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The **FEDERATION OF THE SCIENTIFIC ENGINEERING UNIONS (FSEU)**

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DETERMINATION OF OIL SPILL PARAMETERS IN THE PROCESS OF OIL AND OIL PRODUCTS SPREADING ON THE WATER SURFACE

ОПРЕДЕЛЕНИЕ ПАРАМЕТРОВ НЕФТЯНОГО ПЯТНА В ПРОЦЕССЕ РАСТЕКАНИЯ НЕФТИ И НЕФТЕПРОДУКТОВ ПО ВОДНОЙ ПОВЕРХНОСТИ

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Abstract: The growing marine pollution by oil strengthens the interest not only in the methods of combating their causes, but in methods of their forecasting as well on the basis of modeling and calculation of spreading oil spreading on the sea for some reason or other. The paper dwells on a mathematical model of calculating the area of oil spill spreading. The developed methodology for calculating change in the radius and area of oil spill is represented by function of three arguments: oil product density \( \rho_o \), spillover volume \( V \) and spreading time \( t \).

The proposed model allows forecasting the initial stages of oil spreading. The given methodology enables to determine transit time of the process of oil spill spreading from the first phase to the second one, and from the second to the third one, and the radius and area of oil spill spreading.

KEY WORDS: MATHEMATICAL MODELING, POLLUTION, WATER AREAS, OIL, OIL PRODUCT, SEA.

1. Introduction

In recent years, the interest in studies of mechanism of oil spreading in the marine environment has grown significantly. Total ingress of oil products into the sea at a first approximation is proportional to the volume of the world oil production that conditions the growing marine pollution hazard. Marine pollutions caused by tanker and other ship accidents are the most hazardous because they are not predictable and besides they are of the local nature at their high power. Despite permanent tightening of safety standards, the accidents during transportation of oil products still remain pernicious for the environment.

While planning and carrying out works on combating accidental spills on the sea, there will usually be a need to forecast oil spreading on the sea. These forecasts allow, in particular, warning of possibility of coastal zone pollution by oil, crossing the areas of intensive economic activities by oil spill, vessels’ courses and so on.

2. Prerequisites and means for solving the problem

As is well-known, Black Sea is a landlocked water object, which is of considerable transport importance, based on rapidly developing port infrastructure, which is oriented on the export of oil and oil products. At the same time, this water object has a huge recreation potential, whose development and even its existence can be endangered.

In the near future, the annual volume of oil transportations over Black Sea may be increased to 220-250 tons. Herewith, through the port terminals of: Ukraine there is anticipated to transport up to 50 mln tons per year, Russia – up to 60 mln tons, Georgia – up to 30 mln tons, Bulgaria – up to 25 mln tons and Turkey – about 35 mln tons per year.

Despite permanent tightening of safety standards, transportation of oil products still remain pernicious for the environment. The main problem in seafight transportation of oil and oil products is safeguarding the operation of tankers in part of preventing oil spills, explosions and fires.

Studies of processes associated with oil and oil products spreading on the water surface were performed by many famous scientists. The papers [1,2,3] dwell on spreading of oil slick, which is formed at oil spill on the sea and dynamics of oil pollution in the sea coastal zone. There is proposed a mathematical model of this process.

3. Mathematical model

The modern scientific and technical literature on studies of physical processes of oil spreading on the water surface [4], [5] mostly dwells on three methodologies of calculating the time variations of the radius of oil spill. In these methodologies, the radius of oil spill is represented by function of three arguments: oil product density \( \rho_o \), spillover volume \( V \) and spreading time \( t \).

There is conducted the analysis of the developments in the field of estimating parameters of oil spill during its spreading on the water surface. As a basic one, there has been chosen the Fay methodology, which envisages the phase changes of physical processes during the spreading of oil spill.

In Fay’s theory, oil spreading occurs under gravity and surface tension at different stages by forces of inertia and viscosity [6].

According to Fay methodology [5], oil spreading on the surface usually has three phases: inertial, gravitational-viscose and surface tension phase.

At an initial stage, of high importance are gravity and inertia forces.

\[
R(t)_{1} = k_1 \cdot \left[ g \cdot V \cdot \left( \frac{\rho_o - \rho_w}{\rho_w} \right) \cdot t^2 \right]^{1/3}.
\]

In the gravitational-viscose phase (second one) of oil pollution spill spreading, there are taken into account viscose friction forces in the slick. In this case calculations are made in accordance with formula

\[
R(t)_{2} = k_2 \cdot \left[ g \cdot V^2 \cdot \left( \frac{\rho_o - \rho_w}{\rho_w} \right) \cdot t^2 \cdot \frac{1}{v_w^2} \right]^{1/3}.
\]

During the third phase of oil pollution spill spreading, most prevailed are surface tension forces (surface tension phase). In this case calculations are made by

\[
R(t)_{3} = k_3 \cdot \left[ \sigma^2 \cdot t^3 \cdot \left( \frac{1}{\rho_o^2 \cdot V^2} \right) \right]^{1/3}.
\]

In these expressions, the methodologies for assessing the radius \( R(t) \) of oil spill spreading, there are used the following designations: \( v_w \) – coefficient of kinematic viscosity of water, \( m^2/sec; k_1 = 1,14; k_2 = 1,45; k_3 = 2,3. \sigma \) – resulting surface tension, which according to [6] equals 0,02…0,03 N/m;
Table 1. Variation time (min) of oil spill spreading phases

<table>
<thead>
<tr>
<th>Name</th>
<th>Spillover volume , m³</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>t₁</td>
<td>t₂</td>
<td>t₁</td>
<td>t₂</td>
<td>t₁</td>
</tr>
<tr>
<td>Fuel oil</td>
<td></td>
<td>13.9</td>
<td>22.8</td>
<td>17.5</td>
<td>36.2</td>
<td>22.1</td>
</tr>
<tr>
<td>Oil (hard)</td>
<td></td>
<td>10.5</td>
<td>30.2</td>
<td>13.3</td>
<td>47.9</td>
<td>16.7</td>
</tr>
<tr>
<td>Diesel oil</td>
<td></td>
<td>9.68</td>
<td>32.8</td>
<td>12.2</td>
<td>52.0</td>
<td>15.4</td>
</tr>
<tr>
<td>Petrol</td>
<td></td>
<td>8.4</td>
<td>38.0</td>
<td>10.5</td>
<td>60.2</td>
<td>13.3</td>
</tr>
</tbody>
</table>

A peculiarity of the selected methodology is the necessity of determining the transfer time from the first stage of spreading (inertial one) to the second one (gravitational-viscose), and from the second one – to the third one (surface tension forces phase).

A moment of transfer time (t₁) in the calculations of oil radius according to Fay methodology from the first stage of oil spill spreading to the second one is determined by the formula

\[ t₁ = 2.6173 \cdot V^{\frac{1}{3}} \left( \left[ 1 - \frac{\rho_o}{\rho_w} \right] \cdot g \right)^{\frac{1}{3}} \cdot V^{\frac{1}{3}}. \]

A moment of transfer time (t₂) in the calculations of oil radius according to Fay methodology from the second stage of oil spill spreading to the third one is determined by the formula

\[ t₂ = \frac{1.02 \cdot V^{\frac{2}{3}} \left( 1 - \frac{\rho_o}{\rho_w} \right)}{\sigma} \cdot \left( \frac{1}{3} \cdot v \cdot \rho_w \right). \]

Time required for reaching the maximum oil spill in the surface tension phase (third phase) is determined by the following formula:

\[ t_{max} = \left[ \left( R_{max}^4 \cdot \rho_w^2 \cdot v \cdot \rho_w / (K^4 \cdot \sigma^5) \right) \right]^{\frac{1}{3}}. \]

where, \( K = 2.3 \).

Maximum radius of oil spill for \( \tau_{max} \) is calculated by the formula:

\[ R_{max} = \sqrt[3]{\frac{V}{\pi \cdot h_{min}}}. \]

At a certain stage, surface tension changes its sign, and spreading is stopped. As the observations have shown, that occurs, when the thickness of oil slick is reduced to 0.00003 – 0.0001 (m).

The thickness of oil slick (h) dependent on spreading time is calculated by the following formula:

\[ h = V / (\pi R^2). \]

By using above mentioned formulas, there have been carried out the model calculations of time variation (t), radius (R) of oil spill spreading and the area. Basic amount of spreading oil and oil products are in volumes 25 m³, 50 m³ 100 m³, 200 m³ and 300 m³ (Table 1).

The current radius of oil spill at an initial stage of gravity and inertia forces for \( 0 < t < t₁ \) is determined by formula (1).

The current radius of oil spill in the gravitational-viscose phase (second one) of oil spill spreading for \( t₁ < t < t₂ \) is determined by formula (2).

The current radius of oil spill in the third phase of surface tension for \( t₂ < t < t_{max} \) is determined by formula (3).

Table 1 presents the calculated magnitudes of transit time (min) of oil spill spreading process from the first phase to the second (t₁), and from the second one to the third one (t₂).

Analysis of calculations carried out has shown that maximum time (Table 1) of oil spill spreading by phases at the same power of point source depends essentially on the type of oil and oil products and spillover volumes.

At the accidental spillover volumes 25 m³-100 m³, duration of the gravitational viscose phase of oil spreading may vary from 38 min to 95.6 min dependent on the type of oil products.

At large accidents with spreading of oil and oil products in the volume of 100 m³, the transit time from the gravitational-viscose stage of spreading to the phase of surface tension forces is approximately 119.6 min for the most dense oil product (fuel oil) and exceeds 198.9 min at spreading of petrol.

4. Results and discussion

Actually, in response to accidental spill spreading of oil and oil products spill in the areas of Georgian ports the time from the moment of oil dumping to the beginning of works on gathering the oil-watery mixture is not less than 38 min, i.e. in future, the first stage of spreading may be excluded from consideration (1).

Figures 1 and 2 show the dependence on the variation time of the radius (R) of spill spreading and area on the example of oil with density of 870 kg/m³.

![Fig. 1 Dynamics of oil spill in the first-second (a) and third (b) phases: 1 - V=25 m³; 2 - V=50 m³; 3 - V=100 m³; 4 - V=200 m³; 5 - V=300 m³](image-url)
The analysis of these diagrams (Fig. 1) has shown the nature of change of the radius of oil spill dependent on density and volume is the same. Change of the magnitude of oil spill radius mainly depends on its density and volume.

Fig. 2. Dependence of the area of oil spill (m²) on spillover volume (1...100 m³) and time of diesel fuel spreading

5. Conclusion

The proposed model allows forecasting the initial stages of oil spreading. The given methodology enables to determine transit time of the process of oil spill spreading from the first phase to the second one, and from the second to the third one; the radius and area of oil spill spreading; to assess the required means of oil spill localization, in particular – the length of boom containments.

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Abstract: Considered are inhibitor properties of the tank oil slime. Physical and chemical characteristics of oil and oil slime are given. Given are the data of tests on corrosive stability in atmospheric conditions and by accelerated anticorrosive method. It is shown that the aqueous and organic extract of the tank oil slime has obviously marked inhibitor properties that allow to recommend them for producing anticorrosive paint and varnish coatings.

KEYWORDS: OIL, SLIME, INHIBITORY QUALITIES, PAINT COATINGS.

1. Introduction

In many enterprises of oil and gas industry the oil slime is multitonnage waste. A great amount of oil waste of various type and structure [1,2] is formed after the production, transportation and refining of oil and gas. Only according to the data of gas branch of “Gasprom” the oily waste constitute about 10.0 thousand ton in 2000 where the share of liquid waste is 70 % and paste like and hard ones – 30 %. The amount of formed waste in some enterprises varies from 578 tone a year to 2510 tone a year [3]. In spite of the variety of existing oil slime they could be divided into three general groups according to the conditions of their forming [1]:

- ground (formed as a result of the oil products spillage on the soil during industrial operations and emergency);
- benthonic (formed at subsidence of petrol floods at the bottom of the water reservoir);
- reservoir type (formed during the storage and transportation of oil products in tanks of various constructions)

The refining of such slimes for utilization generally provides the extraction of oil fraction [2] on the use of oil slime for slime concrete production in highway engineering [4]. All types of oily waste contain substances having inhibiting properties against corrosion. The research of slimes for using them in the production of corrosion-resistant paint coatings or for the improvement of their quality will allow to expand the material base of paint coatings products production and will assist the protection of environment.

2. The goal of the research.

To determine physical and chemical characteristics of tank oil slime of Batumi Oil Terminal and to define inhibitory quality of aqueous and organic extracts with the purpose of their use in a production and for the improvement of quality for corrosion-resistant paint coatings (aqueous, half oily, oily prime coating and enamel)

3. Object and research methods.

Tanks used during the processing and storage of oil products in course of time require scraping as the sedimentation (oil slime) appears at the bottom and on the walls reducing the actual space of a tank and affecting the quality of oil products. Systematic scraping of tanks is done at least once a year depending on the types of oil products. But in some cases the scraping can be done earlier than the prescribed period because of changing the filled-in oil products with a high content of organic substances, water and some additives of mechanical impurities [1].

Today Batumi Oil Terminal transfer oil from Azerbaijan (Azerilight Crude Oil) and Kazakhstan (Kumkol Crude Oil, Tengiz Grude Oil). In table 1 physical and chemical data of three types of crude oil are given determined for 6 months of 2011 year are given. The analyses have been carried out in Batumi Laboratory of Georgian branch C B (Intertek Cateb Brett) according to the standards of ASTM [5].

<table>
<thead>
<tr>
<th>Crude oil</th>
<th>Density at 20˚C Kg/m3</th>
<th>Water content, %</th>
<th>Mechanical impurities, %</th>
<th>Freezing point, °C</th>
<th>Sulphur content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tengiz Grude Oil</td>
<td>790,3</td>
<td>0,05</td>
<td>0,009</td>
<td>-33,0</td>
<td>0,517</td>
</tr>
<tr>
<td>Azerilight Crude Oil</td>
<td>846,0</td>
<td>0,18</td>
<td>0,010</td>
<td>-9,0</td>
<td>0,143</td>
</tr>
<tr>
<td>Kumkol Crude Oil</td>
<td>827,0</td>
<td>0,27</td>
<td>0,022</td>
<td>+18,0</td>
<td>0,158</td>
</tr>
</tbody>
</table>

At the same period carried were the analyses of oil slime from the storage located on the terminal territory where the tank oil slime from above mentioned types of oil is collected. The amount of accumulated slime of 200...2500 tone is the danger for environment. The accumulated oil slime is viscous mass of dark brown colour, with a density 933,1 kg/m³ at 80˚C, water content 13,3 %, freezing point +3,0˚C, mechanical impurities 0,443 % and sulphur structure 0,257 %.

