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Application of hardfacing layers for renovation of functional surfaces exposed to abrasive wear

Ján Viňáš1,*, Jakub Brezina1, Štefan Kender1, Dušan Sabadka1
Technical University of Košice, Slovakia1
jan.vinas@tuke.sk

Abstract: The paper presents results of quality evaluation of hardfacing layers applied to functional parts of dredger teeth. Layers were made by arc welding methods MMAW and FCAW. High-alloy types of filler materials were used in the experiment. Their chemical composition allows the production of overlay layers with a high content of carbide particles. These particles ensure high resistance to abrasive wear of the layers. Excavator teeth were made by casting high-grade manganese steels Grade B-3 A 128 / A128M-93. In the experiments, the presence of surface defects of the weld deposit was assessed by visual inspection. The resistance of the hard-facing layers to the effects of abrasive wear was assessed using a Di-1 experimental apparatus and evaluated on the basis of weight loss.

Keywords: HARDFACING LAYERS, RENOVATION, WEAR, CLADDING

1. Introduction

One of the heavy equipment mostly used in construction activities is excavator. This heavy equipment, which is best known as backhoe, is a digging machine used for various applications such as mine materials dredging, digging, levelling of the ground, river dredging and demolition. In excavator, the component used for digging and loading material is called excavator bucket [1]. Excavator bucket is generally equipped with protruding teeth on its edge, which is named bucket teeth. In the application of excavator, bucket teeth will have a direct contact to the ground so that it has a significant impact on the performance in a whole. Therefore, the material used for making the component of bucket teeth should have high endurance to wear and high power [1,2].

Bucket teeth is a component of excavator which is replaced periodically since it has relatively short usage time and is very crucial for ground penetration. One of the failures of bucket teeth is a wear in the part of bucket teeth itself (Fig. 1).

Bucket teeth are one of important parts of an excavator. Bucket teeth functions as material digger. It consists of some components, i.e., bucket, adaptor, and teeth [3,4]. As part of a comprehensive research, the quality of the welds was assessed by a hardness test, a microstructure test and an evaluation of abrasive wear. This paper presents the results of the assessment of abrasive wear.

2. Experimental Materials and Methods

Worn teeth (see Fig. 2) made by casting from the material Grade B-3 A 128 / A128M-93, whose chemical composition and mechanical properties stated by the manufacturer are in Table 1.

![Bucket excavator](image)

**Fig. 1 Bucket excavator**

![Wearing excavator teeth](image)

**Fig. 2 Wearing excavator teeth**

![Damage to the tooth clamping part](image)

**Fig. 3 Damage to the tooth clamping part**

**Table 1: Chemical composition and mechanical properties of steels Grade B-3 A 128 / A128M-93.**

<table>
<thead>
<tr>
<th>Chemical composition in (% wt.)</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.22</td>
<td>13.48</td>
<td>0.911</td>
<td>0.042</td>
<td>0.004</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>Yield strength Rm [MPa]</th>
<th>Proof stress Rp0.2 [MPa]</th>
<th>Elongation [%]</th>
<th>Impact Strength [J]</th>
<th>Hardness [HB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>896</td>
<td>396</td>
<td>40</td>
<td>140</td>
<td>224</td>
<td></td>
</tr>
</tbody>
</table>

Before the renovation, each damaged component is assessed whether its extent of damage is technically and also economically profitable. Inspection of the component, mostly visual resp. ultrasound, surface and internal defects of components (eg. the presence of cracks) are detected, which could cause damage to the component under cyclic dynamic loading. Wear was analyzed by visual control for detecting damage to functional parts of the teeth (see Fig. 3).
Due to damage to tooth surfaces by corrosive fumes, soil and rock impurities, the tooth surface was blasted before hardfacing. (Fig.4).

**Used filler material and cladding parameters**

Manual arc welding (hardfacing) technologies were chosen for the restoration of worn parts of the teeth of earthmoving machines. MMAW method (manual arc welding - marked 111 N ISO 4063) and FCAW method (self-protection tubular wire welding, method marked 114 EN ISO 4063).

For MMAW welding, the additional material E 10-UM-60-CGP – DIN 8555 with a diameter of ø 3.2 mm was used. The chemical composition of the coated basic electrode is in Tab. 2. Clad is not heat treated.

**Table 2: Chemical composition filler material E 10-UM-60-CGP – DIN 8555**

<table>
<thead>
<tr>
<th>Chemical composition in (wt.%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>3.5</td>
</tr>
<tr>
<td>Mn</td>
<td>0.8</td>
</tr>
<tr>
<td>Si</td>
<td>0.8</td>
</tr>
<tr>
<td>Cr</td>
<td>27.5</td>
</tr>
<tr>
<td>Fe</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

For hardfacing by the FCAW method, an additional material was used marked as MF10 – GF – 60 – CG - DIN 8555-83, the chemical composition (Tab. 3). It is a tubular electrode with a diameter of ø 1.6 mm with its own protection. Preheat is not necessary.

**Table 3: Chemical composition filler material MF10 – GF – 60 – CG – DIN 8555-83**

<table>
<thead>
<tr>
<th>Chemical composition in (wt.%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>4.2</td>
</tr>
<tr>
<td>Mn</td>
<td>1.6</td>
</tr>
<tr>
<td>Si</td>
<td>1.3</td>
</tr>
<tr>
<td>Cr</td>
<td>25.4</td>
</tr>
<tr>
<td>Al</td>
<td>0.6</td>
</tr>
<tr>
<td>Fe</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

Teeth made by forging from material - Grade B-3 A 128 / A128M-93 do not need to be preheated before hardfacing, as they are austenitic manganese steels.

The used parameters of tooth hardfacing are in Tab. 4. Clads were made with a CLOOS 303 MC pulse welding rectifier.

**Table 4: Used cladding parameters**

<table>
<thead>
<tr>
<th>Cladding parameters</th>
<th>Method</th>
<th>Filler material</th>
<th>Cladding current [A]</th>
<th>Cladding voltage [V]</th>
<th>Current type / polarity</th>
<th>Wire feed speed [m.min⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>E 10-</td>
<td>90-120</td>
<td>24-26</td>
<td>DC +</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UM-60</td>
<td></td>
<td>CGP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>114</td>
<td>MF10-</td>
<td>240-300</td>
<td>28-30</td>
<td>DC +</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GF-60</td>
<td></td>
<td>CG</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The surface of the clads was cleaned of slag by brushing with a steel brush to eliminate the possible negative effect of slag on the results in the assessment of abrasive wear.

Hardfacing layers were exposed to abrasive wear in a Di-1 device. The effect of loose abrasive on renovated areas was monitored by weight loss.

Mass wear was determined by the relationship:

\[ W_A = m_i - m_0 \text{[g]} \]  

\[ m_0 \text{ – weight of sample before test [g],} \]

\[ m_i \text{ – weight of sample after i-th wear [g].} \]

The elementary increase in mass wear Δ Wh was determined according to the relation:

\[ \Delta W_h = W_{h,i} - W_{h,i-1} \text{[g]} \]

\[ W_{h,i-1} \text{ – weight of sample before i-th wear [g],} \]

\[ W_{h,i} \text{ - weight of sample after i-th wear [g].} \]

Experimentally, alumina with a grain size of dz = 0.9 mm was used as an abrasive for the wading test, which was replaced every 5,103 m.

Test parameters used:

- the speed of movement of the samples in Di-1 is 1,738 m.s⁻¹,
- the test specimens were clamped vertically in the plate head,
- the samples examined were 10mm x 20mm x 90mm,
- immersion of the samples in free abrasive was 60 mm,
- the angle of inclination of the sample to the abrasive was 70º,
- number of samples with weld-on E 10-UM-60-CGP - 3pcs, / sample A /
- number of samples with weld MF10 – GF – 60 – CG - 3pcs, / sample B /
- sample wading distance [m] depending on wading time [min]: (60min = 6260m; 180min = 18780m; 300min = 31300m; 600min = 62600m)

**3. Results and discussion**

The clad deposits were evaluated by visual inspection (Fig. 5). In both renovated teeth, transverse cracks formed in the weld metal during cooling. Based on the literature [5], it is not necessary to crack these cracks. Leideburitic cast irons to remove and repair. They are permissible for this type of component.

---

*Fig. 4 Tooth after blasting*

*Fig. 5 Tooth after cladding*
In FIG. 6 and FIG. 7 documents the test specimens before and after the wading test in bulk abrasive (brown corundum). Radvag XA 220 analytical balances were used to determine the weight of the samples before the experiment and to monitor the effect of the bulk abrasive on the individual samples during the experiment. The measurement results are recorded in (Tab. 5.).

![Fig. 6 Samples A1 – A3](image)

a) before abrasive test  
b) after abrasive test

![Fig. 7 Samples B1 – B3](image)

a) before abrasive test  
b) after abrasive test

Based on the weight losses recorded during the experiment, it can be stated that the hardfaced layers made of both types of additional materials were resistant to the action of the abrasive medium.

**Table 5: Weight differences of the examined samples (in [g])**

<table>
<thead>
<tr>
<th>Sam.</th>
<th>Before wear [g]</th>
<th>60 [min]</th>
<th>180 [min]</th>
<th>300 [min]</th>
<th>600 [min]</th>
<th>W_a [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>197.3877</td>
<td>197.3797</td>
<td>197.3772</td>
<td>197.3748</td>
<td>197.3700</td>
<td>0.0177</td>
</tr>
<tr>
<td>A2</td>
<td>196.2786</td>
<td>196.2694</td>
<td>196.2668</td>
<td>196.2625</td>
<td>196.2571</td>
<td>0.0215</td>
</tr>
<tr>
<td>A3</td>
<td>195.1061</td>
<td>195.0992</td>
<td>195.0970</td>
<td>195.0937</td>
<td>195.0875</td>
<td>0.0186</td>
</tr>
<tr>
<td>B1</td>
<td>194.9027</td>
<td>194.8972</td>
<td>194.8950</td>
<td>194.8925</td>
<td>194.8875</td>
<td>0.0152</td>
</tr>
<tr>
<td>B2</td>
<td>196.0040</td>
<td>195.9984</td>
<td>195.9952</td>
<td>195.9924</td>
<td>195.9869</td>
<td>0.0171</td>
</tr>
<tr>
<td>B3</td>
<td>190.6379</td>
<td>190.6323</td>
<td>190.6296</td>
<td>190.6272</td>
<td>190.6216</td>
<td>0.0163</td>
</tr>
</tbody>
</table>

The effect of the abrasive on the hardfacing layers can be described as cleaning. All residues of slag and oxide coatings from the flux of filler materials were removed from the hardfaced beads.

Clads made with technology 114 (samples B) showed higher wear resistance due to WA mass wear, which was probably due to the small volume of slag and oxide compounds on the surface of the clads, due to the diameter of the tubular wire used (or less slag on the surface of caterpillars after hardfacing). compared to the amount of slag on the surface of clads made by technology 111 (samples A), where the clads (made of additive material E 10-UM-60-CGP) were covered with a thicker layer of slag due to the diameter of the additive material and its thickness.

**4. Conclusions**

Paper presents part of the experiments carried out in evaluating the quality of hardfacing layers of functional surfaces of earthmoving machine components. In practice, these components are stressed by combined wear. It is mainly an abrasive-adhesive wear in combination with high pressures and corrosion. Hardfacing renovation is one of the effective and economically advantageous solutions for extending their service life. Due to the number of renovated components, e.g. dredger teeth are mainly manual welding (hardfacing) methods such as (MMAW - 111; FCAW - 114, 136 FCAW - S - 137 and GMAW - 131, 135, STN EN ISO 4063). The MMAW 111 method is suitable for repairing a small number of parts. Its disadvantage compared to other presented technologies is the limited length of additive material. A more effective way of surface renovation is hardfacing by FCAW methods, resp. GMAW, which enable continuous hardfacing of larger areas, e.g. walls of scoops. Based on the performed experimental tests, it can be stated that both additional materials E 10-UM-60-CGP - DIN 8555) and also MF10 – GF – 60 – CG - DIN 8555-83 are suitable for the renovation of functional - friction surfaces of earthmoving machines. The clad metal shows high resistance to abrasive wear due to a chemical composition which exhibits in microstructure shows carbides precipitated along austenite grain boundaries and sparsely dispersed in the grains

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**5. References**

Balance prediction of the inertia wheel pendulum by using swing up and PID controller

Hilmi Kuşçu¹ and Eray Yılmazlar²
Trakya University, Mechanical Engineering Department, Edirne, Turkey¹
Kırklareli University, Technical Sciences Vocational School, Kırklareli, Turkey²
hilmi@trakya.edu.tr-eray.yilmazlar@klu.edu.tr

Abstract: In this paper, inertia wheel pendulum balance control is performed by using swing up and PID controller. Paper provides predictions on real time design balance system. Predictions were performed through data that were classified and tested by machine learning via MATLAB. Data obtained a result of the analyze of balance positions and swinging times of the wheel different diameters and weights in real-time. Through to this work will be able to predictable which wheel characteristics can be controlled and balanced.

Keywords: MACHINE LEARNING, PID CONTROLLER, WHEEL PENDULUM.

I. Introduction

Inertia wheel pendulum (IWP) is a nonlinear and underactuated system with two degrees of freedom. The pendulum structure consists of a pendulum rod that can swing freely in the vertical axis, a rotating wheel in the same axis with the rod, and a motor that produces a rotational movement[1]. The main purpose of the IWP systems is the alignment of the pendulum wheel on the vertical axis. Balancing is the process of raising and aligning the pendulum with the control methods of the torque produced by the DC motor.

Machine learning is an artificial intelligence field that enables the system to create a model by using learning from past experiences and to make estimation against future situations[2]. Machine learning is used in many disciplines in our age. It provides convenience to devices and people in data analysis, decision making, estimation, conclusion and classification processes. The combination of machine learning and artificial intelligence with devices has enabled the creation of smart, self-guessing capable devices. Today, many systems are used by making use of the capabilities of artificial intelligence. These abilities were used in this study to estimate the balance of the balancing system.

The aim of this study is to control the pendulum wheel in different weights and wheel diameters. In addition, according to the weight and diameter variables to determine the ideal range for the balance of the pendulum is done by machine learning algorithms.

The studies on IWP started in 2001 and continue with many types of control methods and designs[3,4,5]. When the studies on IWP were examined, Hernández controlled the IWP system with PI in 2003 [6]. Victor carried out IWP balancing with limited torque technique in 2005 [7]. Victor made the dynamics and control of the IWP system in 2018 [8]. Jafar controlled the double pendulum mechanism with PID [9].

In this study, 39 different experiments were conducted and balance condition was analyzed together with disturbing factors affecting the system. Rest of the information of this document is organized as follows: Sec. A is devoted to describing IWP system modeling and dynamics. Sec. B indicates the system design procedure and control methods. In Sec. C, data analysis of wheel balance and make a prediction, classification using machine learning application. Then the final section reveals the results of this study.

1.1. Wheel Pendulum System and Dynamic Models

The IWP system consists of three parts. These parts are pendulum rod, pendulum wheel, and dc motor. In the IWP control design, the dynamic model of the system is calculated by the Euler-Lagrange formula 1: Euler-Lagrange Equations (L) is a very useful method of extracting the equations of motion of the dynamic system. For the solution of the Euler-Lagrange equation, firstly there must be a difference in kinetic energy and potential energy [10,11].

\[ L = K_e - P_e \]  \hspace{1cm} (1)

\[ K_e: \text{Total kinetic energy of system} \]
\[ P_e: \text{Total potential energy of system} \]

The total kinetic energy consists of the wheel, the wheel bar and the kinetic energy of the engine. kinetic energy of wheel, kinetic energy of pendulum rod, kinetic energy of motor and total kinetic energy equations describe in (2).

\[ A = J_w + J_p + J_m + m_w l^2 + m_p \left( \frac{1}{2} \right)^2 + m_m l^2 \]  \hspace{1cm} (2)

\[ K_e = \frac{1}{2} A \dot{\theta}^2 + \frac{1}{2} l m_p \dot{\phi}^2 \]  \hspace{1cm} (3)

The total potential energy of the system appears in eq. 4:

\[ P_e = \left( m_w l + m_m l + m_p \frac{1}{2} \right) g \cos \theta \]  \hspace{1cm} (4)
To simplify the equation when defined as \( U \) in eq. 5-6:
\[
U = m_p l_1 + m_w l_2 + m_p \frac{l_1}{2}
\]  
(5)

The Lagrange difference equation appears eq. 7:
\[
\mathcal{L} = \frac{1}{2}A\theta^2 + \frac{1}{2}J_w \dot{\phi}^2 - Ug \cos \theta
\]  
(6)

When the difference equation is written in the general Lagrange expression in 8: and \( q_1=\theta \) accepted \( q_2=\phi \), the equation is determined.
\[
\frac{d}{dt} \left( \frac{\partial \mathcal{L}}{\partial \dot{q}_i} \right) - \left( \frac{\partial \mathcal{L}}{\partial q_i} \right) = \tau_i
\]  
(8)

When differential equation solutions are made, eq. 9-10: is found.
\[
A\ddot{\theta} + J_w \ddot{\phi} - Ug \sin \theta = 0
\]  
(9)

\[
J_w \dot{\theta} + J_w \dot{\phi} = \tau
\]  
(10)

From these eq. the mathematical model of the system is determined in eq. 11:
\[
\begin{bmatrix}
A & J_w \\
J_w & 0
\end{bmatrix}
\begin{bmatrix}
\ddot{\theta} \\
\ddot{\phi}
\end{bmatrix}
+ \begin{bmatrix}
-Ug \sin \theta \\
0
\end{bmatrix} = \begin{bmatrix}
\tau \\
0
\end{bmatrix}
\]  
(11)

2. System Control Method

Different control methods are used at various stages in order to realize the movement of the pendulum from 0 degrees to 180 degrees with the least energy consumption. In the design of the pendulum, the movement is provided by a DC motor with control signals generated by the Arduino control card as shown in the fig. 2 block diagram. During the swing process, the angle and position information are measured by the encoder and conveyed to the control unit for feedback. In this study, two different methods are used.

