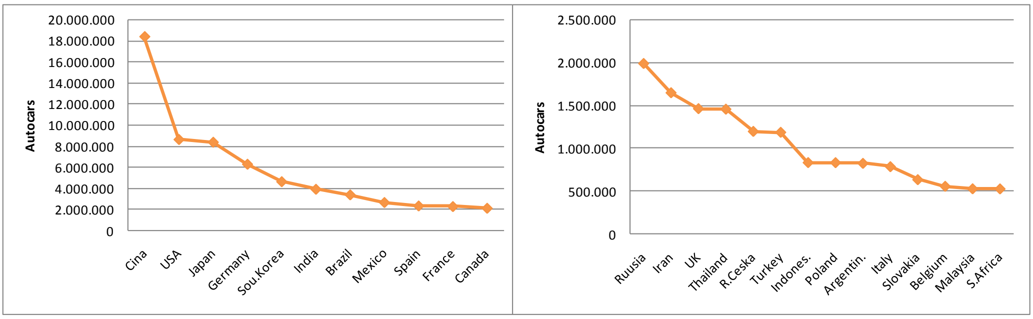
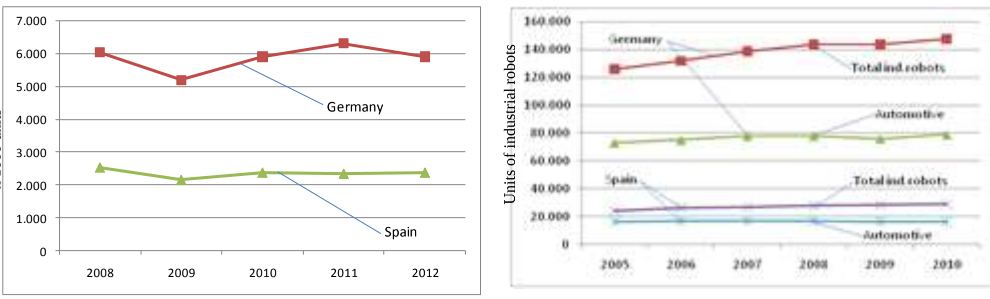



*Figure 6. Annual production in automobile industry in 2011 by countries [4, 5]*

According to figure 6, the first place in production in automobile industry in the World in 2011 takes China with over 18 million vehicles, the second place takes the USA with over 8 million vehicles and the third place takes Japan with over 8 million vehicles. The production trend is logical in automobile industry because the trend is influenced by the installing trend of industrial robots. China is the best example as it is seen in figure 6, because the number of industrial robot applications in China is increasing year after year.

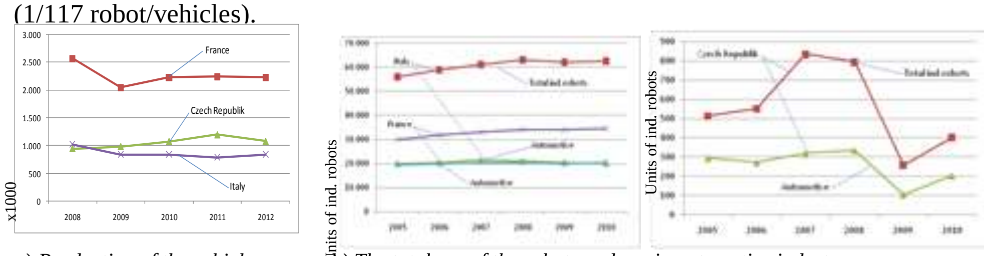
When it comes to the trend of automobile production in Europe, we analysed those countries where the automobile production at annual level is over 500.000 units, and those countries are: Germany, Spain, France, Italy and the Czech Republic. Other countries in Europe are not taken into consideration due to vehicle production under 500.000 units at annual level. The annual trend of vehicle production and total trend of industrial robot application in all industrial branches and in automobile industry in Germany and Spain is shown in figure 7.




*Production of the vehicles* *The total use of the robot and the auto industry*

*Figure 7. Production of vehicles in Germany, Spain and total application of industrial robots in all industrial branches and automobile industry [4, 5, 6, 7, 8]*

According to figure 7, the first place in vehicle production in Europe takes Germany, and the trend of vehicle production moves from 5, 2 million of vehicles to 6, 3 million of vehicles. When analysing the industrial robot application in Germany (right figure), in a period from 2005-2010 has been applied totally 125.000-145.000 of industrial robot units, a part of that number is applied in automobile industry, about 80.000 units at annual level which represents more then 50% of industrial robots which are installed in fabrics that produce vehicles. Considering an average, on one robot comes 75 vehicles (1/75 robot/vehicles). At a same graph has been shown the vehicle production in Spain, and the trend moves from 2 million of vehicles to 2, 5 million of vehicles, while total industrial robot application in Spain at annual level moves from 24.000-29.000 units, and in automobile industry has been installed 16.000-17.000 units which represents about 60% of all installed robots in all industrial branches. In Spain, on one robot comes 117 vehicles (1/117 robot/vehicles).




*a) Production of the vehicles* *b) The total use of the robots and use in automotive industry*

*Figure 8. Production of vehicles in France, Italy, Czech Republic and total application of industrial robots in all industrial branches and automotive industry*

When analyzing the diagrams from figure 8, we conclude according to a) that the motor vehicle production is maximal in France and moves from 2 million to 2.5 million annually, in a period of 2008-2012, the second place takes the Czech Republic where the production moves from 900 thousand to 1, 3 million of motor vehicles, and the third place takes Italy with the production of motor vehicles from 600 thousand to 1.1 million in a period of 2008-2012. In figure 8 b) total industrial robot application has been shown in Italy and France and also the total application in automobile industry. The total trend of industrial robots in all industrial branches in Italy moves from 58.000 to 63.000 of robot units, while the automobile industry uses only 20.000 robot units in a period of 2005-2010.

The industrial robot application trend in France in the same period is from 30.000 to 36.000 of robot units, and automobile industry uses almost as Italy, about 20.000 of robot units. It is obvious that in France, in relation to Italy, is produced more then 2 to 2,5 million vehicles at annual level with almost the same number of installed industrial robots in production drivers in automobile industry. One of the conclusions can be that the industrial robots are not enough functional in drivers for vehicle production in Italy, or that the automation of the production processes hasn't been carried out properly; where in the same automation robots are included. The other conclusion can be that the companies that produce vehicles in France are performing total automation and modernization of the production processes and all lines for vehicle production are introducing innovations, are shortening the production time for production of one vehicle, and in this way are reaching this trend of vehicle production.

The Czech Republic, ever since entering the EU, produces more vehicles than Italy and that trend moves from 900 thousand to 1.1 million vehicles in a period of 2008-2012, although the number of installed industrial robots in production drivers of automobile industry is small and moves from 100-300 of robot units. The reason for such production vehicle trend and robot application in production processes of automobile industry in the Czech Republic is because the German companies dislocated their production in the Czech Republic, and most of the vehicle parts that are produced in Germany come as a semi-finished product in companies for vehicle production in the Czech Republic, where only the montage is carried out. Besides Germany, in the Czech Republic are companies for vehicle production dislocated and the other companies from different countries. This way justifies this trend of vehicle production in the Czech Republic with such small number of installed industrial robots in automobile industry.

## 3. CONCLUSION

According to all derived indicators in this paper it can be certainly predicted that the great robot application in vehicle production will continue to carry on in the future. The new generations of robots with more perfect sensory evaluation, and particularly with robot's vision will have greater application in this industry, and also in industry for production of vehicle parts.

The production of vehicle parts of the renowned world's manufacturers is the chance for the industrial development of the countries in transition, like the Czech Republic. The robot application of the new generation in automobile industry will improve the quality and productivity of part production and of entire vehicle, and it will significantly influence on increasing the competitive competences of firms that produce vehicles for more demanding international market.

The greater robot application in automobile industry will enable more continuous and more flexible production that will significantly contribute to satisfaction of market demand for higher variety of the same types of vehicles, by building certain supporting equipment and securing systems in vehicles. The future production drivers of the vehicle producers will look like „*The fabrics of the future*“ with more and more robots, and less and less production employee. These firms, from day to day, will increase a number of engineers which will have to have a proper knowledge from the modern technician discipline called mechatronics that represents an integration of mechanical engineering, management, electronics and computer science.

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# EXPLOITATION AND ENVIRONMENTALLY ASPECTS OF HYBRID BUSES IN EUROPEAN CITIES

*Slobodan Mišanović* [1],

**UDC:629.342**

**ABSTRACT**: The problem of air pollution, acid rain and the formation of "greenhouse effect", as a result of emissions a carbon dioxide (CO2), from vehicles are found in the developed countries of the EU several decades.

This problem was got primary importance. EU has chosen a strategy of increase number the vehicles with lower emissions of carbon dioxide (CO2). Introduction of city buses with hybrid (diesel-electric) engines in a growing number of EU cities, are first stage in the implementation of the EU strategy which has defined (Transport policy- White Paper 2011) where is the ultimate goal that of the 2050 year, the cities in the EU will be used only vehicles with zero emissions (CO2). Defined strategy for the EU to promote an ecological clean the bus subsystem of public transport, have accelerated all manufacturers of buses in the European market, to produce buses with hybrid power, which allowed that companies for public transport, are used tender procedures for procurement of hybrid buses pursuant to Directive EC/2009/33.

In this paper, is presented experiences in operation of hybrid buses in the some EU cities, which have this type of buses in regular service.

**KEY WORDS**: hybrid bus, exploitation, environment

## EKSPLOATACIJA I EKOLOŠKI ASPEKTI HIBRIDNIH AUTOBUSA U EVROPSKIM GRADOVIMA

**REZIME:** Problem aerozagađenja, kisele kiše i formiranje "efekta staklene bašte", kao rezultat emisije ugljen- dioksida ($CO_2$), iz vozila su se u razvijenim zemljama Evropske unije nekoliko decenija. Ovaj problem je dobio prvorazredni značaj. EU je izabrala strategiju povećanja broja vozila sa niskim emisijama ugljen-dioksida ($CO_2$). Uvođenje gradskih autobusa sa hibridnim (dizel - električni) motorima u sve većem broju gradova EU, su prva faza u realizaciji strategije EU koja je definisana (Saobraćajna politika - Bela knjiga 2011), gde je krajnji cilj da se od 2050. godine u gradovima EU koriste samo vozila sa nultom emisijom $CO_2$. Definisana strategija EU promoviše ekološki čiste podsisteme javnog prevoza, što je ubrzalo sve proizvođače autobusa na evropskom tržištu, da proizvodnju autobusa sa hibridnim pogonom, što je omogućilo da preduzeća za javni prevoz , koriste se tenderske procedure za nabavku hibridnih autobusa u skladu sa Direktivom EC/2009/33. U ovom radu su prikazana iskustva u primeni hibridnih autobusa u nekim gradovima EU, koje imaju ovaj tip autobusa u redovnoj upotrebi.

