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UTILIZATION OF INNOVATIVE TECHNIQUES IN ULTRA-LIGHT AUTOMOBILE PRODUCTION

Prof. Ing. Brezinová J., PhD., Ing. Kender Š. PhD.
Faculty of Mechanical Engineering, Technical University of Košice, the Slovak Republic
janette.brezinova@tuke.sk

Abstract: The paper presents the results of research focused on the use of innovative processes in the production of composite materials. The experimental work was focused on the use of Vacuum Bag Molding technology in the production of the prototype of the Shell Eco-Marathon formula. The car body was designed with 3D modeling and optimized with airflow simulation. Carbon fibers have been used to reduce the vehicle's weight. Some complementary parts were produced using 3D printing.

Keywords: COMPOSITE MATERIALS, CARBON FIBERS, VACUUM BAG MOLDING TECHNOLOGY, 3D MODELING, AIRFLOW SIMULATION

1. Introduction

The Faculty of Engineering of the Technical University in Košice has been actively participating in the Shell Eco-Marathon since 1994. Over the past years the vehicle body has evolved significantly. Initially, it was a monopost construction of iron frame, vehicle body served as a cover. The further effort in vehicle body development was to reduce the weight of the vehicle, reduce rolling resistance and resistance in wheel bearings.

The vehicle underwent facelift since 2006, where the top cover was relocated as close as possible to front axle and drivers compartment. Vehicle B&S 3 facelift at Paul Armagrac circuit in Norgama reached performance of 783.1 km/l of fuel and ranked 47th out of 263 participants.

Since 2016 in vehicle construction a lightweight, carbon fiber-based top cover is used. It is lighter and better in terms of aerodynamic resistance.

During the development of new body model, current information were evaluated and used to design new vehicle. These findings led to a design of new vehicle called Prototype 2017. Composite sandwich body was equipped with carbon frame, that was central and carrying element of the whole vehicle. Steering was improved by reduced friction when cornering. New ceramic bearings that have minimal rolling resistance and high inertia contributed to improved driving performance. Vehicle was also equipped with new engine with capacity of 35 cm³ and power of 1 kW.

The design of new body was carried out in CAD program CATIA V5/R16. Vehicle body was adapted to already designed frame, which ensured perfect rigidity and safety of the vehicle.

The shape of the body was designed based on the optimization of the air flow, Fig.2. Airflow testing was performed in SolidWorks program and CFD analysis was also processed in Ansys program. Two variants of body vehicle were tested, based on the CFD analysis results better variant was selected, Fig. 3-5.

For the improvement of body shapes consecutive testing of designed proportional shapes was carried out. Several designs of vehicle body shapes were tested. Although each component of the vehicle influences its performance, attention has been paid mostly to airflow, reducing the weight and increasing body strength. All designed variants of body were tested and the best result was chosen. The resistance force of the best model represents 25% of the resistance force of the previous model from year 2016.
Body requirements for Shell Eco-Marathon vehicle

Shell company sets the rules for Shell Eco-Marathon vehicle competition. Bodywork requirements are rigidity, low vehicle weight, safety of driver, airflow, manufacturability, surface quality of upper sandwich structure and overall body price. Every team must present technical drawings or overall animation respectively for the project approval. No mechanical part of the vehicle can be visible. The wheels must be placed under the body of the vehicle.

Choosing a sandwich core for Shell Eco-Marathon body

When selecting appropriate material, several aspects had to be taken into account. Material had to be strong enough, but also light to achieve low consumption of the experimental vehicle. Sandwich structure application achieved the mean of these properties. Core of sandwich structure allows the body to be lightened by glass fibers, which are heavier compared to PVC foam and nonwoven polyester by 30%. Experimental vehicle body was composed of two parts, the lower and upper part of body. For the production of body Coremat XM 2mm material was chosen.

This type of material is based on a nonwoven polyester, which was optimized for improved tensile strength properties achieved by resin saturation through hexagonal cells of this material. Microspheres, which prevent excessive imbibition of resin into the polyester, are part of the material as well. Hexagonal structure under the layer of resin stays invisible. The manufacturer indicates reduction of resin by 1000 g/m² per layer thickness. Compared to glass fibers, up to 30% of weight in one composite layer is saved. Using Coremat reduces production time. It is flexible and easy-to-shape material and is suitable in technology of manual composite deposition. It is not suitable for technology of infusion of resin into a closed space. Its application is mostly found in RC models and smaller boat trunks. Coremat XM is available in 2 to 4 mm thickness.

Table 1: Mechanical properties of material Coremat XM 2mm

<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>Unit</th>
<th>Value</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural strength</td>
<td>MPa</td>
<td>8.5</td>
<td>ASTM D790</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>MPa</td>
<td>1250</td>
<td>ASTM D790</td>
</tr>
<tr>
<td>Tensile strength across layers</td>
<td>MPa</td>
<td>4</td>
<td>ASTM C577</td>
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<tr>
<td>Compression strength 10% strain</td>
<td>MPa</td>
<td>10</td>
<td>ISO 844</td>
</tr>
<tr>
<td>Shear strength</td>
<td>MPa</td>
<td>3</td>
<td>ASTM C23736-1</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>MPa</td>
<td>25</td>
<td>ASTM C23736-1</td>
</tr>
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</table>


In the production of experimental vehicle body the sandwich composition of carbon fiber fabric and material Coremat XM was used. Among the first steps of production of the lower part of body was the degreasing of the mold. This step was necessary also due to the prior smoothing of the surface using wool polishing wheels combined with abrasive 3M polishing paste. After degreasing, lower part of produced vehicle body was waxed using application microfibre wipes with basic wax in several layers. After waxing the last layer using basic wax, PVA coating was sprayed on the surface of lower part of produced body vehicle. This coating served as an interlayer, which prevented the joining of two arbitrary coatings with each other. After application of PVA coating, accelerator transparent HAVELpol 1 resin was applied for better bonding with the epoxy resin.
After hardening of connecting resin, other type of resin was applied. This type of resin is characterized by lower viscous density. Its task is to secure connection between deposited fabrics and sandwich core. Epoxy resin was applied separately on both layers. An uniform layer was formed over the entire lower part of the finished mold. The first application of this type of resin was important mainly in terms of better deposition of fabric and molding into desired shape. This process of resin application firstly into the mold is better in terms of improved oversaturation of fabric by resin.

The fourth layer was formed by Coremat XM material. This material in sandwich structure acts as a sandwich core. Material was not applied to the space reserved for wheels. Similar to the previous layers, resin was applied on top. Gaps between the Coremat bands were enhanced by carbon roving. The Coremat layer was closed by glass fabric.

This way was used to form all layers of composite structure. After completing the seventh final layer, the lower part of body was moved to foil sleeve. The suction of resin to fabric was carried out using Vacuum Bag Molding technology over 12 hours.

**VBM technology (Vacuum Bag Molding)** uses a similar procedure to manual wet deposition. On the last layer perforated separating foil is deposited. Next layer is formed by suction layer (absorbent fabric), purpose of which is to absorb excess resin. Mold layered this way is then inserted into space, from which air is sucked out. Vacuum ensures the reduction of pores in composite, compression of reinforcement layers by atmospheric pressure and extrusion of excess resin.

In the production of upper part of experimental vehicle body, formation of air bubbles occurred during the deposition of first carbon layer. These air bubbles are classified as white spots, that can not be removed even by polishing. The cause is an uneven layer of resin and weak contact of first carbon layer with experimental vehicle mold. In the production of lower part of body these errors did not occur due to the smaller surface area and more uniform application of epoxy resin.

The indisputable advantage of the manual deposition of these sandwich compositions is mainly affordability. Technology is very applicable in prototype production, which was used to produce also described experimental vehicle. However, in the production of experimental vehicle body, functional nature of the vehicle was more important than cosmetic errors on the bodywork.

Negative side of this technology is subjective impact on the quality of produced parts. Another error in the production process of experimental sandwich bodywork was the formation of uneven surface and depressions on the rear rounding.

The resulting body of experimental vehicle without carbon frame, engine and accessories weighed about 20 kg. The total weight of the Shell Eco Marathon experimental vehicle was reduced compared to previous experimental model by one third. Current vehicle has a strong carbon frame, but also solid sandwich body. To achieve lower fuel consumption in the next stages of the vehicle development, it is necessary to use sandwich materials. Lower part of the body would have to go through optimization of the sandwich composition to increase the strength of the self-supporting body.
4. Conclusion

Components that are made from composite materials can be manufactured using multiple technologies. The choice of technology depends on the shape of produced component, requirements for its mechanical properties, structure and surface quality, expenses available for production and desired productivity. With a variety of technologies there is a room for choosing such technology, that will meet the exact specified requirements for the final product. There are many technologies available, from quite simple technologies, such as manual wet deposition to more or less sophisticated production methods, that depend on specific technological equipment.

The use of composites in automotive industry has an increasing tendency. The greatest credit for the rising use of these progressive materials lies with large automotive companies focused on production of luxury and electric automobiles. They collaborate with different factories, which focus on development but also the production of carbon fibers itself. More available are also technological production methods of sandwich materials. The greatest potential lies in technologies that are fully capable of series production. 3D trial printing of sandwich structures is also at the forefront of technological options. Evidence is also the new collaboration of automobile manufacturer Honda with one of companies, that deals with these 3D printing technologies. In the process of experimental vehicle production the most available technological method was chosen, namely manual deposition of sandwich structure. Sandwich structure of experimental vehicle has a strength of 70 MPa. Experimental vehicles are great tool for testing a variety of materials and manufacturing processes. In the process of experimental vehicle production the most available technological method was chosen, namely manual deposition of sandwich structure. Sandwich structure of experimental vehicle has a strength of 70 MPa. Experimental vehicles are great tool for testing a variety of materials and manufacturing processes. The process of manual deposition and using the sandwich structure itself might not be directly applicable in current automobile generation, but it is an inspiration for addressing the topics of fuel-reduction and related new emission limits. The process of manufacturing of experimental vehicle can be improved by proposed solutions such as enhancing the suction of epoxy resin and change of technology to a vacuum infusion. Strong sandwich body has a great potential for creating self-supporting body of experimental vehicle.

The development and production of experimental vehicle Shell Eco Marathon was also attended by students of Faculty of engineering, TUKE. In 2017 they participated with this vehicle in international Shell Eco-marathon Europe race in London and officially achieved a distance of 586 km per liter of fuel. In the category of combustion engines they ranked 18th. Race took place at the Queen Elisabeth Olympic Park in London on May 25-28. Students from Košice competed with nearly 200 teams from 28 countries.

Acknowledgments: The authors are grateful to KEGA for support of experimental work under grant KEGA 059TUKE-4/2016.

References:

Abstract: In the paper, fuzzy logic is used to simulate active suspension control of a one-half-car model. Velocity and acceleration of the front and rear wheels and undercarriage velocity above the wheels are taken as input data of the fuzzy logic controller. Active forces improving vehicle driving, ride comfort and handling properties are considered to be the controller outputs. The controller design is proposed to minimize chassis and wheels deflection (sky-hook concept) when uneven road surfaces, pavement points, etc. are acting on tires of the running car. As a result, a comparison of an active suspension fuzzy control and a spring/damper passive suspension is shown using MATLAB simulations.

Keywords: ACTIVE SUSPENSION, FUZZY LOGIC, CONTROL, ONE-HALF-CAR MODEL, SIMULATION, VEHICLE, LINEAR MOTOR, SPRUNG MASS, UNSPRUNG MASS

1. Introduction

At the Czech Technical University in Prague various alternative strategies and innovations to classical passive suspension systems improving ride comfort of the passengers, providing steering stability, maximizing safety and improving handling properties of vehicles, has been researched. In order to improve handling and comfort performance instead of a conventional static spring and damper passive system, an alternative active suspension system has been developed. Certainly, there are numerous variations and different configurations of vibration suspension. In known experimental active systems the force input is usually provided by hydraulic or pneumatic actuators. As an alternative approach to active suspension system design, electromechanical actuators have been studied by the research group. Such actuators provide a direct interface between electronic control and the suspension system. Connection of a passive spring-damper system to an active system has a potential of improving safety and comfort under nominal conditions. Perhaps more important is that such a combination allows continuous adaptation to different road surface quality and driving situations.

A number of studies on structural vibration control have been done recently and practical applications have been realized [1]. It is used both, passive solutions for vibration isolation, and active systems, usually based on PID controllers. In addition, semi-active vibration isolation methods are often proposed and used. Yoshida and Fujio applied such a method to a base in which the viscous damping coefficient is changed for vibration control. Fukushima developed a semi-active composite-tuned mass damper to reduce the wind and the earthquake induced vibrations on tall structures. Different active control methods of various structures were offered by Nishimura et al. Yagiz applied sliding mode control for a multi degree of freedom analytical structural system. In the area of semi-active structural control, Zhou and Chang developed a fuzzy controller and an adaptation law for a structure MR damper system. Shuter and Roschke used a neuro-fuzzy technique to control building models [2]. Liu et al. designed a slightly more intricate fuzzy controller for a magnetorheological damper and were able to reduce vibrations of single-degree of freedom bridge model subjected to random inputs. Simulation of active vibration isolation of a one-quarter-car model with fuzzy logic device has been designed by Nastac [4].

2. Problem Formulation

For the design of active suspension we know how to create a suspension model and how to define objectives of control in order to reach a compromise between contradictory requirements like ride comfort and road holding by changing the force between a wheel and chassis masses. In the past, it has been reported on this problem successively, about the base of optimization techniques, adaptive control and even, H-infinity robust methods [5]. In this paper, fuzzy logic is used to control the active suspension of a one-half-car model that uses linear electrical motor as an actuator. There are taken velocity and acceleration of the front and rear wheels and undercarriage velocity and vertical acceleration above these wheels as input data of the fuzzy logic controller, and active forces $f_1$ and $f_2$ as its output data. The objective of fuzzy control is to minimize chassis deflections to reach passenger comfort and wheels (not to damage the road surface, respectively) when road disturbances are acting upon the running car.

Passenger comfort can be interpreted as an attenuation of sprung mass acceleration or as peak minimization of sprung mass vertical displacement, while good handling can be characterized as an attenuation of unsprung mass acceleration. This effort devoted to passive suspension design is ineffective because improvements to ride comfort are achieved at the expense of handling and vice versa. Instead, the best result can be achieved by active suspension, i.e. when an additional force acts on the system and simultaneously improve both of these conflicting requirements. Another important goal of the control design is to maintain robustness of the closed loop system.

3. Active Suspension System

All suspension systems are designed to meet various specific requirements. In suspension systems, mainly two most important points are supposed to be improved – vibrations absorbing (videlicet passenger comfort) and attenuation of the disturbance transfer to the road (videlicet car handling). The first requirement could be understood as an attenuation of the sprung mass acceleration or as a peak minimization of the sprung mass vertical displacement. The second one is characterized as an attenuation of the force acting on the road or – in simple car models – as an attenuation of the unsprung mass acceleration. The goal is to satisfy both these contradictory requirements.

Satisfactory results can be achieved when an active suspension system generating variable mechanical force acting between the sprung and unsprung masses is used.

Such an actuator can be a linear electric motor [3]. In comparison with traditional actuators that use revolving electromotors and a lead screw or toothed belt, the direct drive linear motor enables contactless transfer of electrical power according to the laws of magnetic induction. The gained electromagnetic force is applied directly without the intervention of mechanical transmission then. Linear electric motors are easily controllable and for features like low friction, high accuracy, high acceleration and velocity, high values of generated forces, high reliability and long lifetime, their usage as shock absorbers seems to be ideal.

Fig.1 shows the basic principle and structure of the linear electric motor used as an actuator in the designed unique active suspension system. The appreciable feature of linear motors is that they directly translate electrical energy into usable mechanical force and motion and back. They are linear shaped.
Linear motor translator movements reach high velocities (up to approximately 4 m/s), accelerations (up to g multiples) and forces (up to 10 kN). The electromagnetic force can be applied directly to the payload without an intervention of mechanical transmission.

![Fig. 1 Linear motor basic design (manufacturer spread sheet).](image)

### 4. Linear Motor Model

In order to verify control algorithms we created a linear motor model including a power amplifier in Matlab/Simulink™. The model enables to demonstrate the conversion of electrical energy to mechanical energy.

In the model, it is assumed that the magnetic field of the secondary part with permanent magnets is sinusoidal, the phases of the primary part coils are star-connected, and a vector control method is used to control the phase current [5]. Here, PWM voltage signal is substituted by its mean value to shorten (about 10 times) the simulation period (inaccuracies caused by such a substitution can be neglected).

The principal inner representation of the model is shown in Fig. 2. The model input vector is given by the instantaneous position [m] necessary to compute the commutation current of the coils, instantaneous velocity [m/s] (the induced voltage of the coils depends on the position and velocity) and desired force [N].

The designed model function we verified comparing dynamics of the model in Fig. 3 and the real motor. The simulation parameters correspond to catalogue parameters of TBX3810 linear motor by Thrust-tube.

For example, time responses caused by changes of the desired force have been compared.

![Fig. 2. Principal inner model representation.](image)

The linear motor input-output model is shown in Fig. 3.

Fig. 4 and Fig. 5 represent simulated and real time responses, respectively (rightangular force signal: 0→200 [N], power supply of 150 [V], velocity: 0 [m/s]).

![Fig. 4 Simulated time response.](image)

Comparing the time responses in Fig. 4 and Fig. 5 it can be seen very good matching level of the model and the real motor behavior.

On the base of the experiments that we completed on the model, we gained values of electric power necessary to be supplied or consumed when velocity and force of the motor are constant. In Fig. 6 an input/output model of the linear motor (with concrete simulation values) is represented.

It results from many experiments we made [5] with TBX3810 linear motor that the designed model describes the real linear motor equipped with necessary auxiliary circuits very authentically and enables to verify control algorithms developed to control the linear motor as an actuator of the active suspension system.

![Fig. 5 Real time response.](image)

![Fig. 6 Linear motor input-output model.](image)
5. One-half-car Suspension Model

In this paper, we are considering a one-half-car model in Fig. 7 which includes two one-quarter-car models connected to a homogenous undercarriage [2]. The undercarriage is determined by its mass - $m$ [kg] (taken as one half of the total body mass - 500 kg), length $L$ [m], (length $L_1$ + $L_2$ = 1,5m + 2,5m = 4m), center of gravity position $T$ [m] (given by $L_1$ and $L_2$) and moment of inertia $J_p$=2700 kgm$^2$.

The motion equations of the car body and the wheels are as follows:

$\begin{align*}
    m_w Z_{w1} &= f_1 + k_{b1}(Z_{w1} - Z_{w2}) - k_{z1}(Z_{z1} - Z_{z2}) + b_{z1}(Z_{z1} - Z_{z2}) \\
    m_{w2} Z_{w2} &= -f_2 + k_{b2}(Z_{w2} - Z_{w1}) - k_{z2}(Z_{z2} - Z_{z1}) + b_{z2}(Z_{z2} - Z_{z1}) \\
    m Z_{z1} &= f_1 - k_{b1}(Z_{z1} - Z_{w1}) - b_{z1}(Z_{z1} - Z_{w1}) = F_1 \\
    m Z_{z2} &= f_2 - k_{b2}(Z_{z2} - Z_{w2}) - b_{z2}(Z_{z2} - Z_{w2}) = F_2
\end{align*}$

where the position variables respect the static equilibrium position: $m_{w1}$, $m_{w2}$ - wheel masses (35 kg each), $k_{b1}$, $k_{b2}$ - passive suspension spring stiffness (16 kN/m each), $k_{z1}$, $k_{z2}$ - tire stiffness (160 000 N/m each), $b_{z1}$, $b_{z2}$ - passive suspension damping coefficients (980 Ns/m each), $f_1$, $f_2$ - active forces between the front/rear sprung and unsprung masses[N], $Z_{w1}$, $Z_{w2}$ - road displacements [m], $Z_{z1}$, $Z_{z2}$ - body (chassis) displacements [m], $Z_{w1}$, $Z_{w2}$ - wheel displacements [m].

To model the road input, we assume that the vehicle is moving at a constant forward speed. Then the vertical velocity is a white noise process which is approximately true for most of real roadways.

The pitching equation is given as:

$F_1 L_2 - F_2 L_1 + J_p \dot{\phi} = 0$  

and motion of the center gravity as:

$F_1 + F_2 - m v_T = 0$

Note that:

$v_{bh} = v_T + \omega L_1$

and

$v_{bh} = v_T - \omega L_2$

where the meaning of constants and variables is as follows: $v_T$ [m/s] - velocity of the center of gravity, $\omega$ [rad s$^{-1}$] - angular velocity, $v_{bh}$ [m/s] - undercarriage velocity above the front wheel, $v_{bh}$ [m/s] - undercarriage velocity above the rear wheel.

6. State-space Model

To transform the motion equations of the one-half-car model to a state space model, the following state variables vector $x$ (9), input variables vector $u$ (14), and the vector of disturbances $v$ (15), are considered:

$9 \quad x = \begin{bmatrix} x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8 \end{bmatrix}^T$

$10 \quad x_1, \ldots, x_3 = \dot{Z}_{bh} - \dot{Z}_{w1}$

$11 \quad x_4 = \dot{Z}_{w1} - \dot{Z}_{z1}$

$12 \quad x_5 = \dot{Z}_{z1} - \dot{Z}_{z2}$

$13 \quad x_6 = \dot{Z}_{w2} - \dot{Z}_{z2}$

$14 \quad u = \begin{bmatrix} f_1, f_2 \end{bmatrix}^T$

Then the motion equations of the one-half-car model for the active suspension can be written in the state space form as follows:

$15 \quad x = Ax + Bu + Fv$

where for the given data A, B and F are stated in [3][5].

To the thanks to the negative real parts of all eigen values of matrix A, the model is stable.

7. Fuzzy Logic Controller

The fuzzy control system consists of three stages: fuzzification, fuzzy inference and defuzzification [3], [4].

