REGIONAL WORKSHOP

TRANSPORT RESEARCH
AND BUSINESS COOPERATION IN SEE
6 - 7 December 2010, Sofia

CONTRIBUTIONS TO DEVELOPMENT AND IMPROVEMENT OF AUTOMOTIVE INDUSTRY BY RESEARCHERS FROM BOSNIA AND HERZEGOVINA

Filipović Ivan, Pikula Boran, Bibić Dževad
ifilipovic@automotivecenter.ba , pikula@automotivecenter.ba ,
bibic@automotivecenter.ba
Automotive center – centar za vozila Sarajevo
Vilsonovo setaliste 10, 71000 Sarajevo, Bosnia and Herzegovina

Summary
Before the last war, Bosnia and Herzegovina had a very important place in automotive industry and transport sector of Ex Yugoslavia. Today, there are several SMEs who have modern factories for production parts and spare parts for automotive industry and great number of different car manufacturers. The existing development trends and objectives for further work can be obtained only by continuous investments in the infrastructure, new technologies, researching and expert's education and training. The greatest contribution to the development and improvement of automotive industry in Bosnia and Herzegovina is given by researchers form universities, institutes and specialized firms. Some achievements in this field, obtained by the experts of Automotive center (AMC) Sarajevo are presented in the paper.
Keywords: *motor vehicle, ecology, injection, dynamics, optimal drive*

Introduction

Before 1992, Bosnia and Herzegovina had a significant part of general development in Ex Yugoslavia, including the transport sector. There were several factories in Sarajevo region, like *Automobile factory TAS* for production of passenger motor vehicles under license of *VW*, *Engine factory FAMOS* for production of diesel engines under license of *Mercedes-Benz* and its own engines for heavy duty vehicles with different purposes, etc. Besides the automotive industry located in Sarajevo, the industries for other transport sectors were in Sarajevo, like the *Vaso Miskin Crni factory* for production of wagons for railway needs and the *VZ Orao* factory for production and repairing parts for jet engines, as well as montage and testing the jet engines. The second center in Bosnia and Herzegovina was the city of Mostar, with *Soko* and *Aluminij* factories, as well as the *Herzegovina auto* known as a factory for production of small busses with up to 35 seats. The rest of automotive industry was located in north and north-east part of Bosnia and Herzegovina, like great number of different factories for production of engine filters under license *Mann humel*, furthermore for production of well known spark plugs *"Bosna"* for SI engines, a battery factory, a tractors factory, etc. Unfortunately, war activities in Bosnia and Herzegovina, in period 1992-1995, completely destroyed the infrastructure of existing automotive industry in Bosnia and Herzegovina. In the same time, accepting modern technologies from Western Europe countries and the world is not on the desired level.

In spite of the fact that some large manufacture systems and SMEs were rebuilt after the last war, the automotive industry in Bosnia and Herzegovina today is still oriented to the production of automotive parts for the first mounting, as well as to the production of spare parts for different car manufacturers. Having in mind this state of the automotive industry, it is very important to notice that factory *CIMOS TMD AI Gradacac* represents a positive example of B&H industry. The factory has a great number of contracts with lot of car manufacturers all over the world. This factory confirms the golden role that the continuous investment in the infrastructure, new technologies, researching and experts education and training can result a progress in any point of view. However, the greatest progress in development and improvement in automotive industry can be obtained by experts who work at universities, institutes and specialized firms, like the firm *"Automotive center - centar za vozila" - AMC* Sarajevo.

The company *"Automotive center - centar za vozila" - AMC* was formed in 2006 by prominent researchers in the field of motor vehicles in Bosnia and Herzegovina, with the aim of monitoring the current European regulations for motor vehicles and their participation in various forms of transport (transport of dangerous goods in accordance with the ADR agreement, the transportation of perishable goods in accordance with the ATP agreement, an international transport in accordance with the ECMT resolutions, etc.). From the beginning of 2009 the company is participating in EU FP7 project *TransBonus* as the first non-government institution and nongovernmental partner in EU FP7 project. In late 2009, the Ministry of Transport and Communications of Bosnia and Herzegovina has appointed the Automotive center - AMC as Professional institution for performing the administrative and technical services in the area of vehicle certification in Bosnia and Herzegovina.

The experts of AMC have made a significant number of different computer programs to simulate the flow of fuel in the overall fuel injection system for diesel engines, including Common rail system, then the definition of thermodynamic processes in IC engines, the dynamics and oscillations of internal combustion engine with a special emphasis on the torsional vibration damper, the simulation of vehicle dynamics in the unsteady cases, definition of fuel consumption, tire-rolling process and the simulation system of active safety vehicles such as ABS and ESP. The current plans for the future research are related to investigation of fluid flows inside the turbochargers and development of new modern brake systems in cooperation with the firm CIMOS TMD AI Gradacac.

The short presentation of the several achievements in mentioned fields are presented in this paper.

Modeling of fuel flows inside the diesel fuel injection system

Investigation of fuel flows inside the injector is the main topic from early beginnings of development of diesel fuel injection systems. Due to complex inside design of injector, a numerous different experimental and numerical methods have been developed and used in past. In case of 1D numerical modeling, a special attention was dedicated to high pressure pipe, while an injector is most often modeled as a blend with known flow coefficient thanks to the experiment. However, development of 3D numerical method based on use of CFD increased knowledge about fuel flows, but it is generally limited to the final segments of injector, i.e. needle seat, sac and nozzle.