The first is the swing up control of the pendulum and the second is the balance control of the pendulum with PID.

The Swing up control does not balance the pendulum to the desired vertical alignment but supports it to arrive in the angular range where the balance will take place. The position of the pendulum wheel is 0° at the beginning. The ramp function or any triggering is applied to start the wheel swinging. As a result of the trigger, the wheel starts to swinging clockwise and counter clockwise. The swinging should be supported to increase the pendulum from 0° to 180° degrees. This support is applied with the torque produced by the DC motor. The support torque is applied when the variable pendulum angle value is maximum and the angular acceleration is zero during the swinging process. As a result of these processes, the pendulum is increased to the desired swinging range. The pendulum control process switches to the balance control range when the swinging operation is complete[12].

Proportional-integral-derivative (PID) controllers are the most important control systems used to control processes, due to their simple and easy design, low cost and wide range of applications [13]. The main purpose of the PID control system is that the controlled process variable reaches the target in minimum time with minimum error difference. The PID control compares the reference value and feedback variables. In order to eliminate the error between two variables, proportional, integral and derivative parameters are applied to the system. These parameters modify according to the system model[14]. These Parameters are used in continuous cycling method and system response methods developed by Ziegler-Nichols. Large settling time and overshoot are minimized by \( K_p \) and \( K_i \) parameters.

3. Prediction Via Machine Learning

Machine learning software algorithms classify, handle and analyze the data in the system and, as a result, perform functions such as make decisions, prediction, and completion. As a result of the machine learning analysis, it increases the accuracy, precision and the value of efficiency by estimating according to similar input analyse data.

3.1 Data Collecting

In this study, 3 different diameter wheels were used in machine learning analysis. Each wheel is fixated with different weights. When the wheel pendulum project was running in different diameter and weight case, data collection operations were collected for machine learning by MATLAB-Arduino serial communication and observation data. As a result of the data collected, it has been measured whether the wheel has reached its balance position and how many swing periods have occurred to reach it.

Table 2. Sample of Wheel Characteristics And Balance data

<table>
<thead>
<tr>
<th>Wheel Radius</th>
<th>Wheel Intertia</th>
<th>Wheel Mass</th>
<th>Settling time</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>9R 550</td>
<td>110</td>
<td>90</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>9R 900</td>
<td>110</td>
<td>90</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>9R 1128</td>
<td>125</td>
<td>90</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>9R 1265</td>
<td>140</td>
<td>90</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>7.5R 666</td>
<td>85</td>
<td>77</td>
<td>80</td>
<td>1</td>
</tr>
<tr>
<td>7.5R 760</td>
<td>115</td>
<td>80</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7.5R 1200</td>
<td>195</td>
<td>90</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7.5R 1375</td>
<td>225</td>
<td>90</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6R 474</td>
<td>73</td>
<td>90</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6R 512</td>
<td>80</td>
<td>92</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6R 611</td>
<td>100</td>
<td>94</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6R 732</td>
<td>110</td>
<td>98</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Training Algorithm

The data were analyzed by MATLAB classification learner and trained for machine learning. As a result of the training, the best accuracy rate was determined and classified with k-Nearest Neighborhood (KNN) algorithm [15].

Euclidean distance was used in the KNN algorithm. Euclidean distance can be explained as the linear distance between two points in the classification process. $x = \{x_1, x_2, ..., x_n\}$ and $y = \{y_1, y_2, ..., y_n\}$ are used by handle the euclidean distance (d) eq. 13: between two points [16]. As a result of machine learning training, confusion matrix and ROC curve appear in the figure 4. True positive and true negative values are over %90. The accuracy is calculated as 92% in the ROC curve.

$$d = \sqrt{\sum_{i=1}^{k} (x_i - y_i)^2} \quad (13)$$

The accuracy, recall, precision and f-measure of the classification process were calculated to determine the true accuracy rate of the prediction system [17].

![Confusion matrix and ROC curve](image)

Fig. 4 Confusion matrix and ROC curve

- False negative (FN) = 0.10
- False positive (FP) = 0.06
- True negative (TN) = 0.94
- True positive (TP) = 0.90

Accuracy: $\frac{TP + TN}{TP + TN + FP + FN} = \frac{0.90 + 0.94}{0.90 + 0.94 + 0.06 + 0.10} = 0.90$ (14)

Recall: $\frac{TP}{TP + FN} = \frac{0.90}{0.90 + 0.10} = 0.90$ (15)

Precision: $\frac{TP}{TP + FP} = \frac{0.90}{0.90 + 0.06} = 0.9375$ (16)

F - measure: $\frac{2 \times \text{recall} \times \text{precision}}{\text{recall} + \text{precision}} = \frac{2 \times 0.90 \times 0.9375}{0.90 + 0.9375} = 0.918$ (17)

As a result of calculations, the actual success rate in the predict process was found to be 91.8 percent.

3.3 Test and Control Operation

The accuracy of the KNN algorithm is tested with values that are different from the training data shown in the table 3. The accuracy of machine learning was 83.33% compared to the predicted rate and the actual values.

<table>
<thead>
<tr>
<th>Wheel Radius</th>
<th>Wheel Intertia</th>
<th>Predict of Balance</th>
<th>Real of Balance</th>
<th>Acc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4R-350</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>5R-400</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>6R-750</td>
<td>140</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>7R-1025</td>
<td>100</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>7R-750</td>
<td>100</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>7R-1400</td>
<td>185</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>8R-1300</td>
<td>140</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>8R-1400</td>
<td>200</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>9R-1000</td>
<td>150</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>9R-1200</td>
<td>130</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>9R-1750</td>
<td>180</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>10R-2000</td>
<td>250</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>11R-2000</td>
<td>150</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>12R-2250</td>
<td>170</td>
<td>0</td>
<td>1</td>
<td>100</td>
</tr>
</tbody>
</table>

Total Accuracy: %83.33

4. Conclusion

In this study a control of nonlinear and underactuated system was achieved by swing up control and PID control at various angle stages. The most significant factors affecting the stability of IWP systems are wheel diameter and wheel weight. These inputs were applied to the IWP system with different values. In the control process, it was observed that the weight supported to balance position until the to an amount. In case the pendulum weight is light or too heavy, the balancing operation was not realized. As the wheel radius expands, the pendulum was more easily balanced with lighter weight in the process.

The novelty of this study unlike the other IWP studies is that the wheel parameters where the balance position takes place is trained by machine learning algorithm and predicts the balance position at different wheel types. When the machine learning balance estimate and the real balance position of the IWP were compared, it was found that the similarity was 83.33%.

As a result of this study, it can be predicted whether the IWP system is stable for the balance position according to the input parameter characteristics using machine learning. In the case of the predicted result of the IWP system is unbalanced, it will be determined that different wheel parameters should be applied for balance. In addition to the model dynamic calculations, the balance state of the IWP system will be determined more accurately. IWP applications will be more realistic because all the factors affecting the balancing process will be taken into account. In the continuation of this study, it is aimed that the input information will be entered into the control card via the interface screen and evaluated in real time with the machine learning.

5. References


Optimization of the parameters of the energy absorbing element of the armored combat vehicle's seat in the conditions of explosive loading

Leonid Davydovskiy¹, Serhiy Bisyk¹, Iliyan Hutov², Iliyan Lilov³, Alexander Kuprinenko⁴, Oleg Yalnytskiy⁵, Central Research Institute of Weapons and Military Equipment of the Armed Forces of Ukraine, Kyiv ¹, Ukraine
Bulgarian Research Institute of Defence - Sofia², Bulgaria, National Military University – Veliko Tarnovo, Bulgaria³
Hetman Petro Sahaidachnyi National Army Academy, Lviv ⁴, Ukraine
Ivan Chernyakhovsky National Defense University of Ukraine, Kyiv ⁵, Ukraine
davidovskiy14@ukr.net, sergey-new@ukr.net

Abstract: The principle of operation of the energy absorbing element, which consists in the conversion of kinetic energy acquired as a result of explosion, into the energy of plastic deformation of a material is considered. To evaluate and select an element, a typical algorithm for optimizing it is developed. This allows using qualitative criteria with the known value of the explosive load to choose the rational parameters of the design and material of the element that will be optimal for a particular armored combat vehicle.

Keywords: EXPLOSIVE LOADING, ENERGY ABSORBING ELEMENT, SEAT, ARMORED COMBAT VEHICLE

1. Introduction

Currently, researches in the field of a hull strength of armored combat vehicles (ACV) have made significant progress. Technical solutions, such as the V-shaped and energy-absorbent bottom structure, the power frame of the armored hull, the antimine screen, etc., allow to ensure the integrity of the ACV’s hull in the event of an explosion. Then, the so-called "throwing effect", caused by the high acceleration of the ACV, which can reach up to 600g in the seat, remains the main impact factor on the crew. This load can be countered with the help of the energy-absorbing seats of crew (EAS) (Fig. 1) [1-3].

Fig. 1 EAS of ACV: a) 1 - a geometric model of the EAS, 2 - place of installation of the EAE, 3 - the seat attachment; b) installation of the EAE.

The objective function of the EAS at blasting of the ACV is to reduce the acceleration to the allowable values of the human injury criteria [4]. The main role here isn't the design of the EAS, but the installation of the EAE (Fig. 1) [1-3].

Fig. 2. Full-scale experiment (right) and numerical simulation (left) of the explosion of the ACV by the explosive charge 6 kg TNT (according to STANAG 4569).

The error between the maximum values of the accelerations obtained during the physical and numerical experiments is 8.5%. This confirms the adequacy of the model for determining the explosive load on the EAS of the ACV for further investigation of the ways of adaptation of the EAE for specific loading conditions.

Progressive deformation of EAE can have different character: axisymmetric; non-asymmetric; mixed and global bending [6-9]. Obviously, much more energy is absorbed in the axisymmetric deformation mode than in the global bending mode, because in such conditions more material is subjected to plastic deformation [8]. The step of the plastic deformation zone also depends on the geometry of the profile (Fig. 3).

Fig. 3 Modes of deformation and plastic deformation zones of different EAE profiles: a - octagonal; b - cylindrical; c - rectangular; d - ellipse.

Optimization of EAE is carried out by a number of qualitative criteria: energy intensity; average and peak load of operation;
specific absorbed energy; absorbed energy per unit length; effective triggering force and optimal working stroke [6,10-13].

The main criterion for evaluating the efficiency of EAE is the amount of energy absorbed $E_A$:

$$E_A(\delta) = \int_0^{\delta_{max}} P_{opt}(\delta) d\delta,$$

(1)

where, $P_e$ is the initial destructive load, $\delta$ is the course of EAE (length of plastic deformed part), and $\delta_{max}$ is the maximal working stroke of EAE (the initial length of EAE).

The EAE must have the optimum triggering force, since the high force will lead to the failure to activate or not to use the entire working stroke of the EAE (Fig. 4a), and at low force there will be a breakdown of the EAE (actuation of the entire working body of the EAE) (Fig. 4d).

From expression (1) we can determine the destructive load:

$$P_e = \frac{\delta}{\delta_{max}},$$

(2)

In addition, the EAE can be defined as the load to which it is necessary to initiate the onset of its deformation, because the ideal condition for absorption is to achieve the force of the actuation and keep it constant throughout the entire working stroke. So, the amount of energy absorbed during blasting is proportional to the force of the actuation of the EAE $P_e$ and its working stroke $\delta_{max}$ (Fig. 4, shaded sections).

The average load for the axisymmetric deformation $P_{av}$ is defined as the ratio of the total absorbed energy $E_A$ to the total deformation, $\delta$:

$$P_{av} = \frac{E_A}{\delta},$$

(3)

In this case, $P_e$ and $P_{av}$ are the priority parameters for evaluating the effectiveness of the EAE. Therefore, in order to prevent injury to crew in the event of a blowout of the ACV, the value should not exceed the limit values of the injury criteria 14.5g, which corresponds to the permissible value of the injury criterion DRI<17.7 (Dynamic Response Index) [4].

The effectiveness of the triggering force is a qualitative criterion for the uniformity of deformation and is determined by the ratio of peak load $P_e$ to average $P_{av}$:

$$\eta_{of} = \frac{P_e}{P_{av}},$$

(4)

For the ideal energy absorption, the optimum triggering force should result in almost 100% activation of the EAE stroke.

Equally important characteristic of EAE is the specific absorbed energy $E_{SA}$, which is determined by the ratio of absorbed energy $E_A$ per unit mass.

$$E_{SA} = \frac{E_A}{m},$$

(5)

The value $E_{SA}$ is the most common parameter for evaluating the efficiency of an EAE in terms of its energy intensity, especially when overall dimensions are important.

In addition, this parameter is usually used as an indicator of the efficiency of the selected material for the EAE, depending on its density, and the mass [8,9].

During the deformation process, not all of the EAE stroke can be used to absorb the kinetic impact energy. The efficiency of EPE stroke is defined as:

$$\eta_{ws} = \frac{\delta}{L},$$

(6)

where $L$ is the initial length of the EAE.

With $\eta_{ws}$, we can determine the maximum allowable working stroke of EAE. Ideally, the initial length of the EAE $L$ should be equal to the working stroke of the EAE $\delta$, but in practice, the stroke efficiency is always less than one $\eta_{ws} < 1$.

Considering the above, the algorithm of optimization and estimation of EAE is constructed [13]. Using the developed algorithm, on the example of a numerical model of the blasting of the ACV, the choice of rational parameters of the EAS was made (Fig. 5).

**Fig. 4** Typical cases of EAE working with different characteristics: a - high $P_e$, the element doesn’t work; b - quite high $P_e$, not all stroke is used; c - optimal $P_e$, sufficiently used working stroke; d - low $P_e$, the breakdown of EAE.

**Fig. 5** The acceleration values for seats in the standard version (a) and in the EAS with the EAE (b).

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4. Literature


Studies of the efficiency of plain bearings used in microturbines

Исследования эффективности подшипников скольжения, применяемых в микротурбинах.

Karpukhin Kirill, Nadareishvili Givi, Kostukov Andrei, Umnitsyn Artem, Yakunin Ruslan

1 – FSUE "NAMI", Moscow, Russian Federation

E-mail: artem.umnicin@nami.ru

Abstract: The article assesses the possibility of using plain bearings (using the example of radial bearings) in high-speed microturbines (up to 60,000 rpm). The results of mathematical modeling of the thermal state of bearings and the oil layer between the shaft and the bearing surface are presented. A detailed description of the stand, designed to analyze the effectiveness of radial and thrust composite plain bearings, is given. The test bench allows testing of radial, thrust and rolling bearings, taking into account the deformation of the shaft from the weight of the turbine and compressor wheels of the microturbine. The results of an experimental study demonstrate high accuracy of calculations.

KEYWORDS: PLAIN BEARING, MICROTURBINE, TEST BENCH, FLUID BEARING, OIL WEDGE

1. Introduction

High-speed (up to 60,000 rpm) microturbines are a perceptive type of engine, providing high specific power, low vibrations, low fuel requirements [1, 2, 3]. However, at the same time, the efficiency (efficiency) of such engines is often lower than that of piston engines. One of the possible ways to increase the efficiency is the use of plain bearings in the design of microturbines [4, 5]. The main advantages of such bearings are vibration resistance, low noise level during operation, compact radial dimensions [6].