The fuzzification stage converts real-number (crisp) input values into fuzzy values whereas the fuzzy inference machine processes the input data and computes the controller outputs in cope with the rule base and data base. These outputs, which are fuzzy values, are converted into real-numbers by the defuzzification stage.

The fuzzy logic controller used for the active suspension has nine inputs (13):

$13 \quad \begin{bmatrix} v_{bh1}, v_{bh1}, v_{bh2}, v_{bh2}, v_{bh3}, v_{bh3}, v_T, v_T, \omega \end{bmatrix}^T$ 

and two outputs: $f_1$ and $f_2$. All membership functions are of triangular form.

Variables ranges are stated experimentally [2] and are given in Tab.1a and Tab.1b below.

Table 1a: Variables ranges

<table>
<thead>
<tr>
<th>$z_0$ [cm]</th>
<th>$v_{bh1}$max [N]</th>
<th>$v_{bh2}$max [N]</th>
<th>$v_T$max [m.s$^{-1}$]</th>
<th>$v_T$min [m.s$^{-1}$]</th>
<th>$\omega$ [rad.s$^{-1}$]</th>
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Table 1b: Variables ranges

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<thead>
<tr>
<th>$v_{bh1}$max [m.s$^{-1}$]</th>
<th>$v_{bh2}$max [m.s$^{-1}$]</th>
<th>$v_T$max [m.s$^{-1}$]</th>
<th>$v_T$min [m.s$^{-1}$]</th>
<th>$v_{bh1}$min [m.s$^{-1}$]</th>
<th>$v_{bh2}$min [m.s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,3</td>
<td>6,8</td>
<td>2,4</td>
<td>0,3</td>
<td>6,8</td>
<td>2,2</td>
</tr>
<tr>
<td>0,5</td>
<td>13,5</td>
<td>4,8</td>
<td>0,5</td>
<td>13,5</td>
<td>4,9</td>
</tr>
</tbody>
</table>

The rule base used in the active suspension system for one-half-car model is represented by 160 rules [3], [5] with fuzzy terms derived by modeling the designer’s knowledge and experience.

There are two types of rules for the one-half-car model. The rules for unsprung masses are corresponding to the rules of the one-quarter-car model [3], [4], [5] and considering:

$v_{bh1}, v_{bh1}, v_{bh2}, v_{bh2}, v_{bh3}, v_{bh3}, v_T, v_T, \omega$ as fuzzy controller inputs, and $f_1$ and $f_2$ as controller outputs.

The output of the fuzzy controller is a fuzzy set of control forces. As processes usually require non-fuzzy values of control, a method of defuzzification called “center of gravity method” is used here [3], [4], [6].

8. Simulation Results

In this section, the controller was tested in order to compare the results of the designed fuzzy logic control with a traditional passive suspension system. As an example, step responses of the unsprung and front/rear sprung masses are shown in Fig8- Fig.11.
From Fig.9 and Fig.10, it is evident that fuzzy controlled active suspension efficiently suppresses sprung mass oscillations that occur when only passive suspension was used.

Diagram in Fig. 13 represents active forces acting on front and rear wheels in order to optimize ride comfort and good handling of the vehicle.

9. Conclusion

In the paper, we briefly described a basic way of fuzzy controlled active suspension system designed for a vehicle one-half-car model.

The entire analysis was developed in Matlab™ Simulink, with Fuzzy Logic Toolbox. The fuzzy inference machine is also on custody of a special module of Simulink. Practically, the entire process of fuzzification - inference – defuzzification is automaton made by the Fuzzy Logic Controller of Simulink™. The inference machine operation is based on the set of rules which link the input variables by the outputs. The set of input variables, output variables and inference rules base derived by modeling the designers knowledge and experience on vibro-isolation devices. The simulation results have been successfully verified on an experimental test stand. The same configuration like in Fig.7 has been used for test stand design and real experiments. Mechanical configuration of the test stand is obvious from Fig.13. Under the tyre there is placed another linear electric motor that uses an input experimental signal described in [5] to generate road displacement (road deviations) under the running wheel.

Fig.13 Experimental test stand

As is mentioned in [2],[3] the controller is developed via Matlab implemented into dSpace a connected to the test stand system.

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References

AN ALTERNATIVE DESIGN OF TESTING BENCH FOR DYNAMIC WHEEL CORNERING FATIGUE TESTS

Sakota Zeljko PhD., Kostic Dimitrije
Institute ‘VINCA’, Center for IC Engine and Motor Vehicles, University of Belgrade, Serbia

sakota@vinca.rs

Abstract: Worldwide test laboratories use complex equipment with high level of automated testing processes due to the larger quantity of samples processed. In order to facilitate the testing of products in domestic, accredited test laboratories, the Center for IC Engine and Vehicles of Vinca Institute developed a testing bench adapted to requirements of the domestic producers. This article presents an examination device designed for cornering fatigue testing of wheels in laboratory conditions. Furthermore, this testing bench allows testing of a wide range of elements and systems associated with the wheel, e.g. hubs, bearings, screw connectors, axles etc. Upon construction, the test bench was evaluated through a number of tests of various wheel specimens. The obtained results confirm the pertinence of this method in the development of the vehicle suspension systems.

Keywords: WHEELS, CORNERING FATIGUE TEST

1. Introduction

Testing of vehicle elements and assemblies is one of the unavoidable stages in the development of automotive industry, whereby this activity is given a special attention. In Serbia, a number of vehicle elements is produced, among which are wheels, which require verification in terms of meeting the quality, i.e. harmonization with relevant world standards in this field.

Worldwide test laboratories use complex equipment with high level of automated testing processes due to the larger quantity of samples processed. In order to facilitate the testing of products in domestic, accredited test laboratories, the Center for IC Engine and Vehicles of Vinca Institute developed a testing bench adapted to requirements of the domestic producers.

Apart from the aforementioned primary purpose, this testing bench allows testing of a wide range of elements and systems associated with the wheel, e.g. hubs, bearings, screw connectors, axles etc.

Technical solution of this test bench was evaluated through a number of tests of various wheel specimens and obtained results confirm the pertinence of this method in the development of the vehicle suspension systems.

2. About wheel testing

The problem is in what way to maximally speed up the dynamic wheel testing by incurring minimum costs. Solutions are usually sought either in the increase of wheel load or in the frequency of load change. Testing conditions need to be true to realistic exploitation conditions, which imposes certain limitations, especially when the wheel testing is performed with a tire where the overload capabilities are of limited nature. An alternative to this is an increase in the wheel rpm up to velocities of close exploitation maximum, which, when the lateral strength of the wheel is concerned, is most easily achieved by affect of load of centrifugal force. Most often, the wheel axis is placed vertically to reduce the effect of gravity on the elements that transmit the lateral force. One of those solutions, such as the one shown in Figure 1 (CFT-5 testing bench [4]), although it possesses the best characteristics in terms of centrifugal force effect on the wheel load, is still not ideal since the weight of the shaft coupled with additional load (axial load on the wheel) is the cause of deviation from the real conditions when exploiting the wheel.

![Fig. 1 CFT-5 testing bench with a detailed overview of the rotating weight](image)

When performing wheel testing on commercial vehicles, it is not easy to implement a solution together with a vertically positioned testing bench axis due to high testing installation height complete with all the accompanying effects such as high vibrations, which require massive stands or some other adequate mechanism.

3. Some shared experiences as regards wheel testing

In a number of countries, wheel testing has already been regulated in the adequate standards (such as USA [3], Japan, UK) and as such has mainly been based on the dynamic wheel testing performed either under lateral or radial load conditions. Apart from the abovementioned tests, tests such as torsional strength and testing of resistance to lateral impact are also present.

The stiffness testing by means of radial load is carried out on the wheel on which the recommended tire is mounted and and which rolls on the roller either on the outside or inside, or perhaps on several smaller rollers that simulate a flat surface. The surface on which the wheel is placed must reflect a smooth road as realistically as possible due to reduced deformations of tires. This kind of dynamic testing entails an overload (up to 70%) in the radial direction, which significantly reduces the lifespan of a tire.

Rollers of various diameters are used for wheel testing in commercial vehicles, but the most common value that we come across is \( d = 1.7 \text{m} \) (SAE), which is also common when performing tire testing. In case when the wheel sits on the inside of the roller, diameter of roller is only slightly bigger compared to a wheel diameter.

Stiffness testing through application of lateral force is carried out either with or without a wheel fitted with a tire. When performing tests on a complete wheel, the load is usually achieved by changing a wheel slope compared to its supporting surface, but this is also possible in a number of different ways. Figure 2 shows
the ZWARP testing bench of MAKRA company [5] with a variable wheel tilting point that sits on the drum on the inside.

Wheel testing without tires is most often used when applying lateral force, for which reason only two types of construction, shown in the Figures 3 and 4 below, are mainly used. The first picture shows a testing bench with a turning wheel attached to the rotating stand. A simulation of the lateral force (torque) is achieved by placing weights or in some other way.

Figure 4 show a more frequently used testing bench that is based on the principle of using centrifugal force that is generated by rotation of eccentrically arranged mass. The wheel is fixed to the stand, whilst the load change reaches the frequency of up to 100,000 changes per hour. In this way, the testing in question lasts significantly shorter.

When testing a wheel with no tire on it, a real-life simulation of workloads on the wheel disk is enabled, but not on the entire wheel. Knowing the fact that fractures occur almost exclusively on the central disk, this method provides a quality assessment in terms of wheel endurance relative to lateral forces.

The determination of the load by applying a bending moment is, for example, performed according to formula below (SAE J267):

\[
M = L \times (r_{st} \times \mu + d) \times K
\]

Where:
- \( M \) means a bending moment
- \( L \) means a vertical wheel load
- \( r_{st} \) means a static wheel radius
- \( \mu \) means an adhesion coefficient (0.7)
- \( K \) means a testing velocity coefficient (1.1 – 1.6)
- \( d \) means a wheel disk eccentricity

The requirement of the mentioned standard is that cracking may occur, naturally depending on the material used, only after a certain number of cycles (most often 60,000). Allowed variation of the bending moment totals +/- 3%.

4. Explanation of essence in the proposed solution

When we tried to tackle this technical solution, the key task was to make a testing bench for the lateral force of wheels of various dimensions, as well as for other associated elements (hubs, bearings, screws, etc.), with the maximum use of existing assemblies, which proved impossible in commercial solutions. We also decided to implement the lateral force over the course of testing, which is one of the main causes of wheel damage.

The essence of the technical solution is to simplify the testing installation in terms of using universal large mass surcafe for dynamic loads without substantially affecting the variation of a wheel bending moment. A relatively simple calculation suggests that when using the centrifugal force of rotational mass (n = 1440 rpm), we can avoid complicated solutions to testing benches for special purposes with vertical positioning of wheel rotation axis. The analysis further suggests that the following load ratio of weights and centrifugal force is as follows:

\[
F_g/F_{cf} = m\times g/m\times r\times\omega^2 = 0.3\%
\]

Where:
- \( r=150\text{mm} \)
- \( \omega=n\times\pi/30=150\text{s}^{-1} \)

The influence of the weight of other elements in the system (shaft, articulated joint, etc.) can be minimized by an optimal selection of dimensions for each sample being tested, but it is easy to see that the moment change is within the allowed +/- 3% (SAE J267).

Effectively measured values indicate that deviations in the bending moment occur due to lateral force that appears during the cycle at the level from 1 to 2% (when testing a wheel of a commercial vehicle rim size 16”, therefore the torque variation is 5daNm).

Figure 5 shows a schematic drawing of a testing bench used for examining the impact of the lateral force on the wheel where the rotation axis is set horizontally. The key elements of the testing bench are as follows:

1 – electric motor drive
2 – articulated joint
3 – centrifugal weights (\( F=m\times r\times\omega^2 \))
4 – rotary shaft with bearings
5 – wheel stand
6 – tested wheel

When applying solutions based on the use of the effects of the centrifugal force, special attention should be paid to safety systems (see Fig.6) that provide an immediate stoppage in the event of
enlargement of diameter in a rotating mass (once the cracking occurs).

**Fig. 6 Position of load weights and automatic shutting down system in the event of increased amplitudes of oscillation**

5. Detailed description of technical solution

As already mentioned, a universal large mass stand on elastic supports was used (see Fig 7) as a basis for the testing bench. The wheel itself is positioned over an adequate stand, which is intended for a nominal wheel diameter of up to 24”, attached to six points.

**Fig. 7 Testing bench for wheel testing complete with measurement-control unit**

Testing device consists of the following below:

- Base structure complete with the supporting elements

  The basic construction has a purpose to fix the testing objects (a wheel). At the same time the construction serves as a carrier of motor drive. The very construction is of a dismantling type, therefore it is possible to provide transfer and repositioning onto another location should the need occur.

- Measuring and control equipment

  The measurement of the bending moment on the wheel is done by using strain gauges mounted on the rotary shaft (the "half-bridge" circuit), and whose calibration is performed by implementation of HBM U1 force transducer (see Fig. 8) that operates on the weight carrier. The signal is closely monitored, digitized and stored on a portable computer over the course of testing bench operation by means of a SK6 slip-ring and "HPSC 3502" amplifier of carrier frequency.

**Fig. 8 Calibration of strain gauges in the shaft using HBM force transducer**

Figure 9 shows a typical fracture detected over the course of wheel testing performed on a delivery vehicle of domestic production.

**Fig. 9 Typical fracture on a wheel disk**

6. Conclusion

The described testing bench technical solution with horizontal direction of rotation axis intended for wheel cornering fatigue tests, meets the requirements of the relevant standards and can be successfully used for vehicles and trailers wheel testing. It can also be widely used when testing other wheel elements such as hubs, shafts, screw connectors, etc.

7. References

INTERACTION BETWEEN ROLLING STOCK AND RAILWAY TRACK WITH OF THE ELASTIC PROPERTIES OF THE BASE

Prof. Dr. Myamlin S. 1, Assoc. Prof. Dr. Bondarenko I. 1
Dnipropetrovsk National University of Railway Transport named after academician V. Lazaryan, Ukraine
sergeymyamlin@gmail.com

Abstract: The main trend in considering the interaction of the railway track and the rolling stock is the studying of the parameters of the rigidity of the interaction. For the study, a model of the track design, described using the basic concepts of the theory of elasticity and the propagation of elastic waves was developed. The study of the peculiarities of the interaction of the rolling stock and the track, taking into account the elastic properties of the base, allows to expand the possibilities of solving the problems of ensuring their functionally safe operation with a certain level of operational efficiency.

Keywords: DYNAMIC PROCESS, OSCILLATIONS, POWER WAVE, PHYSICAL AND MECHANICAL FEATURES OF THE INTERACTION

1. Introduction

The main trend in considering the interaction of the railway track and the rolling stock is the studying of the parameters of the rigidity of the interaction. It is necessary to use not only equivalent parameters obtained in the experiment, but also parameters related to specific interaction conditions. The parameters of the railway track and the rolling stock, are the key to obtaining effective solutions in the tasks of ensuring their functionally safe operation with a certain level of efficiency taking into account the real constructive physical and mechanical features of the interaction.

All the issues related to determining reliable, functional and safe railroad track operation imply the exploration of dynamic processes in the track design that occur under the influence of the rolling stock. A study of the dynamic process interconnects the following tasks: determining the types and magnitudes of the forces acting on the track depending on the position of the wheelset in a track, location and types of the contact between wheels with rails which depend on the condition of the wheels and rails, as well as a change in the stressed-strained state of the track over time. When describing the dynamic process, the magnitudes of vertical forces that act on the track were determined as functions of the longitudinal compressive forces [1]. The magnitudes of transverse forces – by dependences of the calculation of the rolling stock aligning with the track [1, 2]. The question on the types of contact between wheels and rails required separate consideration. Typically, when analyzing the contact between a rail and a wheel, a rail is considered either new or with a side wear of 3.5 mm, at which the rail is believed to be little worn-out, and a side wear of 7.8 mm, at which the rail is considered to be medium worn-out. Papers [3, 4] present modern analysis of the wear of wheels for different profiles. A separate research was conducted by the results of these articles, the outcomes of which are given in [5].

The time of influence of the rolling stock on the railroad track depends on the motion speed. The duration of these processes depends on the physical and structural characteristics of the elements of design of the railroad track. The existing methods for the calculation of parameters of the stressed strained state of the track by the influence of the rolling stock by canons of the method of finite elements or boundary elements describe physical and structural characteristics of the track design elements in full. But they do not take into account such phenomena as the period of the load passage over the elements of the track, the time of occurrence of reactions to the load from these elements, and the correlation of load action time and the duration of processing of this load by elements of the track design. The lack of a temporal component does not allow to describe the dynamic processes in full. The use of quasi dynamic methods changes the essence of dynamic processes. Thus, the application of quasi dynamic forces causes the track deformation, at which the sagging of rails and anchor system shifts along with the motion of the train despite the divergence of occurrence, over time, of maximum sagging in the elements of track design.

In the course of such studies, the calculations are performed for different values of frequency of quasi dynamic excitation, defined as the ratio of speed to the magnitudes of distances between the wheels of one bogie and adjacent bogies, or distance between the supporting elements of the track. And though all acknowledge that the speed of motion affects the frequency of excitation but the magnitude of frequency of excitation, determined by the ratio of the length of the contact area of the rail with the wheel to the duration of dynamic load action on the track (motion speed to length of the contact area) is not used in these calculations. In the physical essence, excitation frequency, inversely proportional to the geometric lengths of position of the wheels in the train, characterizes the recurrence of load occurrence in the examined track intersection. And for static calculations, it characterizes part of the force that acts in the examined track intersection in a certain point in time. When moving the load, the distance between the force application place and the examined intersection changes. Thus, not only the part of the magnitude of forces that acts in the examined intersection also the vector of force changes. And the frequency of excitation, inversely proportional to the period of action of the load by physical essence is characterized by an impulse of load, which acts on the track and allows to apply the basic equation of dynamics.

Thus, in order to examine the dynamic processes of deformability of the track, it is necessary to take into account the differences between static and dynamic characteristics of loads. The changes proposed will make it possible to evaluate the work of a railroad track under the influence of the rolling stock depending on the design features of the track structure over particular period of time. This will allow us to compare characteristics of the track operation, obtained by actual parameters, to characteristics of its work and to determine actual period of its operation. The changes proposed will also provide for the possibility under the assigned operating conditions to define, by the criteria of reliability, the design of the track or measures related to its strengthening with the provision of certain resource of its work.

2. Problem discussion

Currently, many research have been devoted to the study of the mathematical description of the impacts acting from railway track to the rolling stock. In all studies it was believed that the reaction of the railway track to the impact of the rolling stock is instantaneous. In addition, the results of the recorded disturbance obtained on the rolling stock in the experiment are not classified according to the constructions characteristics of the railway tracks. It is assumed that the elastic and dissipative characteristics of the path determine the amplitude-frequency characteristics of the oscillations. But they are yet not classified according to the physical-mechanical and
geometric characteristics of railway track construction elements. To create such classification, it is necessary to study the mechanism for transferring force from the rolling stock to the elements of the track in time. This problem will be theoretically investigated within this work. The problem can be formulated as follows: how do the physic-mechanical properties of railway track elements affect the process of propagation of force from the rolling stock to the construction of the track?

3. Objective and research methodologies

The main purpose of this work is to study the process of transferring force from the rolling stock to the elements of the track in time.

For the study, a model of the track design, described using the basic concepts of the theory of elasticity and the propagation of elastic waves was developed [6, 7].

The mechanism of action of the rolling stock on the track is represented by pulses that excite the contact areas of the rails with wheels located along the track. The excitation of contact areas takes place taking into account the time of occurrence and the effect of loads in them. The specified intervals of the action time of the pulse depend on the speed of the trains. The impulse along the construction of the path is propagated by the power waves. The propagation of a power wave in the elements of the track structure is described as the process of excitation and propagation of volume longitudinal and transverse spherical waves, taking into account their properties.

These introductions made it possible to obtain analytical dependencies to determine the features of dynamic load propagation. These include: two types of transmission frequencies of dynamic load, variable directivity in time, the relationship between the amplitudes of oscillations both within the elements and during the transition from one element to another. That allows us to describe the process of propagation of a power wave in the construction of a track in time, taking into account the inverse reaction of the elements on them.

Underlying this modeling is the existence of wave processes that are caused by both external and own oscillations.

All oscillations generated by the contacting surfaces, which, up to the given point, have not touched or have renewed their contact after a break, propagate by spherical waves. They characterize the main direction of propagation of the wave process from a new or renewed contact between surfaces and account for the contact and local concentrations of stresses and deformations.

All oscillations generated by the contacting surfaces, which, up to the given point, have touched and established contacts, propagate by quasi spherical waves. They characterize the basic direction of propagation of the wave process from the contact point of the surfaces and account for the non-uniformity of oscillating. But one spherical wave of incidence that carries the longitudinal and transverse mode causes four quasi spherical refracted waves: two longitudinal and two transverse. Each of them is heterogeneous, as it has vivid dependence of the change in characteristics in its direction and carries the consequences from the neighboring refracted waves in other directions.

Since in the process of propagation there is the superposition of waves, it characterizes the non-uniformity of the whole process of oscillating. Thus, in every point of the design in a certain period of action, one will observe either homogeneous spherical and (or) non-uniform quasi spherical waves. In general, the oscillations that propagate by quasi spherical waves cannot be predicted based on approximation.

The use of wave properties in the propagation of force in the elements of the track structure allows:

- to establish that the deformability process in the design of the track is due to the presence of wave processes, the nature of which depends on the physic-mechanical and geometric properties of the track elements.

In order to consider the transfer of force between the elements, let us consider the contact pair of a rail-gasket with the characteristics given in Table 1.