The one dimensional mathematical model presented in this paper enables solving fuel flows through inside the injector based on simple elements such as pipes, blends and pipe-volume junctions. On that way, fuel flows have been fully defined in all points of a very complex inner side of the injector and shows characteristic places inside the injector where special care has to be paid during design of new geometric shapes. Considering that, all existing research in the spray characteristics were based on a known pressure in front of the injector, very good initial conditions for calculating the characteristics of dispersed fuel can be obtained with this model, which up until now was not the case.

The injector used for development of mathematical model is the Bosch manufactured injector which consists from an injector holder of *KDAL 80S20/129* type and an injector body of *DLL 25S834* type, with only one nozzle orifice (diameter d_b=0.68 mm and length l_b=2 mm). More information regarding the injector can be found in [1]. Solving of the hydro-dynamics characteristics of fuel inside the injector, according to the state of the art in modeling in this field, should be combination of dimensionless and one-dimensional mathematical models. The physical model presented in the Fig. 1 consists from pipes, spaces with constant and changeable volumes, thin wall orifices with constant and variable flow cross sections (P), combined with the dynamic model of needle movement.

With the aim of verifying mathematical model, measurements of characteristic systems for the fuel injection has been carried out comprising of a linear six-cylindrical high pressure pump of BOSCH manufacturer of PES 6A 95D 410 LS 2542 type with piston diameter of 9.5 *mm* and lift of 8 *mm*. The high pressure pump is connected via the high pressure pipe (of outer diameter of 6 *mm* and inner diameter of 1.8 *mm* and the total length of 1024 *mm)* with injector holder of *KDAL 80S20/129* type *and* injector body of *DLL 25S834* type. View on the used fuel injection system with marked locations of measurement devices is presented in the Fig. 2.

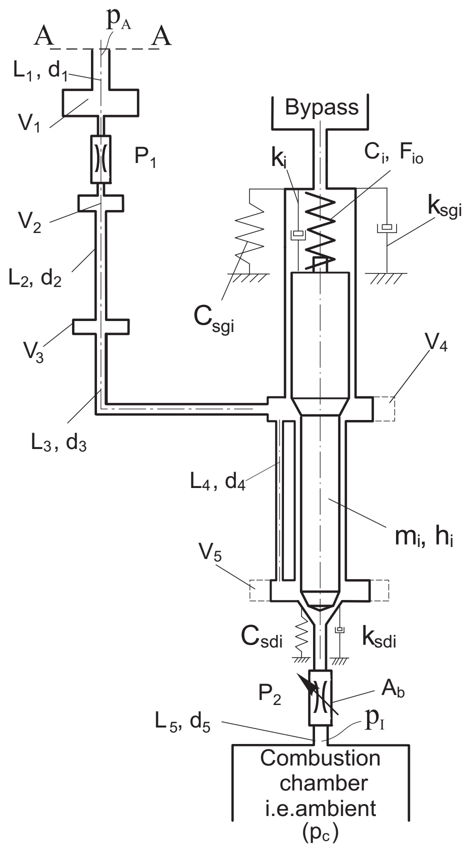

Fig. 1. Physical model of fuel injection system with special attention to the injector modelling

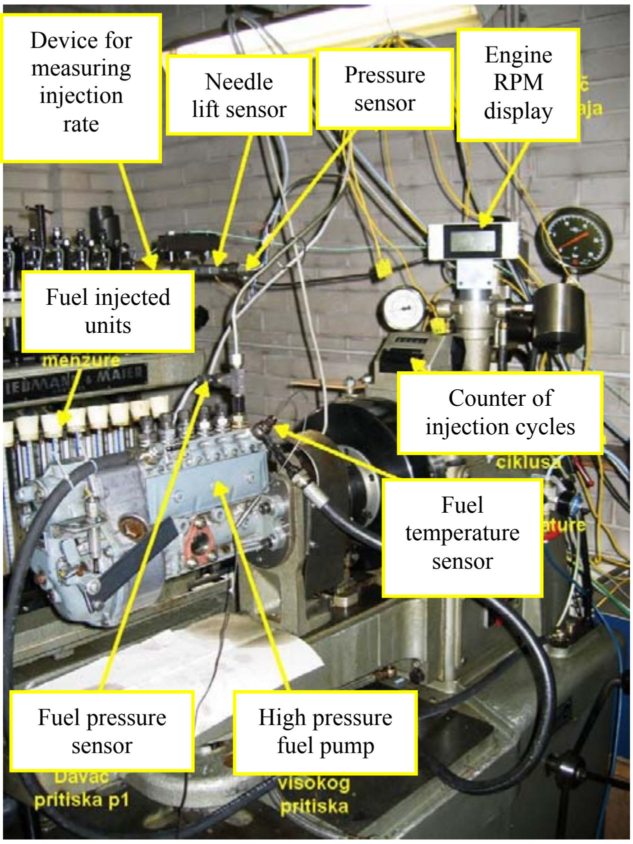

Fig. 2. Fuel injection system with marked locations of measurement devices

The basic equations for fuel flows calculations are:

a) for the pipes with dimensions length L_i and diameter d_i

- Equation of continuity

$$\frac{\partial p}{\partial t} + \rho a^2 \frac{\partial v}{\partial x} = 0 \qquad (1)$$

- Equation of motion

$$\frac{\partial v}{\partial t}+\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\lambda_i v|v|}{2d}=0 \tag{2}$$

b) for volumes (V_j), equation of continuity is used in the following form:

$$\frac{V_j}{E}\frac{dp}{dt}=\sum_{m=1}^{m_k} Q_m \tag{3}$$

where Q_m is the volumetric fuel flow.