2. Mathematical modeling of fluid bearings

Friction losses in sliding bearings depend on the sliding speed and the area of wetted surfaces [7]. With a constant bearing diameter, the only way to reduce the bearing area is to reduce its length. However, it is necessary to take into account the distortion of the shaft under the influence of the load. Therefore, when calculating the bearing, the clearance should provide not only the displacement of the shaft axis to create an oil wedge, but also the minimum thickness of the oil layer even with a strong skew of the shaft.

An important issue is the determination of the required radial clearance in the bearing. The minimum possible clearance between the rotor and the bearing stator (critical oil layer thickness) should not be less than the total height of the microroughness, multiplied by a safety factor of 2 [8].

One of the key parameters is the coefficient pv [9, 10], which determines the indestructibility of the oil film with a lack of lubrication. The calculated bearing must meet these parameters [11, 12].

In the course of work, a variant of a radial plain bearing was considered. Based on the calculations, the skew of the shaft reaches 0.045 mm.

The pressure distribution with a diametral clearance of 0.1 mm is shown in Fig. 2.1 and Fig. 2.2.

Fig.2.1 - Bearing pressure without skew shaft

Fig.2.2 - Bearing pressure with skew shaft

The ratio of the bearing force created under such conditions to the required one as $K_{pv}$. If $K_{pv}$ is more than 100% - this means that the created lifting force is sufficient for bearingless operation. The calculation results are shown in table 2.1.

Table 2.1. Bearing Calculation Results

<table>
<thead>
<tr>
<th>Shaft position</th>
<th>$\delta$, mm</th>
<th>$e$, mm</th>
<th>$h_{min}$, mm</th>
<th>$N_{fr}$, kW</th>
<th>$K_{pv}$, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without skew</td>
<td>0.05</td>
<td>0.023</td>
<td>0.026</td>
<td>0.76</td>
<td>190</td>
</tr>
<tr>
<td>With skew</td>
<td>0.05</td>
<td>0.021</td>
<td>0.007</td>
<td>0.81</td>
<td>35</td>
</tr>
</tbody>
</table>

, $\delta$ - radial clearance, $e$ - eccentricity, $h_{min}$ - minimum thickness of the oil layer, $N_{fr}$ - friction loss power.

3. Calculation of the thermal state of the bearings

According to the results of mathematical modeling, the maximum power of the generated heat reaches 0.81 kW. In this calculation, we neglect the heat from the bearing to the environment and bearings, assuming that in the steady state all heat is removed by oil.

Oil consumption $Q$ will be equal (1).

$$Q = \frac{A}{\rho \cdot c \cdot (t_{out} - t_{in})}$$

, where $A$ - amount of heat; $\rho$ - oil density; $c$ - specific heat of oil; $t_{out}$ - oil temperature at the outlet of the bearing; $t_{in}$ - oil temperature at the inlet to the bearing.

Substituting the characteristics of the oil, and given a temperature difference of not more than 20 degrees, we obtain $Q=21.2$ cm³/s.

4. Test bench for microturbine bearing prototypes.

The test bench was designed and manufactured for bench testing of bearings designed for use in a microturbine. The stand is
designed to test radial and thrust bearings with a shaft speed of up to 60,000 rpm.

The design of the stand provides the following types of tests of microturbine bearings:

- measurement of temperature indicators of the tested bearings;
- measurement of shaft rotation frequency;
- measurement of the moment of resistance of the tested bearings.

The developed design of the test bench allows you to simulate the loads that arise during the operation of a typical design of a microturbine with cantilevered wheels. The general view of the test bench is shown in Fig. 4.1.

The electric motor (1) is a drive device for the shaft (2) passing through the bearing housing (3), which is mounted on the mounting table (4) through the bearing assembly (5). The movable housing design allows measuring the moment of rolling resistance that occurs in composite bearings.

The electric motor allows you to accurately control the shaft speed, as well as measure the relative torque. The electric motor is equipped with a bellows coupling to compensate for misalignment of the bearing housing shaft relative to the motor shaft.

The shaft of the test bench (Fig. 4.2) is made stepped, which allows you to test different models and types of plain bearings on this bench without changing the shaft.

On the lower edge of the bearing housing (Figure 4.3) there are five threaded holes designed to drain the oil. Adapters are screwed into each of these holes. They are equipped with temperature sensors used to assess the temperature of the drained oil. The drain line allows you to combine all the exits from the bearing housing, and bring the drained oil back to the oil station. The hoses used in the drain line have low bending resistance, which allows us to neglect the forces arising from the deformation of the hoses to determine the torque in the tested bearings.

A threaded hole is made in the side of the housing for installing the rod, designed to be moved to the load cell (Fig. 4.4). In addition, the bar provides space for the installation of balancing weights. On the other side of the housing, a threaded hole is also provided for installing the rod with balancing weights, which is necessary to minimize the imbalance of the entire assembly.

The supply line is mounted on a mounting frame, which allows you to transfer the center of rotation of the inlet fitting of the line to the axis of rotation of the housing and thereby minimize the measurement error. The supply line is equipped with three turbine type liquid flow meters, as well as taps that allow you to adjust the oil flow depending on the type of bearing being tested. A protective cover closes the shaft exit from the bearing housing (Fig. 4.5). This casing is necessary as an element of protection in case of failure of the investigated bearings and possible uncontrolled movement of the shaft of the bench with a simulation mass having high kinetic energy.

An oil hydraulic station is used as a device for injecting and maintaining the temperature of the lubricant into the tested plain bearings. Technical characteristics of the stand are shown in table 4.1.
5. The results of the experiment.

In the framework of this article, one type of test is considered that corresponds to the conditions of the mathematical modeling. The conditions of the experiment:

- Shaft rotation speed 60,000 rpm;
- Initial oil temperature 24 °C;
- Oil consumption: 21.2 cm³ / s.

A graph of the temperature of the oil at the outlet of the test bearing relative to is shown in Figure 5.1.

![Graph of oil temperature](image)

As you can see from the graph, the difference between the calculated and experimentally obtained values is less than 1.5°C, which is less than 5%.

5. Conclusion

In this article, a mathematical model was developed for calculating the distribution of oil and temperature in a liquid radial bearing. The model provides high accuracy of calculations, and also allows you to take into account the speed of rotation of the shaft and its skew.

A bench was also designed for testing the sliding bearings of a microturbine with a shaft rotation speed of not more than 60,000 rpm. The design of the stand allows you to analyze information about the temperature state of plain bearings under various conditions of oil supply. In addition, the design of the stand is made in such a way that it is possible to measure the moment of resistance that occurs in the bearings with minimal errors.

6. Acknowledgments

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7. References

Estimation of modal split parameters – a case study

Luka Nováčko1*, Karlo Babojelić1, Nikola Godić2, Lidija Babić1
Faculty of Transport and Traffic Sciences, Zagreb, Croatia1
Growth Strategies Ltd., Zagreb, Croatia2
E-mail: luka.novacko@fpz.unizg.hr, karlo.babojevic@fpz.unizg.hr, god.nikola@gmail.com, lidija.babicka@gmail.com

Abstract: Choosing a mode or type of transportation is certainly one of the most important steps in a classic transportation model, given that it has a significant impact on the traffic planning and transport policy of a city. The choice of transport mode (e.g. passenger car, public transport, bicycle, walking) depends on the availability of transport modes and the generalized cost of transportation by transport mode from origin to destination. The choice of mode of transportation is also significantly influenced by the trip purpose. The most commonly used model for determining the modal split is the logit model. Parameters of utility function for each mode were estimated based on a household travel survey in Slavonski Brod, Croatia using the Biogeme program. The generalized cost and impedance towards using each transport mode is expressed by the utility function. This paper presents a methodology for determining the utility function for each transport mode using the Biogeme program.

KEYWORDS: MODE CHOICE, LOGIT MODEL, UTILITY FUNCTION, BIOGEME

1. Introduction

The mode choice of transport is the third step in a four-step modeling process and is one of the most important steps. It has a significant impact on the traffic planning and traffic policy of the city. The transport mode choice (e.g. car, public transport, bicycle, walking) depends on the availability of transport modes (especially passenger car) and the travel cost for each mode from origin to destination. Factors influencing the mode choice can be divided into three groups of characteristics (1) passenger characteristics (car ownership; possession of a driver’s license; household structure (youth, couple with children, pensioners, singles, etc.)); income; (2) characteristics of travel: trip purpose - trip to work is usually easier to do by public transport due to its regularity, part of the day when traveling; (3) features of the transport system: travel time components: in-vehicle time, waiting time and walking time to each transport mode, monetary cost components (transport ticket, tolls, fuel costs and other operating costs), availability and parking costs, reliability of travel time and regularity of service; comfort and convenience; driving safety and protection while driving; driving skills requirements; opportunities to carry out other activities while driving (telephoning, reading, etc.) [1].

The basic problem of discrete mode choice analysis is the modeling of choices between a set of different alternatives. Utility maximization is taken as the solution. The decision maker selects the alternatives with the greatest utility over the time period. The operational model consists of a parameterized utility function consisting of independent variables and unknown parameters estimated from the sample. The probability of selecting an alternative is defined as the probability that has the greatest utility among all possible alternative solutions [2].

The choice of alternative can be observed because of a multi-stage decision-making process:
1. definition of the choice problem,
2. generation of alternatives,
3. evaluation of attributes of the alternatives,
4. choice of alternative,
5. implementation.

Choice theory is a set of procedures consisting of the following elements: (i) decision maker, (ii) alternatives, (iii) attributes of alternatives, (iv) decision rule. Not every choice behavior of individuals is described by such a decision-making process. An individual may choose a mode of transportation according to a habit, intuition, or imitation of someone else who is considered as an expert or leader. This behavior is presented as a decision-making process in which the decision maker generates only one alternative.

The modal distribution is determined using discrete choice models, ie Logit models. The most widely used discrete choice models are multinomial (MNL) and nested (NL) logit model. Multinomial logit models imply a larger set of alternatives in the final data set (eg alternatives can be car - driver, carpooling, taxi, bicycle, walking, bus, tram, train), while nested models consist of a group of similar alternatives grouped in a nest, in which each alternative belongs to only one nest. A multinomial logit model was used in this study:

\[ P_n(i) = \frac{e^{v_i}}{\sum_{j \in C_n} e^{v_j}} \]

where:
- \( P_n(i) \) = probability of choosing an alternative \( i \),
- \( v_i \) = calibration parameter,
- \( v_i \) = utility of mode \( i \).

The aim of this paper is to estimate the parameters of the utility function for each mode of transport using the Biogeme program based on a household survey. Generalized cost and resistance to a mode of transport are expressed using the utility function. This paper presents a methodology for determining the utility function for each mode of transport using the Biogeme program.

2. Modal split in Croatia by National Transport Model

The National Transport Model for the Republic of Croatia was completed in June 2016, and the model represents the second phase of the development of the Transport Development Strategy of the Republic of Croatia 2017 – 2030. [3]. The reference year for the analysis of the current state of the transport sector in the National Transport Model is 2013, since it is the only year for which all data were available. As part of the research for the needs of developing the National Transport Model in the Republic of Croatia, a travel behavior survey was conducted.

Figure 1. presents the proportion of all trips taken by different modes of transport. The most used transport mode was car with about 51% of all trips (40.8% as a driver and 10.4% as a passenger). Walking was the second most used travelling mode with the proportion of 30% of all trips. The bus was the most often used public transport mode with a share of 7.1%, while overall around 12% of all trips were made by public transport (bus, tram, train, and ferry). About 5% of all trips were made by bicycle [3].
Figure 1. Proportion of all trips taken by different mode of transport at the national level (Source: [4])

According to National Transport Model Croatia is divided into two NUTS regions: Continental Croatia and Adriatic Croatia. Figure 2 shows a map of NUTS-2 regions in Croatia.

Figure 2. Map of Republic of Croatia NUTS-2 regions

The proportion of all trips taken by different transport modes at the regional level reveals a significant difference between Continental and Adriatic Croatia. The ranking order of the mode shares was the same for both regions, though citizens from Adriatic Croatia made more trips by car and by walking while citizens from Continental Croatia used public transport and bicycle more often (Figure 3).

Other results indicate that about 5% of all trips were made by bicycle. Compared to Continental Croatia, citizens from Adriatic Croatia made almost 40% more car trips, 60% more walking trips, 32% fewer public transport trips, and 65% fewer bicycle trips.

3. Case study – Slavonski Brod, Croatia

The household survey was conducted as part of the development of the Sustainable Urban Mobility Plan of the Urban Area of the city of Slavonski Brod (Croatia). Slavonski Brod is in Brod-Posavina County, which is part of Continental Croatia according to the NUTS-2 division. The survey was conducted on a random sample of households, by direct interview, on representative days, in October and November 2019. A total of 5% of the total number of households in the study area were surveyed. The survey was conducted in the household where trained interviewers asked questions related to general household data and data on all trips of each household member that occurred the previous day (origin and destination of trips, travel time, trip purpose, mode choice). A total of 752 household surveys were collected in 36 residential zones.

![Figure 3. Proportion of all trips taken by different modes of transport, at the regional (NUTS-2) level (Source:[4])](image)

The parameters of the utility function for each transport mode were determined by the PandasBiogeme program code. Four types of transport modes were considered: car, bicycle, walking and public transport. The package Biogeme [5] is designed to estimate the parameters of various models using maximum likelihood estimation (MLE). It is particularly designed for discrete choice models. Biogeme is available in three versions.

- **BisonBiogeme** is designed to estimate the parameters of a list of predetermined discrete choice models such as logit, binary probit, nested logit, cross-nested logit, multivariate extreme value models, discrete and continuous mixtures of multivariate extreme value models, models with nonlinear utility functions, models designed for panel data, and heteroscedastic models. It is based on a formal and simple language for model specification.

- **PythonBiogeme** is designed for general purpose parametric models. The specification of the model and of the likelihood function is based on an extension of the Python programming language. A series of discrete choice models are precoded for an easy use. The package is written in C++ and is standalone.

- **PandasBiogeme** is a Python package, that must be imported in a Python code. It relies on the Pandas package for the data manipulation. This is the standard mode of operations of more and more data scientists. The syntax for model specification is almost the same as PythonBiogeme.

The data table from household survey must contain information about trips, travel time for each transport mode and the respondents choice of the transport mode. Each column corresponds to a specific variable, and the row corresponds to a value.

<table>
<thead>
<tr>
<th>Trip_ID</th>
<th>TT_CAR</th>
<th>TT_BIKE</th>
<th>TT_PUT</th>
<th>TT_PED</th>
<th>CHOICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>24</td>
<td>68</td>
<td>106</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>16</td>
<td>40</td>
<td>61</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>4</td>
<td>29</td>
<td>61</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>16</td>
<td>28</td>
<td>58</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>16</td>
<td>20</td>
<td>59</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>94</td>
<td>19</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>18</td>
<td>20</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>82</td>
<td>31</td>
<td>69</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>17</td>
<td>37</td>
<td>68</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>14</td>
<td>32</td>
<td>55</td>
<td>1</td>
</tr>
</tbody>
</table>
The variables defined in the program code were:
- \( \text{Trip-ID} = \text{trip ID} \),
- \( \text{TT-CAR} = \text{travel time by car [min]} \),
- \( \text{TT-BIKE} = \text{travel time by bicycle [min]} \),
- \( \text{TT-PUT} = \text{travel time by public transport - bus [min]} \),
- \( \text{TT-PED} = \text{travel time by walking [min]} \),
- \( \text{CHOICE} = \text{choice of transport mode} \).

The parameters that need to be evaluated to define the logit function are:
- \( \text{ASC-CAR} = \text{(alternative specific constant car)} \),
- \( \text{ASC-BIKE} = \text{(alternative specific constant bike)} \),
- \( \text{ASC-PUT} = \text{(alternative specific constant put)} \),
- \( \text{ASC-PED} = \text{(alternative specific constant ped)} \).

The utility function is defined for each transport mode where the travel time of each transport means is considered:
- \( V_1 = \text{ASC-CAR} + \text{B-TIME} \times \text{TT-CAR}_\text{SCALED} \),
- \( V_2 = \text{ASC-BIKE} + \text{B-TIME} \times \text{TT-BIKE}_\text{SCALED} \),
- \( V_3 = \text{ASC-PUT} + \text{B-TIME} \times \text{TT-PUT}_\text{SCALED} \),
- \( V_4 = \text{ASC-PED} + \text{B-TIME} \times \text{TT-PED}_\text{SCALED} \).