**KLJUČNE REČI**: hibridni autobus, ekspolatacija, okolina

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# EXPLOITATION AND ENVIRONMENTALLY ASPECTS OF HYBRID BUSES IN EUROPEAN CITIES

***Slobodan Mišanović [1]MSc***

**UDC: 629.342**

## 1. INTRODUCTION

The energy and environmental problems at the moment are the major problems that the world faces today. The intensive development of the automotive industry has been one of the hallmarks 20th century. At the beginning of 70-ies of the last century due to the oil crisis in the developed countries of the world, all leading vehicle manufacturers are headed in research of alternative fuels in order to partially mitigate the dependence on fossil fuels. In addition, it is known that fossil fuels as an energy resource will have a limited service life of up to 100 next years (Figure 1).

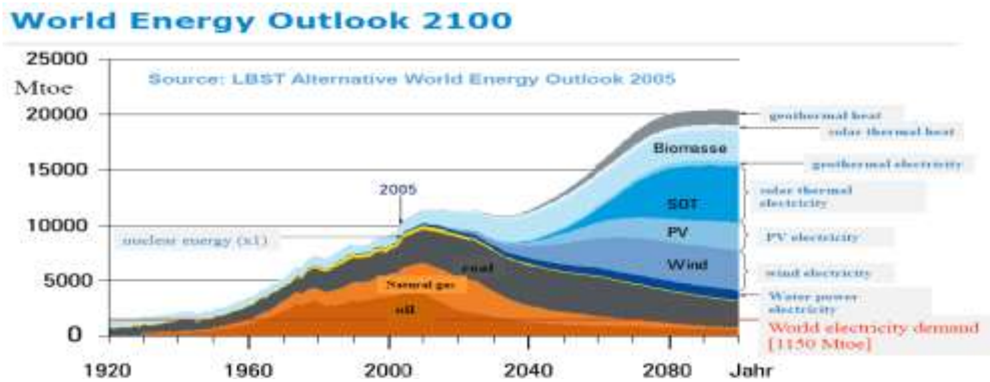



*Figure 1 The use of energy resources in the world to 2100.* [4]

Trend of production, available reserves, volatility of fuel prices (Figure 2), in the past 40 years have accelerated on the experiments with various alternative fuels from which we will mention electric vehicles, solar cells, methanol, vegetable fuel, hydrogen, natural gas, etc.

[1] *Slobodan Mišanović, M.Sc.T.E., GSP "Beograd", Knjeginje Ljubice 29, Beograd, slobodan.misanovic@gsp.co.rs; s.misanovic@yahoo.com*


***Figure 2*** The trend of change in the price of diesel fuel in the EU (2005-2011) Euro/1000 [4]

But the key question that came to the fore and that required an immediate solution has become a matter of ecology, and the rapid increase in environmental pollution as a direct result of burning fossil fuels. The enormous release of carbon dioxide CO2, primarily from automobile engines and industrial plants has led to global warming (Figure 3) and causing the greenhouse effect, acid rain and the formation of damaging the upper layers of the atmosphere.

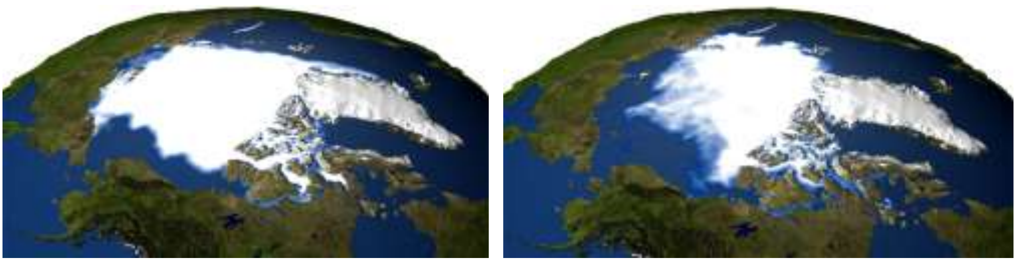


*Figure 3 Global warming, melting ice at the North Pole 1973-2003 year*

**2. PLACE AND ROLE OF BUS SUBSYSTEM TRANSPORTATION IN THE EU**

In the cities of the EU, the bus subsystem of public transport is one of the most important segments of the urban life of the city, which has a direct impact on meeting the socio-economic and other needs of the population.

Thanks to its techno-exploitation advantages and flexibility, its role in the distribution of passengers with highly capacitive lines of public transport such as metro or LRT and urban parts, is irreplaceable. According to the data of UITP's, today in the 100 largest cities in EU operational use is around 54,700 buses urban type, which achieve about 80% of the transport of labour-expressed in km. The EU is the world leader in the production of city buses. Annually produces about 12,000 new buses which are 60% of world production [9].

Most buses use conventionally energy but fossil fuels are one of the main causes of urban pollution and emissions in cities. For these reasons bus subsystem has become important as a major promoter of new technologies in the implementation of sustainable development strategies. The above facts have initiated the adoption of a series of strict standards relating to limit emissions from conventional vehicles to drive, from ECR 49 of 1982, over Euro emission standards (Euro 1 to Euro 6) (Figure 4) in the period 1992 to 2013, the introduction of buses powered by CNG, LPG and bio fuels, has led to significant progress in reducing emissions of gases (CO, NOx, CxHy, PM10). The problem is that the buses and vehicles on conventionally fuels are remaining high emitters of carbon dioxide CO2, as a direct result of burning fossil fuels.

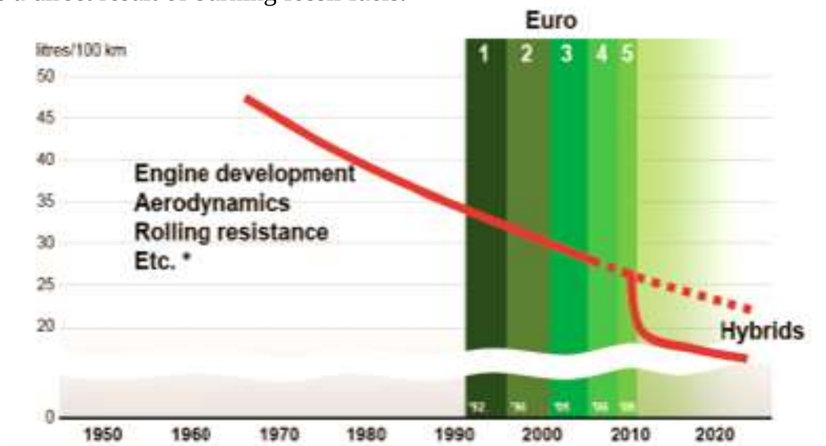



*Figure 4 The evolution of development in terms of bus emissions* [11]

Since December 2010, the EU countries have been applied the EC Directive 33/2009 concerning the promotion of energy efficient and environmentally clean vehicles in road transport, which are used in the public sector such as buses for public transport, utility vehicles, etc. The directive defines a strategy to reduce CO2 emissions by 20% by 2020 year compared to the base year 1990 year [6]. Significantly, the directive regulates the energy and environmental criteria for tendering for procurement of new vehicles, which will be an integral part of the tender documents. This directive defines the price of emission, expressed in Euro / kg for each product: CO2 (0.03 to 0.04 Euro / kg), NOx (0.0044 Euro / g), Non-Methane Hydrocarbons - NMCH (0.001 Euro / g), Particular matter - PM (0.087 Euro / g) [6]. The Directive specifies that the basis for all calculations in terms of calculating the value of the issue or the cost of emissions is g / km, not g / KWh.

### 3. EU-WHITE PAPER OF TRANSPORT

The introduction of hybrid buses (diesel-electric) in the system of public transports passengers in the period 2010-2020 years, is the first step in the implementation of the strategy defined by the EU which is the ultimate goal that by 2050, in cities of the EU , will be only vehicles with pure electric drive or "zero emissions" (CO2) [7].

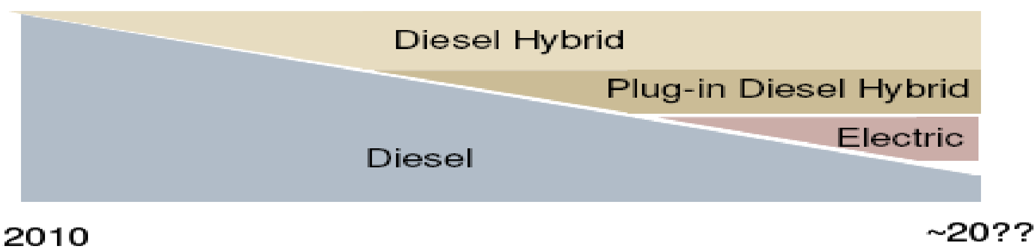
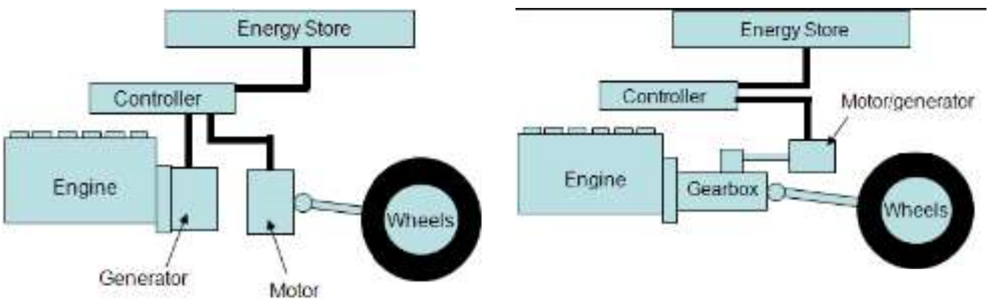


**Figure 5** Forecast *uses of buses for public transport in the EU for the period 2010-2050.*

It is observed that the trend of using diesel-powered buses have a constant tendency of reduce everything to its complete abolition of the 2050 year. (Figure 5) Enhanced Hybrid concept "plug in" will be present after 2015. Introducing the bus with pure electric drive will depend primarily on battery technology, battery capacity; need to provide autonomy of day operation, without charge. The widespread use of this type of drive is expected after the 2020. It should be noted that there are now buses with full electric drive, but their application is limited only to the mini and midi versions, with the range of movement of about 120 km, which is not enough for a regular exploitation. Currently they are developing electric-powered buses with standard lengths of 12 m and articulated 18 m, with different recharge batteries. This concept was presented in 2009, on the one line in Shanghai (China). In Geneva (Switzerland) is currently in the implementation of the project Trolleybus Optimisation System Alimentation - TOSA the introduction of the first buses to electric drive, whose start-up is planned for May 2013. For the period after 2025, provides for the growing use technology of fuel cells (Fuel-Cell), which is used as fuel, hydrogen (H2).

## HYBRID CONCEPT OF CITY BUSES

The concept of buses with hybrid drive is based on the use of two types of drive. Buses have the two engines: diesel engine displacement about 5 litres and the electric motor-generator. Depending of concept in use are serial and parallel types, (Figure 6)




a) Serial hybrid b) Parallel hybrid

*Figure 6 The working principle of the serial and parallel types of hybrid buses*

In a serial-type hybrid (Figure 6a), the diesel engine drives a generator to produce electricity, which accumulates in high capacity battery (ultra cap, Ni MH, Li-ion). The vehicle is powered by electric motor located on the drive shaft. Diesel engine is turned on, when the battery needs to be supplemented, the control unit regulates it. The cooling system prevents overheating and keeps the operating temperature of electrical components. Recovery system uses for electricity to charge the battery during braking mode. Block inverter converts direct current from the battery into AC to drive asynchronous traction motors.