For the definition of the possibilities for using such slime for the production of corrosion-resistant paint coatings the research of inhibitor quality of the given TOS is carried out. For this purpose the water extract TOS was prepared. (100 gr. of oil slime was being boiled in 1 litre of water for one hour)

After freezing the water extract was filtrated and used for performing accelerated corrosion-resistant tests [6]. For comparison the corrosive inhibitor “Malkor” (technical condition 2415-004-56478541-06) and distilled water were used. Corrosion of the plates was valued visually according to the size of the corroded surface of the plates.
The organic extract of the oil slime was got by the extraction of TOS (tank oil slime) with organic solvent (toluene, xylol). The weight 100 gr of TOS was taken and 1 L. of organic solvent was added. The mixture was allowed for 24 hours. The produced extract in various proportions was added into the known paint varnish enamel ГФ-927 (ТУ 6-10-662-95).

The samples covered with enamel were tested for corrosion-resistant both in atmospheric conditions and by accelerated corrosion-resistant method in 3 % sodium chloride solution. As an example the steel plates of mark CT 08 (steel 08) and size 100 x 150 mm were used. The plates were covered both by clean enamel ГФ-927 and enamel with added various amount of organic extract of TOS. The relationship for paint varnish compositions are given in table 2.

### Table 2. Paint varnish composition structure

<table>
<thead>
<tr>
<th>#</th>
<th>Enamel ГФ-927 mas. %</th>
<th>Organic extract TOS, mas. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>98,0</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>95,0</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>93,0</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>90,0</td>
<td>10</td>
</tr>
</tbody>
</table>

The duration of the test in atmospheric condition lasted 24 months but by the accelerated method - 60 days. Corrosive damage was defined according to the changes of mass of the samples (ГОСТ 17322-71).

### 4. Result and discussion

The received data given in figure 1 show that the water extract of TOS has obvious inhibitory quality against corrosion. From the researches [7] done earlier, the qualities of TOS could be used for the production and for the improvement of anticorrosive qualities of paint coatings.

![Fig.1](image1.png) **Fig.1** The corrosion resistance of steel CT 08 (st. 08) in distilled water (A), water extract of tank, slime (B) and in the solution of inhibitor corrosion (C).

In oil refineries the waste is formed after contact cleaning of transformer oil by synthetic aluminosilicate adsorbent-adsorbent oil slime (AOS). It is the product of adsorbent regeneration caught by wet scrubbers.

The AOS consists of 90-94 % aluminosilicate and 5-8 % of petroleum coke consisting of the mix of high condensate aromatic hydrocarbon and naphthenes. Carried out was the work on researching AOS and on its base the technology for the production of anticorrosive ground compositions and underpaints [7] was developed. The inhibitory quality of water extract AOS is given in figure 2.

![Fig.2](image2.png) **Fig.2** Corrosion resistance of the steel G 08 (st. 08) in distilled water (A) and in water extract of adsorbed oil slime (B).

### Table 3. The structure of water-soluble primer on the base of dispersive polyvinylacetate (DPVA) [7]

<table>
<thead>
<tr>
<th>Primer components</th>
<th>Structure of components mas.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPVA</td>
<td>25,0</td>
</tr>
<tr>
<td>AOS (adsorbed oil slime)</td>
<td>40,0</td>
</tr>
<tr>
<td>ZPS (zinc phosphate slime)</td>
<td>4,0, 5, 6, 7</td>
</tr>
<tr>
<td>SAS (surface active substances)</td>
<td>0,4, 0,4, 0,4, 0,4</td>
</tr>
<tr>
<td>5 %-carboxyl methyl cellulose</td>
<td>2, 2, 2, 2</td>
</tr>
<tr>
<td>Water</td>
<td>28,6</td>
</tr>
</tbody>
</table>

### Table 4. Data of anticorrosive tests of primer structure on the base of DPVA in 3 % sodium chloride solution [7]

<table>
<thead>
<tr>
<th>#</th>
<th>Primer structure according to table 2</th>
<th>Share of steel surface under paint coating covered with corrosion after testing, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Structure I</td>
<td>30,0</td>
</tr>
<tr>
<td>2</td>
<td>Structure II</td>
<td>20,0</td>
</tr>
<tr>
<td>3</td>
<td>Structure III</td>
<td>15,0</td>
</tr>
<tr>
<td>4</td>
<td>Structure IV</td>
<td>5,0</td>
</tr>
<tr>
<td>5</td>
<td>Structure V</td>
<td>12,0</td>
</tr>
</tbody>
</table>

The received results on corrosion resistance of paint-varnish compositions on the base of organic extract of TOS are given in table 5.
Table 5. The data of tests on corrosion resistance in atmospheric condition and by accelerated corrosion-resistant method.

<table>
<thead>
<tr>
<th>#</th>
<th>Paint coatings structure</th>
<th>Tests in atmospheric conditions</th>
<th>Tests by accelerated corrosion-resistant method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I structure</td>
<td>0.025</td>
<td>0.088</td>
</tr>
<tr>
<td>2</td>
<td>II structure</td>
<td>0.022</td>
<td>0.079</td>
</tr>
<tr>
<td>3</td>
<td>III structure</td>
<td>0.010</td>
<td>0.067</td>
</tr>
<tr>
<td>4</td>
<td>IV structure</td>
<td>0.015</td>
<td>0.075</td>
</tr>
<tr>
<td>5</td>
<td>V structure</td>
<td>0.018</td>
<td>0.080</td>
</tr>
</tbody>
</table>

Proceeding from the given data (tab 5) the paint coatings with the organic extract of TOS show the best anticorrosive qualities in all cases. The most effective structure is structure III.

5. Conclusion

Given researches show that the water and organic extracts of tank oil slime have obvious inhibitory qualities that allow to recommend them for using during the production of anticorrosive paint coatings. It not only serves the purposes of environmental protection but also allows to expand the material base of paint coatings production.

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ON APPROXIMATING THE PERIODIC SOLUTIONS OF CAPSIZE EQUATION

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Abstract: The motion of a ship in long beam seas could be described by a second-order non-linear differential equation, having the roll angle as variable and depending on four parameters. With the direct forcing amplitude as bifurcation parameter, the dynamical system exhibits either periodic or chaotic behavior, the route to chaos being realized by a period doubling sequence of periodic motions. Some accepted indicators, like bifurcation diagrams, phase planes and Poincare sections have been computed and they confirm the transition from order to chaos. In the main part of the paper, the harmonic balance method is used to obtain approximate solutions for the periodic motions and to predict the period doubling bifurcations by a stability analysis.

Keywords: SHIP CAPSIZE, DIRECT AND PARAMETRIC EXCITATION, ORDER AND CHAOS, PERIODIC SOLUTIONS

1. Introduction

Capsizing is the most disastrous situation in which can find a sailing ship, since it leads to heavy losses of human lives and ship. It primarily affects the fishing boats and small vessels, but in certain circumstances large ships may suffer too, although they satisfy all the existing rules concerning the risk of capsizing [1]. This is why the stability against capsizing is a fundamental requirement when designing a ship. Unfortunately, despite an extensive experimental and theoretical research during the last decades, this undesirable complex phenomenon is not fully understood yet.

The efforts of researchers have been focused on several directions. First, it was found that the majority of capsizing events occur in astern seas, as a result of pure loss of stability, parametric resonance, broaching, cargo shift, water on deck and wind [2]. Second, mathematical models, following an increasing sophistication and capable of predicting well enough the ship dynamics for some given environment conditions, have been proposed. Most of these approaches consider only the ship’s rolling motion, but models with two, three and even six degrees-of-freedom have been developed. A generally accepted model has not yet been established [3, 4]. Finally, some innovative concepts as transient safe basins, transient capsize diagram, index of capsized resistance, and the recent theoretical developments in the dynamical non-linear systems seem to lead to an improved understanding of the ship capsize process [5, 6].

According to Cardo et al [7], it has become habitual to study the capsize dynamics using a one degree-of-freedom nonlinear oscillator taking the form \( \ddot{\theta} + g(\dot{\theta}) + GZ(\theta, t) = f(t) \), with \( \theta \) the roll angle, \( g(\dot{\theta}) \) the damping function, \( GZ(\theta, t) \) a non-linear function which encapsulates the restoring moment, and \( f(t) \) the external forcing function depending on time.

In the present work we shall restrict our attention to the particular case of Thompson’s equation, which models in a simplified fashion the uncoupled roll motion of a ship in periodic beam seas, with both direct and parametric excitation, the latter multiplying the conventional restoring function [8]. The remainder of our paper proceeds as follows. In Section 2 the archetypal model equation of Thompson et al. is presented in the simplest setting possible. In the following two sections, the approximate solutions for the periodic orbits, given by fast Fourier transform and harmonic balance method, are obtained. We close with a short summary and conclusions in Section 5.

2. Capsize equation

In the paper, the following equation, derived by Thompson et al., is further investigated numerically and analytically with a view to prove the period doubling sequence of periodic motions leading to chaos, and finally to capsise:

\[
\ddot{x} + \beta \dot{x} + (x - x^2)(1 + G \cos \omega t) = F \sin \omega t
\]

where

\[
x = \theta, \quad \omega = \omega_r - \frac{A k}{\omega_n}, \quad F = -A k, \quad G = -A k
\]

Here, \( \theta \) represents the roll angle, \( \theta_r \) the angle of vanishing stability, \( \beta \) the non-dimensional damping coefficient, \( \omega_r \) the wave frequency, \( \omega_n \) the natural frequency of the boat, \( A \) the wave height, and \( k \) the wave number. The forcing amplitudes \( F \) and \( G \) stand for direct and parametric excitation, respectively. Finally, a dot denotes differentiation with respect to time. The details about Eq. 1 can be found in [8], where some preliminary numerical studies for \( \omega = 0.85 \) and \( \beta = 0.1 \) are presented.

As a continuation of their work, in the present paper we address a different area of frequencies, namely we set \( \omega = 1.8 \). Other constant values used are \( \beta = 0.1 \), and \( G = 5 F \). With the direct forcing amplitude \( F \) as bifurcation parameter, it was found that the analyzed system exhibits either periodic or chaotic behavior, the route to chaos being realized by a doubling sequence of periodic motions. A sense of the rich dynamical behavior which system (1) displays can be gleaned from the bifurcation diagram \( F - x \) in Fig. 1.  

![Fig. 1 a) Bifurcation diagram F - x for \( \beta = 0.1, \omega = 1.8, G = 5F \); b) The upper – right part of (a) is zoomed for details.](image-url)
To construct this diagram, we started from equilibrium conditions \( x(0) = x(0) = 0 \) and plotted \( x \) at every one forcing cycle with the same phase angle. The first 200 cycles were discarded to avoid transients.

3. Approximate solutions for periodic orbits with Fast Fourier Transform

Fig. 1 shows that for relatively small forcing amplitude \( F \) the system executes oscillations with period \( T = 2\pi / \omega \). As \( F \) is gradually increased the period \(-T\) motion bifurcates into a period \(-2T\) motion. For further increase of forcing period \( 4T, 8T, 16T \), and so on, motions are obtained. When \( F \) outruns 0.286, the response becomes chaotic. The periodic motions could be well approximated by a finite series of the form

\[
x(t) = \sum_{i=0}^{n} \left( a_i \cos \omega t / k + b_i \sin \omega t / k \right)
\]

with coefficients \( a_i, b_i, i=0, n \), real numbers given by Fast Fourier Transform (for short FFT) and \( k \) stands for \( kT \) period. The phase plane plots, and the Fourier spectra for the cosine and sine components (black and red vertical lines, respectively) when \( F = \{0.1, 0.25, 0.27, 0.282\} \) are illustrated in Figs. 2 to 5. The results obtained by FFT method, which include the first 12 harmonics and sub-harmonics, are also presented in the phase planes and are indicated by red asterisks. The blue dots stand for Poincare sections. It is obvious that the agreement between the solution obtained by FFT method, which include the first 12 harmonics and \( b_2 \) as unknowns is obtained:

\[
(4) \quad a_0 \left(1 - a_0\right) - 0.5 \left( a_1^2 + b_1^2 + a_2^2 + b_2^2 \right) + a_1 G(0.5 - a_0) + 0.5 a_2 G - 0.5 G(a_1 a_2 + b_1 b_2) = 0
\]

\[
(5) \quad a_0 G(1 - a_0 - a_2) - 0.5 G(2a_1^2 + a_2^2 + b_2^2) + a_1 \left(-\omega^2 - 2a_0\right) + b_1 \omega(\beta - (a_1 a_2 + b_1 b_2)) = 0
\]

\[
(6) \quad -a_1 \omega(\beta + b_1 \left(-\omega^2 - 2a_0\right))(a_1 b_1 + a_0 b_2)G + b_1 a_2 - b_2 a_1 = F
\]

\[
(7) \quad a_1 G(0.5 - a_0) + a_2 \left(-4\omega^2 - 2a_0\right) + 2b_2 \omega(\beta - a_1 b_1) G - a_2 G - 0.5 \left( a_1^2 + b_1^2 \right) = 0
\]

\[
(8) \quad b_1 G(0.5 - a_0) + b_2 \left(-4\omega^2 - 2a_0\right) - 2a_2 \omega \beta - a_1 b_1 + b_1 b_2 G = 0
\]

This system has been solved for different forcing amplitudes \( F \), equally spaced between 0 and 0.22, using Newton-Raphson method and the findings are displayed in Fig. 6.

4. Approximate solutions for periodic orbits with harmonic balance method

From the dynamical phase diagram depicted in Fig. 1, it is clear that the period bifurcation phenomenon could be regarded as a precursor of the chaotic behavior and, finally, of ship capsizing. To estimate approximately the bifurcation point from period \( T \) – orbit to period \( 2T \) – orbit and the significant jump of the roll amplitudes, in this section a harmonic balance analysis is performed [9].

According to experience gained in working with FFT, we assume a period \( T \) solution of the form (3), with \( n = 2 \) and \( k = 1 \). Substituting it in the capsize equation (1) and balancing the free terms and the coefficients of \( \cos \omega t, \sin \omega t, \cos 2\omega t \) and \( \sin 2\omega t \), the following strong non-linear system of five equations with \( a_0, a_1, a_2, b_1 \) and \( b_2 \) as unknowns is obtained:

Fig. 2 Phase plane plots and the Fourier spectra for capsize equation (1) with \( F = 0.1 \).