Each utility function must be associated with the number or identifier of each alternative using numbering as in the data table (table 1).

\[ V = \{1: V_1, 2: V_2, 3: V_3, 4: V_4\} \]

After defining the utility function, it is necessary to assign each utility function to a specific transport mode using numbering as in the data table. The following numbering was used:
- \( \text{CAR} = 1 \),
- \( \text{BIKE} = 2 \),
- \( \text{PUT} = 3 \),
- \( \text{PED} = 4 \).

\[ \text{av} = \{1: \text{CAR}_{AV\_SP}, 2: \text{BIKE}_{AV\_SP}, 3: \text{PUT}_{AV\_SP}, 4: \text{PED}_{AV\_SP}\} \]

Next, the choice model is defined. The function \( \text{bioLogLogit} \) provides the logarithm of the choice probability of the logit model. It takes three arguments:
1. the dictionary describing the utility functions (\( V \)),
2. the dictionary describing the availability conditions (\( \text{av} \)),
3. the alternative for which the probability must be calculated (CHOICE).

\[ \text{logprob} = \text{bioLogLogit}(V, \text{av}, \text{CHOICE}) \]

The results of the estimated parameters for each mode of transport are shown in Table 2. It is concluded that the p-value of the analyzed parameters is less than 0.05, which means that the results are statistically significant.

**Table 2. Estimation parameters from Biogeme**

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Std err</th>
<th>t-test</th>
<th>p-value</th>
<th>Rob. Std err</th>
<th>Rob. t-test</th>
<th>Rob. p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASC_BIKE</td>
<td>-0.29</td>
<td>0.04</td>
<td>-6.74</td>
<td>1.55e-11</td>
<td>0.04</td>
<td>-6.81</td>
<td>9.82e-12</td>
</tr>
<tr>
<td>ASC_CAR</td>
<td>1.41</td>
<td>0.03</td>
<td>43.80</td>
<td>0.00</td>
<td>0.03</td>
<td>45.50</td>
<td>0.00</td>
</tr>
<tr>
<td>ASC_PED</td>
<td>0.65</td>
<td>0.04</td>
<td>18.40</td>
<td>0.00</td>
<td>0.03</td>
<td>18.70</td>
<td>0.00</td>
</tr>
<tr>
<td>ASC_PUT</td>
<td>-1.77</td>
<td>0.08</td>
<td>-23.20</td>
<td>0.00</td>
<td>0.07</td>
<td>-24.20</td>
<td>0.00</td>
</tr>
<tr>
<td>B_TIME</td>
<td>2.00e-05</td>
<td>2.33e-05</td>
<td>-2.18</td>
<td>0.0295</td>
<td>2.63e-05</td>
<td>-1.92</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The values of the utility function parameters obtained by the computer program PandasBiogeme were used for development of a multimodal transport model of the urban area of Slavonski Brod. The multimodal transport model was developed in the computer program PTV VISUM [6].

Data validation was made by comparing the data obtained by the multimodal transport model and the data collected by the household survey. Figure 4 shows a comparison of the modal distribution obtained by the household travel survey in Slavonski Brod, the multimodal transport model of Slavonski Brod and National Transport Model (Continental Croatia (NUTS-2 region)).

It is concluded that the difference of the parameters obtained by Slavonski Brod model from the household survey for transport modes is as follows: for public transport (PuT) the difference is 0.2%, for bicycle (BIKE) 0.3%, for walking (PED) 0.8% and for car (CAR) 0.1%.

Comparing the results from the National Transport Model (Continental Croatia) and the results from the Slavonski Brod model, the modal distribution for public transport (PuT) differs by 11.7%, for bicycles (BIKE) 3.8%, walking (PED) 0.3% and cars (CAR) 9.4%.

![Figure 4. Comparison of Modal Split of Household Survey, Model and NTM](image)

**4. Conclusion**

The modal distribution is the third step in the classic four-step model. The choice of transport mode is influenced by certain factors that can be divided into passenger characteristics, travel characteristics and transport system characteristics.

The application of discrete choice models determines the modal distribution. The most widely used discrete choice models are the multinomial logit model (MNL) and the Nested logit (NL) model.

The aim of this paper was to estimate the parameters of the utility functions for each observed transport mode using the PandasBiogeme program. The estimation of the parameters is based on a household survey conducted in the city of Slavonski Brod (Croatia). Slavonski Brod is part of Continental Croatia according to the NUTS-2 division.

The estimated utility functions parameters were implemented in the multimodal transport model. The data were analyzed and compared with the conducted household survey in Slavonski Brod and the modal distribution obtained by the National Transport Model.

The difference between the estimated modal distribution of the household survey and the multimodal transport model is less than 1% for all modes of transport. While the difference between the estimated parameters of the Slavonski Brod model and the National Transport Model is a bit larger, but not significantly. However, it must be considered that in the National Transport Model all cities of Republic of Croatia were analyzed in 2013.

**5. References**

Introduction

We are witnessing that numerous car shows have been canceled due to the crisis caused by the emergence and spread of the virus corona throughout the world. An epidemic caused by a corona virus has put a stop to the European auto industry. Car manufacturing is at the heart of European industry, as it employs directly or indirectly, almost 14 million people and this message comes from the European Automobile Manufacturers Association. Today in the time of pandemic the workers of factory “Fiat” in Serbia are on the forced leave.

NEWS IN THE AUTO MOTOR WORLD

The transport sector is the fastest growing energy consumer and producer of greenhouse gases. The new decade symbolically heralds the year of innovations and advancements in automobile sector. Dutch company “Lightyear” has announced that the first “long-range” solar-powered car arrives in 2021. “Lightyear One” will be charged on the household socket, and with a charged battery will be able to cover a distance of 725 kilometers.

At the fair in Las Vegas, a special place was given to electric “Mustang” with 900 hp. Among the many versions of “Ford Mustang”, for this model six-speed manual transmission was designed and the driver has at disposal three regimes, and the system is controlled by a large central touch screen.

The new European drone regulation, in effect July 1st 2020 will require new compliance and registrations by their users. Unfortunately, during 2019, the public learned that “Audi” is withdrawing 138,000 A3 models of the following class, because their airbag does not open due to a malfunction, (models were manufactured between years 2015 and 2019) and these are: 2015-2019 A3 Sedan, 2015-2019 A3 Cabriolet (convertible), 2016-2018 A3 E-Tron (plug-in hybrid), 2017-2019 RS3 (based on the A3), 2015-2016 S3 Sedan (based on the A3).

Also the new “Audi S8” is highlighted. During July 2019, unfortunately, the public learned that the Volkswagen’s choice was: Turkey is more important than Republic of Serbia, i.e., the Volkswagen’s Board of directors announced that it has chosen a location for a factory near the Turkish coastal city of Izmir, and Qatar has probably contributed to this decision (holding 17% of the capital in the German giant). However, a decision has not yet been made ... the outcome is expected!

At the end of 2019, the merger of “Fiat Crasler” and “Peugeot - Citroen”, the two auto giants on the basis of 50:50 and production of 8.7 million cars a year were announced. More recent information comes with the knowledge that these car companies which are in negotiations will sign the merger agreement, which would create the fourth largest car producer in the world.

At the fair in Las Vegas, a special place was given to electric “Mustang” with 900 hp. Among the many versions of “Ford Mustang”, for this model six-speed manual transmission was designed and the driver has at disposal three regimes, and the system is controlled by a large central touch screen. The new European drone regulation, in effect July 1st 2020 will require new compliance and registrations by their users.

Also worth mentioning are the new “Škoda” KamiQ, the “Citroen” C4 Cactus, then the technologie hybrid “Renault” (3 year warranty on 100,000 kilometers) and the BMW X8 is coming soon and promotion can be expected in late 2020 or early 2021.

“BMW” has also introduced a powerful M2 CS that looks powerful with 450 horsepower under the bonnet. Only 2200 copies of this “pocket rocket” will be produced, with maximum speed limited to 280 kilometers per hour, but with the removal of the limiters it can increase up to 300 km/h. It is significant that in addition to the civilian version of BMW will offer racing “CS racing”, because this car certainly belongs on the racetrack.

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“Folkswagen” is also preparing a boom on the market and that is the ordinary Golf, the eighth generation technically superior to the previous or electrical ID.3, with a range of up to 330 kilometers. Company “Mercedes” does not surrender, and so a new version of the recently updated models GLC and GLC cupe has arrived. \(^1\) Production of the new “Nissan Juke” began in October 2019, while production of the “Toyota Land Cruiser” has already exceeded 10,000,000. The premiere of the total all-new “Yaris” came next. The big-small “Yaris” is designed for urban life today. The small electric “Renault” arrives in Europe. Reno’s affordable model “City K-ZE” is currently sold only in China, but the special version of the “K-ZE” is coming to Europe, where it will be more expensive due to certain changes and upgrades. Otherwise, the “City K-ZE” is powered by a 44hp electric motor, reaching a maximum of 105 km /h.

Interesting is also the phenomenon of electric scooters that became almost mandatory means of transport in cities throughout the world. These vehicles necessarily need legal restrictions, and it is interesting that Germany already limits the use of electric scooters.

KEYWORDS: AUTO, REGULATION, WORLD, SERBIA

\(^1\) It is “Mercedes GLC 43 AMG”.

\(^2\) There are 44,000 electric cars registered in Norway and 48,000 in Germany.
Europe by the number of sold electric cars. Far ahead of everyone is still China, with about 628,000 E-vehicles registered between January and June 2019. The famous British brand "Lotus" with a new owner from China ("Gili") presented a new hypercar, "Evia"4, an electric two-seater with 2000 horses, which will be produced in only 130 copies, as the most expensive project in the history of "Lotus". Production should start next year.

The Japanese "Korola" is a hybrid version of the best-selling car of all times. It emerged in 1976, and today the 12th generation of this Japanese car with the new platform and the new look is in front of us. Experts say also with the new sensation in driving, because there is no more diesel engine. The gasoline engine is now lighter and the consumption and emissions of harmful gases are lower.

It is said about smart cities and buildings, alternative energy, energy savings, recycling; the bike is being used more and more, electric scooters have covered the city. In Finland, for example, you can book the nearest city car for you through the mobile phone application, drive it and leave it, where you want. The applications also serve for noise measurement in the city, and citizens of the Finnish capital, Helsinki, are the moving noise measuring devices. It is interesting that during Auto Fair in Frankfurt thousands of citizens demonstrated asking for more activities because of climate changes. It was announced that "strong cars are climate killers"3, and the protest organizer's demands were: to stop using combustion engines, climate-neutral traffic by 2035, speed limits on the highway and a strong German climate policy package.

Environmental groups cite the trend toward bigger and more powerful cars, especially SUBs, contrary to the increase in fuel efficiency in recent decades.

AUTO WORLD IN THE PERIOD OF PANDEMIC

We have witnessed the great struggle of the Chinese people with the epidemic of the deadly coronavirus (Covid-19) virus. All over the world people faced the same problem, especially in Italy, Spain, USA, England, Romania, Brasil, in Serbia too. One can say a superhuman struggle for every life and the effects of calming the epidemic and the gradual normalization of the situation are slowly coming to light, especially in parts of China that have been the most exposed and with the highest casualties among the population.

And before the outbreak of the pandemic caused by this virus, information from exhibition in Tianjin in China came on the helicopter called a "super-sized white shark"4, which resembles a flying saucer, and its prototype is scheduled to launch its first flight in 2020.3 That's how it was planned, and today it is certain that the term has been changed. American National Aeronautics and Space Administration (NASA) has unveiled the "Mars 2020 Rover", which was planned to be launched in July 2019, with its destination in a dried up lake bed on Mars, where it should land in February 2021.

The significant is success of the Korean manufacturers of "Kia" and the electric models that are increasingly in demand. The largest showroom in the region, "Kia Motors Corporation", has been also opened in Serbia, before pandemic. The best-selling model is the "Kia sid".

EXPERIENCE OF SERBIA

In Serbia there is shortage of about 10,000 drivers and from 80,000 active, already about 10,000 so far took the card and certificate for driving motor vehicles through Europe. Drivers are still in the category of the most wanted professions. In Belgrade City Transportation Enterprise is planning to hire 110 new drivers for the largest city carrier.

What are citizens of Belgrade transported by? By the "spaniards" (trams), scooters and "sparrows" (electrical buses operating in the pedestrian zone of the center of the city).

Belgrade needs a metro, though metro is not the only criterion of a smart city. Metro is being built to reduce the number of cars on the streets and to reduce the pollution. The task for all urban transport vehicles is to be "Euro 6" standard, in order to reduce nitrogen oxide emissions for about 80% and to reduce PM emissions by half. The City of Obrenovac will participate in the making a study for the installation of base stations for electric car charging.

The public vehicles began to transport the inhabitants of our capital 27 years ago and there were various vehicles, and the pollution were horse-drawn trams. Today arrival announcements have been modernized .... More decades of traffic problems will largely be resolved by the first subway lines.

Waiting for the metro, the cornerstone should be put in 2020 and today the citizens of Belgrade use rail transport -BG train- (established in 2010) and considered to be the most accurate public transport in the capital. The BG train network has been expanding in recent years, and the authorities promise not to cancel this train with the departure of the first subway. In September 2016, the first e-buses, which became passengers' favorites, began to cruise.

There are more and more electric scooters today, and their introduction in the law is also planned.

CONCLUSION

The state of our planet continues to deteriorate at an alarming rate. Viruses are the most serious threat to humanity. There is a race around the world for a vaccine against this viremia.

Despite all the technical advances across the globe, we are experiencing today with significant climate change also the damage in traffic of about € 120 million that due to the pandemic is caused, i.e. consequences are suffered by road, rail and water traffic, while the most affected is air traffic.

And when the epidemic lets up and stops, the electric car for everyone - the "Opel Corsa" with a range of 337 km - will make us happy. Corsa's "Selection" is the new sixth generation, as well as the "Edition" and Corsa's "Elegance", that won the prestigious "Connected Car Award".

There was a revolution in transportation. Britain is legalizing electric scooters, because the proposed amendments to regulations will allow electric scooters to become legal. The Ministry of Transport in the United Kingdom is responsible for harmonization of regulation and technical rules in order to ensure that electric scooters can be safely used on the British roads (for start in 4 zones: Portsmouth and South Hampton; West England; Derby Nottingham, as well as the West Midlands). Hoping that Great Britain will consolidate a position of leading innovator.

We hope that vaccine against corona virus will be found soon having in mind that numerous scientists all around world are working on its invention.

References

4. Electric scooter (from the company Denver electronics SCO-54220, product from Denmark) with a power of 300W is sold in Serbia for 32 000 dinars, with maximum speed up to 20km/h, the electric brake is on the front wheel and the foot brake on the near, the diameter of the wheel is 6.5 inches, weighing 9.9 pounds and capacity of up to 100 pounds. Display: review - speed, distance, battery consumption.
Development of railway junction Sofia based of project for reconstruction and modernization

Vladimir Popov
University of architecture, civil engineering and geodesy, Sofia, Bulgaria
vpopov.fte@gmail.com

Abstract: From 2013 to 2015, an “Instrument for the preparation of railway projects on the trans-European transport network” is implemented. The project is funded under Priority Axis 5 “Technical Assistance” of the Operational Program Transport 2007-2014. A total of 11 project preparation lots are being developed. The most important are the projects for the development of Sofia railway junction, Burgas railway junction, reconstruction and modernization of existing stations, preparation of detailed development plans and technical design for new stops and buildings, assessment and verification of compliance with the requirements for interoperability. For the technical design phase, the following projects are being developed: “Modernization of the Sofia - Dragoman railway line”, “Modernization of the Sofia - Pernik - Radomir railway line”, “Development of the Sofia railway junction” and “Development of the Burgas railway junction”. Field surveys are conducted to search for archaeological sites within the scope of the projects. The article examines projects in terms of the need for exceptions to Ordinance 55.

Keywords: DESIGN OF RAILWAY LINES, RAILWAY STATIONS, INTEROPERABILITY OF EU RAILWAYS

1. Introduction

The Operational program Transport 2007-2014 is preceded by the ISPA Pre-accession program [1, 2] and a number of preliminary developments and studies [3] for the main railway lines in Bulgaria. Under the project for development of railway junction Sofia [4] technical projects and detailed development plans for railway stations and sections are elaborated: Voluyak, central railway station Sofia, Poduyane, Poduyane distribution, Iskar, Kazichene, Stolinik, Sofia-north, Iliyantsi, Birimirtsi and railway section Kazichene - Elin Pelin Fig. 1.