In the parallel-hybrid concept (Figure 6b) can be to power electric motor or diesel engine directly. Buses are powered with electric traction. When the vehicle reaches a certain speed of 20-25 (km/h) includes a diesel engine that powers the vehicle through the transmission. Depending on the mode and the load can be turned on simultaneously diesel and electric motor. The main components of the hybrid buses: Hybrid unit, diesel engine, inverter module, cooling unit, brake resistor, battery, battery cooling system (Figure 7).

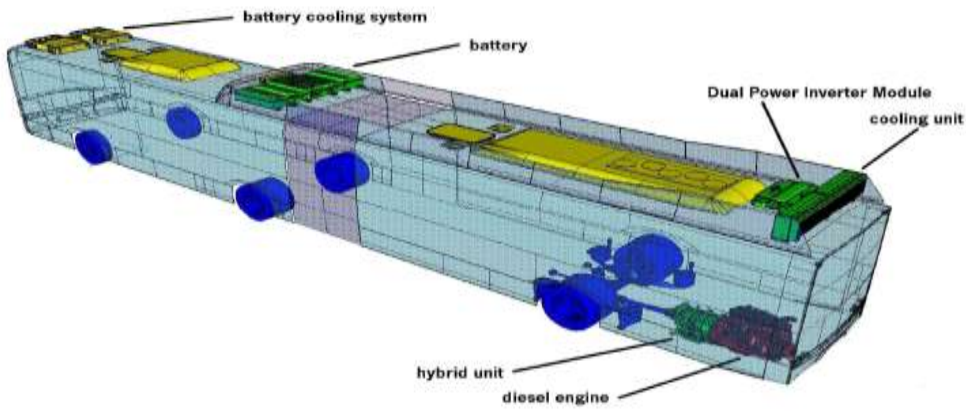



*Figure 7 The main components of the hybrid buses*

Main advantages of the concept of hybrid system in comparison to buses for urban transport with a conventional drive are reflected in:

- Lower consumption of diesel fuel (20 to 40%),
- Reduced CO2 emissions,
- Lower emissions of harmful substances: CO, NOx, CxHy, PM10,
- Lower level of external noise (10-12 dB(A)), and
- Good driving performance (acceleration-deceleration) [3].

## 4. OPERATIONS HYBRID BUSES IN THE EU AND WORLD

The concept of the hybrid buses for public transport has been known since the 1969 year, when the Mercedes-Benz was shown the application of these buses. Their increased utilization in urban public transport is recorded in the early 21st century only. At first it was just a demonstration and observation opportunities primarily techno-exploitation elements, leading bus manufacturers: Mercedes, MAN, Volvo in some EU capitals. Putting into operation of buses with hybrid drive in the EU has begun since 2006 year. The period 2006-2010 was marked by a relatively small number of buses with hybrid drive, which has been involved in regular exploitation. 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. In the period 2010-2011/12 years there is a steady upward trend in hybrid buses in regular operation, on the end of 2010. The EU has been in service 178 buses with hybrid drive but the mid-2012, in service is 1191 buses with hybrid drive. In the following Figure 8, is shown the numbers of hybrid buses by EU countries in 2012.

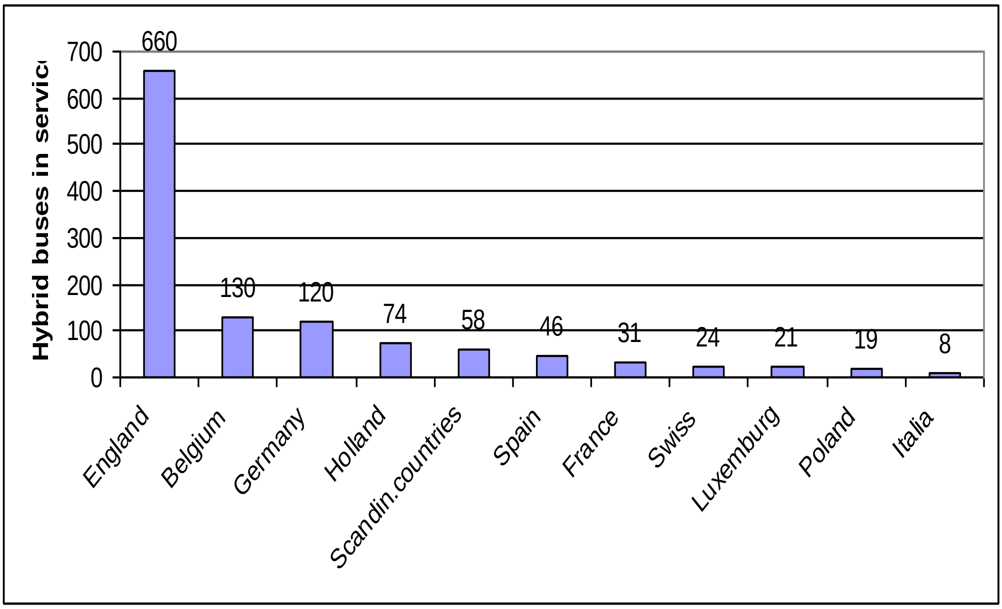



*Figure 8 EU number of hybrid buses in service 2012 year*

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) [5].

In 2012 expected to continue increase the number of buses in use. City of Dijon (F) has published a procurement of 100 new hybrid buses, which will become the city with the largest percentage share of hybrid buses.

Also, should be emphasized that the exploitation of hybrid buses have presented in North America, starting since 1990. According to the data available at end of 2010 in the United States and Canada were in service 6300 buses with hybrid drive. Observed by cities: New York (1812), Toronto (950), Washington (550); Philadelphia (510), Seattle (520), Chicago (228) [5].

Of the types of buses that are used the most common models are: Daimler Orion and New Flyer bus-Xcelsior. At this time all leading bus manufacturers in the EU in its commercial offer are given city buses with hybrid drive. The following Table 1 presents all types of hybrid buses by manufacturers in the EU [5].

The following Figure 9 shows the Volvo 7700 Hybrid with basic technical data [8].

## 5. AN EXAMPLE OF THE EXPLOITATION OF HYBRID BUSES IN LONDON

The Bus transport in London is one of the largest systems of its kind in Europe and the world.

With approximately 8500 buses in service, working on a network of 700 lines, transports around 6.4 million passengers a day [1]. The structure of the fleet consists of: 33% of single vehicle, 62% double-decker and 5% of the articulated. Buses are spent about 240 million litres of diesel fuel per year, which releases exceeding 610 000 tons of carbon dioxide CO2, which represents about 5% of the total emission. Responsibility than bus emissions of gases is 6% for coal hydrogen (Cx Hy), 7.7% for micro particles (PM10), and 8% for carbon monoxide (CO) and 9% for oxides of nitrogen (NOx). [1] This high level of emissions, give rise to adopting a series of measures in London, which began to be implemented from 2000. Its aim is to reduce the level of emissions.

***Table 1*** Manufacturers and types of hybrid buses in the EU

| **Manufacturers** | **Type of drive** | **Energy storage** | **Size** |
|---|---|---|---|
| Evobus | Serial | Li-ion | 18 m |
| MAN | Serial | Ultra capacity | 12 m |
| Volvo | Parallel | Li-ion | 12 m |
| Scania | Serial | Li-ion | 15 m |
| Irisbus | Serial | Li-ion | 12-18 m |
| Solaris | Serial/Parallel | Ultra capacity | 12-18 m |
| Van Hool | Serial | Li-ion | 9-10-18-24 m |
| VDL | Parallel | Li-ion | 12 m |
| Hess | Serial | Ultra capacity | 18-24 m |
| Aleks. Dennis | Serial | Li-ion | 10 m ( DD) |
| Tata-Hyspano | Serial | Li-ion | 12 m |
| Castrosua | Serial | Li-ion | 9,6-11 m |
| Wright | Serial | Li-ion | 12 m (DD) |

Technical Data VOLVO 7700 Hybrid

- Length: 12 000 mm,
- Width: 2 555 mm,
- Height: 3 200 mm,
- Vehicle weight: 18 000 kg,
- Number of doors: 3,
- Number of passengers: 95,
- Hybrid system: parallel Volvo-I-SAM,
- Diesel engine : Volvo D5E, 5 L,
- Power output / torque: 210 hp, 800 Nm,
- Electric motor power output: 160 hp/800 Nm,
- Batteries: Li-ion, and
- Transmission: Volvo-I-Shift automatic.


*Figure 9 Volvo 7700 H, AVL- Luxemburg*

## 6. THE MOST IMPORTANT MEASURES

1) Substitution of old buses with diesel-powered, buses with lower emissions that meet Euro 3, Euro 4, and Euro 5. This phase was particularly pronounced during the period 2001-2006 years, according to data from 2010 year, over 76% of buses meet these emission norms. The most significant reduction was achieved in the micro emissions of PM10 [2]. The following Figure 10 presents annual bus trends of emissions ($CO_2$, NOx, $PM_{10}$) for period 2001-2011 and forecasts for period 2012-2018.

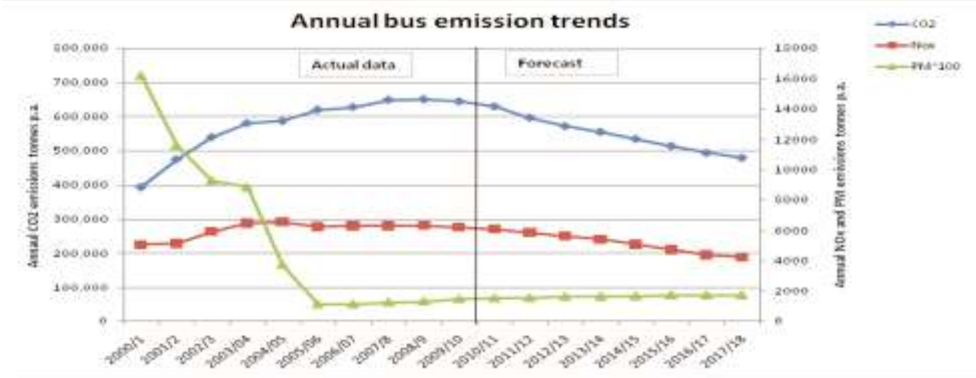



*Figure 10 Annual bus emission trends in London (2001-2018 year)*

2) The introduction of hybrid buses

Putting into operation of hybrid buses has been a strategically decision that started with the implementation of the 2006 year. Currently, 260 hybrid buses are run every day and London is planning introduction of this type bus, total of 600 buses until 2016 year [2].

The following Table 2, presents the results of comparative testing of 3 different types of buses with diesel-powered buses and equivalent to the hybrid [1] on the central line route 159 (Figure11).