The solutions of equations (1) and (2) can be found by use of method of characteristics, while some of numerical methods, convenient for coupling with method of characteristics, is used for finding the solution for equation of continuity (3). The principles for solving the mentioned equations in case of different combinations of pipes, the volumes, the thin wall orifices are presented in [1] and [2]. The coefficients of friction losses (λ_i) in equation (2) and minor losses (expressed by Q_m in the equation (3)) are taken from the [3] and [4]. The equation of needle dynamic motion is expressed in the following form:

$$m_i\frac{d^2 h_i}{dt^2}+k_i\frac{dh_i}{dt}+ch_i=\sum F \tag{4}$$

where m_i is the mass of moving parts, h_i is the lift (travel), k_i is the damping factor, c_i is the stiffness and finally F is the force.
On basis of the mathematical model, a numerical program was developed and used for simulation can calculate the fuel flows inside the injector, the needle movement and the definition of energy potential in order to show transformation of the fuel energy along the injector. Having in mind the Bernoulli equation in following form:

$$p+\rho\frac{v^2}{2}=const. \tag{5}$$

it is easy to define energy potential (level) in every single node of the 1D computation grid inside the injector in every moment of time. Since energy level of diesel fuel inside the injector can be presented in form of the potential energy, that is pressure (*p*) of fuel, as well as in form of the kinetic energy due to velocity (*v*) of fuel flows, it is interesting to show values of the potential and the kinetic energy along inside the injector. The energy potential (level) along the injector in the moment of achieving the maximum of the fuel pressure at the end of high pressure pipe, in case of the maximum of the high pressure pump speed, is presented in the Figure 3.
The examples of the calculated pressure at the exit from nozzle orifice (p_I), based on the measured fuel pressure (p_A), for different high pump speeds n=1100, 900, 700 and 500 min^{-1}, are shown in the Figure 4.

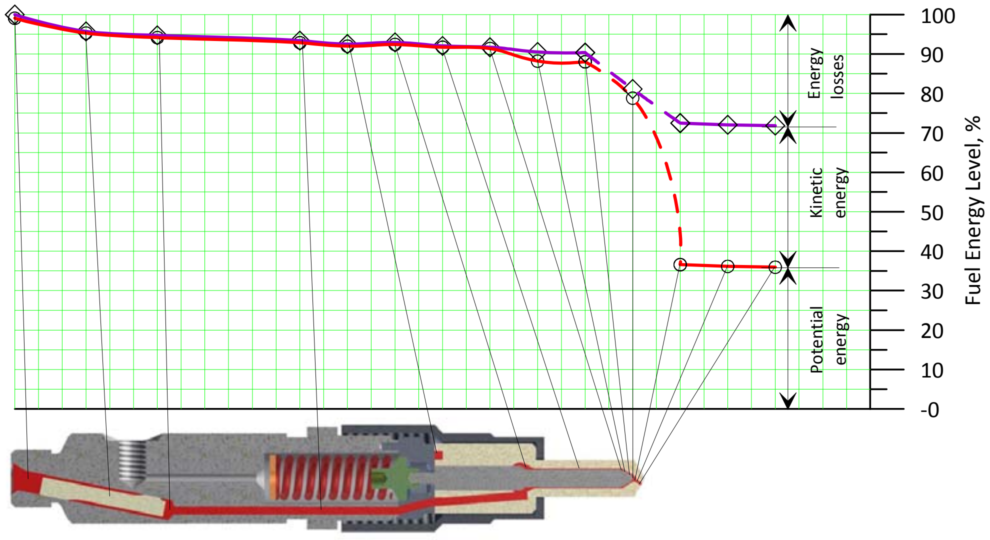

Fig 3. ***Transformation of fuel energy along the injector at maximum value of fuel pressure at the end of high pressure pipe and at the maximum of high pressure pump speed of 1100 rpm***