The Sofia railway junction is located on the Orient/Eastern - Mediterranean corridor of the main European TEN-T network, making it the largest railway transport center in Bulgaria. The project and other similar studies [5] are included in the Sofia Master Plan Essentially, as part of the project for the development of the Sofia railway junction, another, third, railway track is being designed in the section from Voluyak station to Elin Pelin station. It will be specialized in freight transport.

The Sofia - Voluyak project has optimized and reconstructed the turnout track development in Sofia Central Railway Station. A feature of this project is the recommendation of the National Institute of Real Cultural Heritage (NIKNN) for the preservation of the existing reception building at Voluyak station, which causes difficulties in the process of designing the new track development at the station.

2. Exceptions to the norms

Exceptions to the norms [6] are associated with a reduction in design speed, small distances between the beginning or end of the turnouts to the beginning of a transient curve to the end of transient curve (shorter than 25 m), leveling arms shorter than 500 m, leveling slopes in a station larger than allowed in Ordinance 55 [7].

3. Reduction of maximum speed

The maximum design speed [8] is determined by the radius of the horizontal curves, the allowable unbalanced accelerations, the category of railway lines and regulations. Most often it is a short section between the railway turnouts lying on the main track of a station and/or an existing horizontal curve with a small radius.

The compromise was allowed because the normative documents during the construction allowed it. Now the section becomes part of an international transport corridor and the radius needs to increase, but there is no room for a new curve to develop: a short railway section, a limitation in terms of easement boundaries, etc.

For example, the curve after Sofia Central Station in the direction of Sofia North - Fig. 2.

Fig. 1 Master plan of railway junction Sofia

Fig. 2 Sofia Central Station - Sofia North Station

The speed in the section from Sofia Central Station to Sofia North Station should be 100 km per hour and in the project is 60 km per hour, due to lack of sufficient distance and the presence of curves of radius R = 300 m without cant [9] in the tracks of Sofia Central Station i.e. the possible maximum speed is 40 km per hour in the station area because of the radii of lateral track of turnouts.

4. Vertical alignment arms below 500 m and a longitudinal slope of more than 1,5 % of station platforms

The minimum length of the elements of the longitudinal profile (leveling arms) is 500 m, according to Ordinance 55, Art. 41 (1) [7]. The distance between the vertical curves of two adjacent tilts shall not be less than Vpr/4. Exceptionally, in severe terrain or other troubled conditions, the length of an element of the longitudinal profile may be less than that prescribed in par. 1, but not less than 200 m.

This is the case with an existing bridge at km 1+709 near Sofia North Station [6]. The length of the leveling element is 245 m. Which is less than 500 m but more than the minimum value of 200 m. The rationale is the cost of construction (construction of a new bridge), the reduction of the level of tracks in the station by 36 cm, difficulties with water leakage, due to the decrease of the level of the bridge by 1.71 m and drainage of the section. Moreover, the existing situation has short leveling elements, and according to the
According to Ordinance 55, Article 115 (1) [6], in case of new construction, the station tracks, including the turnouts track line, shall be built horizontally and, exceptionally, in a slope not exceeding 1.5 %. In Iliyantsi station part of the station has a slope of 5.53 % and the track turnout’s line has a longitudinal slope of 3.52 %. If a 1.5 % junction is reconstructed, the level will be raised by 0.90 cm (bottom of figure 3). There is a problem with joining an industrial branch and the existing railway to Svetovrachene.

The reconstruction of Iliyantsi railway station is shortly said, from the existing 25 tracks to design 12 tracks Figure 4 and Figure 5. Iliyantsi railway Station is an existing junction station from which directions go to Sofia, Kurilo (Mezdra) and Svetovrachene (Yana). A design version has been developed in line with the future doubling to the Stolnik railway line.

The existing Iliyantsi station has 25 tracks, 11 of which are departure and departure points. The 11th to the 21st tracks are distributive, but currently they are used only as garages, and from the 22nd to the 25th tracks are maneuvers intended for local activity. Iliyantsi railway station is from second railway line. The longest track is 770 m long.

Passenger traffic is served by 4 platforms. The station serves several industrial branches, which are located in all four directions from the station. It is a junction, separates the movement of trains in the directions of Voluyak, Sofia, Divisional post Birimirtsi, Karlovo and Mezdra. Iliyantsi Railway Station is a second category and is located 4+847 km along the second railway line between Sofia North and Kurilo railway stations.

A third railway line starts from this station (Sofia - Karlovo - Burgas). The direction of the kilometer is from Sofia North to Kurilo. As for the main direction, the whole Iliyantsi station is right. Station platform partly inclined 2.5 %.

The main problem here is fire requirements. It is necessary to design a fire road every 10 tracks and necessary statutory fire hydrants on the platforms.

Figures 6 and 7 show the necessary railway crossings. They must meet all safety requirements [10, 11]. They have a special load [12] and flooring [13]. The railroad crossings are not horizontal. The motor way and the railway line have a different longitudinal slope, as shown in Fig.6b and Fig.7.

With the permission of a specialized expert council, the fire road is deployed, exceptionally after 12 railway track. The exception is offset by the provision of additional hydrants on the platforms and the construction of an additional reservoir for the supply of water.
5. Distances below 25 m between start (end) turnout and start (end) transition curve or vertical curve

According to Ordinance 55 [6], art. 73. (1) it is not allowed to place turnouts in the interstation in transitional and vertical curves. The distance from the beginning or end of the turnout to the beginning of a transition curve or a vertical curve is at least 25 m. The exceptions are mainly at Sofia North Station. For example, in front of turnout # 2 towards the beginning of the transition curve, the distance is 6.0 m. It is not less than 6.0 m. An increase of 25 m would mean moving the whole curve. Paragraph 73 of Ordinance 55 [6] explicitly states that this is a long distance railway section between two neighboring stations.

The project of Sofia North is under difficult conditions and in urbanized territory and should be designed as reconstruction [1]. Another problem is the arrangement of the vertical curves relative to the transient curves, bridges and rail turnouts. According to Ordinance 55, Art. 40 (4) vertical curves are located outside the beginning of the transition curve as well as beyond the bridges. The distance from the beginning or end of a transition curve or bridge to the beginning of a vertical curve must be at least 25 m. For category II-th and III-th rail lines, exceptionally in distressed conditions, a distance of at least 6 m may be allowed.

The vertical curve ends 9.65 m from the bridge at km 20 + 065 from the Kazichene - Musachevo railway line, which is more than 6 m designed reinforced concrete railway bridge. The bridge has a continuous ballast prism.

The exception does not reduce traffic safety, the safety of passengers, railway officials and other people, does not increase the likelihood of dangerous consequences and does not affect the interests of other agencies.

Another characteristic exception is the vertical curve that ends 14 m from the bridge at km 20 + 065 from the Kazichene - Musachevo railway line, which is more than 6 m designed reinforced concrete railway bridge. The bridge has a continuous ballast prism.

From km 19 + 982,253 to km 20 + 029,747 the vertical curve of the railway line is designed. The vertical curve of radius R = 5800 m is located 14,319 m from the beginning of the bridge.

The design of a vertical curve near the reinforced concrete bridge from km 20 + 044,066 to km 20 + 085,520 (14,319 m) was made due to the difficult conditions in this area. Levels should take into account the existing track elevations, the boundaries of ownership of the National railway infrastructure company, the crossing at km 19 + 852,328 and the level of high waters in the river below the bridge. The longitudinal profile shows that the bridge is at its highest point in this section, so that the river below the bridge can flow without disturbance. Due to these complex conditions, no reasonable solution can be found for moving the vertical curve farther from the bridge structure.

The decision to move the vertical curve to Kazichene would mean that the other conditions of Ordinance No. 55 [6] could not be fulfilled (the leveling arm length is 500 m). The decision to move the vertical curve to Stolnik would mean that the bridge should be placed lower and the high water level of the river limited. Both solutions would increase costs without additional benefits for the design solution.

The presented decision, which is an exception, meets the minimum length of 6.0 m, which is mentioned under complex conditions in Art. 40, par. 4 of Ordinance No. 55 [6]. The proposed exemption does not reduce the safety of traffic, the safety of passengers, railway employees and other people, does not increase the likelihood of dangerous consequences and does not affect the interests of other agencies, while complying with the requirements of § 2 of the CPA of Ordinance No. 55 of January 29, 2004. Exceptions will not increase the necessary investment costs or the cost of subsequent maintenance of the railway.

The speed limitation in the sections is as in the already performed section Vidin - Calafat for 160 km / h and the border station Vidin [14]. The speed reduction, as in item 3 of the article, is also within the Pleven railway junction [15]. In the section between Pleven West Station and Pleven Central Station there is a curve with a small radius, which limits the maximum speed along the main Sofia - Pleven - Varna railway line.

6. Conclusions

Exemptions from the norms for the design of railway line reconstructions are unpleasant but necessary because of:

- requirements laid down in the terms of reference and the technical specification;
- features of the terrain, which is essentially complex in terms of topography, falls within urbanized territory and has existing infrastructure, including non-cadastral maps;
- existing track links available with shippers - existing industrial branches, because the construction and maintenance of railway lines is not an end in itself, but to serve shippers and passengers with the necessary security, convenience and comfort;
- the need to update the regulatory requirements of documents that came into force after the construction of the railway line - fire regulations, European regulations and technical specifications for interoperability, etc.
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An empirical investigation of hull and propeller vessel performance under the ISO standard 19030

Nikolaos Papageorgiou, Ivaylo Bakalov
Ship propulsion plants Department of the Faculty of Engineering at Nikola Vaptsarov Naval Academy

Abstract: Inefficient energy utilization is intolerable amongst ship operators and regulatory authorities especially in the current era. When the condition of a ship’s hull and or propeller-s degrades, in order to maintain speed, there is a need for more power thus more fuel. A byproduct of the increased fuel consumption is increased Green House Gas emissions that are strictly regulated by international authorities. In the present paper the Hull and Propeller performance will be assessed in terms of fuel consumption reserves and CO2 emissions based on the required levels environmental footprint as indicated by the ISO Standard 19030 created by the International Maritime Organization.

1. Introduction

Degenerative energy utilization is intolerable amongst ship operators and regulatory authorities especially in the current era where fuel prices are continuously increasing, and the environmental footprint is amongst the most important aspects of regulatory authorities. Losses in the performance of a vessel due to deterioration of the propeller and or the hull sometimes are substantial, but it is proven that it is difficult or time consuming assuming all the means are available to quantify them.

Hull and propeller performance allude to the relationship between the state of a ship’s submerged hull and propeller and the power required to move the ship through water at a given speed. Estimation of changes in ship explicit hull and propeller performance after some time makes it conceivable to show the effect of hull and propeller support, fix and retrofit exercises on the general energy efficiency of the ship being referred to. The increase cost of fuel, the maintenance cost of the hull and the mounting environmental regulations make the monitoring of hull conditions an important tool for prudent ship operators, in order to decrease energy waste when it comes to hull and or propeller malfunctions has been regulated from the International Maritime organization with the creation of the ISO 19030.

In the context of the initial part of the ISO19030 it describes the basic principles that exist in order to measure the changes in the performance of the hull and the propeller. It also outlines some performance indicators for hull and propeller maintenance and repair. Further in the next part the basic method that help measure the changes in the performance of the hull and the propeller are described. Other than that, it helps calculate the indicators of performance and provides guidance on the accuracy to be expected by each performance indicator.

The last part outlines some substitute methods that result in lower accuracy but can assist the application of the standard methods. Some can give same or higher accuracy but elements which are not yet broadly used in commercial shipping may be included.

2. Resistance

The resistance of a ship at a given speed is the force required to tow the ship at that speed in smooth water, expecting no impedance from the towing ship. On the off chance that the hull has no extremities, this is known as the bare–hull or towing resistance, and albeit close to, it isn't equivalent to the drive resistance because of hull/propeller collaborations [1]. This absolute resistance is comprised of various components, which are brought about by an assortment of elements and which interface with one another in a somewhat mind-boggling design. So as to manage the inquiry all the more proficiently, it is standard to consider the all-out quiet water resistance as being comprised of four principle components [2].

(a) Frictional resistance, because of the motion of the hull through a viscous fluid.

(b) Wave making resistance, because of the vitality that must be provided persistently by the ship to the wave framework made on the free surface.

(c) Eddy resistance, because of the vitality diverted by vortexes shed from the hull or limbs. This is particularly extreme at the stern where the water might be unfit to pursue the bend and will split far from the hull, offering ascend to vortexes and partition resistance.

(d) Air obstruction experienced by the above water some part of the essential hull and the super structures due to the movement of the ship through the air

In a genuine liquid, the limit layer modifies the virtual shape and length of the body, the weight appointment at the stern is changed and its forward part is reduced. For this circumstance there is a net power on the body acting against the movement, offering rise to an obstruction which is distinctively implied as structure drag, or thick weight drag. The body moreover experiences frictional opposition and perhaps whirlpool obstruction too. The liquid rapidly in contact with the outside of the body is passed on close by the surface, and that in the adjacent locale is gotten going a comparative path as that where the body is moving. This result in a limit layer which gets gradually thicker from the bow to the stern, and in which the speed changes from that of the body at its surface to that reasonable to the potential stream design at the outside edge of the layer [3].

The power gave to the water in the limit layer by the hull is an extent of the frictional opposition. If the body is to some degree blunt at the after end the stream may incline eventually, called the parcel point, along these lines diminishing the total load on the afterbody and adding to the opposition. This division obstruction is demonstrated by an example of twirls which is a channel of essentialness. A ship continuing forward the outside of the sea experiences most of the above kinds of opposition also as finishes a submerged body. Regardless, the closeness of the free surface incorporates a further part. The ensuing weight flow on the hull results really taking shape of a wave structure which spreads out toward the back of the ship and should be industriously recreated. This looks at to a channel of imperative given by the ship and is named the wave making resistance [2].
The frictional obstruction is commonly the most vital fragment of the outright ship opposition. For modestly moderate ships with high square coefficients it adds to about 85% of the full-scale obstruction, while for quick streamlined dislodging hulls it may drop to about half. These characteristics may finish up higher in time due to the extended disagreeableness of the ship surface. Froude's theory was imperative as in he had the choice to part the supreme opposition coefficient in two segments that are weakly dependent upon each other. The dependence of frictional opposition on the Re number was not known during Froude's time and he was experiencing some difficulty extrapolating his model tests to full scale. Before long, his backslide results were particular, and they were being utilized for a long time.

The wave making obstruction of a ship is related to the net power upon the ship due to the normal liquid loads following up on the hull, correspondingly as the frictional opposition is the delayed consequence of the dissipative liquid powers. In case the body is going on or near the free surface this weight assortment causes waves which transmit a long way from the body and pass on with them a particular proportion of essentialness that is dispersed in the ocean. The wave making obstruction would then have the option to be in like manner depicted by the imperativeness utilized by the ship that is critical to keep up the wave structure. Theoretical affirmation of the wave making opposition requires learning of the wave structure delivered by a moving ship.

The principle real speculative undertaking towards estimating the ship wave system was a result of Lord Kelvin in the late nineteenth century. He considered a singular weight point going in a straight line over the outside of the water, passing on waves which join to outline a trademark design. This involves a course of action of transverse waves following behind the point, together with a movement of one of a kind waves transmitting from the point, the whole example being dominantly contained inside two straight lines starting from the weight point and making edges of around 19 degrees on each side of the line of movement. The Kelvin wave example speaks to and explains tremendous quantities of the features of the ship wave structure. The whole wave example moves with the ship, and for an onlooker on the ship the waves appear, apparently, to be stationary. In spite of the way that at first it may give the idea that replacing the ship by a singular weight point is unnecessarily untraveled, it should be borne as a top need this is a far field surmise significant a long way from the body where the geometric qualities of the hull are not self-evident. Kelvin had the alternative to meet up at his model using a general procedure in asymptotic examination, called the method for stationary stage, which he developed unquestionably for the wave obstruction issue. The system allows the unpleasant appraisal of explicit integrals of rapidly influencing limits and it produces two wave frameworks [2].

If frictional drag was the main segment of concern, the pontoons would be exceptionally short to keep the surface territory contacting the water (the wetted surface) to a base. On the off chance that wave-production drag was the main drag, the vessels would be exceptionally long to keep them thin and the waves they produce little. The reality is in the middle of these two, yet streamlining the length requires a somewhat definite information of the estimation of each kind of resistance. A correlation of various producer's items in your boat storage can indicate varieties of a meter or more long, all intended for a similar class and weight of rower. Various hypotheses and fluctuating background levels have prompted various ends.