***Table 2*** Results of tests on the line route 159 ($6^{th}$ February – $5^{th}$ March 2011 year)

| **Type of buses** | **Type of drive** | **Euro norm** | **Consumption L/100 km** | **CO2 (g/km)** | **NOx (g/km)** | **PM (g/km)** |
|---|---|---|---|---|---|---|
| ADL Enviro 400 | Diesel SCR | Euro 4 | 47.6 | 1253 | 6.146 | 0.035 |
| ADL Enviro 400 H | Hybrid Serial-BAE | Euro 4 | 32.3 | 856 | 4.170 | 0.024 |
| Wright Gemini 2 | Diesel SCR | Euro 5 | 47.3 | 1250 | 3.490 | 0.025 |
| Wright Gemini 2 H | Hybrid Serial-Siemens | Euro 4 | 27.7 | 734 | 2.04 | 0.020 |
| Volvo B9TL | Diesel SCR | Euro 4 | 63.0 | 1670 | 4.648 | 0.046 |
| Volvo B5L | Hybrid Parallel-ISAM | EEV | 35.4 | 937 | 2.612 | 0.026 |

From the table 2 it can be observed that for all three types of buses with hybrid drive have had decline in fuel consumption compared to the same bus with diesel propulsion. As a result of less consumption of diesel fuel is lower emissions of $CO_2$, $NO_x$ and PM is shown in Table 2.

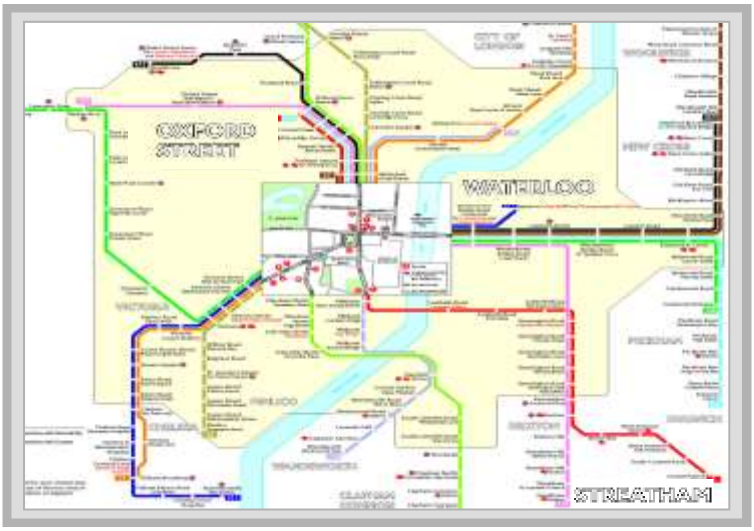



*Figure 11 Pink line-Route 159 ( Marble Arch - Streatham Station)*

*Figure 12 ADL Enviro 400 Hybrid*

The effect of using hybrid buses from the point of emission reductions are: 76% less emissions $C_xH_y$, 98% lower CO emissions, 12% lower $NO_x$ emissions, 31% reduction in fuel consumption and emissions of $CO_2$, 4 dB(A) lower level of external noise. [10]

In addition to the large scale introduction of hybrid buses on the streets of London as the most important measures to reduce emissions and $CO_2$, coming from the bus subsystems [2]:

- Driver training in fuel-efficient driving,
- Use of bio-fuels,

- Introduction of "shut-down" which excludes diesel engine when the vehicle is in the column, traffic lights, stop location,
- "Retrofit" buses with Euro 3 norm of the CRT to reduced NOx emissions (the period 2012-2015),
- Purchase of new buses with Euro 6 emissions standard (from 2015 to 2018),
- Experimental exploitation buses are driven by fuel cells currently has 8 buses in service.

## 7. AN EXAMPLE OF THE EXPLOITATION OF HYBRID BUSES IN THE FLANDERS REGION (BELGIUM)

The company "De Lijn" is the largest operator in the Flanders region (Belgium). Performing public transport in the cities of Bruges, Ghent, Antwerpen. Exploitation of buses with hybrid drive were begun since 2008 years and is currently 130 buses " Van Hool " in regular operation. According to the results of the test on bus line No 3, (Table 3), Van Hool AG 300 D for diesel-powered vehicles and identical with hybrid operation in the winter period, the hybrid bus was had the lower fuel consumption from 12.85 to 16.05% [12].

Table 3 *Comparative results of fuel consumption on buses Van Hool AG 300 H and AG 300D*

| **Period** | **Van HooL AG 300H L/100 Km** | **Van HooL AG 300D L/100 Km** | **%** |
|---|---|---|---|
| 22/10/-22/11/2010 | 47.63 | 55.3 | 13.86 |
| 1/1-31/1/2011 | 49.2 | 58.6 | 16.05 |
| 1/2-28/2/2011 | 49.81 | 57.15 | 12.85 |

The noise level measured on station while bus departure is 82.5 dB(A) for buses with diesel-powered and 72.4 dB(A) with hybrid drive [11].

## 8. AN EXAMPLE OF THE EXPLOITATION OF HYBRID BUSES IN BARCELONA

Company-TMB-has 25 solo buses with hybrid drive, a serial-type by producer Castrosua-MAN. Trial period was begun in 2008/9 on the two hybrid buses. Since 2010 the fleet of hybrids was increasing. Experiences show that the use of hybrids in city driving conditions generate savings of 20-25% compared to an equivalent diesel bus, while the suburban mode, the difference is 10-15%, table 4 [13].

*Table 4 Effects of reducing fuel consumption in different modes*

| **MAN - Castrosua** | **Stop time %** | **Average speed km/h** | **Energy saving %** |
|---|---|---|---|
| City driving conditions | 44 | 12.1 | 20-25 |
| Suburban driving conditions | 32 | 25 | 10-15 |

Interestingly, note that TMB has in service 370 buses powered by CNG. They are planning that some of CNG buses should be reconstructed, installation of equipment Generator-Electric motors and other components and will become buses with Hybrid CNG-powered.

## 9. FURTHER DEVELOPMENT OF THE CONCEPT OF HYBRID BUSES FOR PUBLIC TRANSPORT

Buses with hybrid drive have been gaining increasing importance in many EU companies and cities, thanks to its advantages in energy efficiency and emissions of CO2, compared to a conventional bus. However, the hybrid concept has certain shortcoming which slows massive use especially in less developed countries and cities. The perceived disadvantages are:

- High cost of hybrid buses (higher by 50% compared to the same bus with a diesel-powered),
- Battery life and their price (at present battery technology limits their lifespan to 6-7 years, after which it is necessary to replace the battery, which increases the costs),
- The greater weight of buses,
- Specific maintenance (two engines, highly sophisticated technology, precautions 600 V),
- Additional training for drivers and maintenance workers.

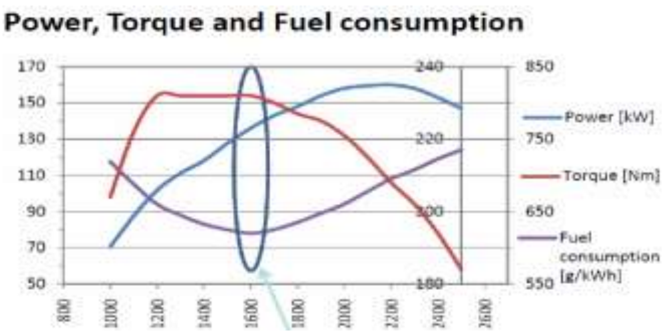



*Figure 13 Optimal mode of serial hybrid "Citaro" [14]*

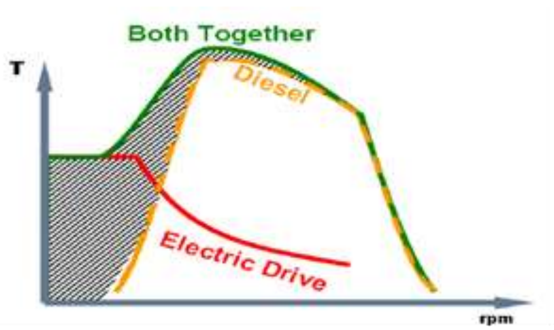



*Figure 14 Parallel hybrid concept" Volvo" [8]*

For most of the hybrid buses depending on the system drive (serial or a parallel) in real operating conditions, it is necessary to review all the influential weights (speed, intensity of passenger flows, terrain ...) on routes where vehicles with hybrid drive working. From that very much depends on the choice of the most suitable vehicle and therefore the effects of use. Figure 13 shows an example of the optimal mode serial-type hybrid Citaro G BlueTec. Figure 14 shows the characteristics of torque for parallel hybrid concept Volvo 7700 H.

In the next period, hybrid buses will have permanent development and improvement as an alternative of diesel buses.

- Improving battery technology that will allow to keep the battery life of 10-12 years, which is approximately the service life of the vehicle,
- Increasing the capacity of the battery which will allow greater autonomy in electric mode, the vehicle,
- At the moment capacity Li-ion battery is 85 Wh / kg. It is expected that in 3-4 years capacity will be about 170 Wh / kg,
- Optimize components of the hybrid propulsion and auxiliary equipment on the vehicle,
- Higher capacity batteries enable supplementing " plug in" while the vehicle is stationary at the station or terminus and thus reduce to a minimum the use of diesel engine, and
- Reducing vehicle weight. By using lighter composite materials, tends to reduce vehicle weight by 1000 kg. This would have the effect of a 7% increase in the efficiency of hybrid buses.

## 10. CONCLUSIONS

Exploitation of hybrid buses in many EU cities is a significant improvement of the transport system of the city, especially in terms of environmental protection, energy efficiency and quality of transport. Experiences in EU cities that use this concept were contributed to identify possible specifics compared to diesel buses, especially in terms of reducing fuel consumption, environmental benefits as well as future trends in the development and promotion of the hybrid concept.

In the period 2011 - 2020 years hybrid buses will significantly contribute to the sustainable development of cities, as the first phase in the use of electric drive, which will be primary in all vehicles for road transport, in a future.

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# FE MODEL OF A MISSING BOLTED JOINTS INFLUENCE ON A GUARDRAIL RESTRAIN SYSTEM DURING IMPACT

*Nikola Avramov*[1]*, teaching assistant, Petar Simonovski, PhD, proffessor*

**UDC: 62.78;608.4**

**ABSTRACT**: The increase in traffic safety and the design of safer roads includes installation of guardrail systems on separate road segments as part of the highway infrastructure for withholding the vehicle back on the road. In cases when there are no authorities to monitor the highway infrastructure or the EU regulations are taken as a recommendation but no obligation, situation like the bad restrain systems installation can occur. One example of not proper installation of the guardrails is misaligning the bolt holes for the fastener connection between the segments usually resulting in removing them. The aim of this study is to examine the influence of missing fastener sets between the guardrail segments. For model initial input and its validation parameters data from real-life accident were taken. This accident was fatal for the passenger's life.