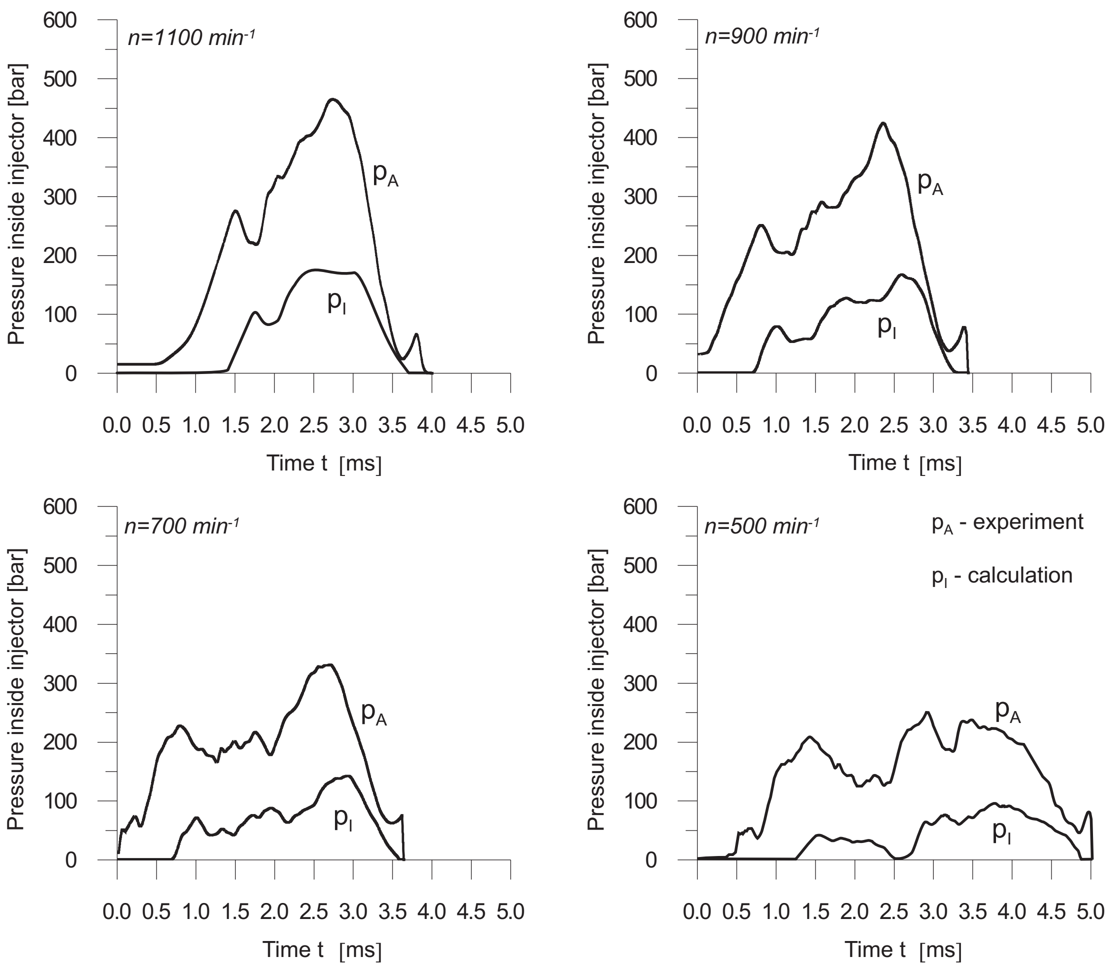

Fig 4. Trend of measured fuel pressure (p_A) and calculated fuel pressure (p_I) for different engine speeds oh high pressure pump

Definition of the optimal (ECO) drive

The development of modern motor vehicles is based on increasing the power and the torque of IC engine providing improvement of the vehicle dynamic properties what can be carried out only by introduction of the new technical and technological solutions in the power train. Thereby, special attention is dedicated to reduce the fuel consumption and the pollutants emissions. Considering light cargo delivery vehicles, insisting to increase the mass of the empty vehicle and its load capacity is the priority. The solution of those complex demands mentioned above is generally the compromise for a car manufacturer, which is confirmed through the certification testing of the vehicle. But, how does it look in the reality? Does the exploitation of some light cargo delivery vehicle truly confirm the results of the certification testing? How much each driver can participate in the realization of such heavy task? Finally, the most important, is it possible to manipulate by costs during exploitation of the vehicle regarding the fuel consumption?

Having in mind these questions, a realization of the following objectives will be presented through: 1) making the calculation of the fuel consumption during vehicle driving by different driving cycles; 2) performing the analysis with a view to define optimal drive regarding to fuel consumption; 3) defining parameters in order to obtain optimal drive conditions considering the fuel consumption; 4) recommending the algorithm to obtain an optimal drive that leads to reduce of fuel consumption.

For this purpose, a one light duty motor vehicle is chosen. The technical data of the light duty motor vehicle can be easily found in [5]. In order to perform further fuel consumption analysis of the light duty cargo delivery vehicle it is necessary to obtain the diagram of the constant specific fuel consumption (g_e) as a function of engine speed and engine load i.e. mean effective pressure (p_e). This diagram, with the constant specific fuel consumptions from 240 to 800 g/kWh, is shown in the Fig. 5.

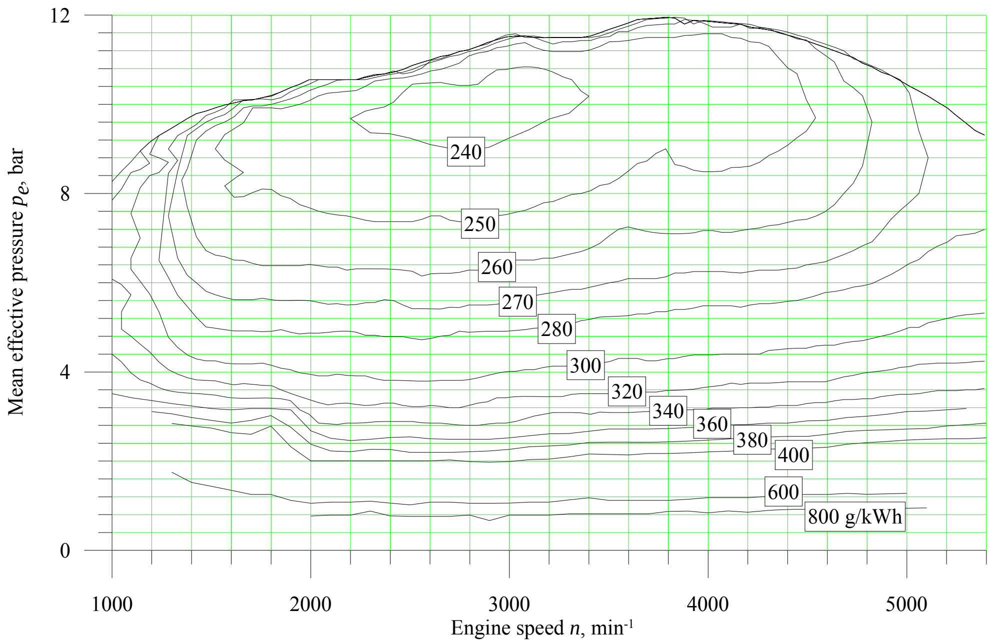

Figure 5. Original fuel consumption diagram

Starting from the motor vehicle, general equation of the vehicle movement [6] and [7] can be written in the following form:

$$\sum R = R_f \pm R_u + R_z \pm R_j = m\,g\,f\cos\alpha \pm m\,g\sin\alpha + \frac{1}{2}c_x\,A\rho v \pm m\lambda_{mj}\frac{dv}{dt} \qquad (6)$$

where are m - vehicle mass, g - ground acceleration, α - road grade, c_x – air drag coefficient, A - vehicle frontal area, v – velocity, ρ - air density, λ_{mj} - rotating component mass coefficient. Inserting known rolling radius of the tire r_d, total propulsion moment at the ground M_T can be written as:

$$M_T = F_T r_d = \sum R\,r_d = \left[m\,g\left(f\cos\alpha \pm \sin\alpha\right) + \frac{1}{2}c_x\,A\rho v \pm m\lambda_{mj}\frac{dv}{dt}\right]r_d \qquad (7)$$

Considering the correlation between effective engine torque and the propulsion moment at the ground always persists, knowing total transmission ratio i_T and efficiency of the transmission η_T, the following equation can be given by:

$$M_e = \frac{M_T}{i_T\eta_T} = \frac{\left[m\,g\left(f\cos\alpha \pm \sin\alpha\right) + \frac{1}{2}c_x\,A\rho v \pm m\lambda_{mj}\frac{dv}{dt}\right]r_d}{i_T\eta_T} \qquad (8)$$

From the expression above the direct correlation between road resistances incorporated in the engine torque value M_e that is used for the motor vehicle movement is obvious. On the other hand, using kinetic correlations, engine *rpm* by which it generates the engine torque needed to overcome total road resistances can be defined by:

$$\omega = \frac{i_T\,v}{r_d} \quad \Rightarrow \quad n = \frac{\omega}{2\pi} \qquad (9)$$

When the values of the engine torque needed to prevail road resistances are clearly defined as well as the corresponding engine *rpm* as a function of total transmission ratio i_T, applying the interpolation method and digitalized form of the fuel consumption diagram given on the Figure 1, the current values of the specific consumption g_e for the related case of the vehicle movement can be calculated.

Thus, with a known density fuel value, the hourly fuel consumption in the volumetric units can be defined as:

$$Q = \frac{G_h}{\rho} = \frac{g_e Pe}{\rho} \quad \left[\frac{l}{h}\right] \qquad (10)$$

Finally it is possible to determine the road travel fuel consumption closer to everyday motor vehicle driver, i.e. fuel consumption by travel made in *l/100 km* by following expression:

$$Q_{l/100\,\mathrm{km}} = Q\frac{100}{v} \quad \left[\frac{l}{100km}\right] \qquad (11)$$

Considering that the fuel consumption, determined during non-stationary driving conditions by given cycle, presents one of the numerous certification tests, by this the fuel consumption values are clearly defined. On the other hand, different road configurations aren`t and cannot be included within this cycle, as well as the different driving methods (cases) that the optimal fuel consumption is defined. Therefore, the driving cycles recording along the same test track in the urban area has done by the different driving methods (cases) i.e. the gear shift for different engine speeds. Besides this test track, driving cycles are recorded, based on CAN BUS and GPS data, for case of driving by various speeds on the open road and along the highway.

Calculation of the fuel consumption was carried out for all of the driving cycles recorded like: driving uphill, horizontal road drive and „open“ drive – intercity drive. In order to determine the fuel consumption, the biggest road grade of 4.29 % was chosen along the test track in the urban area and presented in this paper.

The Fig. 6 shows the realized driving cycles on the same test track and by different ways of driving and obtained results through the both of the cases. Simulation of the various driving cases is imagined to be through the different cases of the gear shifting during the acceleration of the vehicle. The first driving case tend to be by shifting gear around 2500 min^{-1} engine rpm during acceleration, the second driving case is to shifting gear by engine rpm of 3000 min^{-1} during the acceleration of the vehicle, although the third driving case is to shifting gear by engine rpm of 4000 min^{-1} in the first and second gear, until it depends on traffic conditions regarding the other gears shifting, and it is carried out in the range of 3000-3500 min^{-1}.

The clearer picture about the impact of different driving cases over the same test section comparing the results offers the Fig. 6. It can be seen in the Fig. 6 that if the gear shift is carried out later, i.e. achieved by higher engine speed in each of the respective gears, the vehicle performs better dynamic properties in terms of the resulting acceleration of the vehicle. This is the best illustrated in the vehicle speed diagrams as a function of the engine speed. It has to be noted that the driver pushed down the gas pedal evenly through the all driving modes and it is clearly visible on the load diagram.

Keeping in mind the total fuel consumption consumed during the acceleration with different driving cases along the test track the average fuel consumption along the travel made can be defined. The overview of the average fuel consumptions values is shown in the table 1.