Fig. 3 Phase plane plots and the Fourier spectra for capsize equation (1) with \( F = 0.25 \).

Fig. 4 Phase plane plots and the Fourier spectra for capsize equation (1) with \( F = 0.27 \).

Fig. 5 Phase plane plots and the Fourier spectra for capsize equation (1) with \( F = 0.282 \).

Fig. 6 Amplitudes \( a_0, a_1, a_2, b_1 \) and \( b_2 \) for different forcing amplitudes

For \( F = 0.1 \), we found \( a_0 = 0.0062, a_1 = -0.0077, a_2 = 0.0041, b_1 = 0.006, \) and \( b_2 = -0.0067 \). The associated time history and the phase plane (the asterisks) are shown in Fig. 7, along with the solution obtained by numerical integration (the continuous black curve). It could be seen that the agreement between the two solutions is good, with some notable differences at peaks and
and, are given in Appendix.

Continuing to grow the forcing amplitude $F$ above 0.22 will come a time when the period – 2T solution becomes unstable and a period 2T- orbit will replace it. To investigate this bifurcation one considers a perturbed solution of the form $\tilde{x}(t) = x(t) + \delta x(t)$. Replacing the perturbed solution into (1) and noting that $x(t)$ verifies the same equation, we get the following linearized variational equation

$$\delta x = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

where the elements of matrix $[M]$, which are functions of $a_0, a_1, a_2, b_1$ and $b_2$, are given in Appendix.

The period – 1 solution becomes unstable and bifurcates into period – 2 solution when the determinant of matrix M changes its sign from negative to positive [9]. For the analyzed case, this happens when $F \equiv 0.22$, which is in good agreement with value $F \equiv 0.23$ given by numerical integration (see Fig. 8).

Starting with $F \equiv 0.232$, the equation (1) has a solution of the form $T(t)$, which includes the perturbation $\delta x$ given by (10). Replacing it into (1) and balancing the harmonic terms, the following algebraic non-linear system of nine equations is obtained:

$$\frac{d}{dt} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ b_0 \\ b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ b_0 \\ b_1 \\ b_2 \\ b_3 \end{bmatrix}$$

where

$$a_0(t) - a_0 = -a_1 x_1 + b_1 x_2 + a_1 b_1 - a_2 x_1 + b_2 x_2$$

and $X$ is the forcing amplitude. The Newton – Raphson procedure did not work for the system (12) due to the important difference between $a_0$ and $b_1$ on one hand, and the other unknowns.

The period – 1 solution becomes unstable and bifurcates into period – 2 solution when the determinant of matrix M changes its sign from negative to positive [9]. For the analyzed case, this happens when $F \equiv 0.22$, which is in good agreement with value $F \equiv 0.23$ given by numerical integration (see Fig. 8).

Further, for a brief interval of forcing amplitudes’ values the system (1) undergoes a transition from a period 1 to a period 2 motion, this stage being characterized by high-order period motions or even chaos (see Fig. 9).
However, neglecting the small terms like $a_{1/2} a_2$, we were able to estimate the solution of system (12 – 20). The results for $F = 0.25$ are shown in Fig. 10. Again, the agreement between the harmonic balance solution and the numerical one is good enough, the notable differences being associated to the first derivative, $\frac{dx}{dt}$. The period – 2$T$ motion loses quickly its stability (around $F = 0.26$) and, after a new transition stage, turn into a period – 4$T$ motion. The mathematics involved by harmonic balance method becomes from now on quite cumbersome.

5. Conclusions

In the paper, the ship capsize equation provided by Thompson and co-workers was analytically and numerically investigated for a range of frequencies far from resonance conditions. Excepting the fact that capsizing is moving into an area of higher values of forcing amplitudes, the system’s behaviour remains unchanged, i.e. the chaos is shown to occur through a cascade of period doubling bifurcations as the forcing amplitude is increased.

The Fast Fourier Transform has been used to obtain approximate solutions for period – $T$, 2$T$, 4$T$ and 8$T$ motions, and the results proved to be excellent when compared with the numerical ones.

The Harmonic Balance Technique, with appropriate harmonic terms in the assumed solution, allowed us to approximate period $T$ and 2$T$ motions and to estimate the bifurcation between them. Because of the mathematics involved in approximating the higher-order period motions, the above-mentioned method is inadequate to study the next period-doubling bifurcations leading to chaos.

Literature

Abstract: The development of microelectronics intervened greatly in the automotive industry, therefore this fact cannot be ignored in the education. In today’s teaching absent methods, special classrooms and didactic tool, that allow to know the operating principle, processes understanding and also diagnostics of vehicle electronic systems. The project, which is realising at the University of Žilina intended for the modern education of several study programs is presented in this paper.

This project will influence on professional qualifications of project investigators. They will improve their knowledge by means of professional training. New knowledge they will transfer subsequently in the education. The strategic goal of the project is “Reconcile the needs of the knowledge society and the labour market in higher education in the field of automotive technology”.

Keywords: CONTROL SYSTEM, DIAGNOSTICS SYSTEM, VEHICLES

1. Introduction

During the project realisation the modern components of education will be implemented and they should help for removing barriers, creative activities and easier understanding complex processes which are in current vehicles, engines and other transport means.

The goal of this project is the establishment and the equipment of the experimental special classroom in which will be installed the state of the art tool of the vehicle diagnostics and simulations of vehicle electronic systems. When the special classroom will be realised, existing school subjects and study programs will be modified.

The main strategic objective of the project is “reconcile the needs of the knowledge society and the labor market in higher education in the field of automotive technology”.

2. Characteristics and objectives of the project

The specific objective of the project is to improve the attractiveness and innovative forms of education in the field of automotive technology.

The expected result of the project will be an innovative teaching practices in bachelor and master studies. As part of the project it will set up a special education using the latest simulation methods activities of engine systems and vehicles for the purpose of establishing diagnosis. Another result of the project will be an innovative learning materials focused on the latest findings in the field of automotive technology. The objective of improving the quality of study materials and methods in teaching will achieve increased interest of young people in studying engineering disciplines. Implementation of the project is achieved by an increase in professional qualifications investigators pursue vocational training. This knowledge will then be transferred to the learning process.

Target groups of the project:
- University teachers,
- Employees of universities in research and development,
- Doctoral students,
- Students.

Project activities:
1.1 Analysis of the current labor market in relation to the improvement of innovative forms of teaching;

- the aim of this activity is to conduct a comprehensive analysis of the labor market so that pointed to the current situation and development of the automotive industry,
- by means of obtaining information and knowledge about the actual needs of the labor market and society in automotive technology will be able to curricula and teaching processes and thus to innovate in ways that will be high-quality output ready group of graduates;

1.2 The creation of new, sophisticated teaching aids for teaching:
- The aim of this activity is the specification of simulation models of components, design and construction practices for the proper functioning of simulation panels diagnosis of engine vehicles within education,
- By means of obtaining information and knowledge about the actual needs of the labor market and society in the field of automotive technology specialist investigators will be able to prepare an educational methods and techniques to fully exploit the potential of highly specialized simulation panels vehicles;

1.3 Implementation methods of simulation models in the learning process,
- the aim of the activity is the implementation of innovative education forms and its pilot verification in the educational process
- innovation of curricula will take place on the basis of knowledge from previous analyzes and monitoring the behavior of simulation models through the application of new knowledge into curricula and education materials.

Through the implementation of project activities will improve the professional preparedness of concerned department’s student to the actual needs of the labor market.

At the same time university teachers, employees in research and development and training PhD students completing high gain new expertise in automotive technology, thereby increasing their labor market competitiveness.

The main aim of the project is to adapt and innovate higher education methods and processes to the needs of the knowledge society and the labor market in view of the latest trends and directions of development of vehicle technology.

Project realization consists of the involvement of professional researchers, who have the opportunity to increase their expertise through training, exchange programs and international mobility. The project is expected to increase the qualifications of teachers,
university employees in research and development and doctoral students who will participate in the execution of project activities.

The project will create specialized classrooms with modern teaching aids based on the most advanced systems of diagnostic panels that will simulate controllers and other functional activities within the operation of vehicles.

Analysis of all processes, lessons learned result in an adjustment of existing curricula and create new learning materials for students of compulsory subjects and many other optional subjects.

It is expected to increase interest in younger age groups to study the issue to the creation of highly sophisticated experimental teaching simulation-based electronic educational panels.

The present project follows the requirements of the activities in the field of strategic importance for the further development of economy and society and is consistent with the long-term aim of University of Žilina.

Achievement of project objectives and challenges manage to get a flexible and fast-adapting graduates whose inclusion in the labor market due to meeting market requirements will help develop the region and ensure that such companies to greater prosperity and a better quality of life [1].

3. Project management, involvement of partners

The project is led by the Department Transport and Handling equipment for the Faculty of Engineering. Department focuses on tackling vehicle safety against derailment, wheel/rail contact, theory and design of rail vehicles and track maintenance machines, testing braking systems.

The Department develops the theory and application of maintenance of rolling stock as well as machinery and equipment in general, deals with the problems of reliability and development of new systems maintenance, management of maintenance processes using the most advanced software in the field of project management and computerized maintenance management system. It continues also in the traditional areas of research as drive traffic, traffic vehicles and their quality and environmental parameter, with emphasis on reducing noise and vibration.

The Department is also aimed at addressing the various issues of theory and design of reciprocating internal combustion engines and virtual modeling, dedicated to the problems of the environmental burden of energy units equipped with combustion engines, cars and other means of transport.

For the management and implementation of the project the project team corresponds. Its foundation is a combination of internal and external team staff team. The project team consists of: Project manager, coordinator of professional activity, Clerk, Personnel Worker, publicity manager, accountant, financial manager, to public procurement, monitoring manager and project participants [1].

4. Didactic means – training panel

HD Electronik Company offers a variety of teaching resources that will improve the level of teaching. Teaching resources (hardware, software) are supported by extensive written online material that can serve as a basis for teaching the basics of automotive electronics. Expert system “HD Elektronik”, which implements auto-navigation experts in finding complex disorders can serve as a basis for teaching advanced in the field of automotive electronics, for example the realization of postgraduate courses.

A big benefit of superior teaching composition is perfect documentation, which includes in addition to features and work with the system and also a description of the function of the automotive components and description of signals.

Presented teaching tool is able to fully generate real action and real electronic signals of a particular vehicle. To ensure high comfort and economy of teaching is a feature of some mechanical components, e.g. mechanics of combustion engine emulated by the electronics and control unit for the heading to “feel” in the real environment and allows you to perform all the functions flawlessly inside (on board) and parallel pin diagnostics. Teaching material is controlled by a PC and PC teacher students. Both computers have different rights and information. Computer teacher allows you to generate a large number of disorders, while working student is provided with a diagnostic means.

The HD Elektronika Company prepares the description of simulated waveforms. It offers various types of diagnostic panel:

- VEP500/motor – diagnostic panel “Motor”,
- VEP500/BSI – diagnostic panel “Central electronics BSI”,
- VEP500/ABS – diagnostics panel “ABS”,
- VEP500/AIR BAG – diagnostics panel “AIR BAG”,
- VEP500/KL – diagnostics panel “Air Conditioner”,
- VEP500/KE1 – diagnostics panel “Comfortable electronics”,
- VEP500/KE2 – diagnostics panel “Comfortable electronics”.

For VEP500 Škoda Fabia 1.4 16V components are used.

![Fig. 1 Diagnostic panel “Motor” (VEP500/motor) [2]](image1)

![Fig. 2 Diagnostic panel “Central electronics BSI” (VEP500/BSI) [2]](image2)
Functional panel electronics powerplant car with computer – controlled fault simulator – we propose to built a fully functional panel electronics powerplant operated and extensible through the CAN bus, which will be supplemented by computer-controlled simulator disorders.

**Fig. 3** Faults simulator in electrical and electronic circuits (Diagnostic panel “Motor”) [2]

Stats faults in electrical and electronic circuits, diagnostic tools for internal “on-board” diagnostics and “pin” diagnostics. The figure illustrates the principle of the system, its expansion and improvement will take place on the basis of claims guide more students, or new requirements.

Diagnostic panel VEP500/KE2 contains components (electric windows, electric sunroof, electrically operated door mirrors …) with the possibility of simulation disorders. Moving parts are replaced with electronic simulation. The panel can be measured by measuring jacks parallel diagnosis each course selected components. Through diagnostic socked serial diagnostics can blame simulated fault.

Computer teacher teaching staff will enter the task – failure, computer students communicate the results of the test carried out by a series of diagnostic equipment SuperVAG, control the activities of students in locating such as errors using a digital oscilloscope didactic HD25 or engine testers “Diagnostic Analyzer HD34N” and evaluate student activity. Relay switching matrix disorders modular, expandable relay matrix disorders teacher computer controlled by a specified type of fault. Diagnosed system – fully functional panel controlled comfort electronics and extensible via the CAN bus. Diagnostics HD Elektornika is a major manufacturer of this technology and has in its production program wide range of these products and diagnostic devices cooperating companies.

Technical description of the components of version 10.0.2 includes 25 components (approx. 1200 pages ignition, injection, …). The following figures tell us about the work environment HD Elektronika Ltd [2].

**Fig. 4** Detailed description of components [2]

**Fig. 5** Description and construction components [2]

**Fig. 6** Producer and using components [2]

**Fig. 7** Practical involvement [2]
Škoda Fabia – real functioning didactic interactive system. It consists of:

- Two panels “Powerplant” and “BSI”,
- Functions of engine drive (RPM, camshaft, crankshaft) are completely emulated microprocessor,
- Functions of chassis (measurements of velocity) are emulated microprocessor,
- All BSI components and functions are operational,
- Test points for diagnostics are labeled in conformity with the service documentation of Škoda Fabia,
- Properly working control loop between the combustion engine and the control unit ECU. The ECU does not detect any error resulting from a malfunction engine,
- Complete On Board (serial) diagnostics,
- Excellent four channel Pin Diagnostics “Diana”,
- Computer control station teacher is equipped with sophisticated intuitive software. Using this software the teacher can guide the didactic devices. Creating new challenges for teaching and create about a million error combinations that students can solve. Error combinations represents cases of actual practice.
- Student stations are equipped with special software, which stimulates activity and creativity of students. Using this software, the student learns the theoretical and practical principles of operation of automotive components and their cooperation. Students can also learn how to implement and PIN On Board Diagnostics,
- Special instruction increases the activity of the teacher and updated knowledge of students.