2.1 Hull resistance

A ship's calm water resistance is especially impacted by its speed, displacement, and structure of the vessel. The absolute opposition RT comprises of many source-protections R, which can be partitioned into three principle types, frictional resistance (RF), Residual resistance (RR) and air resistance (AR) [2]. The impact of frictional opposition relies upon the wetted surface of the body, while the size of lingering obstruction depicts the vitality lost by the ship setting up waves, whirlpools and by the gooey weight obstruction, which all rely upon the structure lines. For moderate moving boats, for example, tankers and bulkers, the frictional friction and resistance is frequently of the best impact (70-90%) though for quick going boats, for example, panamax compartment transporters, the frictional obstruction may represent as meager as half of the joined obstruction [4]. Air resistance ordinarily speaks to about 2% of the absolute opposition, be that as it may, with a noteworthy increment up to approx. 10% for boats with huge superstructures, for example, holder ships with compartments stacked on deck. On the off chance that breeze opposition is considered; the figures may increment.

Thusly, if water is all things considered ceased by a body, the water will react outwardly of the body with the dynamic weight, realizing a dynamic power on the body. This relationship is used as a reason when figuring or evaluating the source-assurances R of a ship's structure, by techniques for dimensionless coefficients C. As such, C is related to the reference control K, portrayed as the power that the dynamic load of water with the ship's speed V applies on a surface which is comparable to the structure's wetted region AS. Eventually, the induced tally of a particular ship's resistance, which is required for the hidden dimensioning, is normally affirmed and streamlined by testing a model of the ship in a towing tank (Kusuma et al., 2018). In research issues worried about the partition of obstruction into its segments, techniques for extrapolation to the ship, model–ship connection remittance and so forth, the all-out opposition coefficient generally utilized, plotted to a base of the logarithm of Reynolds number \( Rn = V L/\nu \). Bends of this sort have been utilized in before areas. In any predictable arrangement of units, both CT and Rn are dimensionless [2].

3. Propeller factors

The operating conditions of a propeller according to the propeller law are described for free sailing in calm weather. The influence of the propeller size and speed is considered along with different philosophies for optimizing hull and propeller interactions [4].

Propeller configuration is the specialty of orchestrating multi-disciplinary prerequisites and restrictions into a strong last item that proficiently meets the requirements of a ship. It is an iterative strategy that can by and large be partitioned into three collaborating stages: i) the issue portrayal, ii) the starter plan and iii) the structure investigation and improvement stages [1]. In like manner building structure issues, there is a fourth stage where the plan is assessed, generally with a model. Be that as it may, this is occasionally conceivable in propeller propulsion situation, because of the uniqueness of the planned propeller and on the grounds that the assessment happens utilizing full-scale ocean preliminary tests with the last item. This way, propeller configuration requires specific consideration in the structure examination and improvement stage. Mechanized enhancement methodologies can bolster the creator in discovering better plans quicker [5].
Early endeavors to clarify the instrument which is utilized by the propeller to drive the ship centered around the force hypothesis. In this the propeller is viewed as a ‘circle’ fit for granting an expansion of weight or speeding up to the liquid going through it, the instrument by which it does as such being out of sight. Energy hypotheses depend on right essential standards, however, give no sign of the propeller structure which would create the required push. Later advancement pursues the course hypothesis. In its most direct structure, this yields the bleeding edge segment theory of propeller movement, where the propeller is seen as made up of different separate edges, which therefore can be detached into dynamic strips over the edges, from provoking trailing edge [6]. The powers following up on each strip can be surveyed from a data of the general speed of the strip to the water and the geometry of the section shape. The simple powers are then sunk into the parts of push dT the forward way, and of torque dQ in the plane of propeller turn. By plotting bends of dT and dQ along the edge from supervisor to tip, bends of push and torque stacking are acquired which when incorporated will give the all-out push T and torque Q all in all propeller. The propeller efficiency is then characterized by

\[ \eta = \frac{TV_A}{2\pi n Q} \]

The states of cutting-edge frameworks and areas differ fundamentally as indicated by the sort of ship for which the propeller is expected. On the off chance that we consider a segment of the propeller cutting edge at a range r with a pitch edge \( \phi \) and pitch P, and envisioning the sharp edge to work in a relentless medium, at that point in one upset of the propeller it will progress from A to A', a separation called the pitch, P. On the off chance that we unroll the chamber of span r into a level surface, the helix followed out by A will form into a straight-line AM, and the edge

\[ \tan \phi = \frac{P}{2\pi r} \]

s the pitch point. In the event that the screw is turning at n cycles per unit time, at that point in that time it will propel a separation P n and we can get a velocity outline for the area [5].

As on account of resistance, a lot of learning concerning the presentation of propellers can be picked up from examinations on models and it is significant in this way to analyze the connection among model and full-scale results. Dimensional examination can be utilized to set up this connection and in what pursues an articulation will be gotten for the push delivered by a propeller. The push of the propeller, T, could rely on: Mass density of water, \( \rho \). Propeller size, represented by the diameter, D. Speed of advance, VA. Acceleration due to gravity, g. Speed of rotation, n. Pressure in the field, p. Viscosity of the water, \( \mu \).

## 4. ISO 19030

Today hull and propeller performance is a ship efficiency killer. According to the Clean Shipping Coalition in MEPC 63-4-8, poor hull and propeller performance accounts for around 1/10 of world fleet energy cost and GHG emissions. This points to a considerable improvement potential; 1/10 of world fleet energy costs and GHG emissions translates into billions of dollars in extra cost per year and around a 0.3% increase in man-made GHG emissions. The culprits are a combination biofouling and mechanical damages. Most vessels leave the new build yard or subsequent dry-docking with their hull and propeller in a good condition. Then on account of a combination of biofouling and mechanical damage, hull and propeller performance begin to deteriorate.

ISO 19030 has been created to be generally satisfactory by Shipbuilders, ship proprietors, motor producers, covering organizations, grouping social orders, the IMO and so forth. It empowers ship proprietors and operators to contrast hull and propeller arrangements and straightforward and straightforward information, that they can choose the most effective alternatives for their vessels. Estimating the amount pretty much power is required to move the ship through water at a given speed [7].

The standard is sorted out into three sections:

ISO 19030-1 frameworks general standards for how to gauge changes in hull and propeller performance and characterizes the 4 performance pointers for hull and propeller maintenance, fix and retrofit exercises.

ISO 19030-2 characterizes the default technique for estimating changes in hull and propeller performance. It likewise gives direction on the normal precision of every performance pointer.

ISO 19030-3 plots options in contrast to the default strategy. Some will result in lower generally precision however increment appropriateness of the standard. Others may result in same or higher in general precision however incorporate components which are not completely approved in business shipping.

### 4.1 Performance indicators

Change in hull and propeller execution following present out-docking as contrasted and the normal from past out-dockings The adjustment in hull and propeller execution following present out-docking as contrasted and the normal from past out-dockings (where information/estimations are accessible) is valuable for deciding the viability of the dry-docking.

The diagram shows the performance loss quantified in terms of speed loss.

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\[ \text{Performance loss is quantified in terms of speed loss} \]

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The normal change in hull and propeller performance over the period following out-docking as far as possible of the dry-docking interim. The normal change in estimated hull and propeller performance over the period from the out-docking as far as possible of the dry docking interim can be utilized to decide the adequacy of the underwater hull and propeller arrangements including hull coatings utilized and any upkeep exercises that have happened through the span of the dry-docking interim [8].

Change in hull and propeller performance from the beginning of the dry docking interim to a moving normal at any picked time. The deliberate change in hull and propeller performance from the beginning of the dry-docking interim to a moving normal at a picked time during a similar interim can be utilized as a trigger for underwater hull and propeller upkeep, including propeller or potentially hull cleaning [8]. The change in hull and propeller performance estimated when a support occasion can be utilized to decide the viability of a particular upkeep movement that has occurred in the interim between the estimations, including any propeller and additionally hull cleaning.

5. Environmental footprint

Today hull and propeller performance is a ship efficiency killer. As per the Clean Shipping Coalition in MEPC 63-4-8, poor hull and propeller performance represents around 1/10 of world armada vitality cost and GHG discharges. This focuses to an impressive improvement potential; 1/10 of world armada vitality expenses and GHG emanations converts into billions of dollars in additional expenditure every year and around a 0.3% expansion in man-made GHG discharges. The guilty parties are a mix of biofouling and mechanical harms. Most vessels leave the new form yard or drydocking interim to a moving normal at any picked time. The normal change in estimated hull and propeller performance over the period following out-docking as far as possible of the dry docking interim can be utilized to decide the effect of a particular upkeep movement that has occurred in the interim between the estimations, including any propeller and additionally hull cleaning.

6. Conclusions

In the current market where low freight prices are squeezing the margins to its minimum, it is safe assuming that all shipowners would aim to run their fleet as optimum as possible in terms of fuel efficiency. While operating a ship, the hull’s anti fouling system is less efficient. Marine fouling on the hull increases the frictional resistance and the surface of the propeller can be rough and fouled, making the propeller less efficient. The resistance, caused by fouling, can increase significantly throughout a docking interval, with a typical loss in speed of 2-4 % per year. Increased focus on environmental regulations and smaller profit margins at the shipping industry make fleet performance and efficiency key topics within the maritime world. For this, a Ship Performance Monitoring (SPM) software with continuous monitoring can be of valuable assistance to the ship crew and the owner.

The concept and requirement for this system is to measure key parameters onboard, perform processing on these data, and present the results in an easy and intuitive way for the onboard crew and onshore personnel. Based on this continuous monitoring, corrective actions can be planned and performed accordingly, one challenge in this respect is to present a vessel’s performance status or rather degraded performance correct and adequate, in order to decide when maintenance/repairs are appropriate. An example could be indication of high fuel oil consumption on the main engine. The C/E have to interpret and evaluate this fuel flow and find out if this measurement is correct. The root cause for an overconsumption could of course be a reduced performance of the vessel. However, a sensor malfunction, wrong or missing manual recordings, adverse weather, or other external factors can also cause it. Therefore, automatic data collection, filtering, repeatability and transparency in a performance monitoring system are critical elements for the credibility of the SPM system. The combination of displaying instant performance values together with investigating the long trend of important key performance values are keeping the crew and the management continuously updated on a vessel’s performance.

7. References

Energy and exergy analysis of deaerator from combined-cycle power plant

Vedran Mrzljak, Jasna Prpić-Oršić, Jelena Musulin, Daniel Štifanić
Faculty of Engineering, University of Rijeka, Vukovarska 58, 51000 Rijeka, Croatia
E-mail: vedran.mrzljak@riteh.hr, jasna.prpic-orsic@riteh.hr, jmusulin@riteh.hr, dstifanic@riteh.hr

Abstract: Energy and exergy analysis of deaerator from combined-cycle power plant is presented in this paper. The deaerator is analyzed in three operating regimes and in various ambient conditions. The lowest deaerator energy loss of 525.60 kW and the highest energy efficiency of 78.21 % are obtained for the lowest water temperature at the deaerator outlet - in the same operating regime is obtained the lowest deaerator exergy efficiency. Decrease in the ambient temperature resulted simultaneously with an increase in deaerator exergy destruction and with increase in exergy efficiency. Deaerator exergy efficiency in each operating regime and for each observed ambient temperature significantly varies (from 13.82 % to 45.94 %). From the efficiency aspect, deaerator energy and exergy analysis show diametrically opposed results in two observed operating regimes.

KEYWORDS: DEAERATOR, COMBINED-CYCLE POWER PLANT, ENERGY ANALYSIS, EXERGY ANALYSIS

1. Introduction

Steam power plants (independent plants [1] or part of some complex plants [2]) have regenerative condensate/feed water heating system which is used for condensate/feed water heating before its return to steam generator (or more of them) [3, 4]. Condensate/feed water heating resulted with a fuel savings and with increasing of steam power plant efficiency [5]. Such heating system consists of many components which exact number and the complexity of the entire system depends on many parameters.

An inevitable component of condensate/feed water heating system is a deaerator which has two functions: function of deaerating (removing of dissolved gasses from condensate/feed water to prevent erosion of heat exchangers, pipelines and steam generator parts) and function of condensate/feed water heating. Deaerator divides regenerative heating system in two parts - low pressure part between steam condenser and deaerator and high pressure part between deaerator and steam generator, as can be seen for example in [6].

This paper presents an energy and exergy analysis of deaerator which is part of a regenerative heating system in combined-cycle power plant. Analyzed deaerator is investigated in three operating regimes and at three different ambient temperatures in order to obtain a complete picture of its operation. It is interesting that energy and exergy efficiencies in two of three operating regimes show diametrically opposed results, what will be explained and discussed in detail.

2. Description and main characteristics of the analyzed deaerator from combined-cycle power plant

In this analysis is observed the deaerator from combined-cycle power plant, which is used in water/steam part of a combined system [7]. General deaerator scheme and operating points required for the analysis are presented in Fig. 1. Condensate from the main steam condenser [8] is delivered to the analyzed deaerator by using a condensate pump (operating point 1, Fig. 1) [9]. Another input into the analyzed deaerator is steam extracted from the steam turbine (operating point 2, Fig. 1). As presented in Fig. 1, one part of steam extracted from the turbine is used for deaerating and the rest of extracted steam is used for water heating. Analyzed deaerator has only one major fluid stream outlet - it is water stream which is delivered to the main feed water pump (operating point 3, Fig. 1). Due to deaerating and heating processes into the analyzed deaerator, water at the deaerator outlet (in operating point 3) has higher temperature in comparison with condensate at the deaerator inlet (in operating point 1). Another fluid stream outlet from the analyzed deaerator is a stream of gases (which cannot be condensed) and which are released after the deaerating process. Due to low mass flow rate of gasses released after deaerating process (in comparison to other deaerator fluid streams), its stream can be neglected in the deaerator energy and exergy analysis, as shown in the literature [10].

3. Energy and exergy analysis equations

3.1. Overall equations for the energy and exergy analysis of any control volume

The first law of thermodynamics defines energy [11], while the second law of thermodynamics defines exergy analysis [12] of any control volume. Energy analysis of control volume is completely independent of the ambient conditions in which control volume operates [13], while the exergy analysis is significantly influenced by the ambient conditions [14].

Control volume energy analysis

For control volume in steady state, mass flow rate and energy balances, according to [15, 16], can be defined by Eq. 1 and Eq. 2. It should be noted that mass flow rate balance (Eq. 1) assumes no leakage throughout control volume, while in energy balance (Eq. 2) potential and kinetic energies are disregarded:

\[ \Sigma \dot{m}_\text{in} = \Sigma \dot{m}_\text{out} \]  \hspace{1cm} (1)

\[ \Sigma \dot{m}_\text{in} \cdot h_\text{in} + \dot{Q} = \Sigma \dot{m}_\text{out} \cdot h_\text{out} + P \]  \hspace{1cm} (2)

The energy of any fluid flow can be calculated as presented in [17]:

\[ \dot{E}_\text{en} = \dot{m} \cdot h \]  \hspace{1cm} (3)

Overall control volume energy efficiency, according to [18], can be defined as:

\[ \eta_\text{en} = \frac{\text{Energy output}}{\text{Energy input}} \]  \hspace{1cm} (4)
Control volume exergy analysis

Control volume energy balance is defined by Eq. 5. Again, identical to control volume energy balance, potential and kinetic energy can be disregarded [19]:

\[ \sum m_{\text{in}} \cdot \varepsilon_{\text{in}} + \dot{X}_{\text{heat}} = \sum m_{\text{out}} \cdot \varepsilon_{\text{out}} + P + \dot{E}_{\text{ex,D}}. \]  

(5)

Two components of the Eq. 5 should be additionally defined. The first is specific exergy (ε), which is defined according to [20] as:

\[ \varepsilon = (h - h_0) - T_0 (s - s_0). \]  

(6)

while the second is the net exergy transfer by heat at the temperature \( T \) (\( \dot{X}_{\text{heat}} \)), which can be defined as:

\[ \dot{X}_{\text{heat}} = (1 - \frac{T_0}{T}) \cdot \dot{Q}. \]  

(7)

The exergy of any fluid flow is:

\[ \dot{E}_{\text{ex}} = \dot{m} \cdot \varepsilon = \dot{m} \cdot \left[(h - h_0) - T_0 (s - s_0)\right]. \]  

(8)

Overall definition of control volume exergy efficiency, according to [21] is:

\[ \eta_{\text{ex}} = \frac{\text{Exergy output}}{\text{Exergy input}} \]  

(9)

3.2. Energy and exergy analysis equations of the investigated deaerator from combined-cycle power plant

Energy and exergy analysis equations of the investigated deaerator from combined-cycle power plant [22] are based on deaerator operating points presented in Fig. 1. Both analyses (energy and exergy) are of “black box” type, which means that in such analyses deaerator inner structure is irrelevant, it is important only fluid flow streams to and from the deaerator.