Table 1. Physical-mechanical characteristics the contact pair of the rail - gasket

<table>
<thead>
<tr>
<th>Element</th>
<th>Density, kg/m³</th>
<th>Poisson’s coefficient</th>
<th>Young’s modulus, GPa</th>
<th>C₁,l/M²</th>
<th>C₁,transverse/M²</th>
</tr>
</thead>
<tbody>
<tr>
<td>rail</td>
<td>7830</td>
<td>0.3</td>
<td>21.1×10⁹</td>
<td>562</td>
<td>6008</td>
</tr>
<tr>
<td>gasket</td>
<td>918</td>
<td>0.3</td>
<td>21.1×10⁹</td>
<td>382</td>
<td>1572</td>
</tr>
</tbody>
</table>

I - the speed of longitudinal; 2 - the speed of transverse waves in the material.

Angles characterizing the process of transmission of power waves for the contact rail-gasket pair are given in Table 2. Where p-inc – longitudinal wave of incidence and s-inc – transverse wave of incidence, p-refl – refracted longitudinal wave and s-refl – transverse refracted wave, p-refl – longitudinal wave of reflection and s-refl – transverse wave of reflection.

Table 2. Characteristics of the angles of the wave process in the contact pair of the rail - gasket

<table>
<thead>
<tr>
<th>Contact pair</th>
<th>Angles, degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>incidence</td>
<td>reflection</td>
</tr>
<tr>
<td>p-inc</td>
<td>p-refl</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
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<tr>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>s-inc</td>
<td>s-refl</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
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<tr>
<td>40</td>
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<td>60</td>
<td>60</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>80</td>
<td>80</td>
</tr>
</tbody>
</table>

The results shown in Table 2 demonstrate the collecting ability of the gasket. That is, if different forces act on the same surface at angles of 10-80°, the gasket processes them and combines them, directing the common beam characterizing the p-refl angles (0.68-28.83°) for longitudinal waves and s-refl (0.34-4.72°) for transverse waves further. These angles characterize the angles of the reflection process from the edge of the gasket. Knowing the values of the reflection angles at the boundary of the gasket-sleeper contact and the thickness of the gasket, it is possible to form a geometric pattern on the surface of the gasket to improve its damping properties and extend the service life.

For example, Poisson's coefficient for the material (Table 1) of the gasket can vary from 0.3-0.485. If the value of the Poisson coefficient is less than 0.4, the transverse waves will not affect the
work of the gasket. Consequently, with values of the Poisson coefficient, less than 0.4 rail will accept loads transmitted by reflected transverse waves, and the gasket will perceive loads carried only by longitudinal waves. The loads transmitted by longitudinal and transverse waves will be transmitted to gaskets when the values of the Poisson factor are more than 0.4. Consequently, the characteristics of the gasket material will impact the possibility of the destruction of the gasket. In addition, the consideration of these questions in time allows us to predict the concentration of waves in the middle of the gasket, characterizing the concentration of its stress-strain state in time.

b) to determine the direction and amplitudes of oscillations in the elements of the track and their displacement from the impact of the rolling stock considering in time.

The oscillation direction of the particle depends on the direction of propagation and the type of wave (Fig. 1). If the wave is a longitudinal \( P \), it forces a particle to move in the direction of its propagation. If the wave is transverse to the vertical mode of \( SV \), then it forces the particle to move in the plane of propagation, but perpendicular to the direction of propagation. If the wave is transverse to the horizontal mode of \( SH \), a particle oscillates in a plane that is perpendicular to the propagation plane.

Thus, the direction and amplitude of oscillation of particles in time are formed.

The results shown in Table 3 demonstrate coefficients of reflection and refraction of the wave process in a contact pair of rails with gaskets. The values of the coefficients characterize the change in the magnitude of the amplitudes of the reflection and refraction of the wave processes relative to the amplitude of the wave process of the incidence.

### Table 3. Coefficients of reflection and refraction of the wave process in a contact pair of rails with gaskets

<table>
<thead>
<tr>
<th>Angles s- inc, degree</th>
<th>( K_{p-refl} )</th>
<th>( K_{s-refl} )</th>
<th>( K_{p-refl} )</th>
<th>( K_{s-refl} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0,847</td>
<td>0,389</td>
<td>0,378</td>
<td>1,943</td>
</tr>
<tr>
<td>20</td>
<td>0,467</td>
<td>0,712</td>
<td>0,723</td>
<td>1,824</td>
</tr>
<tr>
<td>30</td>
<td>0,029</td>
<td>0,968</td>
<td>0,965</td>
<td>1,725</td>
</tr>
<tr>
<td>40</td>
<td>0,708</td>
<td>5,656</td>
<td>0,064</td>
<td>6,964</td>
</tr>
<tr>
<td>50</td>
<td>0,799</td>
<td>5,960</td>
<td>0,383</td>
<td>4,774</td>
</tr>
</tbody>
</table>

As indicated above, if the value of the Poisson coefficient is less than 0.4, the transverse waves will not affect the work of the gasket. According to the results shown in Table 3 these conditions correspond with angles s- inc more than 50°.

c) to regulate energy transfer and the process of oscillation in the elements of the track design by adjusting the physic-mechanical and geometric characteristics of the elements of the track design.

The results shown in Table 3 prove that the ratio of the amplitudes of reflection and refraction amplitude varies depending on the angle of incidence for one and the same material.

Since the energy transferred by the wave is proportional to the square of the amplitude, then the ratio of energy values in the reflected and refracted waves is different at different angles of incidence. This fact provides the possibility of directed forecasting of the deformability of the elements of the railway track by changing the characteristics of materials and the construction of the elements of the railway track by studying the process of the origin and propagation of power waves.

### 4. Conclusion

The study of the peculiarities of the interaction of the rolling stock and the track, taking into account the elastic properties of the base, allows to expand the possibilities of solving the problems of ensuring their functionally safe operation with a certain level of operational efficiency.

### Literature

Abstract: It is determined that civil aviation in Ukraine has a number of problems that are the result of a chronic crisis in the deep fields of the industry. It is revealed that the "open sky" policy acts as an incentive to increase competition. The analysis of dynamics of the air transportation market of Ukraine is carried out. The decline in demand for air transportation in Ukraine is considered as a continuation of the negative trends in the national economy. The analysis of the Ukrainian airlines market has showed that the share of 4 leading airlines in the total volume of passenger traffic was almost 93%. Regular flights between Ukraine and rest of the world were carried out by 9 domestic airlines (to 39 countries of the world) and 35 foreign airlines from 29 countries of the world. The ratio between international and domestic transportations of Ukrainian carriers during the year amounted to 85% and 15% in favor of international ones. It was found out that leading aviation carriers do not meet the modern requirements of the world aviation community. The study of the air transportation market in relation to specialization by types of business has revealed that nine major types of air carriers were formed. Functioning of Low Cost business model on the market provides a significant change in the structure of aviation. The main specific features of the stages of development of Low Cost business-model airlines are determined. The analysis of the situation on the air transport market was conducted on the basis of PEST-analysis. Measures that make it possible to intensify the process of development of the market of aviation transportations are listed: renewal of the airport infrastructure; establishment of high technical standards for airplanes and air services; security enhancement; modernization of air traffic control procedures; updating sectoral legislation. The prospects for the development of the air transport market of Ukraine are the creation of new organizational forms that fully meet the requirements of the market. Consolidation can occur in several areas: the formation of a national carrier-flagship, merger with foreign companies or consolidation with domestic players in the market.

KEYWORDS: AVIATION, AIR TRANSPORTATION MARKET, BUSINESS-MODEL, AIRPORT INFRASTRUCTURE, PEST-ANALYSIS

1. Introduction

A number of problems, that Ukrainian civil aviation now faces, are, in fact, a consequence of the chronic crisis in the underlying areas of the industry. Organizational crisis is a condition in which forms of organization of market entities do not allow them to function effectively in conditions where the external environment is positively adjusted to these entities.

The "open sky" policy, to which Ukraine aspires, acts as an incentive for competition and, accordingly, an increase in the number of operators (mostly European ones). It will lower the fares and increase the quality of service. However, Ukrainian carriers may lose their positions. In response to increased competition, it is necessary to increase capacity and improve the efficiency of airlines. It is possible to reach this goal in various ways, in particular through consolidation with other participants in the aviation transport market [1].

The study of problems and organizational and economic changes in air transport should begin with the diagnosis of a market situation, because this factor is the most important in eliminating the problems that exist in Ukrainian airlines.

2. Analysis of dynamics of the air transport market in Ukraine

In Ukraine, 78 aviation organizations engaged in transportation or aeronautical chemical works were registered in January 2017. Almost a third of carriers specialize exclusively in passenger transportation. According to experts, more than 85% of passenger traffic is carried out on regular flights and only 15% - on charter flights, with the freight traffic the opposite is the case – almost 90% is on charter flights.

There were 33 domestic airlines operated on the passenger and freight market in 2016. According to the statistics, during the year, 66,300 commercial flights were performed (by 2015 – 74.8 thousand). The number of passengers carried decreased by 2.7 percent compared to the previous year and amounted to 6302.7 thousand people (Table 1). The volume of cargo and mail was 69.1 thousand tons (in 2015 - 78.7 thousand tons).

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Units</th>
<th>Total</th>
<th>including international ones</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>16/15</td>
<td>16/15</td>
</tr>
<tr>
<td>Passengers</td>
<td>thousand</td>
<td>6475,2</td>
<td>6302,7</td>
</tr>
<tr>
<td>including on regular lines</td>
<td>4553,9</td>
<td>4692,8</td>
<td>101,7</td>
</tr>
<tr>
<td>Passengers- kilometers completed</td>
<td>11,6</td>
<td>11,4</td>
<td>98,3</td>
</tr>
<tr>
<td>including on regular lines</td>
<td>7,6</td>
<td>8,1</td>
<td>106</td>
</tr>
<tr>
<td>Cargo and mail transported</td>
<td>78,7</td>
<td>69,1</td>
<td>87,8</td>
</tr>
<tr>
<td>including on regular lines</td>
<td>10,9</td>
<td>13,8</td>
<td>126,6</td>
</tr>
<tr>
<td>on-line kilometers completed (cargo and mail)</td>
<td>239,3</td>
<td>211,0</td>
<td>88,2</td>
</tr>
<tr>
<td>including on regular lines</td>
<td>30,4</td>
<td>39,6</td>
<td>130,3</td>
</tr>
<tr>
<td>Committed flights</td>
<td>thousand</td>
<td>74,8</td>
<td>66,3</td>
</tr>
<tr>
<td>including on regular lines</td>
<td>50,3</td>
<td>45,8</td>
<td>91,1</td>
</tr>
</tbody>
</table>
The decline in demand for air transportation is a continuation of the negative trends of 2015, which arose because of an unstable military-political and economic situation in the country and stoppage of air services between Ukraine and the Russian Federation from October 25, 2015.

A general overview of air transportation by Ukrainian companies is important for analyzing the airline's operating environment (Figure 1).

Commercial flights of domestic and foreign airlines were served by 20 Ukrainian airports in 2015. According to statistics, the number of the aircrafts sent and arrived during the year was 120.7 thousand (versus 142,400 in the previous year). Passenger traffic through Ukraine's airports decreased by 1.8% and amounted to 10695.2 thousand people, mail traffic – by 9.5% and totaled 34.4 thousand tons. At the same time, 68 percent of all serviced passengers and almost 88 percent of cargo flows fell on the Boryspil airport. According to the results of 2016, passenger traffic through the main airport of country, Boryspil increased by 5.6% compared to 2015. There was also growth in passenger traffic at airports in Odessa (at 9.8%), Zaporizhzhya (at 69.9%), and Kherson (by 7.8 times). Passenger traffic through Dnipropetrovsk airport decreased by 22.5%, Kharkiv - by 14.6%, Kyiv (Zhulyany) - by 13.6%, Lviv - by 2.5%. According to the results of 2016, passenger traffic through the Boryspil airport increased by 5.6% compared to 2015.

3. Analysis of the market by types of air carriers

Passenger traffic was performed by 21 Ukrainian airlines in 2016. The share of 4 leading airlines (Ukraine International Airlines, Azure Air Ukraine (Utelier Ukraine), Rose of Winds and Dniproavia) in total passenger transportation accounted for almost 93 percent (Figure 2). At the same time, the growth of volumes of transportation took place only in the airline "International Airlines of Ukraine" (by 28.2%). Passenger transportation of the Azure Air Ukraine (UTair Ukraine) decreased by 12.2% compared to 2015, Dniproavia - by 13.5%, Wind Rose - by 54.9%.

Regular flights between Ukraine and other countries were carried out by 9 domestic airlines to 39 countries of the world and 35 foreign airlines from 29 countries of the world. Ukrainian Airlines transported 4,018.3 thousand people (growth - by 2.4%), and foreign airlines – 3769.3 thousand people (reduction - by 1.1%) (Figure 3). During 2016, five new international airlines were launched on a regular basis: Dniproavia airline from Dnipropetrovsk to Bourgas and from Odessa to Batumi, Ukraine International Airlines from Odessa to Vilnius and from Lviv to Bologna, Atlantic airline Ukraine from Zaporozhye to Istanbul. Passenger transportation between nine Ukrainian cities was carried out by 5 Ukrainian airlines on domestic regular lines, and 611.5 thousand people were transported (versus 629.2 thousand people in 2015).
The average percentage of passenger load on international regular flights of Ukrainian airlines in the reporting period increased compared with the previous year by 6.4 percentage points and reached 79.4%, and on domestic regular flights – by 6.1 percentage points and was 71%.

Transportation of goods and mail in the reporting period was carried out by 19 domestic airlines, 76% of the total volume of traffic was performed by ANTK “Antonov”, “Ukrainian International Airlines”, “Maximus Airlines”, “Zeta Avia” and “Urga”. Most of the transportation was carried out by charter flights in other states within the framework of the UN humanitarian and peacekeeping programs, as well as contracts and agreements with other customers.

The correlation between international and domestic transportations of Ukrainian airlines was 85% to 15% in favor of international ones in 2016.

Unlike international regular flights of Ukrainian airlines, which have not fully recovered compared to the indicator of the previous 2016, a significant increase in traffic volumes was observed in the segment of international charter flights (Figure 4). According to statistics, in 2015 domestic airlines carried out 26.1 thousand commercial charter flights against 23.2 thousand flights in previous year, the number of passengers transported increased by 18.1% and amounted to 2.5 million passengers. Significant volumes of chartered transportation were carried out by the following airlines: “Roze of Winds”, “Ukrainian International Airlines”, “Uteli”-Ukraine”, “Aviatrans K” and “Kharkiv Airlines”.

It should be noted that the competitive pressure on the Ukrainian airlines by foreigners causes certain concerns not only to weak regional companies, but also to leaders. Unlike foreign competitors, regional airlines, as a rule, do not occupy significant positions in the international market and attract for flights to the cities of Ukraine for some reason far from being the best aircrafts and commercial potential. First-class foreign airlines (“British Airways”, “Lufthansa”), as well as airlines of the CIS countries, offering world-class services with almost dumped prices (“Transaero”, “Estonian Airlines”, etc.) are competitors of Kyiv-based airline leaders. Therefore, the confrontation with this pressure requires the mobilization of all resources of airlines and their maximum concentration in this direction. The principle of moving away from internal competition in favor of concentrating maximum efforts on the external one gets even more urgent.

4. Business models in the air transportation market

In the air transportation market, there is a certain specialization in the types of business, resulting in the formation of nine major varieties of air carriers: network airlines; regular international carriers and regional carriers; charter transportation airlines; combined express carriers; cargo operators; mixed airlines; isolated airlines; low cost airlines.

The operation of the relatively new Low Cost business-model in the market makes significant changes to the structure of air transportation, since it is aimed at minimizing costs by refusing additional service. The arrival of low-budget airlines in the market forces national carriers to lower their tariffs, as well as to implement customer loyalty programs. All this affects the general level of competition of Ukrainian carriers.

The Table 2 demonstrates the main features of development stages of Low Cost airlines.

<table>
<thead>
<tr>
<th>Stage</th>
<th>The name of the business-model at the development stage</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Classical Low Cost (70s, 20th century)</td>
<td>Oriented on max minimizing costs and lack of free service. Flight services are carried out to secondary airports at an awkward time, passengers carry luggage independently, the distance between the seats is reduced, and money is not returned to passengers in case of cancellation of the flight.</td>
</tr>
<tr>
<td>2</td>
<td>Low Cost with additional services (80s, 20th century)</td>
<td>Flights are carried out from major airports, soft drinks and light snacks are distributed during the flight, transit flights through hub airports are offered. Example: American “Frontier”, British “EasyJet”, German “Air Berlin”.</td>
</tr>
<tr>
<td>3</td>
<td>Low Cost with a full set of services (90s, 20th century)</td>
<td>Airlines use exclusively new aircrafts, the distance between the seats in the cabin is increased, television and the Internet are on board. Example: American “JetBlue”, Canadian “WestJet”.</td>
</tr>
<tr>
<td>4</td>
<td>Low Cost with Business Class (2000s, XXI Century)</td>
<td>Airlines offered business class travel at prices 30-50% lower than traditional airlines; flights were carried out long distances (Europe-Asia, Asia-USA, Europe-USA). They did not survive the competitive struggle with traditional companies and left the market.</td>
</tr>
<tr>
<td>5</td>
<td>Long Range Low Cost (2010s, XXI Century)</td>
<td>Reduced costs are due to the same type of aircraft, reduced costs for ticket sales, low tariffs for intercontinental airlines, minimum free service. Example: Asian “Air Asia X”, Australian “Jetstar”.</td>
</tr>
</tbody>
</table>

It is dynamic development of the air transportation market of Ukraine takes place, despite certain problems related to the economic situation in the country. To investigate the situation in the air transportation market, PEST-analysis was conducted, which made it possible to analyze the conditions of companies in the domestic aviation market and external factors that affect the conduct of business at an adequate level. PEST analysis is designed to identify political factors (P - political), economic impact (E - economic), social tendencies (S - social) and technological innovations (T - technologies). The work was carried out in two stages: at the first stage, the degree of influence of factors on the activity of airlines in the form of relative normalized weighted coefficients was determined, and at the second stage - the
probability of their influence on the five-point evaluation system, with 5 - the greatest impact, and 1 - the smallest (Table 3).

<table>
<thead>
<tr>
<th>Factors</th>
<th>Weight Coefficient</th>
<th>Direction of Influence</th>
<th>Experts (degree of influence)</th>
<th>Ave-rage rating</th>
<th>Ave-rage weigh-ted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of basic state policy for Ukrainian airlines</td>
<td>0.07</td>
<td>+</td>
<td>3 5 2 4</td>
<td>3.5</td>
<td>0.25</td>
</tr>
<tr>
<td>Incompatibility of Ukrainian legislation in the field of air transport</td>
<td>0.01</td>
<td>+</td>
<td>1 2 1 3</td>
<td>1.75</td>
<td>0.02</td>
</tr>
<tr>
<td>Weak state regulation of competition in the aviation market</td>
<td>0.08</td>
<td>+</td>
<td>5 5 4 3</td>
<td>4.25</td>
<td>0.34</td>
</tr>
<tr>
<td>Lack of means to combat &quot;oligarchization&quot; in the aviation industry</td>
<td>0.04</td>
<td>+</td>
<td>1 2 3 4</td>
<td>2.5</td>
<td>0.10</td>
</tr>
</tbody>
</table>

2. Economic

<table>
<thead>
<tr>
<th>Factors</th>
<th>Weight Coefficient</th>
<th>Direction of Influence</th>
<th>Experts (degree of influence)</th>
<th>Ave-rage rating</th>
<th>Ave-rage weigh-ted</th>
</tr>
</thead>
<tbody>
<tr>
<td>The unstable economic situation in the country</td>
<td>0.04</td>
<td>-</td>
<td>3 2 4 5</td>
<td>3.5</td>
<td>0.14</td>
</tr>
<tr>
<td>Weak investment climate</td>
<td>0.05</td>
<td>+</td>
<td>4 2 3 3</td>
<td>3</td>
<td>0.15</td>
</tr>
<tr>
<td>High customs duties and tariffs</td>
<td>0.06</td>
<td>-</td>
<td>3 3 2 5</td>
<td>3.25</td>
<td>0.20</td>
</tr>
<tr>
<td>Low income level of population</td>
<td>0.08</td>
<td>+</td>
<td>5 4 5 2</td>
<td>4</td>
<td>0.32</td>
</tr>
</tbody>
</table>

3. Technological

<table>
<thead>
<tr>
<th>Factors</th>
<th>Weight Coefficient</th>
<th>Direction of Influence</th>
<th>Experts (degree of influence)</th>
<th>Ave-rage rating</th>
<th>Ave-rage weigh-ted</th>
</tr>
</thead>
<tbody>
<tr>
<td>An outdated fleet of rolling stock</td>
<td>0.08</td>
<td>-</td>
<td>5 5 4 4</td>
<td>4.5</td>
<td>0.36</td>
</tr>
<tr>
<td>Inappropriate level of technology in the organization of the transportation process</td>
<td>0.07</td>
<td>-</td>
<td>2 4 5 5</td>
<td>4</td>
<td>0.28</td>
</tr>
<tr>
<td>Insufficient level of infrastructure development of regional and international airports of Ukraine</td>
<td>0.08</td>
<td>-</td>
<td>5 4 5 3</td>
<td>4.25</td>
<td>0.34</td>
</tr>
<tr>
<td>Insufficient level of the system of transport-logistic complexes</td>
<td>0.05</td>
<td>+</td>
<td>1 3 4 3</td>
<td>2.75</td>
<td>0.14</td>
</tr>
</tbody>
</table>

4. Social

<table>
<thead>
<tr>
<th>Factors</th>
<th>Weight Coefficient</th>
<th>Direction of Influence</th>
<th>Experts (degree of influence)</th>
<th>Ave-rage rating</th>
<th>Ave-rage weigh-ted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age structure of the population</td>
<td>0.07</td>
<td>+</td>
<td>2 4 5 4</td>
<td>3.75</td>
<td>0.26</td>
</tr>
<tr>
<td>Training level</td>
<td>0.06</td>
<td>-</td>
<td>4 3 4 2</td>
<td>3.25</td>
<td>0.20</td>
</tr>
<tr>
<td>Educational level</td>
<td>0.08</td>
<td>+</td>
<td>4 3 5 5</td>
<td>4.25</td>
<td>0.34</td>
</tr>
<tr>
<td>Cultural level</td>
<td>0.06</td>
<td>+</td>
<td>3 2 4 2</td>
<td>2.75</td>
<td>0.17</td>
</tr>
</tbody>
</table>

The following specialists were selected as experts: personnel policy specialists, marketers of the public relations department, economists of the economic and analytical department, legal advisers, leading aviation specialists and employees of the Ministry of Infrastructure of Ukraine.