Although the road traveling fuel consumption values expressed in *l/100km*, on the first sight, seems to be significant, higher than normal road travel fuel consumptions given by the catalogs and displayed by onboard computers but here is important to note that it is about values relevant in the case of the vehicle acceleration driving uphill along the road grade of 4.29%.

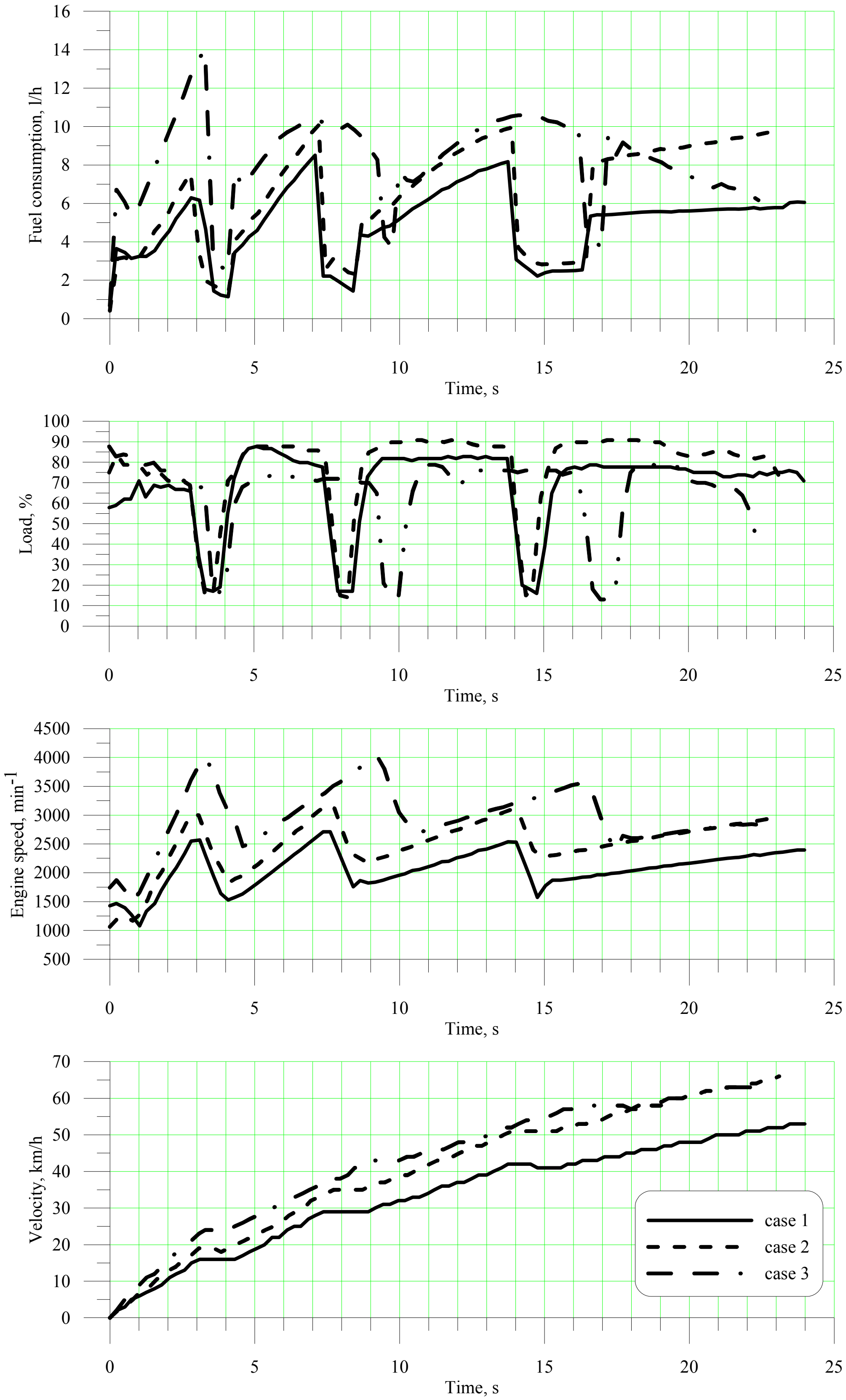

Fig. 6. Comparison display of the specific parameters by different driving cases driving uphill along the road grade of 4.29 %

Table 1.The fuel consumption refers to different driving cases

Driving cycles	Travel during acceleration, *km*	Fuel consumption, *l/100 km*
Case 1	0.248	20.42
Case 2	0.248	22.42
Case 3	0.240	25.06

The relative fuel consumption, defined in order to implement the analysis of fuel consumption by various driving cases, is shown in the table 2.

Table 2. Relative fuel consumption by various driving cases

Driving cycles	Relative fuel consumption, %	Increase of the consumption, %
Case 1	100.00	0.00
Case 2	109.79	9.79
Case 3	122.72	22.76

Based on presented results, it can be concluded that if the gear shift is carried out earlier during acceleration of the vehicle, significant effect to the fuel consumption can be realized, but to the dynamic characteristics of the vehicle as well. It is well known that the gear shift at lower engine speed, especially driving uphill, depends on the experience of the driver and his skills to do it fast enough on that way to vehicle achieves stable drive in the next gear. For this reason, it is necessary to ensure the optimal engine speed to the gear shift what will be analyzed through the further specific driving cases. As an example, if the driving case number 2 is optimal, it would increase the fuel consumption by 11.78% between driving case number 3 and driving case number 2. The same conclusions were obtained in analysis of fuel consumption during acceleration on the horizontal road. The special attention is dedicated to „open drive" – intercity drive.