5. Anticipated benefits and follow-up activities of the project

Human resources development will be ensured through continuous learning and skill transfer to new PhD students and research and development staff. Implementation of the project will increase skills and knowledge of the target groups of the project submitted

University teachers, professional investigators involved in the project will benefit from the experience and knowledge acquired after the end of the project will use the latest ICT gained in the implementation of the project in the education process use modern equipment. Their professional competences will be increased.

Students involved in the project will be able to use new knowledge in practice in the labor market as well as any further education.

The basic benefits of the project can be included:

- use of knowledge and results, in cooperation with professional experience and the professional community,
- addressing common challenges in new partnerships (automotive production, diagnostics),
- processing of technical publications, technical papers,
- development and promotion of professional development of young researchers at a higher quality level,
- increasing the quality of the practical vocational training students for 1st, 2nd and 3rd education degree,
- coordination of further development of HighTech in industry in Slovakia,
- professional participation in global and international forums and conferences,
- implementation of activities that will contribute to increase the motivation of young people to study technical disciplines.

Conclusion

On completion of project activities is expected to be full utilization of the project results in the form of operation of the dedicated classrooms for simulation of electrical management processes for vehicles and engines. An important indicator of sustainable will create learning materials (textbooks, scripts), which will be recording the results of the analysis of labor market needs in the field of automotive technology and the use of innovative models in practice.

After completion of the project we will continue to expand opportunities for studying at our university and ensure the development and progress of the school. This follow-up activity after the project we want to finance from its own resources, subsidies, if necessary EU resources in the form of projects or through sponsorship.

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References

EKOMPAKT, A NEW TECHNOLOGY FOR OBTAINING ENERGY FROM BIOMASS

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Abstract: In the Division of Vehicle Engineering, Wroclaw University of Technology, there is realized the grant which aim is to work out the innovative compact EKOMPAKT module- the installation of electric energy generation from biomass renewable resources by new technology. Research results (primarily simulation) provide necessary data for any modification of the installation in a way that the implementation of a new solution will be possible in diverse locations which are characterized by different working conditions.

KEYWORDS: BIOMASS, MODIFICATION, ENERGY

1. Introduction

Dynamic, global economy development implicates huge market demand for installations generating electric energy from renewable resources in a way that does not have any negative effects on the environment.

Both in Poland and in the world, numerous scientific researches are carried out, which effect is visible in the knowledge concerning gasification processes of solid fuels of natural origins and solids of synthetic origins.

Knowable are: standard gasification technologies (among them chemism of the process, the impact of particular parameters on its progress), combustion technologies of gas received from substrates transformation, catalysts of medium and high caloric combustion of gasified gas product, technologies of heat recovering from technology processes (e.g. ORC systems), methods of combustion gases purifying, technologies of purifying and stabilizing solid products of gasification process, methods: measurement supporting chemical processes, remote control and archiving of installation working parameters.

In the currently knowable technologies, total energy extraction from the acquired fuel is not fulfilled, which is reasoned by technical-economical considerations. Scientific-technological progress is not sufficient in this case.

As an effect of project fulfilling, the new product will be implemented, which fully inscribes into existing technological gap. In the world, there is missing the technology that allows the conditioning of acquired gas and fumes in a way which safety enables their heat energy use.

Carrying out of the present project, enables to work out a new, compact module for obtaining electric energy from biomass. The novelty of this module will result from the making use of innovative technological solutions which are not currently applied in the branch.

2. Assumptions regarding biomass transformation process.

Standard gasification of solid fuels of natural origins and solids of synthetic origins is the issue known and well described in scientific literature. Workings over congregation systems connected with biomass gasification are pursued in the whole world, mainly in the USA and UE countries.

Experimental installation of biomass gasification for obtaining electric energy are launched by such companies as:
- Institut für Wartetechnik w Graz (Austria) – demonstrative installation, gasification in solid bed, gas engine Jenbacher company 38 kWe power (electric energy) [1],
- Blackwater Valley Energy (UK) - demonstrative installation, downdraft gasification of 200kWe power [2],
- Xylowatt (Switzerland) – downdraft gasification, heat interchanger, filter, mud of 55kWe power[3],
- HKV Hogild (Dannemark) – two-sided gasification, heat interchanger, filter of 120kWe power, [4],
- KHD Koln (Germany) - two zonal gasification, mud of 38kWe power, [5],
- Hermogenics Albuquerque (USA) - downdraft gasification of 300kWelectric energy power. [6],
- A.H.T. PyrogasVertriebs GmbH (Germany) - multi zonal gasification modules 50-500 kWe, [7].

EKOMPAKT is technology of new pro energy process of biomass energy extraction together with the elimination of wastes. Project fulfilling enables to work out a new installation module for the process fulfilling.

The novelty of process results from making use of innovative technological solutions which are the issue of the project. The innovation results from carrying out of the process in a way that, there will be fulfilled its subsequent functions:
- Biomass conditioning
- Double phase gasification (the first- pyrolysis where the heat is provided to biomass by radiation, the second- gasification of fluid and solid products by overheated steam)
- Conditioning of gas as fuel (the quality of gas is researched on-line, gas purification and mixing it with other gases in order to obtain the particular mixture parameters),
- Conditioning of fumes (the quality of fumes is researched on-line, for utilization the catalytic systems will be used, among them the DENOSOX system of catalytic denitrifying, desulphurization of fumes)
- Utilization of process solid holdovers to the environmentally harmless form.
- Management of heat energy stream,
- Piloting (individual piloting of each system; integrated piloting of installation system based on mathematical models; working monitoring piloting of particular piloting systems, which when necessary takes its role with the use of artificial intelligence and fuzzy logic when it is ended; piloting in actual time through the use of signal processes).

What is more, electric energy will be obtained in both generator powered by engine and by the multisided use of holdovers heat. Currently working installation for renewable resources gasification does not have such advanced solutions which enable the high electric energy yield with low harmless in the environment.

3. General project conception description

The aim of the project is development of an innovative, on the world scale, compact module for obtaining electric energy mainly from biomass.

The effect of project fulfilling will be the activation of demonstrative installation and testing of compact module EKOPMACT in
which all system elements will be integrated in one standard container. 
The results of demonstrative installation researches will provide necessary data for any process installation modification in order to make the implementation of a new solution in various locations, characterized by different working conditions, possible. Expected economic effects result from introducing the new product into the market and they are supposed to enable the multiple turn of outlays borne for B+R workings in five years from the project beginning. After finishing the project, the demonstrative installation will be used for pursuing further B+R working which aim will be, among others, obtaining synthetic fuels from biomass.

4. Research tasks expected for fulfilling in the project

The key research tasks includes the verification of:

- Installation working on the basis of biomass wastes, which will produce electric energy for sale (positive energy balance) and selling solid product (installation will work without wastes),
- Construction of the reactor for biomass from wastes gasification, which produces medium calorific gas and fluid that are after conditioning will be suitable for feeding engine of unit generating electric current,
- Internal combustion engine modification in a way allowing it to work efficiently and stably while powering it by conditioned gas regardless the type of biomass that empowers the gasifying reactor,
- Unit of biomass dosing and unit of purifying exhaust gases in a way allowing them to be efficient during working of installation empowered by different types of biomass,
- Unit of separating and packaging of wastes from products, to make them obtain solid form which will be possible for transferring it to the natural environment,
- Piloting-measurement system to make possible the semi-automatic, optimal installation working with remote control of its exploitation.

5. Description of researching methods and techniques applied in the project.

Within the frames of fulfilling the project, the following researching methods have been applied:

- Chemical analyses (among them chromatographic ones): chromatographic (GC-FID, GC-MS), spectrometric, usefulness of biogas as engine fuel, waste after gasification process. The analyses will be performed with the use of devices from Pracowni Badań Emisji PWR equipment
  - Quality and quantity parameters evaluation: biogas, fumes, process wastes
  - Toxicological analyses concerning cytotoxicity of fumes emitted from EKOMPACT device (according to PN-EN ISO10993-5). For the researches the line of cell from human lungs lining ((ATCC CCL185).
- Evaluation of fumes toxicity by the use of equivalent toxicity quotient methods,
  - Toxicity evaluation of fumes emitted form installation (actual toxicity)
  - Evaluation of systems for fumes purification efficiency.
- Researches over engine roller performance tester: Engine studies on unique, complexity equipped roller performance tester location dedicated to studies of engines empowered by gas fuel with the system of analyzers based on reference methodology.
  - Methodology of matching engine to EKOMPACT device.
  - Authorial methodology of internal catalyst of combustion process implementation according to method patented by project authors relying on catalytically active substance introduction into the inside of engine combustion chamber (on a special, optimized mover) which enables:
    - Shortening of ignition delay of biogas and air mixture in engine,
    - Carcinogenic emission reduction.
- Thermal characteristics of devices studies: Researches with the use of thermo vision cameras and apparatus for heat inspection which are among the equipment belonging to The Division of Vehicle Engineering, Wroclaw University of Technology.
  - Evaluation of process pursuing parameters and thermal characteristics of devices in the container.
- Numerical simulations: MES- computer calculating programs which use the MES method in static, dynamic, modal analysis issue.
  - Durability calculations of device and units elements and their numerical optimization
  - Numerical CFD simulations, calculations of: turbulent flow, stationary and non-stationary, multi-phase: flows with cavitations
  - Heat flow modeling
  - Combustion processes calculations,
- Proliferation of pollution indicating - flow with constant phase.
  - Calculations of gas and heat flow inside device and its units with numerical optimization of these processes.
  - Numerical simulations CHEM-CAD: numerical modeling of chemical reactions which take place during gasification phase and engine combustion.
    - Process optimization according to chemical reaction process in gasification and combustion process of mixture of known quality and quantity composition, in order to develop device working mode.
  - Numerical simulations MBS (Multibody Simulations): numerical kinematic-dynamic modeling.
  - Optimal packaging of devices and units in container.
- Vibrant acoustic analyses:
  - Acoustic object researches: assignment of pressure level and acoustic power, location of sound sources with the use of probe and acoustic holography.
  - Object vibration research: spectral analysis, modal analysis. In the researches there is planned making use of application for non-stationary acoustic holography, impulse hummer of strength detectors, accelerometers 3-axial PCB-ICP, multichannel dynamic signal analyzer, low frequency microphones, sound level meter with G filter.
  - Optimizing of device according to minimizing noise and vibrations emission.

6. Conclusions

Module EKOMPACT will be a total novelty in the world market. This module, currently, does not have any equivalent which would enable the high yield of electric energy together with providing, at the same time, huge possibility of installation modification for each of users, in order to its optimal adaptability for requirements of localization and charge. There will be implemented the series of totally innovative conceptions and solutions, which will cause the creation of new market for new product.

In development workings it is also predicted the use of gathered experiences for creating future installation generating synthetic, hydrocarbon fluid fuels from biomass gasification (according to new synthesis processes).
Predicted economic effects, connected with introduction of a new product in the market, enable the multiple turn of outlays borne for R+D workings in five years from the project beginning. The implementation of new technology confirms the inception of new, stable work places for high qualified people in the European Union.

7. Literature:

THERMAL COMFORT ASSESSMENT USING HUMAN SUBJECTS

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Abstract: The objective of the present study is to experimentally investigate the thermal comfort inside a car cabin. During the experimental campaign the occupants filled out questionnaires on the thermal sensation vote. The questionnaire contained questions about the local and global state of comfort and were performed according to ISO 14505-3 / 2006 and ISO 10551 / 2001. Each experimental session lasted 30 minutes and each occupant completed four questionnaires as follows: a questionnaire at the entrance in the car cabin, and afterwards one questionnaire every 10 minutes.

Keywords: THERMAL COMFORT, AUTOMOTIVE, HUMAN SUBJECTS (PASSENGERS), QUESTIONNAIRES, THERMAL ENVIRONMENT

1. Introduction

Thermal comfort in vehicles has gained more importance in recent years, one of the main reasons being that time spent by people inside car’s cabins has increased considerably. Optimization of fuel consumption is one of the major issues in the current geopolitical context. European directives adopted emission reduction targets for greenhouse gas emissions in 2020 at a rate of 20% compared to 1990 emissions [1], thus contributing to the promotion of clean and energy efficient vehicles.

The present work is dedicated to the study of cold thermal environments in car through a subjective assessment based on an individual questionnaire which aims to describe thermal sensation felt by occupants. Nowadays vehicles represent a necessity. Unfortunately, thermal comfort in cabin has not been developed simultaneously with this necessity [2].

2. Method

The objective of the present study is to experimentally investigate the thermal comfort inside a car cabin. The evaluation was conducted in the cold season, in Bucharest in a Renault Duster SUV (Sport Utility Vehicle). Several measurements were conducted being used a large number of human subjects.

The main methods for assessing thermal comfort are the following:
- Subjective methods - utilizes subjective scales to determine the sensation felt by the human body. In this case the correctness of the results depends heavily on knowledge and understanding sensations scale used.
- Objective methods – are those models which quantifies physical or physical state using measurements instruments.

The thermal sensation can be predicted but existing thermal comfort standards, e.g. ISO 7730/2005 [3] are based on experiences where people spend longer time. The standard ISO 10551/2001 [4] covers the construction and use of thermal sensation scales and proposes a set of specifications on direct experts assessment of thermal comfort/discomfort expressed by persons subjected to various degrees of thermal stress. This approach has been done in order to supplement the objective measurements with the aim of receiving reliable and comparative data on the subjective aspects of thermal comfort/discomfort. Thermal scales as proposed in the standard have used and questioned in following order:
- Perceptual (How do you feel now? e.g. hot);
- Affective (How do you find it? e.g. comfortable);
- Preference (How would you prefer to be? e.g. cooler);
- Acceptance (acceptable/unacceptable);
- Tolerance (Is the environment tolerable?)

The thermal sensation scale is a 7-degree two-pole scale, comprising a central neutral point and two times 3 degrees of increasing intensity. The central point of indifference corresponds to the absence of hot and cold sensation. The scale corresponds to ISO 14505-3/2006 [5] scale used frequently and the results obtained can be compared to the other studies.

The scales of comfortable and stickiness are asymmetrical 4-degree scale, the effect lacking from the base, these two being negative. These scales balance each other, for example, you cannot feel comfortable if you’re sticky (sweaty).

Preference scales is used when the occupants express how they would prefer to be the indoor environment. Again the scale will validate the answer of thermal sensation scales previously used.