Insufficient state support is a major factor among the political factors. There is no basic state policy for Ukrainian airlines in a difficult competitive environment. The weak point is also a discrepancy of legislation in Ukraine in the field of air transport to international and European standards, including the International Civil Aviation Organization (ICAO), the European Union, the European Civil Aviation Conference (ECAC), and the European Organization for the Safety of Air Navigation (EUROCONTROL). Gradual displacement of a domestic air carrier to foreigners is due to weak state regulation of competition in the aviation market.

Regarding "oligarchization", there are no effective market means to combat this negative phenomenon today. Real methods of countering excessive monopolization and seizing control over the market by one entity are only direct administrative power and prohibitive actions, very unpopular and counteracting normal market laws. Therefore, it is necessary to take measures to prevent the situation with the prerequisites for the oligarchic seizure of the market to eliminate this problem.

For Ukraine, "open skies" means the intensification of the process of the air transportations market development due to: update of airport infrastructure; establishment of high technical standards for airplanes and air services; security enhancement; modernization of air traffic control procedures; updating sectoral legislation, etc. In order to solve these problems, it is necessary to implement the provisions of the Concept for the development of the aviation complex and the development of programs for the period up to 2020 and to ensure the safety of flights by improving the mechanisms of supervision and control of transport activities.

Economic factors include: weak investment climate in the domestic aviation industry; high customs duties and tariffs during the flight; an increase in the inflation rate that affects the rise in fuel prices; the growth of fares for flights. The price policy of flights is controlled and regulated not by the government, but by airlines, which leads to fluctuations in prices for services of various airlines. The growth of the rates of conclusion of various types of agreements with other airline companies for the sale of commercial rights (interlays, block-space agreements, marketing agreements, code-ranging agreements, agreements on joint operation of airlines), as well as the creation of aviation alliances take place. In accordance with social factors, here it is possible to note the regulation of relations in the field of training; taking into account the age structure of the population, the level of education and culture.

Among the technological factors, insufficient level of the system of transport-logistic complexes, insufficient level of regional and international airports infrastructure development in Ukraine can be distinguished. It is necessary for the government of the country to adopt uniform concepts for the development of airports, which will allow passengers to travel more quickly and with greater comfort. There is reluctance to use domestic airplanes for air transportation. There is an inappropriate level of technology in the organization of the transportation process, insufficient information provision.

This issue can be addressed through the introduction of CNS / ATM global satellite systems for air traffic services, automation and computerization of airlines at international level; the creation of a system of transport and logistics complexes (to shorten shipping time, reduce transportation costs and optimize tariffs) and further development of information and logistics technologies [7].

The result of PEST analysis is the selection of key environmental factors that will create the ability and smooth out the threats to companies in the projected period. Analysis of Table 3 allows us to conclude that: the absence of basic public policy for Ukrainian airlines does not allow opportunities to expand business; the lack of compliance of Ukrainian legislation in the field of air transportation with international requirements has little impact; weak state regulation of competition in the aviation market is a major threat to companies, as well as the economy as a whole; economic instability in the country is a threat to the company.

6. Prospects for the development of the air transportation market in Ukraine

Regarding the structure of the aviation market of Ukraine, it should be noted that it is quite clearly divided functionally (airlines, airports, service and provision of structures, aircraft factories, etc.) and technologically (airlines for general transportation and special purpose). However, the global trend of civil aviation development shows that every year in the world aviation practice a large consolidation and integration of market actors is carried out both on a functional and a technological basis — powerful consortia and
alliances of air carriers and structures providing them are created. Alliance forms of interaction have become a necessary condition of existence on the market under current conditions of the economy.

There are three stages of creating alliances:

I. The first stage focused mainly on the production of additional revenue by attracting more passengers by expanding route network and joint marketing.

II. The second stage focuses on cost savings, as well as the continuation and strengthening of cooperation in the first stage, and involves separate agreements in one or more specific areas where joint activities can reduce costs. The implementation of the first two stages does not necessarily combine a long-term alliance. Its disintegration or exit from it are possible; although the longer the alliance exists, the more it is close, especially if cooperation is mainly carried out in the area of cost reduction.

III. The third stage is to unite the alliance, when partners start mixing their assets together and using them jointly, including joint product development and joint ventures to regulate various aspects of their activities. The final stage is the full merger of alliance member companies.

In order to overcome the organizational crisis, it is necessary to create new organizational forms that fully meet the requirements of the market, while the principle of integration and consolidation should become the general line. In the direction of consolidation, the result should be the unification of air companies under the joint coordination and supply – the creation of “alliances” or “consolidated air carriers” (at the state level – a national carrier, at the regional level – regional carrier, at the enterprise level – a specialized group, for example, a consortium of airlines). Consolidation will allow us to solve a number of issues at once, such as the distribution of a competitive market, optimal use of unused capacities, etc.

In the direction of integration, the results should be the merger of air companies with structures whose activities, directly or indirectly, are aimed at ensuring the process of aviation commercial operations. Integration will provide a positive solution to marketing and competition issues, issues of reducing the cost of airline and tariff policy, the problems of efficient supply, the issue of ensuring the inflow of financial resources on favorable terms. Economic mechanisms for solving this are the principles of acquiring (selling) shares, entering (accepting) into an authorized fund, lease relations, long-term preferential investment, establishment of subsidiaries, privatization.

Consequently, consolidation can take place in several areas: the formation of a national carrier-flagman, merger with foreign companies or consolidation with domestic actors in the market. Any reaction to factors of influence will lead to organizational and economic changes in the airlines themselves.

7. Conclusions

Investigation of the factors of influence becomes important in the analysis of the airline's activity. To determine the future behavior of the organization, its management need to know as the internal and the external environment, its potential and trends, and its place among other organizations. The impact of both external and internal factors on the enterprise is diverse. An analysis of the environment gives the company the ability to minimize the dangers and negative effects that it encounters during its operation. Analysis of the internal environment allows company to identify the strengths and weaknesses of the enterprise and outline the prospects for its development. The following specialists were selected as experts: personnel policy specialists, marketers of the public relations department, economists of the economic and analytical department, legal advisers, leading aviation specialists and employees of the Ministry of Infrastructure of Ukraine.

Insufficient state support is a major factor among the political factors. There is no basic state policy for Ukrainian airlines in a difficult competitive environment. The weak point is also a discrepancy legislation of Ukraine in the field of air transport to international and European standards, including the International Civil Aviation Organization (ICAO), the European Union, the European Civil Aviation Conference (ECAC), and the European Organization for the Safety of Air Navigation (EUROCONTROL). Gradual displacement of a domestic air carrier to foreigners is due to weak state regulation of competition in the aviation market.

In sum, it can be argued that the “open sky” policy, increased competition and ownership change have the most significant effect on organizational and economic changes.

Expansion of the presence of foreign airlines in the market significantly affects the competitive situation. The union of Ukrainian airlines is one of the options for strengthening the position of Ukrainian civil aviation, another option may be an alliance with major foreign airlines.

It should be noted that the leading domestic air carriers do not meet the modern requirements of the world aviation community, which results in the low competitiveness of our airlines in the air transportation market in Ukraine and in the world. However, the achievement of high requirements is possible only with the gradual harmonization of Ukrainian legislation with the international, implementation and application of international aviation standards in Ukraine.

8. Reference

RUMOBL – PUBLIC TRANSPORT SOLUTIONS IN SPARSELY POPULATED REGIONS

Ing. Martin Stach (stach@jikord.cz), Ing. Zuzana Jelinková, Ph. D. (rumobil@jikord.cz), JIKORD, Czechia, M.Sc. Dana Sitárová, PhD. (dasi@fstav.uniza.sk), Faculty of Civil Engineering – University of Zilina, Slovakia. Ing. Jiří Čejka, Ph. D. The Institute of Technology and Business in České Budějovice (cejka@mail.vstecb.cz), Czechia.

Abstract: Demographic change is one of main problems in the rural areas of the Central Europe region. Young and active people are moving to bigger towns and cities due to the lack of attractive opportunities and older and less educated people usually remain at the countryside. To attract economically active group of people to rural areas, appropriate public services must be offered there. Public transport offer is of high importance, since its high quality can improve quality of life, better reachability and can also attract more tourists. To attract economically active group of people to rural areas, appropriate public services must be offered there. Public transport offer is of high importance, since its high quality can improve quality of life, better reachability and can also attract more tourists. To attract economically active group of people to rural areas, appropriate public services must be offered there. Public transport offer is of high importance, since its high quality can improve quality of life, better reachability and can also attract more tourists.

KEYWORDS: RURAL AREAS, PILOT PROJECT, DEMOGRAPHIC CHANGE, PUBLIC TRANSPORT.

1 Introduction

RUMOBL is based on transnational cooperation between public authorities and their transport entities who are confronted with a similar challenge to respond to pressures on regional public transport systems caused by demographic change in peripheral areas. Working together in RUMOBL, provide them a platform to exchange their knowledge, to generate learning through launching pilot applications of state-of-the-art tools and solutions and revise their regional transport policies to better suit changing mobility needs. Main outputs of RUMOBL are therefore pilot actions, the elaboration of a RUMOBL Strategy and policy-decisions to implement it in the eight partner regions through an improvement of their transport plans. Pilot actions have allowed testing a number of innovative applications during a period of years 2017-2018, how sparsely populated peripheral areas can be better linked to a primary, secondary or tertiary transport node (access to European and national passenger transport networks). The transnational RUMOBL Strategy indicates to CE regions innovative and transferable public transport approaches - based on jointly analyzed good practices, the combined knowledge of the partners and involved stakeholders, learning from the pilots, and fresh ideas put forward through a transnational social media-based competition. All outcomes are jointly assessed in site-visits, transnational workshops and a coordinated evaluation under the hospices of research institutions participating in RUMOBL.

2 Demographic changes

The substantial problem in rural regions within Europe is demographic change and its repercussion to a population. In many regions, there is a displacement especially of the younger generation migrating to cities. Some areas were also affected by the violent removal of the indigenous population, for example, from the borderland of the Czech Republic, where, after the World War Second, many people, especially Sudeten German, were deported to Germany. Nowadays, these regions are not so popular for living especially among young families, who are leaving this area. Good quality of public services including transport ones could stop this trend, and the number of inhabitants in rural areas could increase.

3 Contributions of JIKORD to the RUMOBL project

JIKORD (South Bohemian coordinator of public transport), an organization established by the South Bohemian Region, is responsible for planning regional transport (bus and rail in public service obligation) operation and expansion of the integrated transport system, and preparation of tenders for the provision of public transport. JIKORD, has implemented pilot action in the low density populated rural area of South Bohemia. Pilot action of JIKORD is introducing bus line, which connects rural region around Kaplice village, with the main TEN-T line of international express trains Praha – Linz, or semi-fast trains České Budějovice – Linz, which have stop in Kaplice railway station. People got fast and comfortable connection with regional capital, city of České Budějovice and interchange possibilities to long-distance and regional trains in České Budějovice to other destinations. Second benefit of this bus line is enhancement of tourism. New connection leads through an attractive tourist area with possibility to visit old castle ruins, or to hike in hills – Šlepičí hory.

4 Pilot projects of the other partners

Focus of the all pilots is on innovative approaches and modern public transport solutions. These started to be tested in the participating partner regions through experimentations since spring 2017. Eight different measures have been implemented. Pilots concern three main objectives:

1) introducing new transport services (buses, microbuses and trains in rural areas),
2) developing IT applications for passengers and transport operating companies,
3) renovating/modernization of transport infrastructure for passengers at transport terminals/stops.
Ministry of Regional Development and Transport of Saxony-Anhalt – MLV (Lead partner)

Pilot project of lead partner is introducing a new bus service to connect towns of Osterburg and Möser and their surroundings operated by volunteering drivers driving a local microbus in their free time. The concept of the project consists of deploying buses for 8 people (optimum size for sparsely populated areas). Drivers are organized in an association and their voluntary work is supported and framed by local PT operators and regional authorities. Residents who are not able to use conventional forms of transport or do not have access to them can stay independent and active in their local communities. In this manner the project raises the residents’ awareness for local public transport offers and encourage them to participate in it. The concept will be tested for 1.5 year.

HŽ putnički prijevoz d.o.o. - Croatian railways

New thematic trains, connecting Croatian capital, City of Zagreb and rural region Ozajl, were introduced by Croatian railways. The principle is to introduce tourist trains on the main line to the city of Karlovac, alongside the regional and underserved rail line to the town of Ozajl, especially on weekends and public holidays. Each ride is promoted and is always associated with another program (such as a tour of the castle, city festivals, or local events). Trains within the RUMOBIL project offer fast connections from the capital, support tourism and regional development and economy. Thanks to a good information campaign, the region is more frequently visited and visitors are using public transport instead of car.

Vysočina Region

The ambition of Vysočina Region was introducing new bus service, especially in the weekends, connecting rural areas with bigger towns in the regions and tourist destinations, as a castle of Lipnice nad Sázavou.

Mazowieckie voivodeship

Polish region, Mazowieckie voivodeship equipped regional trains with GPS sets providing real time information on location and delay of regional trains. The mobile application was developed, enabling to get information about train operation. Also digital interactive kiosks were introduced on the stations.

Modena Region

Public transport service Prontobus is operated in the town of Castelfranco Emilia and its surroundings. It is based on dial-a-ride transport with no fixed lines. Operating of such a system is usually complicated. To simplify it the new software system was developed consisting of:

- web portal (www.rumobil-modena.eu) for the users of the Prontobus service with information about the service and the situation of reservations updated in real time with the possibility to register in order to receive mails or SMS about interesting services recognized for the day after;
- web site dedicated to the management of reservations for the call center;
- app for users of the Prontobus service to view reservations updated in real time and with the ability to book an existing trips directly from the app;
- app for drivers of the Prontobus service to get information about reservation in real time and the trips to be made.

The increase of travelers registered after the activation of the RUMOBIL project was significant and exceeded expectations providing valuable information to be used for the definition of the RUMOBIL strategy (Fig. 1).

Positive feedback came also from the primary stakeholder, the users of the Prontobus service, that in contacts with call center reported appreciation in particular for having real-time reservations available. Another good result is for the call center that has improved the management of reservations. Through a reporting tool it is now possible to elaborate detailed statistics that was not available before. This information is indispensable in order to be able to intervene in the services for a better tuning in future. The drivers also expressed satisfaction, as they now receive the information faster and safely and are no longer distracted from driving by the calls received from the call center if there are any changes to the bookings.

Hungarian towns of Nagykálló and Nyíregyháza and Žilina region in Slovakia have started modernisation of bus stops and rebuilding and intermodal rural transport hub. Main benefit of these projects is better information for passengers in real time, more comfort at waiting area, support of inter-modality and better access to disabled people.

5 Conclusions

All pilot projects have ambitions to support public transport in the rural areas. The pilot projects are still in operation and final evaluation will be done in the second half of the year 2018. First outputs show, that pilot projects are successful and can be replicated in other European rural regions. For more information visit http://www.interreg-central.eu/Content.Node/rumobil.html.

Acknowledgement

This paper is published within the implementation of the project RUMOBIL, co-funded by European Regional Development Fund under Interreg CENTRAL EUROPE (Contract No: CE55).
Abstract: The competition between operators in the public tender in ordering process of train paths in long-distance rail passenger transport is very significant. The partial liberalisation of the rail market in the European Union was already underway in 2010, when all European railway companies with the necessary licenses and safety certificates gained access to railway infrastructure in all Member States. One of the current objectives of the common transport policy laid down in The fourth railway package is to open up the market for national rail passenger services in all Member States from 2019. In 2009, the EU Regulation No. 1370/2007 came into force, which sets out the selection procedures for the award of contracts in public rail transport. There are two forms of contracts for transport services in the public interest, either by tendering the competition for traffic performance, or by directly entering the selected railway company. The aim of this article is to analyse steps of the Slovak government in the first public tenders to provide subsidized transport of a selected line and to determine conditions for this tender. This is a significant moment in the railway market in the Slovak Republic, preparing the opening up of the market for domestic long-distance passenger rail transport.

Keywords: PUBLIC PERFORMANCE, LIBERALIZATION, RAILWAY PASSENGER TRANSPORT, PUBLIC TENDER, COSTS

1. Introduction

The partial liberalisation of the rail market in the European Union (EU) was already underway in 2010, when all European railway companies with the necessary licences and safety certificates gained access to railway infrastructure in all Member States. One of the current objectives of the common transport policy laid down in The fourth railway package is to open up the market for national rail passenger services in all Member States from 2019, while making public tenders for transport service contracts compulsory, in the public interest.

A fundamental step in the liberalisation of the rail freight market has been the separation of railway infrastructure managers from railway companies and consequently providing non-discriminatory access to railway infrastructure to the railway companies in all Member States. [1]

The biggest problem in the opening up of domestic passenger transport is that the tracks upon which traffic is controlled is also subsidised by the State, because it is impossible to create a natural competitive market. The situation has improved because of the impact of European reforms, although the operation of these lines remains costly, so it is not possible to create transparent competition. For this reason, the State continues to control and subsidise traffic performance but the possibility of public competition to secure operations on selected routes followed by their state subsidies is increasingly coming to the fore. [2]

In 2009, the European Parliament and Council Regulation EC No. 1370/2007 came into force, which sets out the selection procedures for the award of contracts in public rail transport. The Slovak Republic’s Ministry of Transport and Regional Development (MTRD) contracted with the best railway company operating rail services (Železničná spoločnosť Slovensko, a.s., The Railway Company Slovakia Inc., or ZSSK) to carry out transport services in the public interest for a period of nine years (2011 to 2020). This contract also includes operations in regional transport, which are agreed together with operations in long-distance transport. [2]

1. The opening up of the market for domestic passenger rail transport services in the Slovak Republic

There are two railway companies with which the State has concluded contracts for transport services in the public interest for domestic passenger transport in the Slovak Republic: ZSSK and the private railway company, RegioJet, Inc. At present, there are two options of providing transport services in the Slovak Republic. The first is when a railway company provides transport services at its own business risk and this principle is applied to lines with sufficient capacity and performance, where there is less risk of potential financial loss to the company. Currently this type of provision of transport service is used by RegioJet Intercity on the Bratislava to Košice line. The second type is when a railway company provides transport services in the public interest. [3]

In January 2012, there was a change on the Bratislava to Košice line because of a sufficient number of services and passenger traffic flows. ZSSK started to operate its Intercity trains as commercial trains from a contract on traffic performance in the public interest. For these trains, there is a separate tariff policy, they are not subsidised by the State and the railway company operates at its own business risk. In December 2014, RegioJet started providing the same transport services on the same line, with the result that ZSSK stopped operating its InterCity trains in January 2016. In December 2016, ZSSK starts again to again to operate the InterCity trains.

2. Call for public tenders in railway transport in the Slovak Republic

There are two forms of contracts for transport services in the public interest, either by tendering the competition for traffic performance following the end of a contract, or by directly entering the selected railway company. A contract for transport services in the public interest by direct assignment to a railway company was realised on the Bratislava to Komarno line. MTRD carried out a tender and awarded the transport service to a specific railway company, RegioJet. The contract was agreed in December 2010 for a period of nine years from March 2012 to December 2020 and the contracted transport performance was stipulated at 1.3 million train kilometres. [4]
The analysis by MTRD showed that, after RegioJet took on the railway passenger transport March 2012, there was visibly increased train traffic on this track (from Dunajska Streda to Bratislava) there is a one-hour period during the day, and half an hour period during peak time), and as a result there is a significant increase in transport performance. Year on year, in the period October 2012 to October 2013, there was an increase of 74% in train kilometres, 146% in passenger kilometres, and 115% in the number of passengers of. It was also noted that there was a reduction in the cost per train kilometre of 5.7€, which represents a cost reduction of 16% when compared with a national carrier. [6]

In September 2015, the first competition for subsidised services in the public interest started, when advance notice of invitation to tender for the long-distance Bratislava to Banská Bystrica line was published and, in November, the tender was declared without publication of the estimated value of services. The price of the services, however, is estimated at over 10 million euros. The deadline for this competition was January 2016 and eight candidates enrolled. As at November 2016, the competition had not yet been evaluated. [7]

3. Characteristic of the long-distance Bratislava to Banská Bystrica line

During 2015, MTRD began to take steps towards the liberalisation of the long-distance domestic rail passenger service on the Bratislava to Banská Bystrica line, which opened up the market for domestic passenger services to a new railway company. The Bratislava to Banská Bystrica line was chosen because of the provision of sufficient transport performance and passenger flows. The liberalisation process of the Bratislava to Banská Bystrica line is still ongoing, and has entered competitive conditions and criteria stage, although the tender had yet to be concluded in 2015. [5]

The object of the competition was to ensure safe, effective and quality transport services to passengers between the cities of Bratislava and Banská Bystrica by long-distance trains. The contract for transport services in the public interest will be concluded with an eventual candidate under the Act of Railroad No. 514/2009. Annual transport performance is expected to be in the range of about 1.5 million train kilometres and the extent of transport operations for the year will be specified by a special addition to the contract. For realised traffic performance, the State will reimburse verifiable losses to the railway companies. In 2016, the extent of total transport performance at ZSSK represented 31,304 million train kilometres, thus the competitive amount represents 4.79% of train kilometres operated by ZSSK. [4]

The Ministry declared that one of the objectives of the competition was to generate the most favourable economic conditions for both the State and the passenger, while ensuring the operation of services achieved the required quality. The State currently reimburses around 6.7€ per train kilometre to ZSSK. Provisionally in this contest it envisaged the inclusion of eight pairs of express trains, which runs daily, and two pairs of extra trains running on Friday and Sunday.[8,9]

The new 2016/17 timetable on the Bratislava to Banská Bystrica line operates nine direct express trains, including eight trains in a two-hour period during the day. Also in the opposite direction there are nine direct express trains, including three trains in the morning one-hour period and the remaining six trains in a two-hour period. The transport has a length of 230 kilometres, achieved travel time is three hours 24 minutes and the average cruising speed is 67.6 kilometres per hour.