Based on the calculation results of the fuel consumption during the cargo delivery vehicle movement by the recorded driving cycles in the urban area, with characteristic of non-stationary ride conditions with a frequent accelerations and decelerations along the strait road, but along the road with the grade angle also, driving cycles of the vehicle in the intercity routes and by the highway as well, corresponding parameters affecting fuel consumption can be defined:

1. *Acceleration of the vehicle* is the most important influenced parameter during non-stationary ride in the urban area. Extreme acceleration is very common followed by extreme deceleration in urban area what suppose to be a consequent influenced parameter by many explorers. Due to that, from big importance is:
   a) In order to avoid extreme acceleration of the vehicle it is necessary to push down gas pedal rationally as possible to have a control by *engine load* values, i.e. by *gas pedal position*
   b) Besides engine load, avoiding of extreme vehicle acceleration is possible to achieve by shifting gears earlier, i.e. shifting gears on lower *engine RPM*.
2. The most important parameter during non-stationary ride in urban area and the intercity routes and by the highway is *driving speed* and *the information about which of the gears is running*. Therefore, the fact known well is that by driving speed of 90 km/h, the vehicle running in the 5th gear accomplishes lower fuel consumption then the vehicle running in 4th gear, etc.
3. *Road configuration* can have a significant influence to the fuel consumption. Thereby it is necessary to make a difference between the uniform strait linear and curvilinear vehicle movement with possibilities to rich lower vehicle speed. Apart from vehicle movement path, very important influenced parameter is the *road grade*, and it is difficult to determine it. Information about road grade is available by modern and very accurate GPS devices, but

installation is doubtful because of its high price. However, information about axle loads can be useful to determine the road grades, but considering change of loads over the acceleration, i.e. over deceleration of the vehicle, its accuracy can be under question. Finally, due to determined vehicle acceleration and engine load, required information about road grade can be obtained, but it takes a lot of data that must be processed by computer with some presumptions, thus it will not be used in the further analysis.

Considering influenced parameters, the following method to accomplish optimal drive can be proposed:

- Analyzing the shape of the fuel consumption diagram (Fig. 5), it can be noted that the constant specific fuel consumption curves reach minimal values in the range of 2500 – 3000 min^{-1}. Although, analyzing the results affecting the fuel consumption during different drive cases, i.e. different engine speed shifting gears, it can be concluded that minimal values has reached throughout the first driving case, i.e. by shifting gear at 2500 min^{-1}. Since shifting gears by this engine speed enables stable ride in the next gear, even traveling uphill, shifting gears UP has to be done exactly by this rpm. In this case, this provides to driver get the information about necessity to shift gear, because of „total inertia" the shifting gear could be by something higher engine speed, let`s say about 2800 min^{-1} where the engine runs still with minimal specific fuel consumption.

- The minimal engine speed necessary to obtain the gears shift from 5th to 4th, from 4th to 3rd, and finally from 3rd to 2nd gear amounts 1200 min^{-1}.

- In order to make registration sudden vehicle decelerations, due to extreme accelerations, because that can lead to intensive wear of the friction surfaces on the break surfaces, continuous acceleration i.e. deceleration is recommended. According to data in [8], common deceleration values amounts about 2.5-3.0 m/s^2. Considering eventual error of the calculated deceleration and because of the inertia of system as well, registration of all vehicle deceleration values over 4 m/s^2 is recommended.

- Having in mind a fact that during vehicle motion downhill could happen the ride with the engine speed that corresponds to recommended engine speed to shift to the next gear, this situation can lead to the additional acceleration of the vehicle reducing-in the break-by-engine effect. That is the reason why the engine load information are so important as well as the information about gas pedal position. Assuming the values OVERRUN or PART THROTTLE are registered by the gas pedal position or below the engine load of 35%, it is not necessary to signalize shifting gears.

- If the engine runs above 3250 min^{-1} during the ride of the vehicle by constant velocity in the 5^{th} gear, warning about the increased fuel consumption is obtained, i.e. uneconomic ride.

The best illustrated view of defined optimal drive is algorithm shown in the Fig. 6. The presented algorithm can serve to assemble the computer program that will enable to achieve optimal drive and fuel consumption of the light duty motor vehicle.