The ISO 14505-3 gives guidelines and specifies a standard test method for the assessment, using human subjects, of thermal comfort in vehicles. The questionnaire used in our study made corresponding to indicates from ISO 14505-3 and it is in Fig. 1.
All measuring campaigns have been made with air flow discharged from the dashboard vents and the footwells, and with ventilation speed on 1st position, as shown in the following figure (Fig. 2).

Survey questionnaires were given to the occupants and a total number of 96 questionnaires were completed and the time for filling the questionnaire was about 2-3 minutes. The general information requested by questionnaire was: date and time of filling, information about the person who had completed the questionnaire (age and sex). For the assessment of the thermal sensation the subjects had to choose an option on the 7-points rating scale and they also had to choose the thermal preference at the time of filling out the questionnaire. They had to answer about the acceptability of the thermal environment and about local thermal discomfort. Based on the questionnaires we could estimate the Thermal Sensation Vote (TSV). The persons interviewed have been informed briefly about reasons for the questionnaire.

As a particularity, uncomfortable and thermal sensation scales were made also for 11 parts of human body: head, front torso, back torso, arms, front and back thighs, front lower legs, back lower legs, foot, ankles and neck.

Surveyed people have been given 4 questionnaires, the first being completed at the entry of the car (minute 0), the other 3 being filled out every 10 minutes. Each session time took 30 minutes.
3. Results and discussions

Regarding the subjects surveyed, 67% are males and 33% are females, with ages between 20 and 40 years.

Although outside temperature was slightly over 0°C and air temperature control button, from heating and ventilation console, was on a neutral position, the passengers thermal sensation vote for the whole body was +3 (hot) in a proportion of 20% (Fig. 5, 7).

Fig. 5: Thermal sensation of whole body

\[
\begin{array}{c}
\text{+3 Hot} \\
\text{+2 Warm} \\
\text{+1 Slightly warm} \\
\text{0 Neutral} \\
\text{-1 Slightly cool} \\
\text{-2 Cool}
\end{array}
\]

Fig. 6: Preference votes of the passengers

The percentage of persons who felt comfortable was only 29%, while 17% felt uncomfortable.

Uncomfortable sensation was felt most intensely at the head, 24% of votes being for very uncomfortable (Fig. 6). On the other hand, ankles sensation was comfortable for 51% of the occupants.

Fig. 7: Thermal discomfort scale

Table 1: Mean TSV values

<table>
<thead>
<tr>
<th>Nr. Pass/ Nr. Minute</th>
<th>minute 0</th>
<th>minute 10</th>
<th>minute 20</th>
<th>minute 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger 1</td>
<td>0.67</td>
<td>0.67</td>
<td>0.67</td>
<td>1.00</td>
</tr>
<tr>
<td>Passenger 2</td>
<td>0.50</td>
<td>0.50</td>
<td>1.50</td>
<td>2.00</td>
</tr>
<tr>
<td>Passenger 3</td>
<td>1.17</td>
<td>1.67</td>
<td>2.17</td>
<td>2.50</td>
</tr>
<tr>
<td>Passenger 4</td>
<td>1.00</td>
<td>1.17</td>
<td>1.67</td>
<td>1.83</td>
</tr>
</tbody>
</table>

TSV-mean value was calculated and the results validate what is written ISO 7730/2005 for certain values of indoor environment [3, 6] (metabolic rate, clothing insulation, air temperature, mean radiant temperature, relative air velocity, water vapors partial pressure), values of TSV must be between (-2…+2).

The passenger from front right place of the car at the end of every session (minute 30) have the mean calculated TSV value +2.5, justified by the fact that the solar radiation was more intense along measurements, and the warm air flow discharged from the dashboard vents were directed to the passenger. Back passengers expressed a thermal sensation similar to the front right passenger, mean TSV in +2.
The graphs in Fig. 9-10 highlights expressed subjective character of thermal sensation of every occupant. Are presented the global thermal sensation of the passengers from the front of vehicle at the beginning and at the end of the measurement sessions. Be observed that one passenger has expressed a positive thermal sensation global and local on scale for most tests, except for the first session when measuring thermal sensation it was mainly cold.

Place from front right of the car was the worst place in terms of thermal sensation felt. Right from the beginning of measuring sessions the local and global thermal feeling was expressed (-2 ... 0), and from session 4 thermal sensation was felt strongly purporting to +3 because of the influence of direct sun radiation.

**Fig. 9:** TSV evolution for passenger 1 a) at minute 0; b) at minute 30

4. Conclusion

This paper is focused on the transient non-uniform environment inside the automotive passenger compartment. The thermal sensation of an automotive passenger is affected by the surrounding environment. The major characteristics of the automobile environment that complicate the determination of passenger thermal comfort are the transient nature and non-uniformity of the passenger compartment thermal/fluid conditions as well as the necessity of large windows which allow the variability of the exterior solar radiation conditions to have a significant influence. These are in addition to the psychological as well as physiological differences among passengers that also play a significant role.

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**References**


Abstract: An internal combustion engine is considered as a material body, which characterized by inertial, elastic and dissipation properties, which are impacted from various forces. Oscillatory motion of a material body occurs in accordance with spectral characteristics of force and frequency responses of the system. The outer surface of the engine generates acoustic energy and causes mechanical noises.

The paper dwells on determining acoustic energy in accordance with the acoustical radiation rate if the radiation coefficient of the object observed is known. Also, the sound of the engine is presented as a sum of its separate acoustic powers, and there is determined the acoustic radiation coefficient of the engine for the entire surface, by using the acoustic radiation coefficient of each surface. Simultaneously, there is determined the vibro-energy distribution in the engine design, the assessment of which is made by means of the energy-transfer coefficient, which generates the frequency responses of vibro-acoustic parameters.

KEY WORDS: INTERNAL COMBUSTION ENGINE; MATERIAL BODY; VIBRO-AcouSTICS; OSCILLATORY MOTION; NOISE; SPECTRAL CHARACTERISTIC; ACOUSTIC RADIATION COEFFICIENT.

1. Introduction

Specific design features and operating modes of mechanisms and details have significant effect on the level of engine noise.

The level of engine noise during operation at nominal mode is quite high and reaches 95-118 dB. Changes of the camshaft rotational frequency from the minimal to maximal value cause a sharp increase of noise level to 12-20 dB, but increasing the load for the engines running on petrol – to 6-8 dB, and for diesels – to 1-2 dB [1].

At the same time, variation or pressure in the cylinders and vibro-energies caused by impact impulses during operation of mechanisms and details are unevenly distributed in the engine design and cause the various-frequency vibrations of the outer surfaces of engine, so the mentioned surfaces radiate the various-frequency acoustic energy. Hence, there takes place formation of the very active elementary surfaces, which represent the main source of structure-borne noises [2].

2. Preconditions and means for resolving the problem

That is why it becomes necessary to determine the impact of structure-borne noise on the value of engine general noise. In this regard, an internal combustion engine is considered as a material body, which characterized by inertial, elastic and dissipation properties, which are impacted from F(t) force. Therefore, spectral characteristics of force and frequency responses of the system cause oscillatory motion of a material body. The oscillation of the studying engine’s outer surface radiates acoustic energy. Simultaneously, it is known that acoustic radiation energy is determined by the radiation rate. If the acoustic radiation coefficient studying object is known, then the radiation power during operation of engine is determined by the formula [3]:

\[ W_m = \sigma \cdot \rho C \cdot S \cdot V^2 \]

where, \( W_m \) – radiation acoustic power, W; \( \sigma \) - radiation coefficient; \( \rho C \) - medium acoustic resistivity, kg/(m²·sec), \( \rho C = 400 \); \( S \) - the area of radiation surface, m²; \( V^2 \) - root-mean-square vibration velocity, m/sec.

We shall name the square of root-mean-square area radiation the vibration velocity reduced to the engine surface. Therefore,

\[ B = S \cdot V^2, \]

where, \( B \) - is a vibration velocity reduced to the surface.

The engine noise can be represented in the form of the sum of acoustic powers of separate surfaces

\[ W_m = \sum_{i=1}^{i_0} W_i, \]

where, \( W_m \) – is the of engine radiation acoustic power, W; \( i_0 \) – surface quantity , by which the outer surface of engine is divided;

\( W_i \) - acoustic power irradiated by the i-th surface of engine, W.

We shall represent the second formula in the following form:

\[ \sigma_m \cdot \rho \cdot C \cdot S_m \cdot V_{m2}^2 = \sum_{i=1}^{i_0} \sigma_i \cdot \rho \cdot C \cdot S_i \cdot V_{i}^2, \]

where, \( \sigma_m \) – engine radiation coefficient;

\( S_m \) – the area of engine’s outer surface, m²;

\( V_{m2}^2 \) - root-mean-square vibration velocity of the entire surface of engine, m/sec;

\( \sigma_i \) – i-th surface radiation coefficient;

\( S_i \) – the area of i-th surface, m²;

\( V_{i}^2 \) - i-th surfaceroot-mean-square vibration velocity, m/sec.

If the engine’s acoustic power is known, the area of the entire surface and root-mean-square vibration velocity of this surface, then the engine’s radiation coefficient is derived from the equation (1):

\[ \sigma_m = \frac{W_m}{(\rho \cdot C \cdot S_m) \cdot V_{m2}^2}, \]

and

\[ S_m = \sum_{i=1}^{i_0} S_i. \]

Based on the basic acoustic theory, with high enough accuracy, the engine’s radiation coefficient can be considered equal to the vibro-acoustic surface radiation coefficient, which has the maximum acoustic power, that is the engine’s radiation coefficient \( \sigma_m \) is equal to radiation coefficient \( \sigma_{i,max} \), which characterizes the maximum “noisy” acoustic radiation, then
The maximum “noisy” acoustic radiation is determined by the maximum values of $S_1 \cdot \bar{V}_i^2$.

The root-mean-square vibration velocity of a given surface can be determined by measuring the vibration velocity level on this surface, then

$$\bar{V}_i^2 = \frac{1}{K_i} V_i^2 \sum_{i=1}^{K_i} 10^{0.1\mu_i K_i}$$

where, $K_i$ – is the number of points measured by the vibration velocity logarithmic level for this surface;

$V_i^2$ – the vibration velocity ultimate value, m/sec;

$L_{\mu K}$ – the vibration velocity logarithmic level at K point on the i-th surface, dB.

The equation shown in parentheses of the formula (3) is the sum of the squares of the vibration velocity at all points. We shall designate:

$$C_i = V_i^2 \sum_{i=1}^{K_i} 10^{0.1\mu_i K_i} = \bar{V}_i^2 \cdot K_i$$

where, $C_i$ – is the sum of the squares of the vibration velocity at all points of the i-th surface, m²/sec².

Then, the root-mean-square vibration velocity of the entire surface of engine for the root-mean-square of the vibration velocities of the known separate surfaces will have the following form:

$$\bar{V}_0^2 = \sum_{i=1}^{i_0} \sum_{i=1}^{i_0} C_i = C_m/K_m$$

where, $C_m$ – is the sum of the squares of the vibration velocity at all points, m²/sec²;

$K_m$ - the number of the vibration velocity points to be measured on the engine’s entire surface.

Assessment of the acoustic radiation is carried out by means of the acoustic power, which represents an absolute integral characteristic of studying object in a special-purpose semispherical chamber. When measuring the engine noise, the level of acoustic power in the free field on its reflecting plane is measured as follows:

$$L_W = L_P - 10 \left( \frac{1}{2\pi r^2} + \frac{4}{A} \right)$$

where, $L_W$ – is a level of acoustic power, dB;

$L_P$ – average level of measuring surface at all points, dB;

$r$ – the radius of measuring semi-sphere, m;

$A$ – the area equivalent to acoustic absorber, m².

Average level of the engine’s acoustic pressure at the values of the corrected braking is determined by the equation:

$$L_P' = \frac{10}{10} \lg \left( 10^{0.1 \mu_P} - 10^{0.1 \mu_0} \right)$$

where, $L_P'$ – is an average level of the engine’s acoustic pressure at the values of the corrected braking, dB;

$L_0'$ – an average level of the acoustic pressure at braking, dB.

Finally, taking into account the noise braking, the level of the engine’s acoustic pressure and the acoustic pressure in the frequency band are determined as follows:

$$L_W = L_P' - 10 \lg \left( \frac{1}{2\pi r^2} + \frac{4}{A} \right)$$

and

$$W = 10^{0.11L_W} \cdot W_0,$$

where, $W_0$=10⁻¹²–acoustic power ultimate value, W.

The impact variable forces arisen during operation of engine cause the engine vibration due to the existence of gaps in different mechanisms and varied direction. As a whole, the engine can be represented as a body oscillating toward the basis (mountings), and transfers vibration energy to the frame of the vehicle, which causes oscillation and vibration of a certain mass of the vehicle. In order to assess efficiency of the engine mounting pillows or vibration energy transferred to the frame, which is a source of noise, it is necessary to consider the notion of the energy transfer coefficient, which is determined as follows

$$W_W = \frac{F_x(t)}{F_y(t)} = \frac{F_p(\omega)}{F_y(\omega)} = W_W(\omega),$$

where, $F_x(t)$ – is a total force on the engine design, and characterized by complex-nature variability. Its determining is impossible analytically. Thus, to determine a total force it is necessary to determine the force of each excitation source during operation of engine.

$F_y(t)$ – is a force, which is excited by oscillation arisen on the frame of the vehicle. Therefore, the motion of oscillation system depends on the acting force properties, which is excited by the action of various sources, and on the engine design features and geometric geometrical sizes.

3. Conclusion

Thus and so, the system’s transfer coefficient can be determined not only under the action of outer harmonic inputs, but by the action of complex spectrums of the acyclic processes on the input and output of the system. So, in order to analyze the vibration energy output impulses in the studying system, it is necessary to know the value of the system’s transfer coefficient $W_W(\omega)$, which can be determined during the outer harmonic inputs, when determining the value $W_W(\omega)$ for some given conditions, and when we know the variability regularities of the acting force impulse dependent on the time, then we can determine its complex spectrum $F_y(\omega)$, and then the reaction of complex spectrum

$$F_x(\omega) = W_W(\omega) \cdot F_y(\omega)$$

Thus and so, in order to determine the transfer coefficient of vibration energy radiated by the separate surfaces of engine, it is necessary:

1. To determine the engine’s radiation coefficient and vibro-frequency responses of energy;

2. To identify the surface of the maximal value $S_1 \bar{V}_1^2$, which among all surfaces is characterized by generation of a high acoustic power;

3. The radiation coefficient of the given surface equals the engine’s radiation coefficient, and the engine noise power is determined by the formula (1);

4. To determine the vibro-frequency responses of vibration energy on the frame of the vehicle.

4. Literature


The direct injection diesel engines have been developed for works, which envisaged improving ecological parameters of engine. The light vehicles fostered by adoption of a new legislation in the developed countries, the use of gaseous fuels is restricted in reciprocating internal combustion engines. Acceleration of this process was also due to the fact that the domestic potential of diesel fuel by 80-90%, smoking of the exhaust – by 3-4 times, the amount of carbon oxides – by 85-90%, the amount of nitric oxides – by 50-60%. The advantage of the gas-diesel engines also consists in fact that the engine can switch to the use of diesel fuel or vice-versa without stopping and reducing power. So, gas as a fuel of engine, naturel, is the best one among the oil-origin fuels. Its use provides high technical and economic parameters. Natural gas is characterized by high anti-detonant degree, favorable conditions for mixture formation and by the best ignition property of mixture with air.