Energy analysis of a deaerator

- Deaerator energy power input:

\[ \dot{E}_{\text{en,in}} = \dot{m}_1 \cdot h_1 + \dot{m}_2 \cdot h_2. \]  

(10)

- Deaerator energy power output:

\[ \dot{E}_{\text{en,out}} = \dot{m}_3 \cdot h_3. \]  

(11)

- Deaerator energy power loss (deaerator energy destruction):

\[ \dot{E}_{\text{en,D}} = \dot{E}_{\text{en,in}} - \dot{E}_{\text{en,out}} = \dot{m}_3 \cdot h_3 - \dot{m}_1 \cdot h_1 - \dot{m}_2 \cdot h_2. \]  

(12)

- Deaerator energy efficiency:

\[ \eta_{\text{en}} = \frac{\dot{E}_{\text{en,out}}}{\dot{E}_{\text{en,in}}} = \frac{\dot{m}_3 \cdot h_3}{\dot{m}_1 \cdot h_1 + \dot{m}_2 \cdot h_2}. \]  

(13)

Exergy analysis of a deaerator

- Deaerator exergy power input:

\[ \dot{E}_{\text{ex,in}} = \dot{m}_1 \cdot \varepsilon_1 + \dot{m}_2 \cdot \varepsilon_2. \]  

(14)

- Deaerator exergy power output:

\[ \dot{E}_{\text{ex,out}} = \dot{m}_3 \cdot \varepsilon_3. \]  

(15)

- Deaerator exergy power loss (deaerator exergy destruction):

\[ \dot{E}_{\text{ex,D}} = \dot{E}_{\text{ex,in}} - \dot{E}_{\text{ex,out}} = \dot{m}_3 \cdot \varepsilon_1 + \dot{m}_2 \cdot \varepsilon_2 - \dot{m}_3 \cdot \varepsilon_3. \]  

(16)

- Deaerator exergy efficiency:

\[ \eta_{\text{ex}} = \frac{\dot{E}_{\text{ex,out}}}{\dot{E}_{\text{ex,in}}} = \frac{\dot{m}_3 \cdot \varepsilon_3}{\dot{m}_1 \cdot \varepsilon_1 + \dot{m}_2 \cdot \varepsilon_2}. \]  

(17)

4. Analyzed deaerator steam/water parameters in three operating regimes

Steam/water parameters (pressures, temperatures and mass flow rates) in each operating point of the analyzed deaerator (Fig. 1) are found in [7] and presented in Table 1 for the first deaerator operating regime, in Table 2 for the second deaerator operating regime and in Table 3 for the third deaerator operating regime. Deaerator operating regimes are related to the water temperature at the deaerator outlet – the highest water temperature at the deaerator outlet denotes first operating regime (Table 1), while the lowest water temperature at the deaerator outlet denotes last (third) operating regime, Table 3.

Steam/water specific enthalpies, specific entropies and specific exergies are calculated by using NIST-REFPROP 9.0 software [23]. Steam/water specific exergies presented in Table 1, Table 2 and Table 3 are calculated for the following ambient state: temperature of 15 °C = 288 K and a pressure of 1 bar.

Table 1. Steam/water parameters of the analyzed deaerator – Operating regime 1 [7]

<table>
<thead>
<tr>
<th>O.P.*</th>
<th>Temperature (K)</th>
<th>Pressure (bar)</th>
<th>Mass flow rate (kg/s)</th>
<th>Specific enthalpy (kJ/kg)</th>
<th>Specific entropy (kJ/kg·K)</th>
<th>Specific exergy (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>362.16</td>
<td>10</td>
<td>12.90</td>
<td>373.60</td>
<td>1.1807</td>
<td>35.116</td>
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<td>453.03</td>
<td>10</td>
<td>1.04</td>
<td>2777.10</td>
<td>6.5850</td>
<td>882.190</td>
</tr>
<tr>
<td>3</td>
<td>368.45</td>
<td>10</td>
<td>13.94</td>
<td>400.05</td>
<td>1.2531</td>
<td>40.713</td>
</tr>
</tbody>
</table>

* O.P. = Operating Point; Operating points refer to Fig. 1.

Table 2. Steam/water parameters of the analyzed deaerator – Operating regime 2 [7]

<table>
<thead>
<tr>
<th>O.P.*</th>
<th>Temperature (K)</th>
<th>Pressure (bar)</th>
<th>Mass flow rate (kg/s)</th>
<th>Specific enthalpy (kJ/kg)</th>
<th>Specific entropy (kJ/kg·K)</th>
<th>Specific exergy (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>354.07</td>
<td>10</td>
<td>5.93</td>
<td>339.63</td>
<td>1.0859</td>
<td>28.467</td>
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<td>2</td>
<td>453.03</td>
<td>10</td>
<td>0.40</td>
<td>2777.10</td>
<td>6.5850</td>
<td>882.190</td>
</tr>
<tr>
<td>3</td>
<td>359.36</td>
<td>10</td>
<td>6.33</td>
<td>361.84</td>
<td>1.1481</td>
<td>32.744</td>
</tr>
</tbody>
</table>

* O.P. = Operating Point; Operating points refer to Fig. 1.

Table 3. Steam/water parameters of the analyzed deaerator – Operating regime 3 [7]

<table>
<thead>
<tr>
<th>O.P.*</th>
<th>Temperature (K)</th>
<th>Pressure (bar)</th>
<th>Mass flow rate (kg/s)</th>
<th>Specific enthalpy (kJ/kg)</th>
<th>Specific entropy (kJ/kg·K)</th>
<th>Specific exergy (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>293.15</td>
<td>10</td>
<td>9.12</td>
<td>84.85</td>
<td>0.2963</td>
<td>1.091</td>
</tr>
<tr>
<td>2</td>
<td>453.03</td>
<td>10</td>
<td>0.59</td>
<td>2777.10</td>
<td>6.5850</td>
<td>882.190</td>
</tr>
<tr>
<td>3</td>
<td>368.45</td>
<td>10</td>
<td>9.71</td>
<td>194.31</td>
<td>0.6539</td>
<td>7.551</td>
</tr>
</tbody>
</table>

* O.P. = Operating Point; Operating points refer to Fig. 1.

5. The results of deaerator energy and exergy analyses with discussion

5.1. The results of deaerator energy analysis

The results of deaerator energy analysis in each observed operating regime remains the same regardless of the conditions of the ambient in which deaerator operates. According to Eq. 12, in each deaerator operating regime energy power input is the sum of the deaerator energy power output and energy power loss (energy destruction) – which are presented in Fig. 2.

From Fig. 2 can be observed that in Operating regime 1 deaerator has the highest energy power output (5576.70 kW) and simultaneously the highest energy power loss (2130.93 kW). In comparison with Operating regime 1, in deaerator Operating regime
2 energy power output and energy power loss significantly decreases, while in Operating regime 3 deaerator has the lowest energy power output (1886.75 kW) and the lowest energy power loss (525.60 kW).

It can be concluded that the decrease in temperature of water at deaerator outlet (operating point 3, Fig. 1) resulted with a decrease in deaerator energy power output and simultaneously with decrease in deaerator energy power loss (energy destruction).

![Fig. 2. Change in energy power output and energy power loss of the analyzed deaerator in three operating regimes](image)

From Operating regime 1 to Operating regime 3 deaerator energy efficiency continuously increases (from 72.35 % in Operating regime 1 to 78.21 % in Operating regime 3), Fig. 3. This trend of deaerator energy efficiency is reverse proportional to deaerator energy power loss (energy destruction) which continuously decreases from Operating regime 1 to Operating regime 3, Fig. 2 and Fig. 3.

Furthermore, it can be concluded that analyzed deaerator has the highest energy efficiency (and the lowest energy power loss) at the lowest temperature of water at the deaerator outlet, Fig. 3 and Table 3.

![Fig. 3. Change in energy efficiency of the analyzed deaerator in three operating regimes](image)

5.2. The results of deaerator exergy analysis

Deaerator exergy analysis is performed in all three operating regimes and for three different ambient temperatures (5 °C, 10 °C and 15 °C) in order to investigate the deaerator exergy destruction and efficiency in different states of the ambient.

From Fig. 4 can be seen that analyzed deaerator has different trends when compared exergy and energy destructions (Fig. 2). Both energy and exergy destructions (losses) are the highest for deaerator Operating regime 1, but the lowest deaerator exergy destruction occurs in Operating regime 2, regardless of the observed ambient temperature (the lowest deaerator energy destruction occurs in Operating regime 3 – Fig. 2).

Decrease in the ambient temperature resulted with an increase in deaerator exergy destruction, regardless of observed operating regime. Denaerator exergy destruction in Operating regime 1 is the highest influenced with the change in the ambient temperature, while deaerator exergy destruction in Operating regime 3 is the lowest influenced with the change in the ambient temperature, Fig. 4.

![Fig. 4. Change in the exergy destruction of the analyzed deaerator in three operating regimes and at three ambient temperatures](image)

Decrease of the ambient temperature increases deaerator exergy destruction (Fig. 4) and simultaneously increases deaerator exergy efficiency, regardless of the observed operating regime, Fig. 5.

In Operating regime 1 analyzed deaerator has the highest exergy efficiencies which vary from 41.41 % at the ambient temperature of 15 °C to 45.94 % at the ambient temperature of 5 °C. In the same operating regime, the deaerator has the lowest energy efficiency (72.35 %, Fig. 3).

In Operating regime 2, at the same ambient temperature, deaerator exergy efficiency is slightly lower in comparison with Operating regime 1. 

Denaerator Operating regime 3 is the most interesting to observe (in this operating regime the water temperature at the deaerator outlet is the lowest, Table 3). In Operating regime 3, analyzed deaerator has the highest energy efficiency (78.21 %, Fig. 3), while its exergy efficiency does not exceed 21.03 %, even at the lowest ambient temperature, Fig. 5. Such low exergy efficiency of deaerator in Operating regime 3 is the result of low fluid temperatures (water inlet and outlet), which are very close to the ambient temperature – Table 3.

Deaerator Operating regimes 1 and 3 are the best example of one control volume operating regimes in which energy and exergy analysis gives totally opposed results from the efficiency aspect, Fig. 3 and Fig. 5.

![Fig. 5. Change in exergy efficiency of the analyzed deaerator in three operating regimes and at three ambient temperatures](image)

6. Conclusions

In this paper is presented energy and exergy analysis of deaerator from combined-cycle power plant. It is analyzed the change in energy and exergy losses and efficiencies in three deaerator operating regimes and for three different ambient temperatures. The most important conclusions of the analysis are:

- Deaerator energy analysis shows that a decrease in the water temperature at deaerator outlet resulted with simultaneous decrease of deaerator energy loss and increase in energy efficiency. The lowest deaerator energy loss and the highest energy efficiency (525.60 kW and 78.21 %) are obtained for the lowest water temperature at the deaerator outlet of 319.35 K (Operating regime 3).
7. Acknowledgment

This research has been supported by the Croatian Science Foundation under the project IP-2018-01-3739, CEEPUS network III-HR-0108, European Regional Development Fund under the grant KK.01.1.01.0009 (DATACROSS), University of Rijeka scientific grant uniri-tehnic-18-275-1447, and University of Rijeka scientific grant uniri-tehnic-18-18-1146.

8. References


The possibility and analysis of using gas as an alternative fuel in the diesel engine

Chumburidze Giorgi, Kochadze Teimuraz, Topuria Romanoz,
Akaki Tsereteli State University - Kutaisi, Georgia
Georgetchumburidze1010@gmail.com, Temo1954@gmail.com , r.topuria@gmail.com ;

Abstract: the article considers the possibilities of diesel engine operation on gaseous fuels, as well as their advantages over standard engines. The focus is on the possibility of running effectively the gas-diesel cycle so that it is brought to the processes occurring in the engine with forced ignition as close as possible. The article also discusses the issues related to optimization of the processes occurring in the gas-diesel engine, which will bring the gas-diesel cycle close to the petrol-running cycle. There are also identified ways to improve the economic and environmental performance of the diesel engine.

KEY WORDS: DIESEL ENGINE, CARBURATION, FUEL INJECTION, TOXICITY.

1. Introduction

Vehicle Internal combustion engines (ICE) mainly use the liquid fuels of petroleum origin, which are characterized by intensive pollution of the environment, e.g. by existence of a large amount of various harmful substances in the exhaust gases. Use of alternative fuels is an option to reduce environmental pollution. First of all, such fuel is a natural gas (NG), as it’s resource is large and at the same time NG is cheap, as unlike a liquid fuel obtained from oil, NG does not require significant recycling before use. The uniformity of the composition and the absence of contaminating substances give the NG fuel a number of positive properties. The main components of natural gas are: methane, ethane and butane. Methane has the ability to generate greater specific weight heat compared to gasoline, although its ability to generate volumetric heat is much smaller than that of gasoline or diesel fuels. In addition, for combustion of different types of fuels in engines, it is particularly important not the calorific value of the fuel itself, but the ability to generate heat from the Air-Gas working mixtures. It is known that the calorific value of the Air– Methane mixture is 90% of the same characteristic of the Air-Gasoline mixture, and 95% in the case of Air-Diesel fuel mixture, which should lead to a reduction in liter capacity of an ICE in the case of natural gas use. The ignition temperature of the Air-Methane fuel mixture exceeds 180-220 K compared to the Air-Gasoline fuel mixture, indicating the ability to work with high compression rate, which is essential for a diesel engine.

Due to its physico-chemical properties, NG provides the possibility of some expansion of the ignition interval, which, in turn, ensures better regulation of the internal combustion engine power. When using gas fuels in engines, a Air-Methane mixture is more advantageous than Air-Liquid fuel vapor mixture, as the air to fuel volumetric ratio is smaller - \( L_0 = 9.52 \, \text{m}^3/\text{m}^3 \). Under other equal conditions, the smaller the \( L_0 \), the easier it is to ensure good working mixture. It is also important that both components of Air-NG mixture are in a gaseous state.

A number of negative properties of NG as an engine fuel also should be mentioned: a relatively low combustion speed compared to the Air-Liquid fuel mixture; there may be other hydrocarbons in natural gas such as: propane, butane, pentane, etc., which makes the fuel more prone to detonation. Estimation of overall properties of fuel energy presumes determination of the quantity of heat which can be obtained in the process of transforming into the mechanical work in each cycle of ICE. In this regard, the heat of combustion of fuel mixture is also influenced by two other factors: a) the effect of fuel properties on the filling degree of cylinders and b) the composition of the working mixture during which the engine develops nominal power.

One of the most promising workflows for a diesel transport engine is the Natural Gas / Diesel dual fuel cycle. The NG/Diesel dual fuel process has potential advantages over the spark ignition process. It is known that the efficiency of diesel engine \( \eta_e \) is not less than 0.42-0.44. Both external and internal formation of air-fuel mixture are used in the the NG / Diesel cycle.

External formation of the air – fuel mixture due to its simple construction has gained wide application in transport ICEs. In this case, the mixer is made in the form of a nozzle built into the air tract. Gas is supplied to the mixer at a pressure close to atmospheric, in order to exclude both gas leakage into the environment and outside air penetration into the intake tract. The NG attractive properties for better air-gas mixture formation also make it possible for wide application of internal mixing. A particular difficulty is the high temperature (650-700°C) of NG self-ignition, which significantly exceeds the self-ignition temperature of diesel fuel (320-380°C).

For the maximum approximation to this process, we can consider the injection of NG into the cylinder at the end of the compression process and ignition of mixture with a small dose of the diesel liquid fuel not exceeding 15-20% of total fuel amount. That will allow to use a serial diesel engine without changing the compression rate.

Due to the low density and low volumetric heat of combustion the cryogenic storage methods are increasingly being used for the NG. That requires the development of special System for fuel preparation and delivery. Reducing toxic emissions and defining promising ways to increase fuel economy and reliability in this type of prospective engines also is a very urgent task.

It is important to implement an external mixing process in the diesel engine, which directly determines both the economy of the ICE and the importance of environmental parameters in the exhaust. During such a cycle, it is important to note that the Air-Gas mixture is ignited by a small amount of liquid fuel (explosive quantity) and in this case can be used a) a conventional standard diesel engine fuel system that provides engine performance on two types of fuel (in such case consumption of liquid fuel can’t be less than those on idle and small loads) or b) with a specially designed fuel delivery system that provides a minimum of 7-10% supply of combustible liquid fuel. In addition, it is difficult to regulate the load of engine, as it is difficult to regulate the quality of the air-fuel mixture and it is necessary to provide such a fuel supply equipment that convincingly provides qualitative regulation of engine load.