4. Proposal for ensuring rail passenger transport on Bratislava - Banská Bystrica line

When creation proposal of long-distance rail passenger transport of Bratislava – Banská Bystrica line we take into account the conditions, which were set out in the Notice of public tender announced by the MTRD. The total extent of the services is defined as the minimum level. To fulfill the object of the contract it is required at least 7 trains or train units with a minimum capacity of 530 seats for each train or train unit. It is also required the creation of at least one operational reserve (one train or train unit). For ensuring long-distance transport on the Bratislava - Banská Bystrica line was selected the bi-current locomotive type 363. This locomotive has four axles, a box shape and it’s design speed is 140 kilometres per hour. It is designed for trains on electrified lines, where the electricity supply system is changing. To ensure rail passenger transport in required quality services, they were also selected second class carriages (Bmpe type) for passengers. These wagons are intended for long-distance transport and designed to meet the requirements of international transport and interoperability. Bmpe carriage has open-space interior and the automatic sliding entrance doors, which speed up passengers boarding. [5]

5. Calculation of total costs when ensuring rail passenger transport on the Bratislava – Banská Bystrica line

Calculation of total costs, which may be incurred when providing passenger rail transport at the selected relation, is based on the average costs calculated per year.

Railway infrastructure costs

When calculation railway infrastructure costs, it is needed to find out the gross train weight according to the formula (1):

\[ Q = Q_2 + Q_{lo} + n_{m} \times 0.08 [t] \] (1)

where \( Q \) is gross train weight [t], \( Q_{lo} \) is locomotive weight [t], \( Q_{m} \) is carriages weight, \( n_{m} \) is number of seats available and then the gross train weight calculation is:

\[ Q = (87 + 7 \ast 43 + 7 \ast 76) \ast 0.08 = 430.56 \approx 431 \text{ t} \]

Railway infrastructure costs are calculated according to the Decree of the Railway Regulatory Authority No. 3/2010 setting the charges for the access to railway infrastructure. These costs include charge for the minimal access package and charge for the access to the service devices. There are six line categories in the Decree, and because of this, lines have to be divided into categories. There is the first category line Bratislava Palarikovo with its length 81 kilometres and the second category line Palarikovo – Banská Bystrica with its length 149 km.

First, it is needed to calculate charge for the minimal access package, according to the formula:

\[ U_{tp} = U_1 + U_2 + U_3 \] (2)

where \( U_1 \) is charge for ordering and allocation of the capacity, \( U_2 \) is charge for the management and organisation of traffic, \( U_3 \) is charge for ensuring the infrastructure serviceability. Second, there is needed the calculation of charge for the access to the service devices, following the formula:

\[ U_{tp} = U_{tp1} + U_{tp2} \] (3)

where \( U_{tp1} \) is charge for using of electrical supply device and \( U_{tp2} \) is charge for using railway stations. Charges for the access to railway infrastructure according to track category are shown in the Table 1.

Table 1: Charges for the access to the railway infrastructure

<table>
<thead>
<tr>
<th>Track section</th>
<th>U_1</th>
<th>U_2</th>
<th>U_3</th>
<th>U_{tp1}</th>
<th>U_{tp2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bratislava - Palarikovo</td>
<td>1.6767</td>
<td>77.598</td>
<td>45.76832</td>
<td>25.774</td>
<td>25.929</td>
</tr>
<tr>
<td>2. Palarikovo - B. Bystrica</td>
<td>2.831</td>
<td>131.269</td>
<td>80.98016</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: authors
Total charges for the access to railway infrastructure is 391.826 € per one train and 2 823 754.71 € per one train per one year.

Costs of rolling stocks

It was not possible to determine an exact rent of rolling stocks (because of trade secret) then the rent was based on acquisition cost of locomotive and carriages. Rental price was set at 60 € per hour per locomotive and 27 € per hour per carriage. In proposal, there is one locomotive and seven carriages to ensure the condition of 530 seats available in each train. The cost of the carriages and locomotive are both calculated by the following formula [6]:

\[ N_{VR} = P_{V,R} \times n_{VR} \times t \times I_{VR} [€/year] \]  

(4)

where \( N_{VR} \) are total rolling stock costs, \( P_{V,R} \) is rent for locomotive/carriages, \( n_{VR} \) is number of days per day, \( t \) is hours per day, \( I_{VR} \) is the number of locomotives/carriages in all trains. Then the calculation of locomotive costs is:

\[ N_{L} = 60 \times 365 \times 24 \times 8 = 4 204 800 € \]

\[ N_{F} = 27 \times 365 \times 24 \times 56 = 13 245 120 € \]

The total rolling stock costs (for locomotives and for carriages together) are 17 449 920 € per one year.

Costs of locomotive and train crews

Costs of locomotive and train crews are calculated by using the gross wage of train drivers and conductors. The high of gross wage is based on analysis of the costs of operating the trains on the relation Bratislava – Komarno. These data were recalculated by index. The gross wage is set on 920 € for the train drivers and 750 € for the conductors. Indirect costs for train drivers is set 500 € and 300 € for the conductors. When formation the working turn for employees, the number of train drives was set on 22 people and the number of conductors was set on 88 people. Employer’s contributions are at 35.2 % of gross wages. Costs of locomotive and train crews are calculated by the following formula:

\[ N_{LC/TC} = P_{LC/TC} \times (CCP + N_{n}) \times I_{TF} [€] \]  

(5)

where \( N_{n} \) are costs of train drivers/conductors, \( P_{LC/TC} \) is the number of train drivers/conductors, \( CCP \) is the total labour cost (gross wage + employer’s contributions) and \( N_{n} \) are indirect costs of train drivers/conductors. Then the final calculations of locomotive and train crews are:

\[ N_{LC} = 22 \times (1311794 + 500) \times (1 + \frac{1181}{100}) = 44 526 € \]

\[ N_{TC} = 88 \times (1014 + 300) \times (1 + \frac{1181}{100}) = 128 733.1 € \]

Total costs of all locomotive crews are 512 534.11 € per year and for locomotive crews are 1 544 797.27 € per year.

Costs of energy

\[ N_{E} = \frac{1}{1000} \times Q \times L \times m_{e} \times S_{e} [€] \]  

(6)

where \( Q \) is total gross weight of train, \( L \) is the length of crossing electrified tracks, \( m_{e} \) is energy consumption for specific type of locomotive and \( S_{e} \) is rate of energy (price for 1 kWh of electricity). Then the calculation costs of energy are:

\[ N_{E} = \frac{1}{1000} \times 431 \times 230 \times 25 \times 0.15 = 371.7 €/per \text{ one train} \]

Energy consumption for the locomotive type 363 is 25kWh/1000 hrtkm according to the Study of the Transport research centre in the Czech Republic. Total costs of energy are 2 678 527.08 € per year.

Total costs

Total costs are comprised of direct and indirect costs. Direct costs are calculated above, it means the summation of railway infrastructure costs, costs of rolling stocks, costs of locomotive and train crews and costs of energy. Indirect costs include costs of the tickets selling, costs of services for passengers in railway stations, insurance costs etc. and comprise 20 % of direct costs. The high of direct and indirect costs is shown in the Table 2.

| Source: authors |

Table 2: Calculation of total costs

<table>
<thead>
<tr>
<th>Total costs [€/year]</th>
<th>Direct costs 25 019 133.16</th>
<th>Indirect costs 6 254 783.29</th>
<th>Total costs 31 273 916.45</th>
</tr>
</thead>
</table>

Revenues

The high of revenues was determined based on the current occupancy of all connections on the relation Bratislava – Banska Bystrica last year. The occupation is divided into three track sections on this relation (Bratislava – Sala, Sala – Levice, Levice – Banska Bystrica). There are two tables for occupancy because of considerably different number of passengers during the peak and off-peak hours. The occupation, which we consider when calculating average revenues, was decreased of the number of passengers using complimentary transport. It was considered the average rate 0.066 € per one kilometre when calculating the revenues. The occupancies (with and without the complimentary transport passengers) and revenues during the peak and off-peak hours on selected track section are shown in the Table 3 and the Table 4. Then total average revenues for all trains on the Bratislava – Banska Bystrica line according to current occupancy are 17 205 828.34 € per one year.

| Source: authors according to [6] |

Table 3: Revenues during the peak hours

<table>
<thead>
<tr>
<th>Track section</th>
<th>Occupancy [%]</th>
<th>Occupancy by paying passengers [%]</th>
<th>Distance [km]</th>
<th>Revenues for one train [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bratislava – Sala 95 54.15 60 1 085.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sala – Levice 65 37.05 72 891.49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levice – B. Bystrica 50 28.50 98 933.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Bystrica – Levice 60 34.20 98 1 121.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levice – Sala 70 39.90 72 960.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sala – Bratislava 85 48.45 60 971.50</td>
<td></td>
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</tbody>
</table>

| Source: authors according to [6] |

Table 4: Revenues during the off-peak hours

<table>
<thead>
<tr>
<th>Track section</th>
<th>Occupancy [%]</th>
<th>Occupancy by paying passengers [%]</th>
<th>Distance [km]</th>
<th>Revenue s for one train [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bratislava – Sala 40 22.80 60 457.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sala – Levice 35 19.95 72 480.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levice – B. Bystrica 45 25.65 98 840.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Bystrica – Levice 30 17.10 98 560.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levice – Sala 45 34.20 72 617.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sala – Bratislava 60 48.45 60 685.76</td>
<td></td>
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</tbody>
</table>

The difference between revenues and costs is shown in the Table 5. The amount of compensation for provided services on the Bratislava - Banska Bystrica line ranges from 13.8 to 16.3 million € per year by available information.
Table 5: Revenues and costs

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenues</td>
<td>18 278 923.22 €</td>
<td></td>
</tr>
<tr>
<td>Direct costs</td>
<td>25 019 133.16 €</td>
<td></td>
</tr>
<tr>
<td>Indirect costs</td>
<td>6 254 783.29 €</td>
<td></td>
</tr>
<tr>
<td>Total costs</td>
<td>31 273 916.45 €</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>-12 994 993.23 €</td>
<td></td>
</tr>
</tbody>
</table>

Source: authors

There will be new modern and well equipped trains or train units on selected line, which will provide good conditions for passengers while travelling and also ensure the higher quality and comfort ability [10]. New selected railway undertaking has to ensure more train connections (in both directions), what will probably increase the number of passengers. Based on this, there are expected higher revenues about 10 % in future. Increasing of revenues will reduce the amount of compensation of economically justified costs.

6. Conclusion

Nowadays it is expected arrival of a new railway undertaking that will provide its transport services on selected line. Therefore, it is important to design appropriate solutions that would be beneficial not only for new provider of transport services, but also for all the travelling public. This is a significant moment in the railway market in the Slovak Republic, preparing the opening up of the market for domestic long-distance passenger rail transport for competition in the provision of transport services in the public interest. This is a comprehensive process that achieves the desired effect only if it is well prepared. The priority, from the perspective of the passenger, is transit time and it should be noted that the line for competition already has a significant competitor in the form of road traffic, with the completion of the highway R1, where travel time is two hours and 50 minutes by bus and two hours and five minutes by car.

Acknowledgement

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References

1. Introduction

The task of quality standards for services in the regional rail passenger transport are intended to establish a uniform level of provided services, while drawing inspiration from EN 13816. The quality standards have to be set according to the strategic needs of passengers, so that they can be set as a basis of a contract with a customer to a minimum uniform level of quality of service provided. Measuring and evaluating the quality of services in regional passenger rail transport also need to be compared in relation to other modes of public transport. It is necessary to know the perception of quality services as well its value for the client (passenger). Consequently it is needed to set a permanent process of quality evaluation provided services. Important is the view on the quality of evaluation provided services. Important is the view on the quality of provided services in passenger transport by the subject under the transport market. The role of public authorities is regulation given the impact of the transport process on the society and environment. The main aim of clients public services is established on a mutually intertwined and customer quality and sufficiently simple comprehensive public transport system while minimizing financial claims. The intention of the public passenger transport is to build a competitive system to motorized individual transport. On the support of these aims it is necessary to establish new methodology on the definition of quality requirements in the regional rail passenger transport. This methodology currently does not exist.

2. The proposal of methodology for rating quality standards

The basic principle of policy quality of services in regional passenger transport is to satisfy the customer's requirements, therefore, focus on compliance with the established quality standards. The role of the order body of the transport services is to ensure optimal transport accessibility of regions with the effective use of resources and to implement the principles of transport policy. The task of the coordinator undertake to fulfil the requirements of standard EN ISO 9001: 2009 and STN EN 13816. Based on the above coordinator shall establish and maintain a quality management system. Next is necessary to apply the principles of improvement of all processes affecting the quality of services provided in public passenger transport. The effective providing of quality services requires introducing control processes for the any activity, which affects the fulfillment of customer requirements.

The task of the provider of the service is to ensure all activities associated with the provision of transport services in the appropriate quality to meet all established standards of service quality. The carrier (railway undertaking) must ensure the safe, convenient, fast and affordable transport for passenger (customer) at a maximum fulfillment of their requirements. Railway undertaking (carrier) must provide the services for passengers in accordance with approved quality standards at European level in order to retain existing customers potentially increase the demand for transport services. The carrier must also ensure the high quality standard of its staff and technical resources. The most valuable asset of the company is the professional qualifications and skill of staff. For this reason it is necessary to monitoring constantly the increasing proficiency as well career development of employees and in relation to the fulfillment of defined quality criteria relating to staff and their approach to customers.

The proposed methodology is based on premise to provide the maximum value for customers. Realisation of transport services is the responsibility of the carrier. Ensuring transport service is public service that must satisfy the transport needs of the population in the region. The requirements of passenger (costumer) defines subject, which ordered transport performance. In the proposed methodology is rated the level of provided services in regional passenger transport that are ordered by transport body (state or region). This body is responsible for evaluating customer (passenger) requirements and coordinating transport performances.

Methodology integrates the solution for the evaluation of quality standards in regional passenger rail transport on two levels [1]:

- relationship between order body of transport services and carrier
- relationship between order body of transport services and customer (passenger)
- relationship between order body of transport services and infrastructure manager.

This relationship must be evaluated separately. For drawing up overall evaluation of quality standards in the regional rail passenger transport was designed a flowchart. This flowchart is on Figure 1.
As the first step to create the flowchart was necessary to define the core of the process. The next step was to define the roles of the process.

3. Evaluation services of rail carriers

Evaluation of service rail undertaking is based on quality standards setting and subsequent evaluation of its fulfilment.

Selection criteria of quality – search for measurable quality criteria, which will be part of the contractual obligation of the carrier in providing the ordered transport services. Especially are oriented on transport processes.

Incorporation quality criteria in the contract for the provision of transport services – implementation the defined quality standard that is measurable in the contract. Defining the standard must be accurate and must contain defined penalties. This activity includes the overall concept of the contractual relationship between the order body and carrier. It comes to the entire agreement and all its terms.

![Flowchart of Evaluation services of rail carriers](source: authors)

**Figure 1** The methodology of rating quality standards in the regional passenger rail transport
Periodical control of fulfillment the quality criteria, which are incorporated into contract - submitter checks at regular intervals compliance with agreed quality standard. Usually physical check shall be made in the form of "hidden buying" staff of submitter. The carrier has to tolerate control, which is also enshrined in the agreement. The carrier has duties making of traffic statistics, mainly statistic of selling travel tickets, passenger flows, the number of cancelled trains and compliance of timetable.

Level of services meets the requirements of the order body – the order body based to control submitter compares the level of provided services and according to the contract. In case the submitter find out failure to comply with the defined quality standards, can impose the carrier sanctions.

Submitter dissatisfaction: identified deficiencies can be sanctioned – order body shall examine, whether it is possible to penalize unfulfilled the quality standards. Deficiencies can be found based to control of order body or from the realized quality assessment based on customer survey.

Impose sanctions on carriers under to contract – submitter imposes sanctions based on identified deficiencies that can be sanctioned under the contract.

Request for correction of deficiencies – when is impossible to penalize identified deficiencies, order body invites carrier for remedial action to restore of quality standards provided services.

Extraordinary control of fulfilment of contractual criteria – order body shall realize a random controls that are oriented on the quality standards provided by railway undertaking.

4. Evaluation of passenger satisfaction

Evaluation of passenger satisfaction (customers) with provided transport services is based on the realization of regular traffic survey, which also includes quality assessment. This process implements the proposed steps according to the proposed methodology for measuring of provided quality services. The proposed methodology for examining the quality of the customer and determines the value of the transport service perceived transport users.

- Selection for criteria of quality – search for measurable criteria of quality, which are part of the quality assessment transport services. Is the most important step that allow to get perception of service quality and to determine customer expectations. It is realized by survey.

- Selection of the method quality assessment – choice of objective assessment methods (Saty’s method, benchmarking etc.). On these methods we can obtain concrete and objective results.

- Set the importance weights of criteria – setting the weights for proposed criteria by chosen approach.

- Evaluating the measurement of quality provided services – it is necessary put the accent on the methodically correct procedure when we evaluate measurement of quality provided services.

- Level of service meets the requirements of the order body – there is assessed perceived satisfaction and maximum value of customer satisfaction. There can be used approach of multi-criteria analysis. In case the quality level of provided services meets the customer's perspective, then is processed an comprehensive assessment. In case when customer is not satisfied with quality level of provided services, is need to check the finding dissatisfaction according to the concluded contract. Then carrier must make remedies for improve standards of quality.

- Identified deficiencies are incorporated in the contract with the carrier – after finding that the customer are dissatisfied with the criteria of quality standards the procedure continues as in the case of previous step. It is searching possibility how this deficiencies to penalise.

- Quality evaluation of transportation serviceability in region – task of this activity is quality evaluation of rail transport and its impact to transportation serviceability assessment of region. It is an activity of order body who responds to the transport needs of the population. The transport needs of the population come up from order body's surveys also from customer transport surveys.

- Selection criterion of quality – task of this activity is set quality criteria of rail transportation serviceability in selected region. Selection comes out from previous activities and from basis assessment results. Then are choosed a relevant quality standards, which are measurable.

- Quality standards processing of transportation serviceability of region – task of this activity is a concretization a detailed elaboration of quality standards processing in regional transport.

5. Comprehensive evaluation of the quality of provided services in regional transportation

Methodology of evaluation quality standards in regional rail passenger transport assesses from point of view of order body and at some time evaluates request for carrier and includes the evaluating the measurement of quality provided services. The generalized methodology is based on successive steps. Task of this methodology is searching measurable quality criteria.

Quality standards allow monitoring, evaluating and comparing single criteria of provided services. The evaluating the measurement of quality provided services brings to measures and help to continuously improve the quality services. Quality standards of regional rail passenger transport shall be binding for all railway undertakings that provide rail passenger services. Infrastructure manager must participate on fulfil the same standards. Update of quality standards should be implemented as a rule once a year, after consultation with all stakeholders.

Method of evaluating must respect requirements of multi-criteria background, for example if customers (passenger) demand from carrier fulfilment of a number of quality characteristics at once.

By providing the transport service is necessary to define service specifications, evaluation process and then regularly measure and control the process of providing services.

Part of the methods evaluation of quality must also be creating a rating scale. A rating scale gives the possibility to compare measured values and then reconsider quality of provided services.

[3]

Task of comprehensive evaluation is the harmonized assessment quality of services as from the customer's perspective as well as from the perspective submitter. Customer satisfaction is achieved if the level of quality of service provided meets the requirements of the customer and also corresponds to the required level of perceived quality from the customer's perspective. These facts could mean satisfied the submitter and cycle of evaluating should be end in that period.

In the event that the quality of provided services does not satisfy the requirements of the customer, it is necessary to take corrective measures to improve quality standards. It is necessary to repeat the evaluation process of quality services on the part of the carrier (railway undertaking).
The task of order body (coordinator of transport performances) as a key player in the assessment of quality standards, measuring the quality of services and control contract standards is to represent the interest of customers by providing the public transport services.

6. Conclusion

At present the offer of provided services in regional rail passenger transport oriented only on their ordering and financing. It represents the quantitative view. Quality of provided services is not monitoring and evaluating systematically. This fact causes inadequate quality level of provided services. The aim is creating of transport system with high quality of provided services. High quality of provided services not only fulfils the expectation of present customer, but could get new customer.

Quality standards of regional rail passenger transport are intended for one level of quality. These standards are based on European’s norms – concrete STN EN 13 816 and respects strategic requirements customers. Their direct applicability is possible in the submitter’s contract. Application of quality standards to praxes does mean makes a new subject – coordinator. Coordinator will be to work on the ordering performance in the public services. Than is necessary accept the new contract between the submitter, coordinator and provider of transport services (carrier).

Proposed methodology of quality assessment can be used for comparing integrated transport systems by the quality level. The methodology can be used also as a evaluating of provided services in the relationships submitter and supplier (railway undertakings, infrastructure manager). The methodology does not exactly define the role and mission submitter from coordinator of an integrated transport system – It perceives their same level.

The proposal of methodology full accept the transport policy of EU specifically the White paper 2011 - Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system, also quality norms and transportation operational programme in horizon 2020. These facts creating a space to meet the objective of promoting the development of public railway passenger transport by increasing its quality level.