During gas fuel conversion of the existing engines, their ignition is made by the ignition system, which uses a spark plug or by small dose of the detonative liquid fuel. Up until now, the mixture self-ignition at the end of the compression process had not been used in the engines running on a gas fuel, which is used in diesel engines. The main difficulty in implementing the self-ignition cycle consists in fact that the engine can switch to the use of diesel fuel or vice-versa without stopping and reducing power. So, gas as a fuel of engine, naturel, is the best one among the oil-origin fuels. Its use provides high technical and economic parameters. Natural gas is characterized by high anti-detonant degree, favorable conditions for mixture formation and by the best ignition property of mixture with air.

Meeting the growing demands for transport power, providing with cheap and environmentally safe fuel, and at the same time, for more effective use of natural resources, it is necessary to find the ways to enhance fractional composition of oil and alternative types of fuel.

2. Preconditions and means for resolving the problem

One of the ways of increasing efficiency of liquid fuel is implementing the gas-diesel cycle in the internal combustion engines, where the basic fuel is a natural gas, but the working mixture ignition is made by diesel fuel (ignition fuze dosage). In this case, the torch power of fuel mixture ignition fuze is significantly higher than in the engines with spark-plug ignition that significantly effects on the course of working process. The use of a gas-diesel working process reduces consumption of operating liquid fuel by 80-90%, smoking of the exhaust – by 3-4 times, the amount of carbon oxides – by 85-90%, the amount of nitric oxides – by 50-60%. The advantage of the gas-diesel engines also consists in fact that the engine can switch to the use of diesel fuel or vice-versa without stopping and reducing power. So, gas as a fuel of engine, naturel, is the best one among the oil-origin fuels. Its use provides high technical and economic parameters. Natural gas is characterized by high anti-detonant degree, favorable conditions for mixture formation and by the best ignition property of mixture with air.

During gas fuel conversion of the existing engines, their ignition is made by the ignition system, which uses a spark plug or by small dose of the detonative liquid fuel. Up until now, the mixture self-ignition at the end of the compression process had not been used in the engines running on a gas fuel, which is used in diesel engines. The main difficulty in implementing the self-ignition cycle consists in fact that the engine can switch to the use of diesel fuel or vice-versa without stopping and reducing power. So, gas as a fuel of engine, naturel, is the best one among the oil-origin fuels. Its use provides high technical and economic parameters. Natural gas is characterized by high anti-detonant degree, favorable conditions for mixture formation and by the best ignition property of mixture with air.

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diesels (Table 1) is achieved by high degree of isochoric growth of pressure.

Operation of gas-diesel engine, which is characterized by the geometric parameters of basic engines becomes like operation of engine with heat supply at a constant volume \((V=\text{const})\), i.e. the engine cycle running on petrol, where the cutoff ratio \(\rho=1\), and mixture formation mostly occurs outside the cylinder in a special-purpose mixer by regulating the quality of mixture. In this case, the compressor-less (Trinkler) diesel and gas-diesel cycles are shown in Fig.1, which shows the diesel cycle PV on the diagram as \(\text{aczz''ba}\) curve, but the gas-diesel cycle – as \(\text{aczz'ba}\) curve, therefore the gas-diesel cycle becomes like a heat supply cycle at a constant volume \((V=\text{const})\). In this case, for the analysis of cycle efficiency we shall use the following formulas for calculating thermal efficiency:

\[
\eta_{t1} = 1 - \frac{1}{\varepsilon \gamma^\gamma - 1} \frac{\lambda \rho^x - 1}{\lambda \rho^x - 1 + \lambda \rho^x (\gamma - 1)}, \quad \eta_{t10} = 1 - \frac{1}{\varepsilon \gamma^\gamma - 1}
\]

Comparison of above shown cycles has shown that in the conditions of the same geometric parameters, the gas-diesel cycle is more efficient, than the compressor-less diesel cycle. Comparing them in TS coordinate system better shows the advantage of the gas-diesel cycle (Fig. 2) that means that in case of implementing the gas-diesel cycle the larger amount of heat will be converted into the useful operation, since in TS coordinates, the area \(\text{Abz'ba}\) is larger than the \(\text{aczz'ba}\) area.

3. Conclusion

As is also well-known, the diesel engine represents the engines with a larger volume, that means that power developed by a unit work volume is lower in comparison with engines running on petrol. This is explained by high magnitude of the excess air coefficient \(\alpha = 1.3-1.36\) at a nominal mode of engine. During operation with the gas-diesel cycle at the mode corresponding to the nominal power, the excess air coefficient should be \(\alpha = 1\). In this case, the engine’s work volume will be completely used profitably and, at the same time, we won’t have such amount of heat, which is required for heating of the excess air.

So, the above described analysis has shown that when implementing the gas-diesel cycle, the engine’s efficiency and ecological parameters are improved.

4. Literature

1. Introduction

As a result of growing demands for mobility and high consumer expectations of society, the reliability of the transport service becomes more modern, necessary and significant. Today, the main challenge for transport operators is to provide a more reliable and quality transport services. This is so, because more reliable transport services are a prerequisite for addressing the needs of current users and an opportunity for attract new ones. The routes, characterized by unreliable transport services, experience difficulties in attracting new passengers or suffer from a reduction in passenger flows over time.

Significant are efforts, which are being made in this direction. These efforts are justified, because improving the level of reliability of transport services benefit both users (reducing the time of travel, improving the quality of the service provided, etc), and for operators (a higher level of competitiveness, more efficient use of resources, more revenue, etc.).

The reliability of the transport service can be defined as the ratio between the proposed (referred to in the schedule) and actually realized public transport services. The interaction between the supply of a transport service (consisting of order activities, the main of which are moving people and material objects in space and time) and her demand reflect the actual level of reliability relevant transport system. Unreliability of the transport service appearing in interaction of two sides. Of the supply side consists of services such as time travel and space. Of the passenger side is determined by their behavior and experience. The patterns of passengers’ behavior in different situations such as before arrival time or delay of vehicles reflect different way perception of the reliability of the trip. In the current article is examining impact a reliability of the transport process on users.

2. Importance of the reliability of the public transport service

Along with growth of the economy increases and the mobility of the population. It must be recognized, that monitoring development of mobility (based on data from the National Statistics Institute), we see that the number of trips made by public transport is much smaller than those made by road (fig1).

To increase the role of public transport in total mobility is necessary significant improvement in quality of services, offering public transport. Enhancing the reliability of the transport service is one of the main factors for increasing hers quality.

It should be noted, that in public transport the main process is operation of the vehicles. The result of this process is vehicle journeys, including actual times of departure and arrival. The schedule in this case is of fundamental importance, because it defines the standards for time and place of travel. Ideally, the vehicles arrive and depart according to the scheduled time. In reality, large part of the trips does not coincide with those specified in the schedule. This is so, because transport system operates in an environment under the influence of a wide variety of influencing factors like: passengers and driver’s behavior, weather conditions, road conditions and etc. Something more, the result of impaired functioning of the transport system is unreliable service, which itself leads to consequences for both transport operators and consumers.

The relationship between transport operators, users and reliability of service is presented in Fig. 2.

Reliability of transport services is controlled by transport operators. By the level of reliability of the service provided, which the user perceives, supply side may affect in transport demand. Namely provided level of reliability of service determined this whether the traveler will use public transport services or would prefer another way of moving. Therefore reliability affects in passengers behavior.

The relationship between the demand side and the reliability of service is expressed in consumer behavior. They turn influence by increasing or reducing transport demand. It must be recognized, that both transport operators and users influence the reliability of the service, but without a doubt that reliability is important for both sides.
3. Analysis of the reliability on public transport service

The time is considered the most valuable resource of modern society. Today all activities in each area are focusing in attempts to be fully utilized. In the field of public transport services, this no makes exception.

Today the main task facing transport operators is to achieving compliance actual with planned service. In this sense, it is important that timely arrival and departure of vehicles from the respective stop along the route.

Taking into account the environment in which they operate there is always the probability of one with some of the variability. The value of this variability determines the level of reliability of the service provided. When it comes to the reliability of a transport line punctuality and regularity are the most commonly used indicators in practice. The collection and processing of real data on travel times of bus service is a good way to assess the reliability of the line. For this purpose study on the bus № 9 in Sofia has made. Used methodology proposed in the work [4], which considered approach to measuring the impact of unreliability on users:

- Analysis of transit schedule adherence.
- Calculation of passenger impacts caused by service reliability and determination of the average additional travel time.

3.1. Analysis of the punctuality of the service

Schedule trip time to the line is 26 minutes. The value of this time varies depending on the different periods of the day (Figure 3). At peak hours reaches 35 minutes with difference between the maximum and minimum values 9 minutes. This value is more than 1/3 of the average travel time (29.5 minutes), leading to significant deviations from the schedule along the line. In non-peak hours reaches 29 minutes with a difference seven minutes, and the mean travel time 22.7 minutes.

Tracking the variability of the vehicle travel time along the line is shown in Figure 5. The focus is on the variability of travel time, so that the variability of the departure time is not taken into account. As a whole, variability increases along the route, because of the possibility of occurrence of random events (congestion, traffic accidents, road signage, weather conditions, the passengers and driver’s behavior, etc.) which breaking the normal functioning of the transport system.
3.2. Analysis of the regularity of the service

The regularity of service is determined by the variability of the headways vehicles. The reason for this can be, as variable times of travel, as and time of boarding and alight of passengers, which differ depending on their characteristics and number.

One of the ways to describe the regularity of a single transport line is by using the percentage of deviation from schedule. This indicator expresses the deviation of actual headway compared with scheduled ones.

\[ R_j = \frac{\sum |H_{ij} - h_{ij}|}{k_j} \]

where:
- \( R_j \) - relative regularity for stop j;
- \( H_{ij} \) - scheduled headway for vehicle i at stop j;
- \( h_{ij} \) - actual headway for vehicle i at stop j;
- \( k_j \) - number of vehicles serving stop j.

Figure 6 presents a diagram that tracks the distribution of irregularity in all stops along the line.

The obtained value for the regularity of the whole line is average 27% deviation from the schedule headway in rush hour and 11% in off-peak hours. Similar to punctuality, regularity at the beginning of the line is better, decreasing with each stop. At the end in the line, regularity is much worse than average, due to increased variability.

Obtained values for the punctuality and regularity of the provided service, help to illustrate the level of reliability, but they do not completely coincide with the perception of passengers. These indicators focus on variability in terms of supply, thereby ignoring the impact on users. Using the punctuality and regularity, impact for passengers of earlier or delay is examined in the same way. In practice, however, this is not so. With the introduction of the indicator additional travel time [1] can be determined quantify the impact of unreliability on users.

4. Researching and modeling of the impact of reliability of provided service on the users

For the users of the transport service, travel time including waiting time on vehicle is essential.

The waiting time, is the time from the moment of the passenger’s arrival at the stop until the moment of the boarding in vehicle. This time is different for passengers, depending on the model of their arrival [1].

The first model is when passengers plan their trip, taking into account the schedule. This pattern is typical of the users, which use services with low frequency. For them, adherence to the schedule is the most important measure of reliability, because the deviation influencing at waiting times. Driving ahead of schedule, leads of the user’s point of view to miss the vehicle and respectively extended the waiting time i.e. waiting time is extended by the full headway before a new vehicle arrives. Figure 5 shows distribution of the punctuality of the departure of vehicles on stops along the route in non-peak hours, where the headway is 20 minutes.

It should be noted, that the majority of journeys of vehicles be carried out prior the scheduled headway. This is so, because the foreseen scheduled time of journey is in accordance with the time window, which guarantees less difference in the value traveling times in different periods. The lack of punctuality is reason to extend the travel time of passengers. For them unreliability is expressed in additional waiting time for the next vehicle.

The average additional waiting time for the passenger for each stop is calculated by determining the delay (in case of delayed vehicles) and headway (in case of untimely arrival of the vehicles).

\[ T_{w,lij} = \frac{\sum T_{w,lij}}{m_{lij}} \]

where:
- \( T_{w,lij} \) - average additional waiting time per passenger due to unreliability of line l at stop j;
- \( T_{w,lij} \) - average additional waiting time per passenger due to unreliability of vehicle i of line l at stop j;
- \( m_{lij} \) - number of trips of line l.

Figure 8 shows the results about obtained average waiting additional time for the passenger for each stop on the bus line.
Fig. 9 shows the distribution of the irregularity of vehicles on stops from the routing line. The impact on passengers, transforming the irregularity in additional waiting time (Formula 5) is presented in Figure 10.

\[ T_{\text{w,j}} = \sum_j (\alpha_{l,j} \cdot T_{\text{w,j}}) \text{ with } \sum_j \alpha_{l,j} = 1 \]

where:

- \( T_{\text{w,j}} \) - average additional travel time per passenger on the complete line.
- \( \alpha_{l,j} \) - proportion of passengers of line \( l \) boarding at stop \( j \).

The resulting value (2.51 min) is lower compared to the values of other stops, wherein the additional time reaches to 10 minutes per passenger. The reason for this is the pattern of demand on the line. The majority of them, beginning their journey in the first stops, where additional time is less, respectively, and the average is lower compared to the values of the rest stops.

It should be noted that unreliability leads to an average increase in the total travel time by about 36%, in terms that, the average travel time of a passenger is 7 minutes.

The second model is when passengers arrive randomly. This pattern is typical for passengers using services with high frequency. For them, to comply with an interval is the most important measure of reliability, because the headway between vehicles determined the waiting time.