2. Preconditions and means for resolving the problem

The above stated helps us to carry out such a task formulation, which allows the conversion of diesel engine into NG / Diesel dual fuel engine, particularly a) creation of such high effective working process with good ecological characteristics, in which the use of diesel fuel is limited and NG is used in all the intervals of engine speed and loading b) use biofuel with better characteristics in combination with NG instead of diesel. This is directly related to the air-fuel mixture formation in the combustion chamber from the moment of fuel injection to the ignition of the last element of the combustible fuel. These goals include the process of macro-distribution of the elementary volumes of fuel in the space occupied by the oxidizer, as well as the subsequent micro-mixing, i.e. the provision of contact between the molecules of both components required for the combustion reaction.

The air-fuel mixture formation process can be divided into the following stages:
1. The introduction of liquid fuel in the form of a jet into the Air-NG mixture volume. In this case, the defining parameter is the hydrodynamic conditions of the fuel supply system;

2. The disassembly of the supplied liquid fuel jet into separate droplets (foggy condition). The efficiency of this process in terms of dispersion and volume distribution depends on both: the conditions of the first stage (fuel jet outflow velocity, fuel initial concern, physical properties, etc.), as well as environmental conditions (degree of Air-Gas mixture turbulence, flow direction and physical characteristics);

3. The steam micro-mixing - the process of liquid fuel evaporation and diffusion by the joint heat exchange between the diesel fuel and the Air-NG mixture. These processes take place mainly in parallel with the combustion and end in the flame zone. Although the pre-flame stage directly determines spatial distribution of the flame zone, the conditions of its state, and so on, on different work regimes of ICE.

Therefore, the nature of the NG / Diesel dual engine process is affected by the proportion of heat injected by the fuel, the pre-injection angle, and the mixing method. NG / Diesel dual fuel cycle is characterized with two peaks of heat emission. The first peak corresponds to the combustion process of the combustible liquid fuel. By reducing the dose of this fuel and increasing the dose of NG, the first peak decreases, while the second increases, and after reaching a certain ratio, the first peak may disappear. In this case, if an increase in the second peak is achieved, then it is possible to reduce the dosed amount of combustible liquid fuel, which will positively affect the parameters of the NG / Diesel dual cycle.

NG / Diesel dual cycle approach to the spark ignition cycle will allow us to analyze its advantages when using different types of gaseous fuels. An essential condition in the engine is the external formation of Air-NG mixture. It should also be noted that in this case the construction of the diesel engine remains unchanged, only the gas fuel system is added with minor changes. Required gas fueling system is already used in engines with spark ignition.

Let consider the ideal cycles of diesel engine running on standard and gaseous fuels, which are shown in PV and TS diagrams in Fig. 1. and Fig. 2:

![Fig. 1. The ideal cycles of diesel on standard fuel](image1)

As can be seen from the figure the construction parameters of the engines (V_c, V_b, u and air distribution phases) are the same. The standard diesel cycle on the PV diagram corresponds to the ac′z′ba diagram, where the supplied heat is q1 = q1 + q2, while the heat dissipated is q2. The NG engine cycle corresponds to the ac′z′ba diagram, where the supplied heat is q1 and the dissipated heat is q2.

It is likely that the gas-powered engine diagram may be more or less equal to the standard diesel engine diagram space, which corresponds to the amount of heat expended in favor, which means that at equal conditions \( \eta_{bo} \geq \eta_{ld} \) also, if we consider their meaning \( \eta_{bo} = 1 - \frac{1}{\pi \cdot (1 - \frac{\omega^3 - 1}{\omega^3 - \omega})} \) and \( \eta_{ld} = 1 - \frac{1}{\pi \cdot (1 - \frac{\omega^3 - 1}{\omega^3 - \omega})} \). From the comparison of the formula, it seems clear that they will be equal to each other when \( \omega = 1 \). If \( \omega > 1 \) then in conditions of constant pressure on the line, an increase in heat losses occurs, which is transmitted to the cooling environment due to an increase in the volume. Also noteworthy is the fact, that the standard diesel engine uses more heat to evaporate the fuel during Air – Fuel mixture formation than in case of Air -NG mixture as the amount of injected liquid fuel here is considerably less. Reduction of the meaning of the point C is also important in NG / Diesel dual cycle engines. Decreased density of the Air-Fuel mixture leads to the reduction of the pressure at the end of the compression, as the volume of the Air-NG mixture is greater than in case of liquid fuel. Besides, the heat dissipation during formation of Air-NG mixture is reduced, which can lead to a heat compensation of about 80-90%. It can also be noted that if the supercharging is to be carried out, then a complete compensation of power of the NG / Diesel dual cycle is possible. The efficiency of engine operation can also be assessed by the coefficients:

\[ \theta = \frac{T_{max}}{T_{min}} = \frac{T_z}{T_a} = \frac{T_z}{T_b} = \theta'\theta'' \quad \text{and} \quad \pi = \frac{P_{max}}{P_{min}} = \frac{P_{max}}{P_b} = \frac{P_b}{P_{min}} = \pi'\pi'' \]

In this case values of \( \theta' \) and \( \pi' \) are important, as high values of these coefficients provide more perfect work of ICE.

3. Conclusion

Therefore, natural gas, both liquified and gaseous, is a clean, safe, economical, and practical fuel that meets existing and planned regulations and requirements for internal combustion engines: it can significantly reduce solid particles (C) and
greenhouse gases (CO2); emission of Sulphur oxides as well as solid particles is almost at zero level. Unlike liquid petroleum fuel, liquefied NG technologies lead to the 90% less emission of nitrogen oxides (NOx), 20-25% less emission of carbon dioxide (CO2). At the same time content of other harmful substances in the form of CO and CH is also very low.

4. References
Indexes of gas engine converted from a tractor diesel

Zaharchuk Victor, Zaharchuk Oleg,
Faculty of Mechanical Engineering – Lutsk National Technical University, Ukraine
E-mail: Zaharchukov205@gmail.com

Abstract: The experience of foreign companies on conversion of diesel vehicles for natural gas operation was analyzed. The results of computer simulations of the gas engine and diesel duty cycle were presented. The features of the gas engine power system converted from the D-243 tractor diesel are shown. The efficiency of the entire range of speed and load modes of a gas engine converted from D-243 diesel to run on natural gas has been experimentally confirmed by reducing the compression ratio from 16 to 12 and equipping it with a gas supply system and ignition system. Its effective power is close to that of a base diesel engine, equivalent to a specific fuel efficiency of up to 25% higher than that of a diesel engine. There is no carbon black in the exhaust gas of the gas engine. The emissions of certain harmful substances in some modes of operation of the gas engine are higher than that of the diesel, but the total toxicity of the exhaust gases resulting from carbon monoxide in the gas engine is 1.96 times lower than that of the diesel.

Keywords: GAS ENGINE, NATURAL GAS, COMPRESSION RATIO, DIESEL

INTRODUCTION

One of the tendencies, directed on reducing of the exhaust gas emissions of internal combustion engines and saving natural resources, is a transition into the alternative fuels. There are a lot of oil fuels substitutes for vehicles exist nowadays. An expedience of introduction of every type of fuel is determined after the technical and economic indices of extraction or receipt of fuel, by transport and saving, by presence of resources, by ecological indices, etc. But lately ecological and economic indices predominate.

PREREQUISITES AND MEANS FOR SOLVING THE PROBLEM

Natural gas (CNG) is the most real for wide use, because it has a number of advantages in comparison with liquid fuel. CNG has higher octane number than the best sorts of petrol and it is possible to use it in engines with high compression ratio. As it enters the cylinders in the gaseous state, a rarefaction of motor oil is eliminated, even during the cold starting of engine, what multiplies the period of its service and diminishes the wear of engine details. In comparison with petrol while work on the CNG more homogeneous mixture appears, the even distributing of mixture on cylinders takes place. It gives the possibility to use poor fuel-air mixtures. It is more rationally to use the engines with high compression ratio, which were created on the basis of diesels. The gas engine has the power 143,4 kW at 2800 rpm. The reserve of torque is about 13%. By tests results of gas engine, the highest value of effective efficiency equals to 0,367 at 1800 rpm on the full-load curve. Without the oxidizing neutralizer engine satisfies the LEV requirements, and equipped with it – to the ULEV norms. The general run in exploitation equals to 160 000 km.

The German firms MAN and „Daimler Benz“ converted diesels into gas engines. In the first case compression ratio changed from 18 to 14. Hence, engine power reduced from 117,6 to 95,6 kW. In the second case diesel and his gas analogue developed power to 126 kW and torque 600 and 640 N·m correspondingly. The data about the exhaust gas emissions were not published [3].
Gas engines are developed in MVRI (Russia) on the base of KamAZ diesels. A gas engine without supercharging, which as well as the base diesel, developed power 143 kW at 2200 rpm with $\alpha = 1.35$ [4] was created. The torque did not also change. Compression ratio changed from 17 to 13. $C_{\text{JHe}}$ emissions diminished in 1.9 times, CO – 2.2 times, and the content of NO\textsubscript{2} in exhaust gas diminished from 15 g/kW·h to 12.3 g/kW·h.

Summing aforementioned, the necessity to estimate the possibility of the converting diesels without supercharging which were made by other factories of the CIS countries, and which are exploited in Ukraine, rose up, and to specify some results of previous researches, which are contradictory. With this purpose diesel D-240, which is widely used in the agricultural technique and road transport vehicles was reequipped into the gas engine at the motor-car engines laboratory of the Lutsk state technical university.

**SOLUTION OF THE EXAMINED PROBLEM**

Analyzing a thermal coefficient of useful effect and middle pressure of the Otto cycle it is clear, that in the duty cycle of gas engine it is expediently to realize compression ratio, that does not exceed 12. At the first stage of researches a mathematical model and program of gas engine work cycle computation for PC was worked out. It allows to define its power and economic indicators and to get the optimum values of construction parameters and of engine work cycle. Basic data are given in table 1, and the results of computer design of duty cycle of gas engine and base diesel are given in table 2. On the basis of these data the unfolded indicator-diagrams of gas engine and diesel (fig.1) were made. The got results testify of the possibility of work of the D-243 engine on CNG. A reduction of mean effective pressure is related to reduction of mechanical efficiency; a reduction of effective fuel rate is conditioned by application of richer gas mixtures; a reduction of effective power is insignificant and related to reduction of volumetric efficiency and application of fuel with lower heat value.

**Table 1. Basic data to computation of work cycle of the D-243 engine**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression ratio</td>
<td>Diesel 16</td>
</tr>
<tr>
<td>Crankshaft speed, rpm</td>
<td>2200</td>
</tr>
<tr>
<td>Excess air coefficient</td>
<td>1.5</td>
</tr>
<tr>
<td>Coefficient of combustion warmth use</td>
<td>0.77</td>
</tr>
<tr>
<td>Charge preheating, K</td>
<td>20</td>
</tr>
<tr>
<td>Intake end temperature, K</td>
<td>900</td>
</tr>
<tr>
<td>Lower combustion warmth of fuel, MJ/kg (MJ/m³)</td>
<td>42.5</td>
</tr>
<tr>
<td>Mass part of carbon in the diesel fuel</td>
<td>0.87</td>
</tr>
<tr>
<td>Mass part of hydrogen in the diesel fuel</td>
<td>0.126</td>
</tr>
<tr>
<td>Mass part of oxygen in the diesel fuel</td>
<td>0.004</td>
</tr>
<tr>
<td>Mass part of methane in CNG</td>
<td>-0.95</td>
</tr>
<tr>
<td>Mass part of nitrogen in CNG</td>
<td>-0.04</td>
</tr>
<tr>
<td>Mass part of carbon dioxide in CNG</td>
<td>-0.01</td>
</tr>
</tbody>
</table>

**Table 2. Results of computer design of work cycle of the D-243 engine**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric efficiency</td>
<td>Diesel 0.77</td>
</tr>
<tr>
<td></td>
<td>Gas engine 0.71</td>
</tr>
<tr>
<td>Combustion end temperature, K</td>
<td>2318</td>
</tr>
<tr>
<td></td>
<td>2461</td>
</tr>
<tr>
<td>Combustion end pressure, MPa</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td>7.4</td>
</tr>
</tbody>
</table>

The re-equipment of diesel into the gas engine has become the second stage of researches. On the reequipped engine spark-plugs BRISK L15YC are set instead the of sprayers (fig.2). The fuel pump of high pressure was reequipped for the fastening of distributor, a billow of which is driven into motion from the camshaft of pump; the electronic ignition with the inductive sensor in the distributor is set (fig. 3). A gas mixer is set on the inlet collector on the base the K126-G carburetor with baffle fin for the gas feeding, and also gas reducing gears of high and low pressure and other gas equipment.

Compression ratio of gas engine is reduced from 16 to 12 by setting the head of cylinders the block of 3 gaskets by the general thickness of 4.5 mm. That is a diesel was converted into the engine with spark ignition and external mixture formation. Re-equipment of diesel into the gas engine was made with the possibility of its reverse converting into diesel.

The experimental tests of converted gas engine included the motor researches on the electric brake stand. The base of the stand is the balancer electric machine by power 40 kW and by the maximal brake power 77 kW at the rotor rotation speed 2000 rpm and the dynamometer with the scale of 0...50 kg.
Rotational speed, air consumption, gaseous fuel consumption, residual gases temperature were measured. Emission of engine exhaust gas components such as CO, CO₂, C₄H₁₀ and NOₓ was measured by exhaust-gas analyzers. At the beginning of tests an optimum ignition advance angle was determined and set.

RESULTS AND DISCUSSION

The gas engine worked firmly on all modes. Its load characteristic got on crankshaft rotation speed 1400 rpm is shown on fig. 4.

The analysis of the characteristic shows that while operating on natural gas, engine power increased from 40 kW to 41.4 kW (by 3.4 %). Some increase in power is explained by the operation of the engine at the values of the coefficient of excess air α = 0.99…1.1. The equivalent specific effective fuel consumption (in mJ / (kWh)) of the gas engine increased by 16.8…25.6 % compared with a diesel engine.

The complex of gas analyzing equipment was used to measure the concentrations of harmful substances in exhaust gases by the components: carbon monoxide CO, hydrocarbons C₄H₁₀ and nitrogen oxides NOₓ.

The concentrations of CO in the gas engine are higher than diesel at idle and low loads, and somewhat less at maximum load. The same pattern is typical for C₄H₁₀ hydrocarbons, most of which is methane CH₄. Emissions of NOₓ in diesel are less at medium loads but more at maximum. Also, there is no soot in the exhaust gases of the gas engine, but these emissions take place in the diesel engine.

If the difference in total toxicity is practically absent at low loads, the total toxicity of the gas engine is reduced to 55 % compared to diesel in the case of increasing the load to maximum values (Fig. 4) [5].

Comparisons of fuel economy and toxicity of gas engine and diesel were carried out on the basis of the techniques of rules of UN CE Regulation R 49. The emissions of certain harmful substances in some modes of operation of the gas engine are higher than that of the diesel engine. The total toxicity of ΣCO of the exhaust gases, reduced to carbon monoxide CO of the gas engine, is 294.5and diesel – 578.3. The solids content is completely absent in the exhaust gases of the gas engine. Thus, the environmental indicators of the gas engine are 1.96 times better than that of a diesel engine. The value of energy cost indicators were obtained during engine operation on various types of fuel. The average total values of the equivalent specific effective fuel consumption are – 18.2 MJ/kW•h when the engine is running on natural gas, 14.8 MJ/kW•h on diesel fuel. So, the gas engine consumes 18.7 % more fuel, reduced to single energy units than diesel. Nevertheless, it can be argued that a high-efficiency gas engine will work with good indicators on biogas as well. High energy indicators of the engine were obtained due to the correct choice of design and adjustment parameters, in particular the degree of compression of the engine and the installation angle of ignition timing.

CONCLUSIONS

The analysis of received results proves the expedience of the diesel conversion into gas engines. In particular setting of such engines instead of diesels in the city buses would considerably improve ecological situation in cities. The high power indices in gas engines, converted from diesels, are received due to the possibility of realization of large values of compression degree. In transitions gas expenditure of the fuel-lubricant materials is twice diminished. The period of recoupment of investments on the converting is from 9 to 16 months.

The temperature of exhaust gases of gas engine is higher in the comparison with diesel. Obviously, that the end combustion temperature is higher too. That is why the next stage of researches is an estimation of operating reliability of converted gas engine. And the first step in this direction will be the removal of indicator-diagram of gas engine, its comparison with computation diagram and with the diesel indicator-diagram.

REFERENCES