**KEY WORDS**: accident severity, bolted joints, finite element method, guardrail segments

# FE MODEL ZA ANALIZU UTICAJA MEDOSTATALA ELEMENATE VEZE NA SIGURNOSNE OGRADE TOKOM SUDARA

**REZIME:** Porast broja saobraćajnih nezgoda i projektovanje bezbednih puteva obuhvata postavljanje sistema odbojnika pored saobraćajnica, kao deo putne infrastrukture koja ima zadatak da vozilo vrati u saobraćajnu traku. U slučajevima kada nadležni ne prate postavljanje infrastrukture na auto-putevima ili se EU regulativa shvata kao preporuka a ne obaveza, situacija sa neadekvatnim postavljanjem zaštitnih sistema može da se dogodi. Jedan primer je neodgovarajuće postavljanje sigurnosne ograde zbog nesaosnog vezivanja segmenata, što često dovodi do razdvajanja i uklanjanja segmenata. Cilj ovog rada je ispitivanje uticaja uklanjanja elemenata veze između segmenata zaštitne ograde. Kao ulazni parametri i parametri na osnovu kojih je izvršena validacija modela korišćeni su podaci dobijeni u relanim nezgodama, koje su imale smrtni ishod.

**KLJUČNE REČI**: jačina nezgode, vijčani spojevi, metoda konačnih elemenata, segmenti sigurnosnih ograda

[1] *Nikola Avramov, Faculty of Mechanical Engineering, Skopje, Macedonia, Karpos 2 bb, nikola.avramov@mf.edu.mk*

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# FE MODEL OF A MISSING BOLTED JOINTS INFLUENCE ON A GUARDRAIL RESTRAIN SYSTEM DURING IMPACT

***Nikola Avramov[1], teaching assistant, Petar Simonovski, PhD, proffessor***

**UDC:62.78;608.4**

## 1. INTRODUCTION

The most common road vehicles restrain systems that are used on the roads are W-beam, bridge parapets, concrete barriers, etc. and they differ by their ability to retain different types of vehicle out runs. Single sided W-beam guardrail segments with metal posts compressed in the ground is the most frequent type of guardrail found on the highways. The existing European normative EN1317:1998 is the framework for the guardrail design. Trough different parameters thresholds among which the most important are ASI (acceleration severity index) and PHD (post impact head deceleration) the vehicle impact severity level is approached [1][2]. The regulative is determining for example both the maximum deceleration in the passenger compartment considering the vehicle and the maximum guardrail deflection for specific type of impact, given in the test matrix. If all of the parameters are within the prescribed range and if other obligations are fulfilled like the vehicle motion after the impact should be in the specified exit box boundaries, nothing is allowed to penetrate in the passenger compartment and no part of the guardrail system should be separated from it becoming danger for the other road users. Or the guardrails are designed to absorb the energy coming from the vehicle motion safely lowering the velocity through desired vehicle path.

The road restrain systems installation on different highway sections depends on the vehicle frequency, most common types of vehicles driving on that road, maximum permitted velocity, coming turns etc. The highway inspection authorities considering these facts will decide about the minimum containment level that the restrain system has to fulfill. According to the regulations the guardrail should comply with the criteria for the defined containment level. In reality the impact parameters can vary significantly but proper standard implementation means maximum safety for all crash scenarios.

The importance of the guardrail protection comes from the fact that in most of the countries the restrain systems normative is accepted as regulation. The stated is confirmed with the following extracts of different EU-countries regulations.

- Finland (Finnish Transport Agency) - „Barriers bearing the CE mark and complying with standard SFS-EN 1317-5 are used on roads if they satisfy the requirements set out in this guide. “
- Germany (Forschungsgesellschaft für Straßen- und Verkehrswesen) - „Vehicle restraint systems must meet the requirements of DIN EN 1317 - Restraint systems on roads. The compliance with the requirements must be verified by presenting the relevant test reports.“

*[1] Nikola Avramov, Faculty of Mechanical Engineering, Skopje, Macedonia, Karpos 2 bb, nikola.avramov@mf.edu.mk*

- Norway (The Directorate of Public Roads) - „…it has been harmonized with the common European guidelines for testing and approval of vehicle restraint systems - NS EN 1317, which was prepared under the auspices of CEN and set by Norwegian Standard.“
- United Kingdom (The Highways Agency) - „This Standard describes the procedures to be followed by the various parties involved in the design and provision of various types of Road Restraint Systems.“

## 2. FE MODELS

### 2.1. Vehicle model

For FEM vehicle model the Ford Taurus (model year 2001) is chosen because its closeness to the European mid-sized vehicle fleet [3]. The model was developed for general purposes so it needed some modifications to address certain deficiencies in the vehicle to barrier simulations. The model had to undergo some modifications for lowering the simulation time and bringing the response closer to the realistic.

- removing parts of less importance for the vehicle behavior.
- adding element mass adequate to the removed parts mass. The element mass was added at the B-pillars because of the position of the centre of gravity at the mid plane between the B-pillars trough the vehicle width.
- fixing the free turning of the wheel with the first contact to the guardrail and consequently the change of the load path. During the research phase it was seen from the crash test videos that the wheel experience slight inclination after the engagement during the oblique collision.
- mass was added to the accelerometers to damp the oscillation amplitude of high frequency noise and getting more stable results.

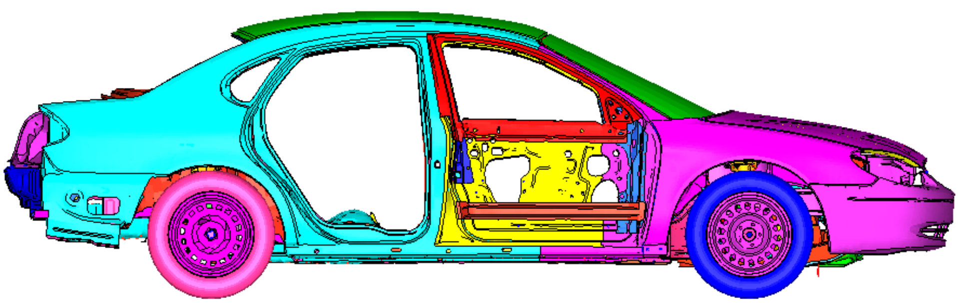

*Figure 1. Simplified vehicle geometry model*

### 2.2. Guardrail model

The guardrail consists of twelve segments or rails and thirteen support posts compressed in the ground. For the rails connection eight pairs of fastener sets are used, and for the rail to post connection one pair of fastener is used. For a more accurate representation the guardrail model had to undertake some adjustments like:

- the bolt to nut connection is modeled by using beam connection, specifying the beam stiffness, cross-section area and the mass density. This type of connection gives us the possibility of defining the pre-load force as initial force acting in the beam direction joining the segments together and is used as more direct approach instead of already known methods of temperature difference or initial strain method. The joining components, bolt and nut are modeled with their standard dimensions except modeling the threads which was found in the literature as non-essential factor affecting the results [4]. They are tied together with linear beam between connecting nodes, first as the centre node of spider rigid body elements around the circumference at the end of the bolt head and the second one as the centre node of spider rigid body elements around the hole at the beginning of the nut (Fig.2).
- the soil is modeled as a solid cylinder meshed with hexagonal elements, with a centre hole trimmed with the projection nodes of the post.
- the contact on separate segments is defined trough the static and dynamic coefficient of friction, one between the guardrails segments, other between the post and the ground and the last between the vehicle and the guardrail elements.
- guardrail end elements are connected by dampers to rigid constrains. Dampers are used because they have the possibility to absorb energy, corresponding to the deformation of the adjacent rails. For adequate representation the “length of need” according to NCHRP 350 as a general rule should not be less than 30m for a flexible barrier, and in this case is 48,3m [5].
- local weakening around the fastener holes. From the crash analysis was concluded that the bolt head is pulled out of the guardrail segment. These local deformations are reached in the model by defining lower Young’s elastic modulus for the elements around the holes that will enable the fastener unbuckle (Fig.2).

## 3. MODEL VERIFICATION

One of the possible arrangements of improper guardrail installation is shown on Fig.3. The numerical FE model verification will be done trough comparison by visual inspection of the guardrail elements involved in a real crash accident with the appropriate virtual model.

Real crash tests only are used as verification tools accompanied by measurements and videos for the specific case. The scene investigation provided information about the deformation modes of the guardrail components and some relevant measurements for the verification are the holes openings, segments final displacement and magnitude of the posts bending.

The initial impact parameters were gathered from the police reports. The vehicle closing speed was 141 km/h, angle of impact 8 degrees and vehicle weight including the driver was approximately 1710kg.