Figure 9 shows the distribution of the irregularity of vehicles on stops from the routing line. The impact on passengers, transforming the irregularity in additional waiting time (Formula 5) is presented in Figure 10.

\[ T_{(\text{w,})} = \frac{H_j}{2} + \left(1 + \frac{V_H_j}{H_j}\right) \]

where:

- \( T_{(w,j)} \) – passenger waiting time at stop \( j \);
- \( H_j \) – actual headway at stop \( j \);
- \( V_H_j \) – the variance of the headways at stop \( j \).

The result again is that passengers at the end of the line are the most affected, because the total travel time will be extended by 10%.

In view of the results obtained, related to the effects of the reliability of provided service on users, we can conclude that the individual components of the travel time is influenced by variable headways, departure times, trip times and arrival times of vehicles (Table 1).

<table>
<thead>
<tr>
<th>Types of service variability</th>
<th>Main impacts on variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variability of departure times</td>
<td>Waiting time</td>
</tr>
<tr>
<td>Variability of headways</td>
<td>Waiting time</td>
</tr>
<tr>
<td>Variability of trip times</td>
<td>In-vehicle time</td>
</tr>
<tr>
<td>Variability of arrival times</td>
<td>Arrival time</td>
</tr>
</tbody>
</table>

Table 1. Types of service variability

5. Conclusion

The variability of the service provided is an unwanted effect during operation of the transport system. The appearance of variability is the reason for reducing the level of reliability, which in turn has consequences for both transport operators and consumers.

In terms of the supply side, the unreliability is an expression of impaired functioning of the transport system, leading to inefficient use of resources, reduce demand, more costs and less revenue.

From consumer point of view, unreliability is expressed in extra travel time, which they could use for other more productive activities. The value of extended time (based on their experiences) the user takes into account in making process a decision. Exactly this value determines whether users will continue use the services of public transport systems, or would prefer another mode of transport.

The attention of transport operators should be directed to the analysis of reasons leading to the variability of service and focus on those of them, on which they can impact. In this way, they have able to take measures to reduce variability. This will enable them to meet the requirements of current users and the ability to attract new ones. Something more, reliability of the transport service, may affect the future use of public transport systems.

References

ELECTRIC MOBILITY IN THE BALTICS

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Abstract: The Baltic States have no fuel resources needed for internal combustion engines. Oil products are imported. Internal combustion automobiles make a negative effect on the surrounding environment, as they produce toxic emissions and noises. One of the ways how to use electric energy – a resource produced in the Baltic States – is the exploitation of electric vehicles. The use of electric vehicles in the Baltic States began in 2010. Since this year, the best infrastructures for electric vehicles and their charging have been created in Estonia. The paper analyses the quantitative and qualitative specifics of electric vehicles and their infrastructures in the Baltic States as well as reviews the development prospects.

Keywords: ELECTRIC VEHICLES, CHARGING POINTS, ALGORITHM OF CALCULATION, NUMBER OF CHARGING STATIONS, NUMBER OF ELECTRIC VEHICLES

1. Introduction

At present, electric vehicles of several kinds are exploited in the Baltic States. Electric bicycles were among the first electric vehicles to appear in the market. Initially, electric bicycles used lead-gel batteries. Over the past three years, lithium-ion batteries were also used, yet, such a structure raises the cost of a bicycle by 30-35%. Compared with other electric vehicles, electric bicycles have significant advantages, for example, comparatively low prices and exploitation costs as well as the possibility to continue riding by pedalling if their batteries are discharged. Bicycles belong to the group of electric vehicles that can be relatively easily and cheaply converted into electric vehicles, using a standard electric bicycle conversion kit.

The firm Impresso which sells low-speed electric vehicles operates in Latvia since 2007 1. The speed of low-speed electric vehicles is within a range of 25-45 km/h, and a few modifications of them may participate in road traffic. Low-speed electric vehicles are used on golf courses and in other closed territories, for example, in sea ports and in the territory of Latvia’s Children’s Hospital. Such vehicles are mainly used for tourist tours in the towns of Sigulda and Jurmala.

The year 2010 may be regarded as the year when the use of electric vehicles was begun in the Baltic States; the exploitation of converted electric vehicles was started in Lithuania and Estonia. In 2011, two Fiat Fiorino electric vehicles were begun to be used in Latvia [2]. These vehicles were the first mass-production electric automobiles that were registered for road traffic in Latvia. In 2011, a charging infrastructure began developing in the Baltic States as well. Due to the fact that serious electric mobility involves the introduction of passenger electric vehicles, the paper will analyse in detail particularly this kind of electric mobility.

2. Aspects of electric mobility

In order to provide electric mobility, first of all, electric vehicles are necessary. Charging stations or other kinds of charging devices, sales of electric vehicles and their spare parts, technical support and repairs contribute to a wider use of electric vehicles. With electric vehicles developing, such vehicles are used for passenger transport, in agriculture and for water and air transport.

Electric vehicles may be charged from the regular 220 V alternating current mains as well as at fast- or medium fast-charging stations. At fast-charging stations, 80% of the full battery capacity can be recharged in 30 minutes. A classification of the most popular energy replenishment stations for electric vehicles developed according to their uses is presented in Figure 1.

Charging stations may be publicly available or located in closed territories where only the owners of a charging station may recharge their vehicles. If exploiting a small number of electric automobiles in a region, charging services at expensive charging stations are unprofitable for their owners, as their payback period is too long.

Auto manufacturers usually set high standards for electric vehicle maintenance stations, for example, a charging station of certain design must be established in the territory of the maintenance station and specific tools must be purchased.

3. Electric automobiles in the Baltic States

In comparison with internal combustion engine automobiles, electric automobiles are expensive.

The opportunities for their use are limited as well. For this reason, a faster increase in the number of electric automobiles may be observed when government support is provided. Such a trend was observed both in Latvia in 2014 when 176 electric automobiles were purchased within a CCFI project and in Estonia in the period 2011-2014 within the Elmo project, purchasing 486 electric automobiles [3, 4, 5].

In Estonia the most popular electric automobile, purchased within the project, was Nissan Leaf (266 automobiles), while in Latvia 5 automobiles of this model were bought. In Latvia, the most popular electric automobile was Volkswagen e-Up (135 electric automobiles), while in Estonia 14 automobiles of this model were purchased. The distribution of other electric automobiles by model, purchased under the government support schemes in Latvia and Estonia, is shown in Figure 2.
4. Algorithm for calculating the characteristics of electric mobility

An algorithm for calculating various comparable indicators has to be created to perform a comparative analysis of electric mobility in the Baltics. The number of charging stations in an analysed region may be calculated as follows:

\[ N_s = \frac{S}{N_{CP}}, \]  

(1)

where:  
\( S \) – area of the analysed region, km\(^2\);  
\( N_{CP} \) – number of charging stations in the analysed region.

The number of charging stations on main roads may be calculated according to the formula:

\[ N_{CP}^{mag} = \frac{L_{mag}}{N_{CP}}, \]  

(2)

where:  
\( L_{mag} \) – length of the analysed main roads, km.

The smaller this indicator is, the better quality infrastructure is available outside cities and charging stations are available within shorter ranges.

The efficiency of introduction of electric vehicle charging stations is expressed by the number of the stations constructed per year:

\[ N_{CP/Y} = \frac{n_{CP}}{T}, \]  

(3)

where:  
\( n_{CP} \) – number of electric vehicle charging stations constructed in the analysis period, units;  
\( T \) – analysis period, usually measured in years.

The ratio of the number of charging stations to the number of electric automobiles or the number of electric automobiles per charging station:

\[ I_{EV} = \frac{N_{EV}}{N_{CP}}, \]  

(4)

where:  
\( N_{EV} \) – number of electric vehicles in the analysed region;  
\( N_{CP} \) – number of charging stations in the analysed region.

This indicator is important until the moment when a sufficient number of electric vehicle charging stations is available in the country.

An analysis of electric mobility may be performed employing indicators such as number of electric vehicles per charging station and per charging spot, population per charging station, availability ratio for charging stations and the average number of charging spots per station, but an analysis of such characteristics is available in another research study by the authors of the present research [6, 7].

5. Calculation results and analysis of the characteristics of electric mobility

The data used for the calculations are summarised in Table 1.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Latvia</th>
<th>Lithuania</th>
<th>Estonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of electric vehicles</td>
<td>194</td>
<td>69</td>
<td>1163</td>
</tr>
<tr>
<td>Number of charging stations</td>
<td>15</td>
<td>14</td>
<td>165</td>
</tr>
<tr>
<td>Area, km(^2)</td>
<td>64589</td>
<td>65303</td>
<td>45226</td>
</tr>
<tr>
<td>Main roads, km</td>
<td>1653</td>
<td>6667</td>
<td>3993</td>
</tr>
<tr>
<td>Distance to the nearest charging station, km</td>
<td>260</td>
<td>180</td>
<td>50</td>
</tr>
<tr>
<td>Average electric vehicle range, km</td>
<td></td>
<td></td>
<td>130</td>
</tr>
</tbody>
</table>

The density of charging stations in the analysed region are presented in Figure 3.

An analysis of the number of charging stations per area shows that the situation in Lithuania and Latvia is similar – a charging station per 4.6 thousand square kilometers, – which is quite insufficient. In Estonia, its network of charging stations fully ensures travelling over the entire territory, with a charging station per 274 km\(^2\).

The numbers of charging stations on main roads are presented in Figure 4.

An analysis of the locations of stations in relation to the main roads is not very objective, as the total length of motor roads in Latvia is the shortest, and only one charging station is available on motor roads outside cities. If calculated per total length of main motor roads, the best situation is in Estonia – one station per distance of 24 km.
The efficiency of introduction of electric vehicle charging stations are expressed by the number of the stations constructed per year and are shown in Figure 5.

The introduction rate of charging stations in Estonia is excellent, reaching 82 stations per year. In Latvia and Lithuania, this indicator is 16 times lower.

The ratio of the number of charging stations to the number of electric automobiles for each country is shown in Figure 6.

In Latvia, the number of electric automobiles is relatively large (194), while the number of charging stations is small. For this reason, the number of electric automobiles per charging station is large – almost 13 electric automobiles. There is only one fast-charging station in Latvia that can serve more than 20 electric automobiles a day. Although the number of charging stations in Estonia is large, the number of electric automobiles serviced a day considerably exceeds the demand in this country, as fast-charging stations are used that can service 6600 automobiles a day.

**Conclusions**

1. Under various government support schemes, 18 electric automobiles of various models were purchased in Latvia and Estonia. The key factor in the choice of vehicles was the simple way of purchasing the particular model and its popularity, as well as its price.

2. In Latvia, Volkswagen e-Up (135 EV) was the most popular model purchased under the government support scheme, while in Estonia it was Nissan Leaf (266 EV).

3. A classification of energy replenishment stations for electric vehicles and a scheme for their exploitation, depending on the location of a station, were developed.

4. In Estonia, one charging station is available per territory of 274.1 km², which ensures a full coverage of charging stations. In Latvia and Lithuania, these indicators are, on average, 17 times lower.

5. Any analysis of charging stations in relation to the total length of main motor roads is not very objective, as the charging stations are mostly concentrated in the largest cities, and the total lengths of main motor roads in the analysed countries significantly differ and do not correlate with the area of the country.

6. The introduction rate of charging stations in Estonia is 82 units per year, whereas in Latvia and Lithuania this indicator is only 4.7 per year.

7. Among the Baltic States, the greatest number of electric automobiles per charging station is reported in Latvia, and the charging stations are not able to service all electric automobiles, as they use slow-charging technology (6-8 h). There is only one fast-charging station in Latvia, which is located by the Road Traffic Safety Directorate building.

8. In Estonia, fast-charging stations whose total capacity is 6600 electric automobiles a day are exploited; the stations can service 6 times more electric automobiles than their number in Estonia at present. Among the Baltic States, the highest level of electric mobility is observed in Estonia, with the charging stations covering the entire territory of the country.

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METHODOLOGY FOR DETERMINING THE VISCOSE OIL RHEOLOGY IN LABORATORY CONDITIONS

МЕТОДИКА ОПРЕДЕЛЕНИЯ РЕОЛОГИЧЕСКИХ ПОКАЗАТЕЛЕЙ ВЯЗКОЙ НЕФТИ В ЛАБОРАТОННЫХ УСЛОВИЯХ

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Abstract: The crude oil samples produced from various fields are characterized by wide range of rheological characteristics. On the quantitative indicators of these parameters and, consequently, on the hydraulic resistance of the oil flow movement through the pipeline, significantly depend the possibilities of increasing the pipeline transport carrying capacity. The created physical model enables to determine rheological parameters of crude oil of various types, such as dynamic viscosity and solidification temperature with the dependence on preheating temperature and concentration of specialty solvents.

KEY WORDS: CRUDE OIL; RHEOLOGICAL CHARACTERISTICS; PIPELINE TRANSPORT CARRYING CAPACITY.

1. Introduction

It is commonly understood that at the current stage in developing the transport systems in the world, pipeline transport represents its particular type, whose role is essential in the process of continuous transportation of oil, oil products and natural gases at long distances.

One of the major parameters of pipeline transport is its high carrying capacity, increasing of which is possible by increasing conveyance speed of transported oil products. However, the oil transportation process through the pipeline, which has a high viscosity and wax content, is a complex process from both technical and technological standpoint.

An increase in the movement speed of viscose liquids through the pipeline with a minimum energy inputs is possible with improving such rheological parameters resisting movement, as density, viscosity, stock point and so on. Improvement of mentioned parameters is possible by using such effective methods as: thermal treatment; supplement of depressing agents; supplement of hydrocarbon diluents; mechanical action; heating of transported product up to a certain temperature in heat-exchanging devices.

2. Preconditions and means for resolving the problem

This experiment is aimed at studying the influence of change in rheological parameters on the speed of oil movement through the pipeline in different temperature conditions.

On the basis of experimental research, there have been determined the speed of oil movement through the pipeline at various temperatures and the appropriate consumed pumping power that is an important parameter with a view to energy-efficiency of transportation process.

For achieving the designated objectives of research, the experimental device was created. Fig. 1 presents a diagram of the experimental device. The operating principle of the device is as follows: the object of research – oil having initial temperature of experimental device. The operating principle of the device is as follows. On the surface of wax crystals, there are adsorbed the resinous substances concentrated in oil. At low oil preheating temperature, some wax crystals is dissolved and the released resinous substances are adsorbed on the surface of non-diluted wax crystals. Subsequent cooling results in that the small wax crystals fallen out of the solution form a tight structure increasing an effective viscosity and oil stagnation temperature. At elevation of oil preheating temperature, the number of dissolved wax crystals, and accordingly the number of the released resinous substances go up. During subsequent cooling, the non-adsorbed resinous substances foster the formation of large wax crystals that has a positive impact on the rheological characteristics of oil. The maximum effect of thermal treatment is achieved when all wax crystals are dissolved at heating. However, further overheating of oil results in irreversible disintegration of resinous substances concentrated in it, and the effect of thermal treatment goes down [1].