Acknowledgement

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Literature

5. EN 13816 Transportation. Logistics and services. Public passenger transport. Definition, objectives and measurement of quality of service.
A PORT COMMUNITY SYSTEM OF GEORGIA AND ITS ROLE IN WORLD MARITIME TRANSPORT

СИСТЕМА ПОРТОВ ГРУЗИИ И ЕЕ РОЛЬ В МИРОВОМ МОРСКОМ СУДОХОДСТВЕ

Prof. Dr. Purtskhvanidze G., Assoc. Prof. Dr. Gvetadze V., Doctoral candidate Varshanidze A., Master Turmanidze T.
Akaki Tsereteli state University - Kutaisi, Georgia
E-mail: gia58-58@mail.ru, gvetadze57@mail.ru, bms164@mail.ru, teona.turmanidze@mail.ru

Abstract: Ports constitute one of the most important nodes of transport networks, and they represent the border control points and the freight handling points, the administrative service centers, place of the implementation of trade procedures, as well as the link connecting the land and maritime routes. The functioning of the international transport corridor depends to a large extent on the ports and maritime transport efficiency. Despite significant investments, the operations of port and ships are mostly non-standard, which hinders the development of the maritime transport sector. However, infrastructure is not the major obstacle to maritime transport development. National regulatory policy should be revised in keeping with the growing popularity of the concept of economic globalization and supply network. It is necessary to reform the relevant roles of the private sector and the State, where the latter is represented by state-owned companies and state monopolies.

KEYWORDS: TRANSPORT EFFICIENCY; ECONOMIC GLOBALIZATION; TRANSPORT CORRIDOR.

1. Introduction

The paper provides an overview of a port system of Georgia and its development opportunities and options.

Ports constitute one of the most important nodes of transport networks, and they represent the border control points and the freight handling points, the administrative service centers, place of the implementation of trade procedures, as well as the link connecting the land and maritime routes. The functioning of the international transport corridor depends to a large extent on the ports and maritime transport efficiency.

Despite significant investments, the operations of port and ships are mostly non-standard, which hinders the development of the maritime transport sector. However, infrastructure is not the major obstacle to maritime transport development. National regulatory policy should be revised in keeping with the growing popularity of the concept of economic globalization and supply network. It is necessary to reform the relevant roles of the private sector and the State, where the latter is represented by state-owned companies and state monopolies [1].

2. Preconditions and means for resolving the problem

Georgia is an integral part of the Eurasian transport corridor. The location of Georgia creates unique opportunities for socio-economic development: the seaside allows us for developing intensively sea transport, ports, the area of marine products – fishing, tourist and recreational infrastructure. Georgian ports terminal throughput is guaranteed by the current trade-economic and transport processes occurring across the enormous Eurasian land mass.

Georgia's port system comprises 2 ports of Poti and Batumi, as well as Supsa and Kulevi specialized oil terminals [2].

Poti and Batumi represent an intermodal gateway to the eastern coast of the Black Sea, from where the road goes west to the Black Sea, Turkey and Europe, and east to the Caucasus and Asia. Both ports serve regular ferry and container routes linked to other ports of the Black Sea and Mediterranean Sea.

Batumi port is a significant link in the Europe-Caucasus-Asia Transport Corridor, which originates in Europe and after crossing Bulgaria, Romania and Ukraine through the Black Sea, it ties the Caspian Sea region countries - Azerbaijan, Kazakhstan, Turkmenistan and so on.

The main competitors of Batumi port in the Black Sea region are: the ports of Odessa and Ilyichevsk in Ukraine, and Novorossiysk and Tuapse in Russia.

The advantage of Batumi port is that Ukraine's maritime territory freezes in the winter, and in the Russian ports, the strong winds are often blowing in the winter.

Batumi port has a container terminal and a harbor complex for servicing of ferries, as well as the dry cargo and passenger terminals. Figure 1 illustrates Batumi port scheme.
Container terminal throughput is 100,000 TEU per year. This terminal has the open storage spaces and load-carrying equipment, which are specialized in the handling of containers for the intended or storage purposes.

The ferry runs between Varna, Ilychevsky and Batumi harbors. The ferry system is completely automated. Nominal annual throughput of terminal is approximately 700,000 tons.

Dry cargo terminal provides servicing of large and small ships. It is specialized in handling of scrap metal (intended or storage purposes), bulk, liquid, general and breakbulk cargo. Dry cargo terminal’s maximum throughput is 2.0 million tons per year.

The passenger terminal is located in the center of Batumi, along the coastal boulevard. The terminal's throughput is approximately 180,000 passengers per year. The passenger harbors provide servicing of passenger ships and the Ro-Ro type passenger-cargo ferries.

The main factor for the development of port was and remains the Caspian Sea oil. The Batumi Oil Terminal offers its customers the services for transportation of oil and oil products from Kazakhstan, Azerbaijan, Turkmenistan, Georgia and other countries.

The total area of the terminal is about 90 hectares, where five tank parks and oil discharging complexes. The main advantage of the oil terminal is the convenience of storage and transportation of various types of oil and oil products. The terminal transport up to 22 types of oil and oil products. Oil is supplied to Batumi Oil Terminal via Georgian Railway, by railroad tank cars, unloading of which is carried out at the modern railway overpasses.

The oil terminal’s throughput is up to 15 million tons per year. The terminal is specialized in handling of crude oil and practically all types of oil products - diesel fuel, petrol, heating oil, etc.

Poti Port is a connecting link for cargo transportation from Turkey, Middle East and Europe to Central Asia countries and Afghanistan. Figure 2 illustrates the cargo harbors of Poti port.

Fig. 1. Batumi port scheme
Poti Port carries out the carriage in three main directions:
- the carriage from the border strip adjacent to Azerbaijan and Russia – Samur-Yalama;
- the carriage to Turkmenistan, Afghanistan, Tajikistan and Uzbekistan by a ferry Baku-Turkmenbashi;
- the carriage to Kazakhstan, Uzbekistan and Kyrgyzstan by a ferry Baku-Aktau.

The continuous delays in the ferries Baku-Turkmenistan and Baku-Aktau, as well as in the border zones adjacent to Afghanistan (in the direction of Serhetabat-Turgundi and Galaba-Khairaton) significantly increases transit time from the port of Poti.

Kulevi Oil Terminal

The Kulevi LLC "Black Sea Terminal" construction began in 2000, and it was opened on May 16, 2008. The terminal's throughput is up to 10 million tonnes of oil products per year, including: 3 million tons of oil, 3 million tons of diesel and 4 million tons of heating oil. The overall storage capacity of the tank park is 320 thousand cubic meters, with the prospect of increase up to 380 thousand tons. There are two berths in the terminal for discharging oil products, which provide servicing of tankers with tonnage up to 100 thousand tons. Hourly loading performance is from 1000 to 8000 cubic meters per hour. The object has its own port-approach railway station, where 180 oil tank cars can be placed simultaneously waiting for discharging. The railway overpasses allow for discharging 168 oil tank cars simultaneously.

Supsa Marine Terminal

The Supsa Marine Terminal, the last point of the Baku-Supsa pipeline, was opened on April 17, 1999, in a Supsa Village. The terminal has 4 tanks, with tonnage of 40000 tons each. The quantity of cargo handled in 2015 was 4.2 million tons. Annual throughput is 7 million tonnes.

In the first seven months of 2017, Georgia's ports and the marine terminals handled 9.6 million tonnes of cargo, which was 3% less than in the previous year.

The absence of a deep-water port is considered to be one of the weaknesses of the transport corridor connecting Europe and Asia. Large ships cannot enter the ports of Poti and Batumi. Chartering of small-size ships costs almost the same amount as servicing of a much larger ship. This increases the cargo owner's costs of shipping, and consequently, this somewhat devalues the positive side of a physically shorter route.

As a result of the analysis, it has been established that the possibility of servicing of large ships in the case of the existence of a deep-water port will reduce shipping costs by about $160 per container.

Realizing this need, on December 24, 2017, there was started the construction of the Anaklia's deep-water sea port, which is being implemented by the Anaklia Development Consortium [3]. The Consortium comprises the "TBC Holding" and the American Investment Holding "Conti International", which implements infrastructure and construction projects. The contractors of the Anaklia Development Consortium are also the well-known sea-port design company "Moffatt & Nichol" and Dutch consulting company "Maritime & Transport Business Solutions", which is specialized in the issues of port transactions. Figure 3 illustrates Anaklia port scheme.
In the longer term, the port is expected to reach 100 million tons of throughput, but at the first stage it is planned to construct three phases are planned. The first 3 phases should be constructed within 12 years. For the first three years, the port’s throughput will be 7 million tonnes, and by the 12th year, it will reach 40 million tons of cargo.

3. Conclusion

The construction of the new ports in Georgia, as well as the development and expansion of the existing ones will result in the necessity of a new resettlement policy, which involves the creation of the new port settlements, and in some cases, the creation of new city or cities, terminals and technical service zones. If we continue in this direction, Georgia’s economy can be developed very quickly, moreover, in case of increasing cargo flows, we may need additional labor resources.

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THE NUMERICAL INVESTIGATION OF HIGH SPEED TRAIN-TUNNEL
INTERACTION AT ENTRANCE AND EXIT

Res.Assist. Ahmet Y.1, Res.Assist. Taner Ç.1, Prof. Dr. Nurten V.1
Yıldız Technical University, Turkey

Email: ahmety@yildiz.edu.tr, tcosgun@yildiz.edu.tr, vardar@yildiz.edu.tr

Abstract: In the study, the flow pattern due to the interaction between a high-speed train and the tunnel at the model scale was analyzed. Six different tunnel entry geometries were used variably for a single train speed. The most important issues as a condition of comfort in high speed trains are noise and vibration. In particular, flow-induced noise is triggered by pressure changes in the flow. For each geometry, the pressure changes at the tunnel entrance and at the tunnel exit are plotted with depending on time. As a result, the least amount of pressure change was found in the tunnel entrance model with openings in the side walls.

Keywords: COMPUTATIONAL FLUID DYNAMICS, HIGH SPEED TRAINS, OVERSET MESH, PRESSURE CHANGES

1. Introduction

In recent decades, with the increase of international economic activities, transportation have become an important issue all over the world. The amount of passengers and goods that can be carried in a single time and duration of transportation are critical parameters in economic transportation systems. For this reason, railway transportation is an important alternative by being faster than sea transport and having more load carrying capacity than airlines. Although the cargo capacities of the vehicles used in railway are high, as well as marine transport, the transportation time is not short enough. Thus, there is an increasing afford to speed up the vehicles on the sea and railway transport. However, the increase of the speed of vehicles causes some problems, which are mainly drag, noise and vibration. Especially in high speed rail systems, most of the energy wasted to overcome the drag of the air with the speed up of the vehicle. Besides, when the rail systems are considered, the vibration and the noise are important issues due to the interaction of vehicles with non-vehicle elements such as tunnels. This problems creates an undesirable environment considering the passenger comfort.

In the literature, it is possible to reach some studies examining this problem. Ogawa and Fujii [1] numerically studied the flow induced by a high-speed train moving in a tunnel using three-dimensional compressible Navier-Stokes equations. In time-dependent solutions, the focus is on the compression wave that causes the noise burst at the entrance and exit of the tunnel. The calculated pressure increments in the tunnel are compared with the measured data. It is stated that the compression wave in the tunnel depends on the tunnel position. Kwon et al. [2] studied the effect of the high-speed train nose geometry on explosion in their work and investigated. In this context, six different entrance concepts were determined and flow analyzes were made for each geometries. The results were analyzed in terms of pressure changes.

2. Mathematical Model

The equations that model the three-dimensional, incompressible, time-dependent turbulent flow around the high-speed train, which are Navier-Stokes equations, are given below. The k-epsilon turbulence model is used to model the turbulent behavior [5].

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0
\]

\[
\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla) \mathbf{u} = -\nabla p + \mu \nabla^2 \mathbf{u} + \frac{\rho}{
\mu}
\]

\[
\frac{\partial \rho k}{\partial t} + \nabla \cdot (\rho \mathbf{u} k) = \nabla \cdot \left[ \frac{\mu_t}{\epsilon} \nabla \mathbf{u} \right] + P_e - \rho f
\]

\[
\frac{\partial \rho \epsilon}{\partial t} + \nabla \cdot (\rho \mathbf{u} \epsilon) = \nabla \cdot \left[ \frac{\mu_t}{\epsilon} \nabla \mathbf{u} \right] + \frac{C_1}{C_2} P_e - \rho f - \rho \frac{\partial \epsilon}{\partial t}
\]

\[
\rho k \frac{\partial \mathbf{u}}{\partial t} + \rho \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla \rho + \frac{\mu_t}{\epsilon} \nabla^2 \mathbf{u} + \frac{C_1}{C_2} \rho \frac{\partial \epsilon}{\partial t}
\]

\[
\frac{\partial \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u} \mathbf{u}) = \nabla \cdot \left[ \frac{\mu_t}{\epsilon} \nabla \mathbf{u} \right] + P_e - \rho f
\]

3. Numerical Method

The model train and model tunnel cross-sections used in the numerical study are shown in Fig. 1 Model height \( H_{\text{train}} = 980 \) mm, width \( B_{\text{train}} = 900 \) mm and is length \( L_{\text{train}} = 16000 \) mm, model tunnel main dimensions are tunnel diameter \( D_{\text{tunnel}} = 1250 \) mm and tunnel length \( L_{\text{tunnel}} = 47900 \) mm. Scale factor is chosen 1/10.

The speed of the model train is taken as 3 m / s which is equal to the 108 km/h for full scale. Fig. 2 shows tunnel entrance geometry variations.
Fig. 2 Tunnel entrance geometry variations

Fig. 3 shows the solution grid for the domain used in the study. Solution domain is created by using unstructured hexahedral elements. As a result of solution grid dependency study, 1378300 grid elements were used in domain solution grid. Movement of the train is modeled with overset meshing technique. All computations are carried out via commercial code, CD ADAPCO Star-CCM+.

4. Results

Fig. 4 shows the time-dependent pressure measurement locations at the inlet and outlet of the tunnel.

The solution is completed with the voyage of the train, which is started from the outside of the tunnel, passing through it and going out of the tunnel again. The train's nose was entered the tunnel at the sixth second of the solution, while the tail was entered at the eleventh second. Besides, the nose and tail of the train was come out of the tunnel at the twentieth and twenty-fifth second of the solution, respectively. Fig. 5 shows the time-dependent pressure values for all geometries in the tunnel entrance section.

As can be shown in Fig. 5, the same pressure values are obtained for all geometries at the beginning of the movement at the outside the tunnel. When the train gets closer to the tunnel entrance, it is seen that the pressure values are varying for different entrance geometries. The lowest pressure change was obtained in the "Case 1", by considering the entrance of both the nose and the tail of the train. Besides that, when the entrance effects of the nose and tail regions of the train are compared, it is seen that the pressure variation is much higher in the tail zone. The maximum pressure variations were obtained in the "Case 6" geometry. Fig. 6 shows the time-dependent pressure values for all geometries in the tunnel exit section.

The tunnel exit pressure values are quite different from the tunnel entrance pressure values. A two-peaks curve is obtained at the outlet while an oscillatory pressure distribution is obtained at the inlet region. As mentioned before, at twentieth second, the train's nose region, and at twenty-fifth second, the tail region of the train came out from the tunnel. In contrast to the inlet zone, the minimum pressure variation is found in the "Case 5" geometry. However, it was observed that the maximum pressure change was obtained in the "Case 1" geometry.

5. Conclusion

Six different tunnel entrance geometries have been investigated in the study in order to investigate the high-speed train-tunnel interaction and to show the effect of different tunnel entrance geometries. The pressure values against time at entrance and exit of the tunnel are presented. When the results are examined, the lowest pressure variation for the tunnel entrance is obtained by the "Case 1" geometry, which has large openings on the top surface. On the other hand, the lowest pressure change for the tunnel exit is observed in the "Case 5" geometry, which is a parabolic nozzle. These sudden pressure variations may be explained by the aerodynamic structure formed by the movement of the train into a narrower area. When the optimal cases are considered, at the entrance of the tunnel, the high-pressured air in the nose region of the train is balanced by atmospheric air and the pressure change is reduced by the openings at the tunnel entrance. At tunnel exit, pressure variations are reduced, by the gradual movement of the high pressured air at the inside of the tunnel through the atmospheric pressure level, using the nozzle geometry.
6. References


LIQUID FUEL TEMPERATURE, PRESSURE AND INJECTION RATE INFLUENCE ON INJECTOR NOZZLE REYNOLDS NUMBER AND CONTRACTION COEFFICIENT

PhD. Mrzljak Vedran, Student Žarković Božica, Prof. PhD. Prpić-Oršić Jasna
Faculty of Engineering, University of Rijeka, Vukovarska 58, 51000 Rijeka, Croatia
E-mail: vedran.mrzljak@riteh.hr, bozica.zarkovic@gmail.com, jasna.prpic-orsic@riteh.hr

Abstract: The influences of liquid fuel temperature, pressure and injection rate on fuel contraction coefficient and Reynolds number during a fuel injection were investigated in this paper. Nozzle geometry parameters remained constant during the whole numerical analysis. Calculations were performed with a standard diesel fuel D2. Increase in liquid fuel temperature cause increase in fuel contraction coefficient. Fuel temperature increase resulted in a slight increase in contraction coefficient at low fuel pressures, while at high fuel pressures increase in fuel temperature causes significant increase in fuel contraction coefficient. Increase of fuel pressure resulted in a decrease in liquid fuel contraction coefficient, for every fuel injection rate and for every fuel temperature. Reynolds number increases with an increase in fuel temperature and also with an increase in fuel injection rate. The main goal of presented analysis is to be usable not only for one fuel injector and its nozzles, but for a large number of the fuel injectors and for many liquid fuels.

KEYWORDS: LIQUID FUEL, FUEL INJECTOR NOZZLE, CONTRACTION COEFFICIENT, REYNOLDS NUMBER

1. Introduction

In internal combustion engine fuel temperature, pressure and injection rate as well as the injector nozzle geometry strongly affect the fuel atomization process. A liquid fuel atomization process has a strong influence on the engine combustion process and on exhaust emissions. However, due to the small length and time scales during the fuel injection process, it is still a challenge to capture and explain the physics and influences behind those processes.

Internal nozzle flow influence on spray atomization along with fuel properties and injection rates was investigated by several authors in the past [1], [2]. Newer investigations about this topic is presented by Madero and Axelbaum [3] which was investigated fuel spray breakup and structure of spray flames for low-volatility wet fuels. Greenberg [4] investigated the impact of the initial droplet size distribution on the behavior of an edge flame. Nozzle configuration effects on internal flow and primary spray breakup for flash boiling fuel sprays was analyzed by Wu et al. [5] while Abianeh et al. [6] investigated the nozzle flow influence and characteristics on multi-component fuel spray evaporation process.

Experimental study on fuel spray characteristics under atmospheric and pressurized cross-flow conditions presented Guo et al. [7].

The impact of the injector nozzle geometry and fuel properties on fuel injection, fuel atomization and evaporation processes must be involved in any detail internal combustion engine simulation, as the one presented in [8] for a high speed direct injection turbocharged diesel engine. The same impact is inevitable in simulations of large marine two-stroke slow speed diesel engines [9].

2. Liquid fuel contraction coefficient

Liquid fuel contraction is liquid stream constriction which occurs because the fluid streamlines cannot abruptly change direction. For the fuel injector nozzle, the fluid streamlines are unable to closely follow the sharp angle in the nozzle wall. Maximum contraction is the place in a liquid fuel stream where the diameter of the stream is the lowest. The maximum contraction takes place slightly downstream of the fuel injector nozzle, Fig. 1.

According to Fig. 1, the liquid fuel contraction coefficient for the fuel injector nozzle is defined as a ratio of liquid fuel stream diameter at maximum contraction point and the nozzle diameter:

$$C_d = \frac{d_{MC}}{d}$$  

(1)

where: $C_d$ = liquid fuel contraction coefficient, $d_{MC}$ = liquid fuel stream diameter at maximum contraction point, $d$ = nozzle diameter.

Liquid fuel contraction coefficient value is always lower than 1 and depends on the fuel stream parameters (pressure, temperature and injection rate) as well as on nozzle geometry.

3. Injector nozzle geometry parameters

The main goal of presented mathematical model in this analysis is to be usable not only for one fuel injector and its nozzles, but for a large number of the fuel injectors and for many liquid fuels. As analysis baseline is used fuel injector DLLA 775 from [10].

Three fuel injector nozzle geometry parameters which influenced liquid fuel contraction and Reynolds number are nozzle diameter ($d$), nozzle length ($l$) and nozzle inlet radius ($r$). The nozzle inlet radius value is usually shown as a ratio of nozzle diameter ($r_{id}$), what was also adopted in presented analysis.

In analysis were selected nozzle geometry parameters similar to ones for fuel injector DLLA 775 [10], which are the most used in practice. Selected nozzle geometry parameters remain unchanged throughout the analysis.

The variables which strongly influenced fuel contraction coefficient and Reynolds number are fuel pressure, fuel temperature and fuel injection rate. Those variables were varied.

4. Liquid diesel fuel used in the analysis

In analysis was used diesel fuel D2, which main characteristics and specifications are presented in Table 1. Although the analysis is made with diesel fuel D2, the mathematical description of the liquid fuel contraction coefficient and the Reynolds number allows the usage of any standard or alternative liquid fuel.