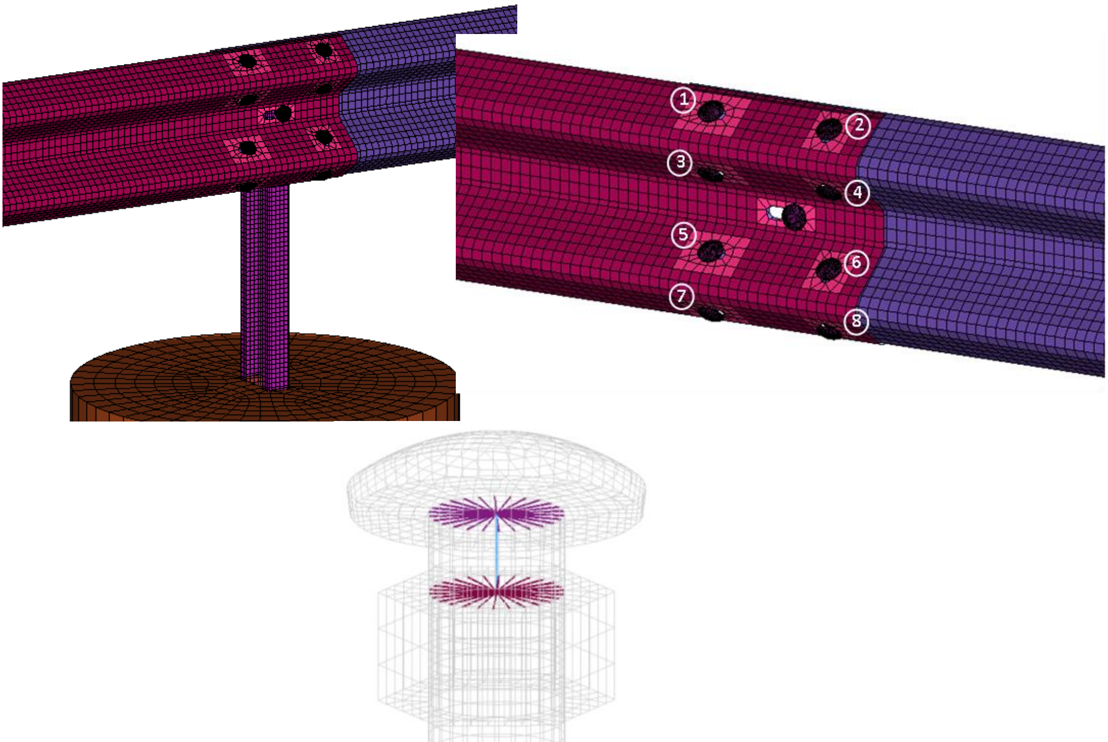


*Figure 2. Fastener sets connecting elements and weakened areas*

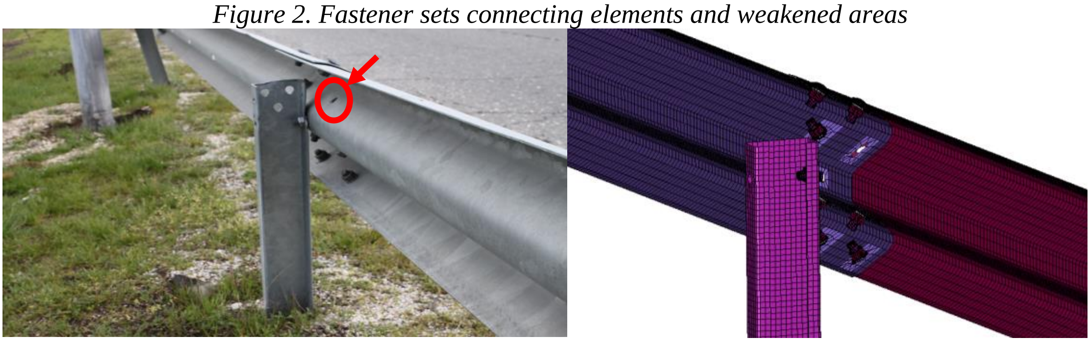

*Figure 3. Real and FE missing fastener set model*

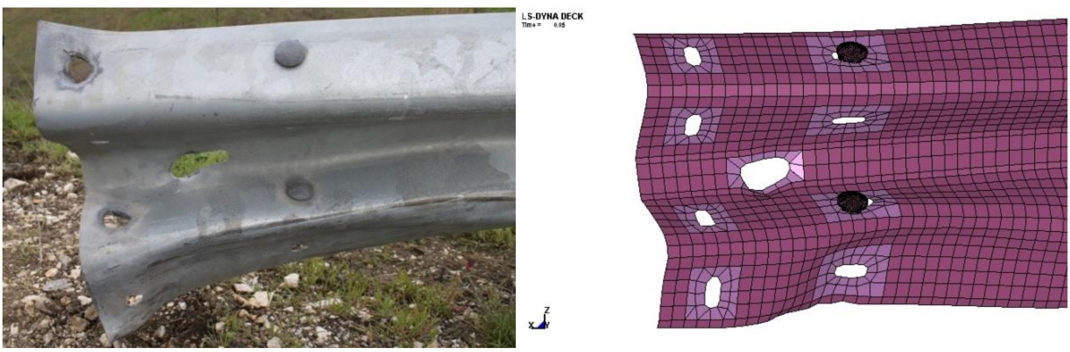


*Figure 4. Real and FE segment deformation mode*

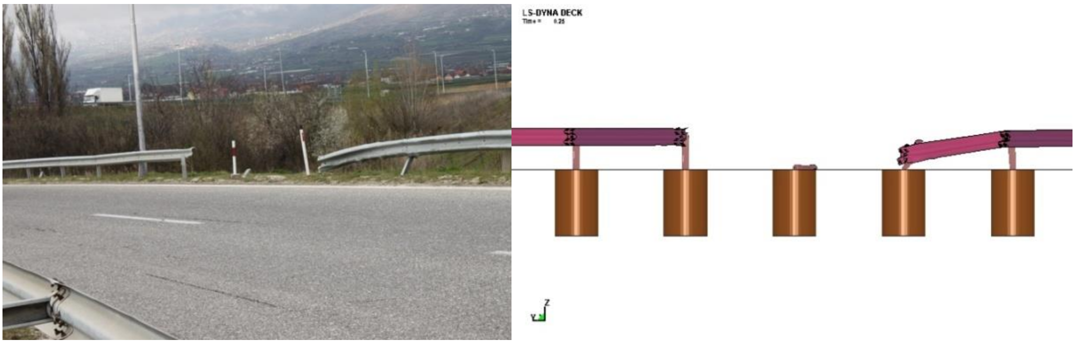


*Figure 5. Real and FE accident severity*

From visual observation, part of it presented on the pictures above (Fig.4 and Fig.5), can be seen the close behavior of the guardrail FE model and the scenes from the real-life accident. The first picture shows the fastener hole widening as a result of local deformations, clearly seen on the photograph taken at the place of the accident. As the impact progresses the segments are being subjected to complex deformation modes, both bending and shear, causing bolted joints pulling through the deformed holes [6]. On the second picture the segment separation on the place of the vehicle run off can be seen. Two of the segments have been carried away by the vehicle and were found several meters away from the place of impact.

As noted before some of the segments were connected with less than the needed eight fastener sets. At the point of impact the segments were connected with seven or fasteners number 1,2,3,5,6,7 and 8 as marked on Fig.2 and the adjacent segments were connected with only four fasteners 1,2,5 and 6, which can be seen by the hole imprints on Fig.4. The result and the consequences of this badly installed guardrail are enormous and can be noted as a fact that there was nearly no absorption of the guardrail segments or the vehicle just passed through and ran off the road.

## 4. RESULTS AND DISCUSSION

For analyzing the missing bolted joints influence on a guardrail segment separation, fasteners for segment to segment connection have been removed. At first the outer (ones farther away from the post connection, bolts number 1,2,7 and 8) and afterwards the inner (ones closer to the post, bolts number 3,4,5 and 6). Both are compared with the real accident outcome.

For grading guardrails performance parameters from European normative [1,2] are used.

- Acceleration severity index (ASI)

This parameter measures the severity of the vehicle motion over a person seated in the proximity of a chosen point during an impact.

$$ASI(t)=\sqrt{\left[\left(\frac{\overline{a x}}{\hat{a x}}\right)^2+\left(\frac{\overline{a y}}{\hat{a y}}\right)^2+\left(\frac{\overline{a z}}{\hat{a z}}\right)^2\right]}, \qquad (1)$$

where $\hat{ax}$, $\hat{ay}$, $\hat{az}$ are the threshold values of a human body accelerations (for passengers using safety belts ax = 12g, ay = 9g, az = 10g) and $\overline{ax}$, $\overline{ay}$, $\overline{az}$ are the accelerations of a driver seating point, averaged over a time interval of 50ms.

*Table 1. Acceleration severity index*

| | accident | with outer | with inner |
|---|---|---|---|
| ASI [/] | 1.4052 | 1.5498 | 1.3711 |

- Post Impact Head Deceleration (PHD)

This is the maximum value of an averaged longitudinal and transversal component accelerations of a vehicle centre of gravity computed over 10ms. It is assumed that the head remains in contact with the vehicle after the impact for the rest of the time period.

$$PHD = \max \sqrt{\left(\ddot{x}_C\right)^2 + \left(\ddot{y}_C\right)^2}$$

*Table 2. Post impact head deceleration*

| | accident | with outer | with inner |
|---|---|---|---|
| PHD [g] | 16.8285 | 18.5612 | 16.4201 |

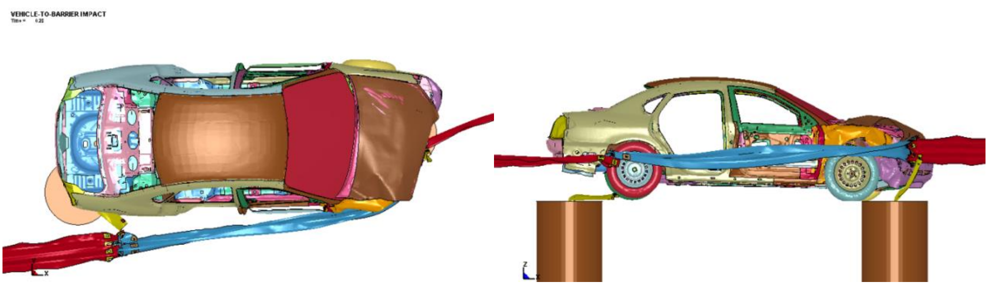


*Figure 6. Vehicle and guardrail deformation modes at time 0.28 [s]*

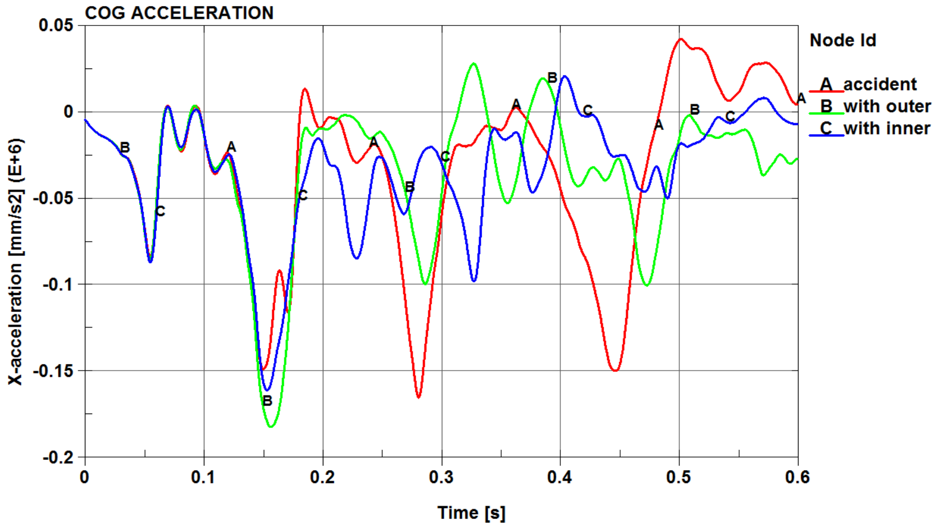


*Figure 7. Centre of gravity acceleration*

The diagram on Fig.7 presented above shows the vehicle centre of gravity acceleration curve. Some of the impact characteristic tracing points are described. At the beginning of the crash the acceleration impulse follows same trend which is expected till more of the structures interact. The first contact of the vehicle to guardrail starts at 0.01s. At 0.05s the vehicle wheel comes into contact with the guardrail post but no wheel snagging occurs because the wheel slides outside the post. The second vehicle to post interaction occurs at 0.15s when the direct impact separates the post from the guardrail. At the time of 0.28s the guardrail deforms so that it gets the vehicle front shape and together with the coming post holds back the vehicle (Fig.6). The last acceleration peak happens at 0.45s and this is the time when the third post directly subjected to the impact breaks the connection with the rails. For the rest of the time duration the guardrail segments separate and the accelerations are getting lower.

From the presented tables of ASI and PHD the highest values are for the case of segments connected with only outer fasteners, following the one for the real accident and the last is with only inner fastener case. This corresponds to the acceleration peaks occurring at the same order as stated but for different time moment.

## 5. CONCLUSION

Properly modeled and verified model can be adequate replacement of the actual crash tests. The models have to address certain modifications for bringing the response closer for the corresponding test. The state of the art achievements in this paper are in the direction of general improvements of the FEM models in the virtual impact testing and the influence of the missing fastener in the guardrail installation during impact.

The vehicle to guardrail model used can be appropriate representative considering the above stated modifications. Some of the adjustments made are: parts of less importance of the model can be removed with no influence to the response and replaced with element mass, like the back parts of the vehicle in the front impact tests, and being aware of not re-positioning the vehicle centre of gravity; there is no driver's response to the steering wheel and the vehicle front wheels are turning freely resulting in changing the driving path, the adjustments are in fixing the turning of the wheel; damping the oscillations by adding mass to the accelerometers that are modeled as a solid rigid cubes with its edges defining local coordinate system and measuring the origin acceleration.