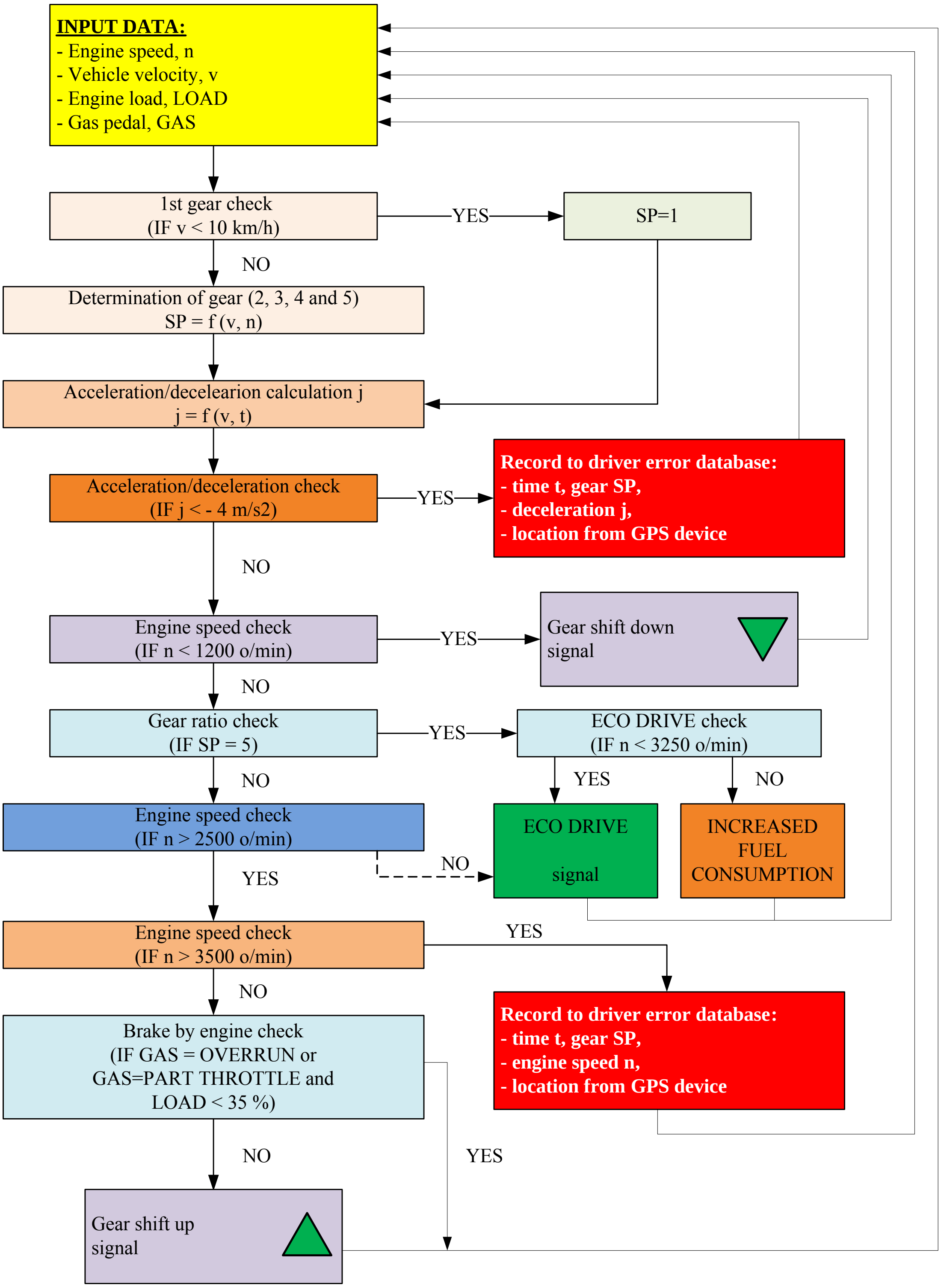

Fig.6. Algorithm to achieve the optimal drive and optimal fuel consumption

The presented algorithm for obtaining the optimal drive regarding the fuel consumption was implemented in more than 100 light duty vehicles of firm Coca Cola HBC Sarajevo. Importance of this successful conducted analysis can be recognize in the reduction of fuel consumptions up to 15 % during the first month of the implementation.

Conclusions

The paper presents results from only 2 projects where the experts from firm *Automotive center – centar za vozila* Sarajevo were involved. Besides the results in presented research fields, the significant effort was done in the field of alternative fuels use, investigation of pollutants emissions from motor vehicles, a torsional vibration problem area including application of torsional damper, vehicle dynamics with special dedication to active safety systems, tire tolling processes, etc. In all mentioned fields, the experts have own developed computer programs and simulation software. Formation of new laboratories in Bosnia and Herzegovina, like laboratory for turbochargers and modern brake systems, together with cooperation with automotive industry in WBC, the new possibilities for researching and development new technologies can be achieved. Obtaining these plans will help researchers and experts from Bosnia and Herzegovina to participate in modern European and world research projects.

References

[1] Pikula B.: Istraživanje karakteristika sistema za ubrizgavanje pri upotrebi dizela, biodizela i njihovih mješavina u različitim eksploatacionim uslovima, (English title: Investigation of Characteristics of Fuel Injection System by Use of Diesel, Biodiesel and its Blends in Different Exploitation Conditions" – Doctoral dissertation, Faculty of Mechanical Engineering, University of Sarajevo, 2007

[2] Filipović I., Bibić Dž., Pikula B.: Sistemi za dobavu goriva kod dizel motora, (English title: Fuel Injection System at Diesel Engines), Faculty of Mechanical Engineering, University of Sarajevo, 2010

[3] Franzimi J., Finnemore J.: Fluid mechanics with engineering applications, 9th edition, Mc Graw - Hill, 1997

[4] White F.: Fluid mechanics, 5th edition, Mc Graw - Hill, 2003

[5] Katalog - VW gospodarska vozila Caddy, 2008

[6] Gillespie T. D.: „Fundamentals of vehicle dynamics", SAE, Warrendale, 1992

[7] Dacić S.. Trobradović M.. Pikula B.: „Osnove dinamike vozila – Zbirka zadataka", (English title: Fundamentals of vehicle dynamics – Exercises), Faculty of Mechanical Engineering, University of Sarajevo, 2008

[8] Todorović. J. B.: "Kočenje motornih vozila" (English title: Braking of Motor vehicles), Zavod za udžbenike i nastavna sredstva, Beograd, 1988