<table>
<thead>
<tr>
<th>Liquid diesel fuel D2 property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur content</td>
<td>0.3 percentage of mass</td>
</tr>
<tr>
<td>Molecular mass</td>
<td>198 kg/kmol</td>
</tr>
<tr>
<td>Density at 15.5 °C</td>
<td>0.842 g/cm³</td>
</tr>
<tr>
<td>Kinematic viscosity at 38 °C</td>
<td>2.84 · 10⁻⁶ m²/s</td>
</tr>
<tr>
<td>Critical pressure</td>
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</tr>
<tr>
<td>Critical temperature</td>
<td>453 °C</td>
</tr>
<tr>
<td>Boiling point</td>
<td>266 °C</td>
</tr>
<tr>
<td>Flash point</td>
<td>75 °C</td>
</tr>
<tr>
<td>Aniline point</td>
<td>71.7 °C</td>
</tr>
</tbody>
</table>

Fig. 1. Liquid fuel contraction coefficient definition for fuel injector nozzle
5. Liquid diesel fuel D2 thermodynamics properties necessary for analysis

5.1. Density of liquid diesel fuel D2

Liquid diesel fuel D2 density dependence on the fuel pressure and temperature is given by the following equation [11]:

$$\rho = \rho_0 \left(1 + \frac{\rho_0 \cdot d \cdot 10^{-3}}{\rho} \right)$$  \hspace{1cm} (2)

where: \(\rho\) = liquid fuel current density \((g/cm^3)\), \(\rho_0 = 0.845 \text{ g/cm}^3\) (liquid fuel density on the environmental pressure = 1 bar and temperature = 25 \(^\circ\)C), \(\rho\) = liquid fuel current pressure \((\text{Pa})\), \(E = 19.6 \cdot 10^5 \text{ Pa}\) (liquid fuel elasticity module), \(\Delta t = \) liquid fuel temperature above the environment temperature, \(A = 1350 \text{ \(^\circ\)C}\) (reciprocal value of the liquid fuel thermal expansion coefficient).

5.2. Dynamic viscosity of liquid diesel fuel D2

Liquid diesel fuel D2 dynamic viscosity change can be calculated by a second degree polynomial [11]:

$$\mu = A(t) + B_1(t) \cdot p + B_2(t) \cdot p^2$$  \hspace{1cm} (3)

$$A(t) = 5.92723 \cdot 10^{-7} + 0.0030803 \cdot \exp\left(\frac{t-17.45789}{13.98351}\right) + 0.0036761 \cdot \exp\left(-\frac{t-17.45789}{77.77}\right)$$  \hspace{1cm} (4)

$$B_1(t) = 8.02964 \cdot 10^{-6} - 1.17256 \cdot 10^{-7} \cdot t + 3.82129 \cdot 10^{-10} \cdot t^2 + 1.30035 \cdot 10^{-12} \cdot t^3$$  \hspace{1cm} (5)

$$B_2(t) = 2.21756 \cdot 10^{-9} \cdot \exp\left(-\frac{t-20}{9.126829}\right) + 5.85318 \cdot 10^{-9} \cdot \exp\left(-\frac{t-20}{51.453}\right)$$  \hspace{1cm} (6)

where: \(p\) = liquid fuel current pressure \((\text{bar})\), \(t\) = liquid fuel current temperature \((\text{\(^\circ\)C})\), \(\mu\) = liquid fuel current dynamic viscosity \((\text{kg/m} \cdot \text{s})\).

6. Liquid fuel Reynolds number and contraction coefficient

The Reynolds number for the fuel injector nozzle is defined by the expression:

$$Re = \frac{\rho \cdot v_i \cdot d \cdot 10^{-3}}{\mu}$$  \hspace{1cm} (7)

where: \(\rho\) = liquid fuel density \((\text{kg/m}^3)\), \(v_i\) = liquid fuel injection rate \((\text{m/s})\), \(d\) = nozzle diameter \((\text{mm})\), \(\mu\) = liquid fuel dynamic viscosity \((\text{kg/m} \cdot \text{s})\).

Reynolds number coefficient \(f\) used in the contraction coefficient equation was calculated by the equation:

$$f = \text{Max}(0.316, \frac{Re^{0.25}}{4d^2})$$  \hspace{1cm} (8)

Contraction loss coefficient \(K_n\) is a function of nozzle inlet radius \(r\) and nozzle diameter \(d\) ratio. According to [12] contraction loss coefficient \(K_n\) can be defined by the following polynomial:

$$K_n = 162.52076 \cdot (r/d)^3 - 143.12017 \cdot (r/d)^3 + 47.86559 \cdot (r/d)^2 - 7.50909 \cdot (r/d) + 0.51243$$  \hspace{1cm} (9)

where: \(K_n\) = contraction loss coefficient (-), \(r\) = nozzle inlet radius \((\text{mm})\), \(d\) = nozzle diameter \((\text{mm})\).
For any fuel pressure is valid a fact that the increase in fuel temperature causes an increase in contraction coefficient, for any fuel injection rate. Increase in fuel injection rate causes a different change of contraction coefficient for low fuel pressures (Fig. 2) in comparison with high fuel pressures (Fig. 4).

At high fuel pressures, increases in the fuel injection rate (from 10 m/s to 500 m/s) causes a continuous and significant increase in contraction coefficient, when the fuel is on environmental temperature (25 °C). For higher fuel temperatures, an increase in contraction coefficient during the increase in injection rate is significant only for lower injection rates (from 10 m/s to 250 m/s).

Change in Reynolds number for different fuel injection rates and temperatures at fuel pressure of 2000 bar is presented in Fig. 5. When compared Fig. 5 (fuel pressure 2000 bar) and Fig. 3 (fuel pressure 800 bar) it can be concluded that a change in Reynolds number during the change in the fuel injection rate and fuel temperature has the same trend for every fuel pressure.

The only significant influence of fuel pressure on Reynolds number can be seen in the Reynolds number value. Increase in fuel pressure causes decrease in Reynolds number, for the same fuel injector nozzle operating parameters. At fuel pressure of 2000 bar, Fig. 5, maximum Reynolds number does not exceed Re = 7500, while at fuel pressure of 800 bars, Fig. 3, maximum Reynolds number reaches almost Re = 21000. Again, for both fuel pressures, the maximum Reynolds number was obtained at the highest fuel temperature and at the highest injection rate.

Change in liquid fuel contraction coefficient for different fuel pressures and injection rates, for the same fuel injector nozzle operating parameters, but for increased fuel temperatures was presented in Fig. 7 for fuel temperature of 40 °C and in Fig. 8 for fuel temperature of 70 °C.

As in Fig. 6, increase of fuel pressure resulted in a decrease in liquid fuel contraction coefficient, for every fuel injection rate, and the decrease is the highest for the lowest observed fuel injection rate (100 m/s).

When compared Fig. 6 and Fig. 7, it can be noted that the increase in fuel temperature from 25 °C to 40 °C resulted in a slight increase in contraction coefficient at low fuel pressures, while at high fuel pressures increase in fuel temperature causes significant increase in fuel contraction coefficient, for any injection rate. This conclusion and comparison with lower fuel temperature is also valid when fuel temperature is the highest observed (70 °C, Fig. 8).
any fuel temperature. Dispersion of Reynolds numbers for different fuel injection rates are the highest at the lowest fuel pressures while the same dispersion is the lowest for the highest observed fuel pressures, what is a valid conclusion for every fuel temperature.

Change in fuel temperature influences only the Reynolds number value. For every fuel temperature, the highest Reynolds numbers were obtained at the lowest fuel pressure and at the highest fuel injection rate. Increase in fuel temperature resulted in an increase in Reynolds number.

Change in fuel temperature influences only the Reynolds number value. For every fuel temperature, the highest Reynolds numbers were obtained at the lowest fuel pressure and at the highest fuel injection rate. Increase in fuel temperature resulted in an increase in Reynolds number.

8. Conclusion

In this paper we investigated influences of liquid fuel temperature, pressure and injection rate on fuel contraction coefficient and Reynolds number during fuel injection. Nozzle geometry parameters remained constant during the whole numerical analysis. As expected, fuel temperature, pressure and injection rate are very influential parameters which can significantly change the fuel contraction coefficient and Reynolds number. Calculations were performed with a standard diesel fuel D2.

Increase in liquid fuel temperature cause increase in fuel contraction coefficient. Fuel temperature increase resulted in a slight increase in contraction coefficient at low fuel pressures, while at high fuel pressures increase in fuel temperature causes significant increase in fuel contraction coefficient. To obtain contraction coefficient as high as possible, for low fuel pressures is advisable to increase the fuel injection rate, but not much higher than 100 m/s. At high fuel pressures, increases in the fuel injection rate causes a continuous and significant increase in contraction coefficient when the fuel is on environmental temperature (25 °C), while for higher fuel temperatures increase in contraction coefficient during the increase in injection rate is significant only for lower injection rates. Increase of fuel pressure resulted in a decrease in liquid fuel contraction coefficient, for every fuel injection rate and for every fuel temperature.

Reynolds number increases with an increase in fuel temperature and also with an increase in fuel injection rate. During the increase in injection rate, the increase in Reynolds number is as high as the fuel temperature increase, so the highest Reynolds numbers were obtained for the highest observed fuel temperature and injection rate. Change in Reynolds number during the change in the fuel injection rate and fuel temperature has the same trend for every fuel pressure. For every fuel temperature, the highest Reynolds numbers were obtained at the lowest fuel pressure and at the highest fuel injection rate. Increase in fuel pressure causes decrease in Reynolds number for every fuel temperature and injection rate.

The main goal of presented analysis is to be usable not only for one fuel injector and its nozzles, but for a large number of the fuel injectors and for many liquid fuels. Future research will be based on investigations of the same fuel and fuel injector operating parameters for alternative fuels and its comparison with presented ones for a standard diesel fuel.

9. Acknowledgment

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10. References

THE EFFECT OF N-BUTANOL ADDITIONS TO DIESEL FUEL ON ENGINE PERFORMANCE AND EXHAUST EMISSIONS

Prof. Labeckas G. PhD., Prof. Slavinskas S. PhD.
Faculty of Agricultural Engineering – Power and Transport Machinery Engineering Institute, Aleksandras Stulginskis University, Lithuania
gvdonas.labeckas@asu.lt; stasys.slavinskas@asu.lt

Abstract: The article deals with the effects of butanol-diesel fuel blends on performance and exhaust emissions of a turbocharged CRDI 1154 HP (85 kW) diesel engine. Load characteristics were taken when running with normal diesel fuel and n-butanol-diesel fuel blends DB1, DB2, DB3, and DB4 possessing 1wt%, 2wt%, 3wt%, and 4wt% of fuel-oxygen at speeds of 1800 and 2500 rpm. The auto-ignition delay increased by 15.5%, burn angle MBF 50 and the combustion ended 7.6% and 6.5% earlier in the cycle, bsfc and engine efficiency were 2.8% and 1.9% higher when using fuel blend DB4 than the respective delay of 17.4°, 20.9° and 61.2° CADs, 234.4 g/kWh and 0.361 a fully loaded (100%) straight diesel develops at speed of 2500 rpm. The NOx, CO, THC emissions, and smoke decreased by 5.1%, 29.5%, 3.7 times, and 48.1% against the respective values of 1020 ppm, 563 ppm, 260 ppm, and 12.9% a straight diesel develops under these test conditions.

Keywords: DIESEL ENGINE, N-BUTANOL-DIESEL FUEL BLENDS, AUTO-IGNITION, ENGINE EFFICIENCY, EMISSIONS

1. Introduction
The environmental air pollution problems were identified in the first Clean Air Act enacted by Congress of the United States on July 14, 1955 [1]. To reduce air pollution the effects of ethanol, petrol, and rapeseed oil [2], ethanol-diesel-biodiesel [3], and oxygenated diesel-HRD fuel blends [4,5] on DI engine performance and exhaust emissions were investigated. The other researchers investigated the effects of various vegetable oils [6], or biodiesel [7] and their blends with ethanol, n-butanol or DME [8] because n-butanol is more preferable as oxygen source than ethanol due to advantageous properties such as better density, viscosity and thus lubricity, higher hydrogen content, net heating value and the cetane number that may possibly affect performance and engine-out emissions.

The purpose of the research was to study the effects of diesel-n-butanol fuel blends on the auto-ignition delay, combustion history, maximum heat release rate, burn angles MBF 50, MBF 90 representing the end of combustion, brake specific fuel consumption, brake thermal efficiency, exhaust smoke, and NOx, CO, THC emissions of a turbocharged CRDI diesel engine running at various loads (bmep) and speeds of 1800 and 2500 rpm.

2. Experimental set up and research methodology
A turbocharged, CRDI diesel engine FIAT 1.9 JTD 8V 115 HP (85 kW) with a displacement volume of 1.91 dm³ and compression ratio of 18:1 was used for the experimental tests. The uncooled air entered the capacity chamber and the cylinder at a controllable boost pressure of 0.160 MPa and the temperature of 85 °C. The EGR system was switched off to eliminate the potential side effects on the engine performance. The electronic control unit EDC-15C7 CR governed the timing and the duration of the fuel injection. The purpose of the research was to study the effects of diesel-n-butanol fuel blends on the auto-ignition delay, combustion history, maximum heat release rate, burn angles MBF 50, MBF 90 representing the end of combustion, brake specific fuel consumption, brake thermal efficiency, exhaust smoke, and NOx, CO, THC emissions of a turbocharged CRDI diesel engine running at various loads (bmep) and speeds of 1800 and 2500 rpm.

Load characteristics with a diesel fuel (DF) EN 590 (class 1) as a ‘baseline’ fuel and its 95.375/4.625 wt% (DB1), 90.749/9.251 wt% (DB2), 86.124/13.876 wt% (DB3) and 81.499/18.501 wt% (DB4) blends with n-butanol (B) were taken at speeds of 1800 and 2500 rpm. The combustion phenomena, heat release rate, engine performance, smoke, and emissions revealed when using fuel blends DB1, DB2, DB3 and DB4 involving 1 wt%, 2 wt%, 3 wt%, and 4 wt% of butanol-oxygen were compared with the respective values the reference diesel fuel develops under these test conditions.

A high-speed indicating system with AVL angle encoder 365C and pressure transducer GU24D coupled to the microIFEM piezoelectric amplifier and signal acquisition platform IndiModul 622, was introduced for the recording, acquisition, and processing of crank-angle-pressure signals in the first cylinder. The data post-processing software AVL CONCERTO™ advanced version 4.5 was used to enhance the productivity and measurement accuracy of the test results. The net heat release rate was calculated by using the AVL BOOST program, summarized over 100 engine cycles in-cylinder pressure-data, instantaneous cylinder volume, and their first order derivatives with respect to crank angle.

The engine torque was measured by using an electrical dynamometer KS-56-4 with a definition rate of ±1 Nm, and the speed with crank angle encoder 365C. A real-time air-mass flow into the cylinders was measured with the AVL air-mass flow meter and fuel mass consumption for every load-speed setting point was recorded with the AVL dynamic fuel balance 733S flex-fuel system.

The start of injection (SOI) was recorded by using the Kistler piezoelectric pressure sensor ASMBS 470004-1 mounted on a high pressure tube in front of the injector. The pressure sensor was coupled to the Kistler 2-channel charge amplifier-module 4665 mounted on the signals conditioning platform-compact 2854A to record high-pressure history at the injector with an accuracy of ±0.5% in the pressure variation range of 0–200 MPa.

The auto-ignition delay was determined as a period in CADs between the start of injection (SOI) and the start of combustion (SOC) with an accuracy of ± 0.1°. As the start of injection was taken crank angle, at which the fuel pressure in a high-pressure tube drops temporary down due to the opening of the nozzle-needle-valve of the injector. As the start of combustion was taken crank angle, at which the total heat release-rate crosses the zero line and changes its value from the minus side to the plus side.

3. Analysis of properties of the tested fuel blends
Conventional automotive diesel fuel was produced at the oil refinery “Orlen Lietuva” and satisfied the requirements of standard EN-590:2009+A1. The n-butanol (CH3CH2CH2OH) was produced at Ltd. „Sigma-Aldrich“, Germany (Seelze) and satisfied the requirements of standard 1.00988.6025 1-Butanol EMPOVE® ESSENTIAL NF. Molecular weight of diesel fuel is about 180 [3] and that of 74 belongs to n-butanol [8]. Kinematic viscosity

Fig. 1. Schematic arrangement of the engine test stand: (1) AVL crank-angle encoder; (2) piezoelectric in-cylinder pressure transducer; (3) fuel high-pressure line transducer mounted in front of the injector; (4) air boost pressure sensor mounted in the intake manifold.
of a diesel fuel is 2.13 mm/s at 40 °C, while that of n-butanol compiles 2.97 mm/s at 20 °C. Lubricity, HFR VSD at 60 °C, of n-butanol is lower (622 µm) that that (459 µm) of a diesel fuel, but small amounts of n-butanol added to diesel fuel do not provide a risk to the fuel system. Main properties of a butanol, diesel fuel and small amounts of n-butanol added to diesel fuel do not provide a risk to the fuel system. Main properties of a butanol, diesel fuel and their blends are listed in Table 1.

A normal butanol is built up from straight chain hydrocarbons, contains 21.62 wt% of oxygen and is practically free of aromatics, nitrogen, and sulphur and possess the cetane number value of 25.0 that is threefold higher than that of ethanol. Initial/final boiling points of a diesel fuel (177.8/345.0 °C) are higher than a single boiling point of 117.7 °C of n-butanol. Thus, n-butanol contributes to faster evaporation of the fuel, enhances mixing rate of the air and fuel vapours and improves homogeneity of combustible mixture.

The density and viscosity of fuel blends were measured with the device Anton Paar SVM 3000 with an accuracy of ±0.0002 g/cm³ and 0.1% at the temperature of 40 ± 0.001 °C. Whereas the cetane number of oxygenated diesel-n-butanol fuel blends was computed by using typical methodology developed in the U.S. at the National Renewable Energy Laboratory [9]. This methodology assumes that the cetane number of obtained blend is a linear combination of the cetane numbers of the original fuel-components in its composition.

### 4. Results and discussion

It should be noted that the start of injection (SOI) of a pilot fuel portion was under computer control to be automatically advanced by 6.0° CADs with the load (bmepp) increased within the tested range at speed of 2500 rpm. Therefore, the SOI occurred earlier in the cycle BTDC to ensure well-timed auto-ignition and complete combustion of the fuel when running an engine at the high load. In result, the auto-ignition delay increased with increasing engine load, - because the oxidation reactions of the fuel started earlier in the engine cycle at a lower both pressure and temperature inside the cylinder (Fig. 2).

The ignition delay increased by 1.2-13.5%, 1.1-7.5% and 2.3-15.5% when running with diesel-n-butanol fuel blends DB1-DB4 against, 16.3°, 17.4° and 17.4° CADs, diesel fuel auto-ignites at the respective 0.587, 0.975 and 1.307 MPa loads. The relatively longer ignition delay for diesel-n-butanol fuel blends DB1-DB4 can be reasonably attributed to the lower cetane number of the fuel (Table 1). The next reason, the latent heat of vaporisation of n-butanol, 581.4 kJ/kg, is 2.15 times higher than that, 270 kJ/kg, of diesel fuel. Finally, the auto-ignition temperature of n-butanol is about 385 °C, which is much higher than that, 250 °C, of a fossil diesel fuel. The relative increase in auto-ignition delay time was slightly greater when running an engine at both the lowest and the highest loads at speed of 2500 rpm because the effect of fuel cetane number is greater, if time needed to preheat, evaporate of the fuel droplets, and auto-ignite of air-fuel vapours is extremely limited.

It is important to study how the combustion of various diesel-n-butanol fuel blends affects changes in burn angle MBF 50 because it represents the center of a gravity of heat release rate (HRR) characteristic and thus affects fuel-energy conversion efficiency of an engine. The shorter is the crank angle ATDC at which the 50% of energy releases in the cycle, the lower will be heat losses of the expansion stroke and thus higher engine efficiency can be attained.

### Table 1: Basic properties of a diesel fuel, n-butanol and diesel-n-butanol fuel blends.

<table>
<thead>
<tr>
<th>Property parameters</th>
<th>Diesel fuel (class 1)</th>
<th>n-butanol (CH₂CH₂CH₂OH)</th>
<th>Diesel-n-butanol, DB1</th>
<th>Diesel-n-butanol, DB2</th>
<th>Diesel-n-butanol, DB3</th>
<th>Diesel-n-butanol, DB4</th>
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<tbody>
<tr>
<td>Fuel-bound oxygen, max wt%</td>
<td>0.00</td>
<td>21.62</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Percentage of butanol in blend, wt%</td>
<td>-</td>
<td>-</td>
<td>4.625</td>
<td>9.251</td>
<td>13.876</td>
<td>18.501</td>
</tr>
<tr>
<td>Density at 20 °C, kg/m³</td>
<td>832.7</td>
<td>811.0</td>
<td>831.7</td>
<td>830.7</td>
<td>829.7</td>
<td>828.7</td>
</tr>
<tr>
<td>Cetane number</td>
<td>51.4</td>
<td>25.0</td>
<td>50.2</td>
<td>49.0</td>
<td>47.7</td>
<td>46.5</td>
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<tr>
<td>Carbon, max wt%</td>
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<td>85.66</td>
<td>84.65</td>
<td>83.65</td>
<td>82.64</td>
</tr>
<tr>
<td>Hydrogen, wt%</td>
<td>13.33</td>
<td>13.51</td>
<td>13.34</td>
<td>13.35</td>
<td>13.35</td>
<td>13.36</td>
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<tr>
<td>Carbon-to-hydrogen ratio (C/H)</td>
<td>6.50</td>
<td>4.80</td>
<td>6.42</td>
<td>6.34</td>
<td>6.27</td>
<td>6.19</td>
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<tr>
<td>Net heating value, kJ/kg</td>
<td>43.00</td>
<td>33.10</td>
<td>42.54</td>
<td>42.08</td>
<td>41.63</td>
<td>41.17</td>
</tr>
</tbody>
</table>

![Fig. 2. The auto-ignition delay in CADs as a function of engine load (bmepp) when running with diesel-n-butanol fuel blends at speed of 2500 rpm.](image-url)

![Fig. 3. Burn angle MBF 50 as a function of engine load (bmepp) when running with diesel-n-butanol fuel blends at speed of 2500 rpm.](image-url)

A butanol-oxygen accelerated the combustion reactions to make a difference between the diesel fuel and oxygenated fuel blends.
Burn angle MBF 90, which represents the end of combustion, was 1.4-3.4%, 3.7-30.2%, 2.1-26.7% and 0.0-1.5%, 2.0-2.1%, 1.0-6.5% lower when running with blends DB1-DB4 than those values of 50.10, 54.30, 58.00 and 53.10, 56.10, 61.20 CADs the combustion of diesel fuel ends up for the respective loads at speeds of 1800 and 2500 rpm. The role of butanol-oxygen on the end of combustion is less significant when running at a higher speed because of higher turbulence intensity, swirl, and temperature inside the cylinder.