The advantages of virtual testing methods are used for finding the influence of the missing guardrail bolted joints stimulated from real crash accident. The conclusions regarding the fasteners are the following. Missing inner bolted joints is much severe than missing the outer ones. The difference in acceleration severity index between both is about 11.5%. For impacts in guardrail restrains with only outer fastener sets between the rails, from the post impact head deceleration can be assumed that the human head is for almost 2g's higher deceleration subjected to.

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# THE ANALYSIS OF SUBFRAME INFLUENCE ON CAR BODY BEHAVIOUR

***[1]Milan Milovanović, Miroslav Demić, Saša Jovanović,***

**UDC:621.9-112.3**

**ABSTRACT:** The development of the carrying construction of one producer is an endless process. In addition to the analysis of carrying construction behaviour, it is necessary to take into account the influence of additionally installed drive units onto the carrying construction behaviour. In this paper, the influence of subframe on carrying construction behaviour, is shown. With the aim of presenting the results, behaviour of carrying construction in conditions of quasi-static test has been shown, as well as in conditions of simulation of front impact test.

**KEYWORDS:** car body, behaviour, influence.

## ANALIZA UTICAJA POLUŠASIJE NA PONAŠANJE KAROSERIJE

**UDC:621.9-112.3**

**Rezime**

Razvoj noseće konstrukcije za jednog proizvođača je beskrajan proces. Pored analize ponašanja noseće konstrukcije, neophodno je uzeti u obzir uticaj naknadno postavljenih pogonskih jedinica na ponašanja noseće konstrukcije. U ovom radu prikazan je uticaj polušasije na ponašanje noseće konstrukcije. U cilju prikazivanje rezultata istraživanja, noćeća konstrukcija je izložena uslovima kvazi - statičkog ispitivanja, kao i uslovima simulacije uslova testa prednjeg čeonog sudara.

**KEIVORDS:** karoserija, ponašanje , uticaj.

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## THE ANALYSIS OF SUBFRAME INFLUENCE ON CAR BODY BEHAVIOUR

*Milan Milovanović[1], PhD, Miroslav Demić, PhD, professor, Saša Jovanović, MSc*

**UDC:621.9-112.3**

# INTRODUCTION

The level of success of the construction is the reflection of the design period, as shown in Figure 1, where the carrying construction of vehicle Zastava Yugo**,** designed in the 70-ties of the last century, is presented. The carrying construction was similar to the carrying construction of other FIAT models, with the frontal frame construction considerably influenced by the construction of the front vehicle suspension system. The functions of the front suspension system of the vehicle did not include the stiffening of the frontal frame. The designed directions of car body deformation are specific due to the characteristic position of front longitudinal supports, which direct deformation considerably towards longitudinal roof supports, and less towards car floor. There was no connection with the car floor elements on the frontal part, which was unfavourable from the aspect of carrying construction loading.

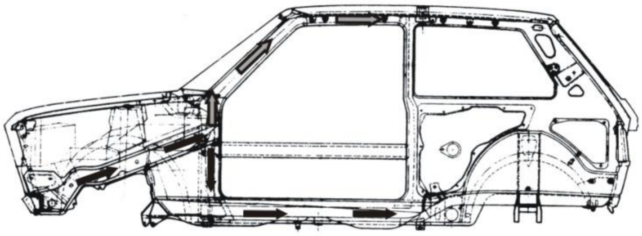

***Figure 1*** Vehicle Yugo - car body

Car body of vehicle Zastava10 is a car body of modern concept, with car body shown in Figure 2. Frontal frame was strengthened considerably; together with front vehicle suspension system, it makes a set which is of great importance for car body behaviour at front impact. The installed subframe the frontal frame. Front longitudinal supports, which direct deformation towards car floor, are also important. With the purpose of satisfying side impact conditions, side shell frame, with prominent pillar B and lateral longitudinal supports of floor, was strengthened considerably. Side door frame was strengthened additionally.

[1] *Milan Milovanović, Zastava vehicles group, Kosovska 4, 34000 Kragujevac, SERBIA, siljakg@sbb.rs*

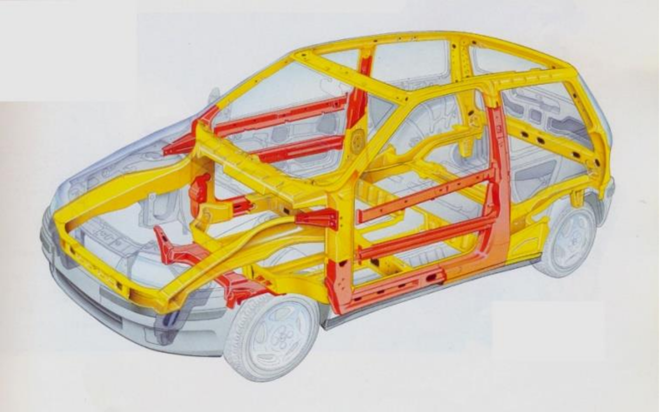

***Figure 2*** Vehicle Zastava10 (Punto FIAT) - car body

The carrying construction of this car body is also robust and adjusted to the by-law demands. With the aim of strengthening the construction, sheet metals of increased strength, which strengthen the construction with significant weight reduction, were also applied. When designing the carrying construction of one vehicle may occur, they are:

- Carrying construction of the existing model is improved (minor reconstruction).
- Major reconstruction.
- The designing of both the new generation of carrying construction and vehicle elements which influence its behaviour.

The third case occurred when designing vehicle Zastava10 car body, where a completely new carrying construction was designed with the aim of satisfying market demands in the following ten-year period. The development of the carrying construction was accompanied by a significant improvement of both the solution for front vehicle suspension system and interconnections of all other drive units in frontal part with car body. The results of such a procedure are shown in Figure 2.

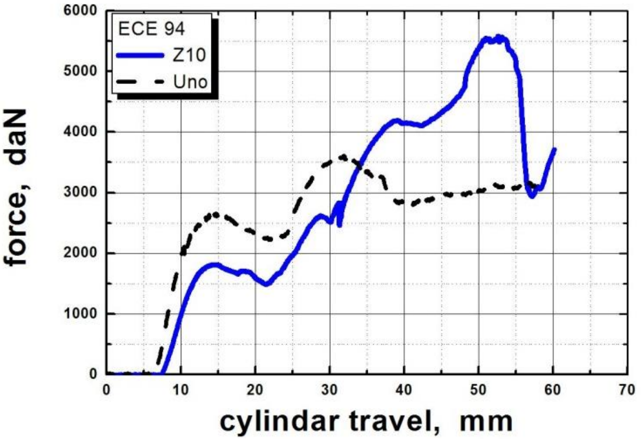


***Figure 3*** Comparative display of dependence force - travel for vehicle Zastava10 and model Uno

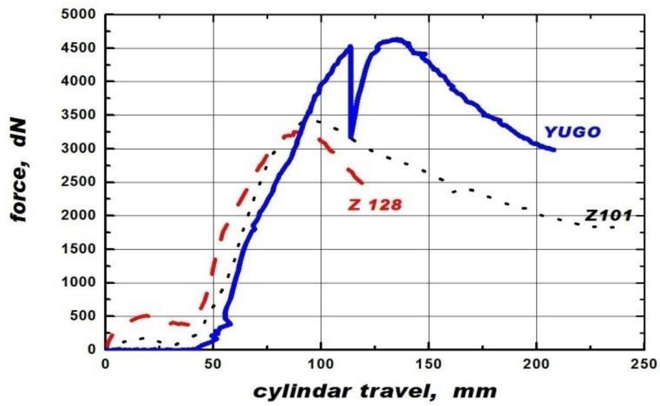


***Figure 4*** Comparative display of effect of car body improvement

Improvement of one model of any producer inevitably leads to improvement of vehicle construction. For the behaviour of the older vehicle car body (car body of vehicle Uno), it is typical that large deformations first appear on the connection of front longitudinal supports and partition wall, then the deformations occur on side shell frame, and finally the construction collapse occurs /3/. In this way, with directed collapse point, the desired objective is accomplished. In new vehicle model car body, considerably higher level of force is achieved, and the behaviour of car body is significantly improved. Deformations of the carrying construction in the front part are insignificant and also directed regarding point and direction. Side shell frame is slightly deformed, i.e. passenger space deformation is minimal, see Figure 6 and 7. Regardless of stricter investigation conditions, increase of force achieved for car body of vehicle Z10 compared with car body of vehicle Uno is significant, which indicates that great efforts were invested in order to accomplish such a result, see Figure 3.

The following model which was developed in Zastava was vehicle Yugo, which maintained many elements of vehicle Z101/128 (carrying constriction type, front vehicle suspension system, drive unit suspension etc.). FIgure 4 shows the comparative display of obtained improvement of vehicle Yugo behaviour. Critical point in car body behaviour can be observed, which can also be the consequence of the welding quality. In vehicles Z101 and Z128, since the front part is the same, almost identical accomplished force was obtained. Model Yugo exceeded the previous model significantly, which was expected as it was the new model. However, the realized difference was limited by the similar front vehicle suspension system, i.e. realized carrying construction, which was adjusted to this system.

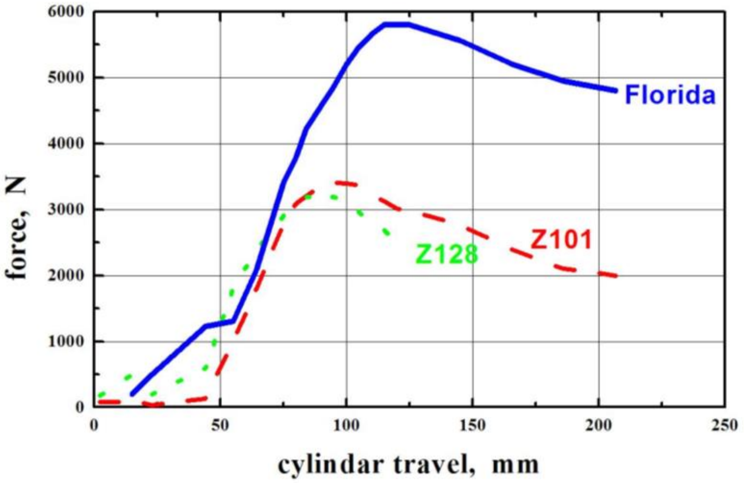


***Figure 5*** Improvement on vehicle Florida car body

When developing vehicle Zastava Florida (90-ties of the last century), the opportunity was not taken to change the construction of front system for vehicle suspension, the consequence of which would be the change of carrying construction in the front part. Figure 5 shows the accomplished improved level of car body behaviour, which was not sufficient to satisfy by-law ECE 94. I Maintenance of the same construction of front vehicle suspension system also had a lot of influence on vehicle Florida car body.

***Figure 6*** *Display of installed drive units*

# ANALYSIS OF SUBFRAME INFLUENCE ON CAR BODY BEHAVIOUR

The developed method was focussed on obtaining data on car body behaviour at impact test. The concept of monitoring the behaviour of car body itself, regardless of the influence of additionally installed car body parts, i.e. influence of drive units installed on the vehicle, was selected. The initial assumption was that each installed drive unit would have a positive influence on car body behaviour and that such influence should be taken into account in later stages of the analyses, but not in the initial designing phase.