Fig. 4. The brake thermal efficiency as a function of engine load (bmep) when running with diesel-n-butanol fuel blends at speed of 2500 rpm.

The engine thermal efficiency increased with increasing load and reached the highest value of 0.373 (1.6%) when using the most oxygenated fuel blend than that of 0.367 a fully loaded (1.174 MPa) straight diesel develops at speed of 2500 rpm (Fig. 4). The bigger is a lack of air-born oxygen inside the cylinder, the greater the need for the fuel-bound oxygen to burn the fuel completely and ensure engine efficiency. The results show that there does not exist a fuel blend, which could ensure the best possible engine efficiency within wide range of engine loads and speeds. Lapuerta et al. also did not observe any decrease in engine efficiency because the fuel consumption increased proportionally to its lower heating value when diesel-n-butanol fuel blends up to 20 vol% were used in a Euro 6 engine following the New European Driving Cycle [10].

Fig. 5. The nitrogen oxide emissions (NOx) as a function of engine load (bmep) when using diesel-n-butanol fuel blends at speed of 2500 rpm.

The NOx production depends on the ignition delay time and the amount of the fuel premixed for rapid combustion, maximum heat release rate, combustion duration, pressure inside the cylinder, and adiabatic flame temperature [11]. Therefore, the NOx emissions from combustion of fuel blend DB1 (1.0 wt%) increased only by 3.9%, 3.8% and 2.1% when running at light loads of bmep = 0.311, 0.583 and 0.778 MPa against, 128. 240 and 374 ppm, a straight diesel produces at speed of 2500 rpm. Whereas the biggest NOx emissions of 618, 892 and 1075 ppm emerged namely from combustion of oxygen-free diesel fuel when running under higher loads of bmep = 0.979, 1.174 and 1.320 MPa at the latter speed (Fig. 5). The combustion of fuel blend DB2 generated NOx emissions similar as a straight diesel produces, but slightly more, 588, 897 and 1036 ppm, than the respective diesel-n-butanol fuel blends DB1, DB3 and DB4 produce for these test conditions. Thus, the increased fuel-bound oxygen mass content is important, but equally important is air-to-fuel equivalence ratio "lambda" (load), the temperature inside the cylinder and the residence time in a high temperature on which the NOx production mainly depends [12].

The production of CO emissions depends on engine load, speed, and the availability of the air-born and the fuel-bound oxygen in the cylinder. When running with diesel-n-butanol fuel blends, an extra fuel-bound oxygen comes with an essential help to burn the fuel completely and reduce pollutant emissions, if in the combustion chamber is a lack of air-born oxygen. Because time needed for the oxidation reactions is limited at the high speed of 2500 rpm, CO emissions decreased from 300 ppm to 235, 175, 120 ppm with engine load increased from bmep = 0.311 MPa to 0.584, 0.779, 0.980 MPa to increase ones again to 145 and 560 ppm for the higher bmep = 1.174 and 1.320 MPa when running a straight diesel at speed of 2500 rpm (Fig. 6).

Fig. 6. The carbon monoxide emissions (CO) as a function of engine load (bmep) when using diesel-n-butanol fuel blends at speed of 2500 rpm.

These emissions are always higher when running at light loads because of the low temperature inside the cylinder whereas the following CO emissions increase with engine load caused the lack of air-born oxygen needed to convert all carbon in the fuel to CO2 and all hydrogen to H2O. For these reasons, the CO production increased with increasing fuel-oxygen mass content because n-butanol added to diesel fuel reduced net heating value of the fuel and thus temperature inside the cylinder at low-load operation. Whereas the CO production progressively decreased from the highest value of 800 ppm (DB1) to 545 (DB2), 530 (DB3) and 395 ppm (DB4) with adding of n-butanol to diesel fuel when running under the highest load of bmep = 1.320 MPa at speed of 2500 rpm.

Fig. 7. The total unburned hydrocarbons (THC) as a function of engine load (bmep) when using diesel-n-butanol fuel blends at speeds of 2500 rpm.
The THC emissions increased by 50.0% and 10.0% against the respective values a straight diesel produces for light loads of bnmep = 0.311 and 0.583 MPa when running with a slightly (1.0 wt%) oxygenated fuel blend DB1 at speed of 2500 rpm. The emissions decreased for a higher load of bnmep = 1.174 MPa. Actually, the production of THC emissions became 7.7% then 2.4, 2.0 and 3.7 times lower when using the respective fuel blends DB1, DB2, DB3 and DB4 than that value of 260 ppm a fully loaded, bnmep = 1.320 MPa, straight diesel produces at speed of 2500 rpm (Fig. 7).

The higher brake thermal efficiency (Fig. 4), lower CO (Fig. 6) and THC (Fig. 7) emissions were accompanied by 25.6%, 26.4% and 48.1% less exhaust smoke generated from combustion of fuel blends DB2, DB3 and DB4 than that, 12.9%, a straight diesel produces at speed of 2500 rpm. Apart of fuel-bound oxygen, to lower smoke contributed lower density, viscosity, C/H atoms ratio, absence of aromatics in n-butanol composition, and stoichiometric air-fuel ratio of fuel blends that reduced the need for air-born oxygen on which transparency of the exhaust mainly depends.

Summary and conclusions

The auto-ignition delay period of a pilot diesel-n-butanol fuel blends DB1-DB4 portions increased by 3.9-13.8% and 2.3-15.5% against, 15.2° and 17.4° CADs, the normal diesel fuel auto-ignites when running a fully loaded (100%) turbocharged CRDI diesel engine at the respective speeds of 1800 and 2500 rpm.

Burn angle MBF 50 occurred 0.0-6.5% and 4.7-7.6% earlier in the cycle when running a fully loaded engine with oxygenated fuel blends DB1-DB4 than that 17.2° and 20.9° CADs the 50% mass-portion of a diesel fuel gets burned at speeds of 1800 and 2500 rpm. While the effect of diesel-n-butanol fuel blends on the end of combustion was minor for all loads tested at speed of 2500 rpm.

Brake specific fuel consumption increased to 230.0 (0.9%), 232.3 (1.9%), 234.5 (2.9%), and 234.4 g/kWh (2.8%) for the respective fuel blends DB1, DB2, DB3 and DB4 against that value of 228.0 g/kWh of a straight diesel running at bnmep = 1.174 MPa and speed of 2500 rpm.

The brake thermal efficiency increased to 0.383 for diesel-n-butanol fuel blend DB3 (3.0 wt%) and 0.377 for a straight diesel when running at bnmep = 1.174 MPa and the low speed of 1800 rpm. The highest engine efficiency of 0.373 (1.6%) suggested the most oxygenated blend DB4 (4.0 wt%) compared with that of 0.367 a straight diesel develops for bnmep = 1.174 MPa at speed of 2500 rpm.

The production of total NOx emissions decreased to the lowest values of 955 ppm (1.5%) and 1020 (5.1%) ppm when running at bnmep = 1.590 MPa and 1.320 MPa, with the most oxygenated fuel blend DB 4 (4.0 wt%) at speeds of 1800 and 2500 rpm. Whereas CO emissions decreased by 2.7%, 5.4% and 29.5% when running with fuel blends DB2, DB3 and DB4 against that, 560 ppm, a straight diesel produces for 1.320 MPa load at speed of 2500 rpm.

THC emissions decreased 2.4, 2.0 and 3.7 times, when running with fuel blends DB2, DB3 and DB 4 against that value of 260 ppm a fully loaded, bnmep = 1.320 MPa, straight diesel produces at high speed of 2500 rpm. Transparency of the exhaust was also 25.6%, 26.4% and 48.1% better when using the respective blends than that, 12.9%, a straight diesel produces for considered test conditions.

Acknowledgements

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References
RESEARCH OF USING THE ALTERNATIVE FUELS FOR IMPROVING THE INDICATORS OF THE TRACTOR DIESEL WORK

L.V. Denezhko, A.A. Sadov, A.D. Ustyugov, I.M. Milstein
Federal state educational institution of higher education "Ural State Agrarian University"
Ekaterinburg, Karla Liebknechtea, 42.

Topicality: The urgency of the issue under consideration is stipulated by large-scale international research and is confirmed by the Russian Federation Government Decree No. 1-P of 08.01.2009 "Main Directions of State Policy in the Sphere of Energy Efficiency Improvement on the Basis of Using Renewable Energy Sources for the Period to 2020" and the Decree of the President of the Russian Federation from July 7, 2011 № 899 on priority directions of development of science, technology and technics in the Russian Federation.

According to the analytical agency "AUTOSTAT", as of 2017 there are 3.7 million of trucks in the Russian Federation, of which the ecological standards "Euro-4" (and above) correspond only 14%, and annually are used more than 20 million tons of freight transport, which in the amount of processing oil to diesel gas oil is more than 70 million tons of diesel gas oil. From the above, it can be concluded that in order to solve the fuel issue and preserve the environment, it is necessary to study the performance of the diesel engine using diesel composite fuel and transfer to transport to alternative fuels.

As a raw material for the production of alternative fuels is attractive biomass, such as oilseeds and waste from processing plants. As a result of the growing demand for ricinolic oil by industry, it is necessary to study its application as a component for the production of diesel composite fuel.

However, the viscosity of ricinolic oil is higher than that of diesel gas oil, so it can only be used as an additive to low-viscosity components. As a result of the addition of diesel fuel and bioethanol to ricinolic oil, with preliminary preparation, decreases viscosity and are improved low-temperature properties. This mixture can be suitable for use on transport-technological machines, the point of view of qualitative spraying in areas with a moderate climate.

As a result of the growing demand for ricinolic oil by industry, it is necessary to study its application as a component for the production of diesel composite fuel. However, the viscosity of ricinolic oil is higher than that of diesel gas oil, therefore ricinolic oil can only be used as an additive to low-viscosity components. As a result of the addition of diesel fuel and bioethanol to ricinolic oil, with preliminary preparation, decreases viscosity and are improved low-temperature properties.

According to the results of numerous studies, was revealed a decrease in the toxicity index of the exhaust gases of the engine, while operating with the DCF. This becomes very important at the present time.

1. INTRODUCTION.

In modern times, the development of motor and tractor technics is greatly influenced by:
- tightening of environmental norms on emissions of toxic substances;
- methods for increasing energy efficiency.

Today, the Russian Federation produces more than 100 million tons of motor fuel produced in the traditional way from oil (Figure No. 1) [2];

At the same time, the dynamics of reserves growth due to revaluation and geological exploration remains at the level of 2007 and 2008, which means that with an intensive increase in the number of stationary and mobile consumers of petroleum products, the demand for petroleum products may exceed the growth dynamics of reserves. As a result, there will be an intensive decrease in the world reserves of oil deposits. [2]

Therefore, one of the main ways of developing agricultural and logging production can be considered a partial transfer to alternative fuels from biomass. This will solve the problem of replacing petroleum fuel, significantly expand the resource base for fuel production, facilitate the solution of fuel supply issues for vehicles and fixed installations remote from large settlements. This can reduce the prime cost of production, subject to the independent production of components of the DCF or in cooperation with other manufacturers. [13,14]

As a raw material is attractive biomass for obtaining an alternative fuel, such as oilseeds and waste from the processing industry.

As a result of growing demand for ricinolic oil, which is used in many industries, and the resumption of research in the Russian Federation aimed at selecting and processing castor oil plant, there is a need to investigate ricinolic oil and bioethanol as biocomponents for the production of diesel composite fuel. [14,15]

The parameters of the D-240 engine performance were studied using 7 mixtures with different component ratios: diesel gas oil (DO) + ricinolic oil (RicO) + alcohol (Al), respectively (mixture 1, mixture 2, mixture 3, mixture 4, mixture 5, mixture 6, mixture 7) according to Prokopenko R. M., Horosh A.I., Bashirova R.M., determined on the basis of the working cycle of the engine D-240 and are presented below the dependences on the concentrations of the components.

The article compares the obtained results with the indicators of traditional diesel gas oil.

KEY WORDS: DIESEL COMPOSITE FUEL (DCF), DIESEL, INTERNAL COMBUSTION ENGINE, MIXTURE, POWER, ECONOMY, ALTERNATIVE TYPE OF MOTOR FUEL, RICINIC OIL, CASTOR OIL, BIOETHANOL.

2. RESEARCH OF WORK INDICATORS OF TRACTOR DIESEL ENGINE.

For using DCF on the basis of bioethanol and ricinolic oil produced from castor oil plant, was made a study of the effect of the constituent components on the economic, power performance of the diesel engine operating cycle.

The parameters of the D-240 engine performance were studied using 7 mixtures with different component ratios: diesel gas oil (DO) + ricinolic oil (RicO) + alcohol (Al), respectively (mixture 1, mixture 2, mixture 3, mixture 4, mixture 5, mixture 6, mixture 7) according to Prokopenko R. M., Horosh A.I., Bashirova R.M. [9,10,11] presented in Table 3.

For calculation, it is necessary to determine the content of the basic substances in ricinolic oil according to the method of Egaizaryants C. B. [12] and calculate the elementary composition of the mixture, which is determined by the content of C, H, O by the Mendeleev D.I. formula and compared with similar mixtures studied without the addition of bioethanol.
Table No. 2 - Elementary composition of mixtures.

<table>
<thead>
<tr>
<th>№</th>
<th>Indicators</th>
<th>Carbon C</th>
<th>Hydrogen H</th>
<th>Oxygen O</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>DO444</td>
<td>0,870</td>
<td>0,126</td>
<td>0,004</td>
</tr>
<tr>
<td>2.</td>
<td>Mixture 1 RicO+DO</td>
<td>0,8495151</td>
<td>0,1239453</td>
<td>0,0265396</td>
</tr>
<tr>
<td>3.</td>
<td>Mixture 2 RicO+DO</td>
<td>0,8426868</td>
<td>0,1232604</td>
<td>0,0340528</td>
</tr>
<tr>
<td>4.</td>
<td>Mixture 3 RicO+DO</td>
<td>0,8358585</td>
<td>0,1225755</td>
<td>0,041566</td>
</tr>
<tr>
<td>5.</td>
<td>Mixture 1</td>
<td>0,7032584</td>
<td>0,1253704</td>
<td>0,1713712</td>
</tr>
<tr>
<td>6.</td>
<td>Mixture 2</td>
<td>0,7244589</td>
<td>0,1234731</td>
<td>0,152068</td>
</tr>
<tr>
<td>7.</td>
<td>Mixture 3</td>
<td>0,74871575</td>
<td>0,12389425</td>
<td>0,12739</td>
</tr>
<tr>
<td>8.</td>
<td>Mixture 4</td>
<td>0,7517721</td>
<td>0,1262127</td>
<td>0,1220152</td>
</tr>
<tr>
<td>9.</td>
<td>Mixture 5</td>
<td>0,76237235</td>
<td>0,12526405</td>
<td>0,1123636</td>
</tr>
<tr>
<td>10.</td>
<td>Mixture 6</td>
<td>0,7729726</td>
<td>0,1243154</td>
<td>0,102712</td>
</tr>
<tr>
<td>11.</td>
<td>Mixture 7</td>
<td>0,8214863</td>
<td>0,1251577</td>
<td>0,053356</td>
</tr>
</tbody>
</table>

From the obtained data, it can be seen that the addition of bioethanol increases the amount of oxygen and hydrogen in the elemental composition of the mixture. The study of the mixture viscosity revealed that it is possible to increase the proportion of ricin oil without adversely affecting the quality of the spray by adding bioethanol.

Table No. 3 - Indicators of the working cycle of a diesel engine using mixtures of different concentrations.

<table>
<thead>
<tr>
<th>№</th>
<th>Indicators</th>
<th>DO</th>
<th>Mixture 1</th>
<th>Mixture 2</th>
<th>Mixture 3</th>
<th>Mixture 4</th>
<th>Mixture 5</th>
<th>Mixture 6</th>
<th>Mixture 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Heat of fuel combustion, MJ / kg</td>
<td>42,5</td>
<td>34,964</td>
<td>35,702</td>
<td>36,837</td>
<td>37,238</td>
<td>37,607</td>
<td>37,975</td>
<td>40,249</td>
</tr>
<tr>
<td>2.</td>
<td>Amount of air, kg / kg of fuel</td>
<td>14.35</td>
<td>11.68</td>
<td>11.94</td>
<td>12.34</td>
<td>12.48</td>
<td>12.61</td>
<td>12.74</td>
<td>13.54</td>
</tr>
<tr>
<td>3.</td>
<td>Index of molecular change</td>
<td>1,041</td>
<td>1,0589</td>
<td>1,0559</td>
<td>1,0531</td>
<td>1,0531</td>
<td>1,0518</td>
<td>1,0505</td>
<td>1,0456</td>
</tr>
<tr>
<td>4.</td>
<td>Combustion temperature, °K</td>
<td>2158,0</td>
<td>2149,53</td>
<td>2153,28</td>
<td>2157,4</td>
<td>2156,07</td>
<td>2157,77</td>
<td>2159,3</td>
<td>2165</td>
</tr>
<tr>
<td>5.</td>
<td>Mean effective pressure, MPa</td>
<td>0,7233</td>
<td>0,718</td>
<td>0,71</td>
<td>0,716</td>
<td>0,715</td>
<td>0,714</td>
<td>0,714</td>
<td>0,711</td>
</tr>
<tr>
<td>6.</td>
<td>Effective coefficient of efficiency</td>
<td>0,363</td>
<td>0,353</td>
<td>0,338</td>
<td>0,352</td>
<td>0,352</td>
<td>0,352</td>
<td>0,352</td>
<td>0,351</td>
</tr>
<tr>
<td>7.</td>
<td>Effective flow density</td>
<td>233,3</td>
<td>291,48</td>
<td>282,7</td>
<td>276,86</td>
<td>274,114</td>
<td>271,54</td>
<td>269,04</td>
<td>254,15</td>
</tr>
<tr>
<td>9.</td>
<td>Change in power, %</td>
<td>-</td>
<td>-0,62%</td>
<td>-0,83%</td>
<td>-0,98%</td>
<td>-1,1%</td>
<td>-1,2%</td>
<td>-1,302%</td>
<td>-1,7%</td>
</tr>
<tr>
<td>10.</td>
<td>Change in specific fuel consumption, %</td>
<td>-</td>
<td>+24,94%</td>
<td>+27,68%</td>
<td>+18,67%</td>
<td>+17,49%</td>
<td>+16,36%</td>
<td>+15,32%</td>
<td>+8,94%</td>
</tr>
</tbody>
</table>

Figure No. 3 - Change in the heat of fuel combustion.
It can be seen that the high content of alcohol significantly influences the reduction of the heat of the fuel combustion, for example, a mixture of 80% DO and 20% RicO has a combustion heat of 40.986 MJ / kg, and a similar mixture with an alcohol of 80x10x10 already has 40.24 MJ / kg. Due to the addition of bioethanol, the viscosity of the mixture and the low-temperature properties are significantly reduced: the turbidity and crystallization temperature decreases and makes it suitable for use in standard diesel power systems, in terms of quality spraying. [5,8]

Figure No. 4 - Change in the amount of air required for combustion.

An important feature of the addition of bioethanol in diesel composite fuel mix is the reduction in the required amount of air for firing 1 kg of fuel. From this it can be concluded that for the transfer of the diesel internal combustion engine (ICE) with the system without adjusting the amount of air supplied, it is necessary to modernize the air supply system of the internal combustion engine.

Figure No. 5 - Change in the combustion temperature of the mixture.

Thus, it is possible to operate the ICE on a depleted fuel-air mixture without modernization, which affects negatively the response of the piston diesel ICE. It is necessary to change the amount of supplied air depending on the added components concentrations.
Increasing the proportion of bioethanol also affects the combustion temperature. According to calculations, it was revealed: the lower the amount of diesel fuel is and the higher the amount of alcohol is, the lower the combustion temperature of the mixture is. But with the addition of not more than 25% of the biocomponents, the combustion temperature rises according to the made calculations.

**Figure No. 6 - Change in the efficient specific fuel consumption.**

According to the schedule, a significant increase in the specific fuel consumption is affected by an increase amount of bioethanol.

If we compare the mixture with the 60% content of DO, it can be seen that the specific consumption increases on average by 2.5 g / kW with a change in the alcohol content for every 5%.

**Figure No. 7 - Change in effective power.**

But the presence of alcohol favorably influences the performance of ICE, so based on the obtained data on the example of mixtures with a 60% content of DO, it is evident that when the alcohol content is changed by 5%, the effective power increases on the 62-70 W.

3. **CONCLUSIONS**

1. As a result of reducing the required amount of air for combustion of mixture, occurs a significant change in the \( \alpha \) coefficient - a coefficient of air excess;
2. The addition of bioethanol makes it possible to increase the proportion of ricinoc oil in the mixture without adversely affecting the quality of the spray;
3. The increased share of biocomponents allows increasing the autonomy of the enterprise and reducing the cost of products;
4. The specific consumption increases by an average on 2.5 g / kW with a change in alcohol increase by every 5%;
5. With an increase in the content of alcohol for every 5%, the effective power increases by an average on 62-70 W, compared to similar proportions of RicO and DO without the addition of alcohol.
6. It was found that the lower the amount of diesel gas oil is and the higher the amount of alcohol is, the lower the combustion temperature of the mixture is. But with the addition of not more than 25% of the biocomponents, the combustion temperature rises according to the performed calculations.

4. **CONSEQUENCE.**

A multicomponent diesel composite fuel made from castor oil plant and traditional petroleum feedstocks can be used to solve the problems of oil fuel substitution. It is more advantageous to use it at enterprises situated far from large settlements, in connection with which it is possible to achieve a reduction in the cost of production, provided that the components are produced independently or in cooperation with other producers.
5. CONFLICT OF INTEREST
The authors confirm that the presented data do not contain a conflict of interest.

6. GRATITUDES
The work was prepared with the support of the Ural State Agrarian University in Ekaterinburg.

7. REFERENCES