With the aim of getting closer to impact tests, the experiment was carried out in order to determine the influence of vehicle drive units which are installed on the car body. The following elements were installed on the investigated car body: propulsion group, part of steering mechanism and vehicle suspension system with subframe, as shown in Figure 6, with upgraded car body. The installed drive units were mainly the ones which could influence the behaviour of frontal frame. The installing conditions were identical to those on the vehicle.

Concerning the initial test conditions, nothing was changed regarding: device, investigation conditions, measuring points and car body estimation method. The initial analysis of car body behaviour was performed via visual monitoring of car body.

***Figure 7*** The initial position of car body with drive units

Figure 7 shows the initial position of the investigated car body with installed drive units, where the initial position of the wheel in relation to car body can be seen clearly. In the initial test phase, the first car body deformations appeared on the front outer coating (mudguard). The initial deformation occurred on front part of front longitudinal support, in front of front wheel axis, see Figure 8.

***Figure 8*** The first inter- phase

Figure 9 shows the following inter- phase. The increased deformations of side door opening caused the windshields glass to start falling out. The deformation on front left longitudinal support was still increasing. The final position of the deformed car body is shown in Figure 10. In the given case, the extreme deformations occurred in the front part and at side door opening.

***Figure 9*** The second inter- phase

***Figure 10*** The final position

Major deformations also occurred on car body with installed drive units, with subframe, on front part of front longitudinal supports, figure 11, which was the consequence of the influence of subframe which had stiffened the front frame in the partition wall zone. Intensive deformation occurred at side door opening and windshield glass opening. Character of front frame deformation was considerably changed.

***Figure 11*** Appearance of front frame

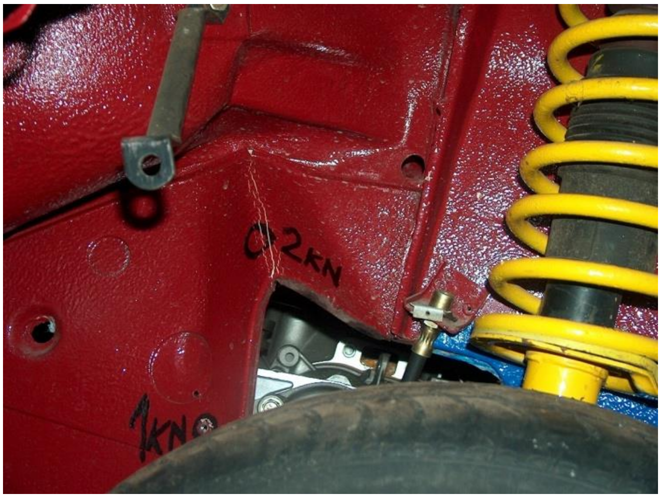


***Figure 12*** Front inner mudguard after the test

***Figure 13*** Partition wall after the test

Figure 11, 12 and 13 show the front part of vehicle Florida car body, on which the drive units were installed, after the quasi - static test. Here, as well, major deformation of car body was obtained on the left side, but it was significantly smaller than on the ″bare″ car body. Redistribution of load and increased deformations of front left longitudinal support occurred in front part. The installed drive units caused the significant changes of character of critical zones deformations. In case of this test, as well, critical zones, similar to those in investigations of car body without drive units, were located.

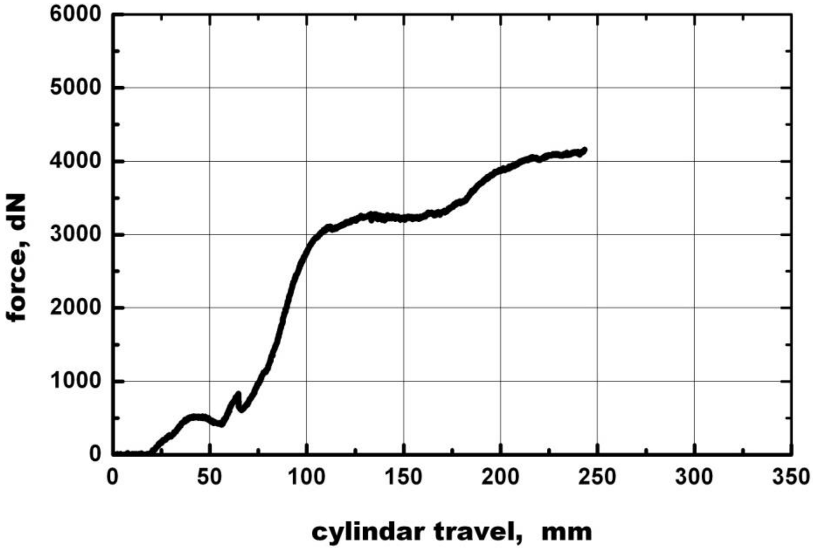


***Figure 14*** Force - travel dependence of cylinder on "bare" car body

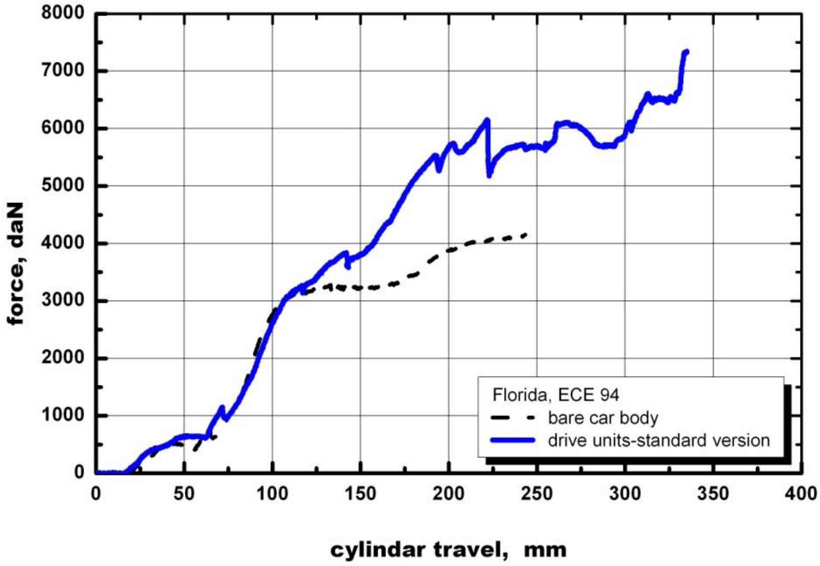


***Figure 15*** Influence of installed drive units - standard vehicle version

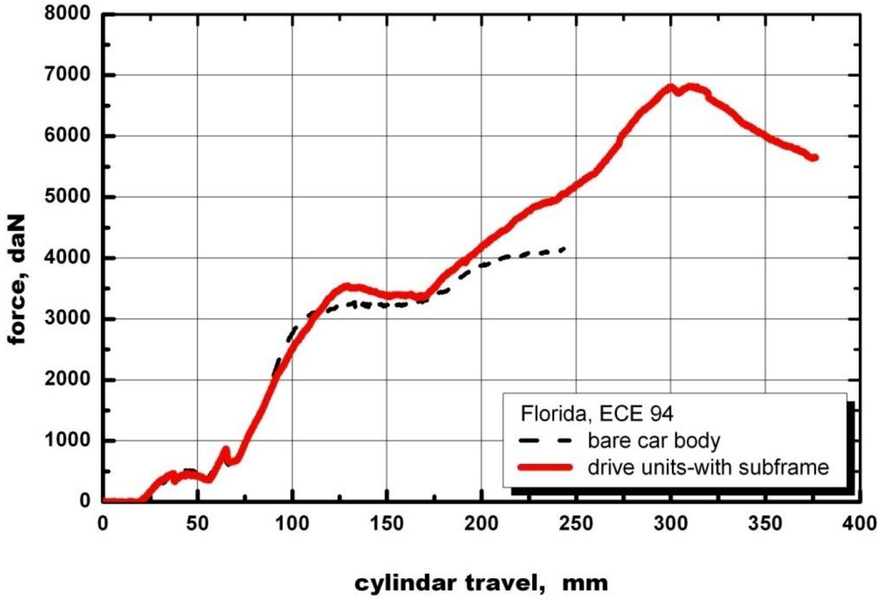


***Figure 16*** Influence of installed drive units – with subframe

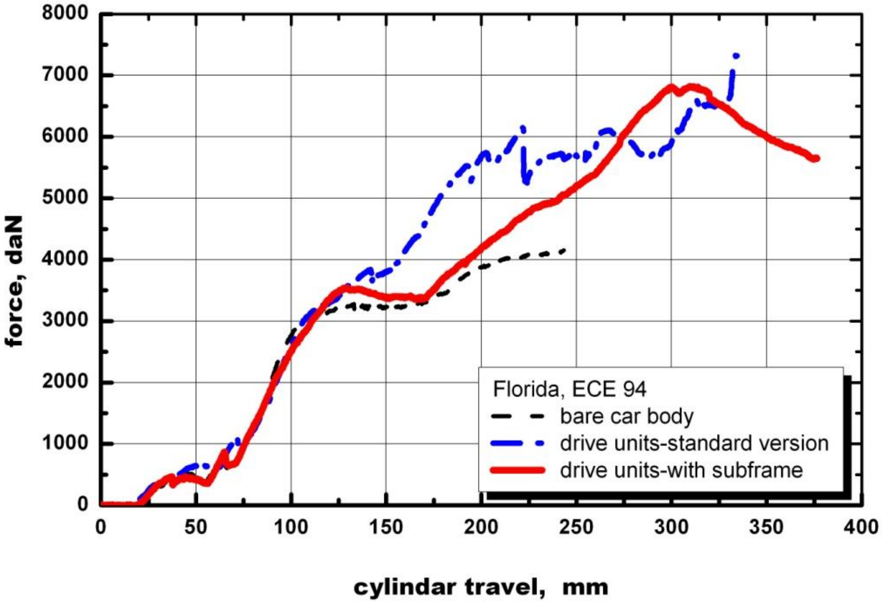


***Figure 17*** Comparative display of the influence of installed drive units

As expected, the installed serial drive units influenced the behaviour of car body, which was manifested by increased force at construction fracture. The first critical zone was less prominent, which was probably the consequence of contact between the wheel and car body.

As expected, the installed drive units with subframe influenced the behaviour of car body, which was manifested by increased force at construction fracture. The first critical zone was more prominent, which was probably the consequence of the lack of contact between the wheel and car body**.**

On serially installed drive units, deformation of front part towards partition wall occurs; its character, however, becomes significantly improved after the contact of wheel and gearbox with the car body. In the case of subframe, after the deformation of front longitudinal supports, the influence of subframe, visible at the end of the test, occurs. Car body deformation character has been considerably changed.

# CONCLUSIONS

The development and introduction of new solutions in car industry is a necessity. The presented results indicate the influence of installed drive units which must be taken into account when making calculations and in the initial project phase.

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**MVM** *Editorial Board*
*University of Kragujevac*
*Faculty of Engineering*
*Sestre Janjić 6, 34000 Kragujevac, Serbia*
*Tel.: +381/34/335990; Fax: + 381/34/333192*
***www.mvm.fink.rs***