Since the content of wax in various types of oil is different, an optimal temperature of thermal treatment is determined by an experiment for each type of waxy oil.

Fig. 1.2 shows the effect of a temperature of thermal treatment on the rheological parameters of studying oil.

The analysis of the experimental research has shown that at a temperature of thermal treatment ($T_{th}$) of about 60°C, the solidification temperature not only decreases, but, on the contrary, even increases. Further elevation of the thermal treatment temperature results in reduction of a solidification temperature ($T_{sn}$).
Starting from the values of $t_{\text{o}, \geq} 105^\circ C$ a solidification temperature of thermally treated oil increases again. The nature of dependence of the effective viscosity ($V_0$) of studying oil shows that sharp decrease of $V_0$ occurs only at $t_{\text{o}, \leq} 20^\circ C$, and further elevation of temperature practically does not provide effect.

On this account, the optimal temperature of thermal treatment of studying oil is $90^\circ C$.

![Fig. 1.2. The effect of a temperature of thermal treatment on the rheological parameters of oil](image)

1 – Solidification temperature; 2 – Kinematic viscosity

After determining the optimal preheating temperature of oil, the objective of the experimental research was study of changes in pump delivery switched in the main line and in consumed power.

As a rule, during dispatching of oil to the dispatch stations, there mostly used the piston compressors and centrifugal pump units. In addition, transportation by using the piston compressors can be carried out at a height of 6-7.5 meters, and they are characterized by fairly high efficiency and continuity of supply, although they set in motion from the electrical or internal combustion engines that is associated with additional expenses.

At the present stage, with a view to oil transportation, in comparison of with the piston compressors the preferred devices are the centrifugal pump units, which are distinguished by high efficiency and simplicity of a design. In addition, it is well-known that such pump units considerably react to viscosity of transported oil. In particular, in addition to increasing viscosity, the pump unit cannot provide pressure and supply characteristics determined by published data.

### 3. Conclusion

The experimental studies that we carried out have shown that within the given preheating temperature interval (40-150°C) of studying oil, pressure developed by centrifugal pump units switched in the main line, speed and efficiency of supply go up, and besides power consumed by pumping unit from the network goes down. In particular, within the given temperature interval, pump delivery increased by 3-5%, and accordingly the efficiency increased by 75-80%, as well as power consumed from the network reduced by 5-8%.

Based on the analysis of the experimental studies, we can conclude that it is necessary to place pump unit in the dispatching stations just after the heat-exchanging device. It should be also noted that the experimental studies carried out enable us to determine the optimal preheating temperature of studying oil (oil product), which an important parameter for choosing the type of the heat-exchanging device and for determining the optimal geometrical sizes by way of mathematical calculations. All this is aimed at increasing the carrying capacity of the long-distance pipeline and enhancing its economic efficiency. This efficiency will be even more important, if we will use in the heat-exchanging devices the natural energy sources, such as geothermal waters and solar power.

### 4. Literature

STUDYING OF SOIL SURFACE SUBSIDENCE UPON LONG LENGTH UNDERGROUND PIPELINES PENETRATION

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Abstract: Initial stresses of soil body are important upon penetration of long length underground pipelines (tunnels) into soil. If there is a free space between casing (lining) and body the soil grains move to the free space. Value of free space is called “soil loss”. Movements may occur due to this free space filling with soil at the daylight surface. If the movements reach a great significance, aboveground structures and neighboring underground structures may be significantly damaged. Therefore, an evaluation of soil subsidence and pipeline (tunnel) stability are of great concern upon the pipelines (tunnels) designing.

KEY WORDS: PIPELINE PENETRATION, SUBSIDENCE, DISPLACEMENTS, ALVEOLE, TUNNELS

1. Introduction

According to methods used for calculation of soil surface subsidence in consequence of the pipeline penetration, the soil subsidence trough is bell-shaped [1-5]. It is supposed that subsidence trough volume will be equal to the total volume of “lost soil” occurring upon the pipeline penetration. “Soil loss” volume is generally expressed in a percentage from the volume of all excavated soil. Value of “soil loss” depends on various factors, the most important of which are methods of pipeline construction, quality of works and geotechnical conditions. Experience of construction engineers is also of big importance. Maximum value of soil subsidence and width of subsidence trough depend on the soil loss volume, pipeline (tunnel) burial depth, geologic properties of rocks, etc. Methods for subsidence trough parameters detection are described in details in the first chapter. The authors of the paper divide the soil surface subsidence by shielding into four categories [6-9]:

- subsidence’s before and above the face;
- subsidence’s occurred due to earth excavation;
- subsidence’s occurring in the process of grout injection outside of the pipeline casing (tunnel lining);
- long lasting subsidence’s connected with deformation of the pipeline casing (tunnel lining).

2. Materials and Methods

Reasons of the subsidence’s by shielding are in Figure 1. Lack of balance between the soil and soil water pressure and shield head backpressure. If an advance speed and excavated soil delivery speed are not synchronized with an earth pressure balance in the shield, pressure in a face chamber becomes different from the soil and soil water pressure in the face, this leads to the soil movement before and above the shield. If the chamber pressure is lower than the soil and soil water pressure, the surface subsidence takes place. Otherwise the surface is lifted. These events are determined by a release of one of counter pressures in the face and occurrence of elastoplastic deformations by higher pressure. Disturbance of soil conditions by the shield moving. A change of soil condition in consequence of the shield moving and shield’s external surface friction on soil may lead to lifting or subsidence of surrounding soil or surface. An external tapping of soil for changing of the shield machine direction may also produce a soil softening.

Generation of the free space beyond the tail casing by the shield machine movement and unsatisfactory injection of the grout. In view of generation of the mentioned free space soil on the shield casing is subsided, herewith the elastoplastic deformations take place in the soil, which are caused by the release of surrounding soils stressing. However, value of soil subsidence depends on grout material, time and places of injection, as well as pressure and volume of injection. Excessive injection pressure may be a reason of temporary lifting of soils.

Deformation and displacement of primary tunnel lining: if joint bolts of the tunnel lining are not tightened enough, tunnel rings may be deformed. This increases the soil subsidence after coming of next tunnel ring out of the lining tail in consequence of increasing of the free clearance or lining deformation under unbalanced (uncompensated) loads.

Reduction of ground water level: if water runs out of the face to the shield or runs out of the primary casing (lining) through joints, the level of ground water is reduced and this leads to the soil subsidence. These subsidence’s are caused by increase of soil effective pressure. The subsidence’s caused by water-bearing soil may be conventionally divided into two categories, which are actually dependant. The first category includes subsidence’s occurring immediately upon earth excavation. The second category includes long-term...
subsidence’s occurring especially in soft, compressible rocks.

Moreover, the subsidence sources may be vibrations from drilling and operation of rock loaders. Such subsidence’s have been marked in running soils of different types and in solid rocks with soft rocks above.

In paper there are the following main constructive and technology factors, upon which depend the soil surface subsidence’s by shield construction of pipelines (tunnels) [10]:

i. Excess and release of rocks in the face;
ii. Movement of shields with angle of attack,
iii. Increased construction clearance,
iv. Lining flexibility,
v. Deformation of shields and their vibrations.

An interesting fact provided in the paper of T.W. Hulme, etc [11]. shall be pointed out. Upon a scientific follow up of the Singapore MRT construction an equivalent model had been created. A bench test of the equivalent model enabled determination that the subsidence’s may appear due to soils consolidation in consequence of change of pore pressure caused by creation of supplementary pressure in the face zone upon the pipeline penetration.

2.1. Application of reciprocal theorem for evaluation of the soil surface subsidence upon the pipelines (tunnels) penetration: An analytical method of the soil surface subsidence based on the reciprocal theorem may be as follows. If constant force F applied to in a direction at a point A of elastic, anisotropic, nonhomogeneous space generates at other point B in β direction a movement equal to u, then the same force F applied at point B in β direction will generate at point A in a direction a movement equal to u (see Fig. 2).

![Fig. 2: Constant force F applied to point A,B](image)

![Fig. 3: Calculation model for detection of movements in space upon the vertical force influence](image)
Known analytical solutions for movement of soil points of elastic space upon influence of vertical forces are used for this purpose. An initial data for calculation of vertical movements of soil surface are functions of movement of alveole contour provided in Figure 3.

Lining boundary stresses are defined based on Flamant solution [12]:

\[ \sigma_r = \frac{2F}{\pi r} \cos \theta = \frac{2F z}{\pi r^2} \]  

(1)

Normal stresses in two orthogonally related directions: along the tunnel axis \( \sigma_z = \frac{V}{1-\nu} \sigma_r \) and in normal direction \( \theta \), \( \sigma_\theta = \frac{V}{1-\nu} \sigma_r \). Radial displacements of contour upon action of normal stresses directed perpendicular to the cylinder axis (see Fig. 4) have been obtained by S.P. Timoshenko.

\[
\begin{align*}
\varphi &= \left( A r^2 + B r^4 + C \frac{1}{r^2} + D \right) \cos 2\theta \\
\sigma_r &= \frac{1}{r} \frac{\partial \varphi}{\partial r} + \frac{1}{r} \frac{\partial^2 \varphi}{\partial \theta^2} = \left( 2A + \frac{6C}{r^2} + \frac{4D}{r^2} \right) \cos 2\theta \\
\sigma_\theta &= \frac{\partial^2 \varphi}{\partial \theta^2} = \left( 2A + 12B r^2 + \frac{6C}{r^2} \right) \cos 2\theta \\
\tau_{r\theta} &= \frac{\partial}{\partial r} \left( \frac{1}{r} \frac{\partial \varphi}{\partial \theta} \right) = \left( 2A + 6B r^2 - \frac{6C}{r^2} + \frac{2D}{r^2} \right) \sin 2\theta
\end{align*}
\]

where

\[ A = -\frac{S}{4} ; \quad B = 0 ; \quad C = -\frac{a^4}{4} S ; \quad D = \frac{a^2}{2} S \]

after substitution of values of \( A, B, C \) we will get

\[ \begin{align*}
\sigma_r &= \frac{S}{2} \left( 1 + \frac{a^2}{r^2} \right) + \frac{3}{2} \left( 1 + \frac{a^2}{r^2} \right) \cos 2\theta \\
\sigma_\theta &= \frac{S}{2} \left( 1 + \frac{a^2}{r^2} \right) - \frac{3}{2} \left( 1 + \frac{a^2}{r^2} \right) \cos 2\theta \\
\end{align*} \]

\[
\begin{align*}
\varphi &= \left( A r^2 + B r^4 + C \frac{1}{r^2} + D \right) \cos 2\theta \\
\sigma_r &= \frac{1}{r} \frac{\partial \varphi}{\partial r} + \frac{1}{r} \frac{\partial^2 \varphi}{\partial \theta^2} = \left( 2A + \frac{6C}{r^2} + \frac{4D}{r^2} \right) \cos 2\theta \\
\sigma_\theta &= \frac{\partial^2 \varphi}{\partial \theta^2} = \left( 2A + 12B r^2 + \frac{6C}{r^2} \right) \cos 2\theta \\
\tau_{r\theta} &= \frac{\partial}{\partial r} \left( \frac{1}{r} \frac{\partial \varphi}{\partial \theta} \right) = \left( 2A + 6B r^2 - \frac{6C}{r^2} + \frac{2D}{r^2} \right) \sin 2\theta
\end{align*}
\]

Following the Hooke’s law

\[ \begin{align*}
\varepsilon_r &= \frac{\partial u}{\partial r} = \frac{1}{E} (\sigma_r - \nu \sigma_\theta) \\
\varepsilon_\theta &= \frac{\partial v}{\partial \theta} = \frac{1}{E} (\sigma_r - \nu \sigma_r) \\
\gamma_{r\theta} &= \frac{1}{G} \tau_{r\theta}
\end{align*} \]

Substituting \( \sigma_r \) and \( \sigma_\theta \) to the Hooke’s law:

\[ \begin{align*}
\frac{\partial u}{\partial r} &= \frac{S}{2} \left( 4 a^2 - r^2 a^2 + r^4 \cos 2\theta + 3 a^4 \cos 2\theta - 4 r^2 a^2 \cos 2\theta \right) \\
\frac{\partial v}{\partial \theta} &= \frac{S}{2} \left( 4 a^2 - r^2 a^2 + r^4 \cos 2\theta - 3 a^4 \cos 2\theta + v r^4 + v r^2 a^2 \right)
\end{align*} \]

After integration we get

\[ u = \frac{S}{2} \left( -v r^4 + r^4 + v r^4 \cos 2\theta - a^4 \cos 2\theta + r^4 \cos 2\theta + a^4 \cos 2\theta \right) + f(\theta), \]
\[
v = \frac{S}{2Er^3} \left( \theta r^4 + r^2a^2\theta - \frac{1}{2}r^4 \sin 2\theta - \frac{3}{2}a^4 \sin 2\theta + r^4\nu \theta \right) - \int f(\theta)d\theta + F(r)
\]

where \( r = a \) and \( \theta = 0 \) laying along \( x \) axis

\[
u_n = \frac{a\sigma_r - \nu}{E(1-\nu)}(1 + 2\theta \cos 2\theta)
\]

The radial displacements of contour by normal stresses perpendicular to the cylinder axis:

\[
u_r = \frac{a\sigma_r}{E(1-\nu)}(1 - 2\theta \cos 2\theta), \text{ (angle } \theta \text{ is replaced with angle } \theta + \pi).
\]

The radial displacements of contour by normal stresses in the direction of the cylinder axis:

\[
u_z = \frac{a\sigma_z}{E} \Rightarrow u_r = \frac{a\sigma_r}{E(1-\nu)}V^2
\]

Mean radial displacements at unsubstantiated alveole from a force applied at land surface are defined by formula:

\[
\Delta u_r = \Delta u_{n_r} + \Delta u_{r_2} + \Delta u_{r_3}.
\]

After substitution of expressions for mean radial displacements takes the form of:

\[
\Delta u_r = \frac{2a\sigma_r}{E} \left( \frac{V}{1-\nu} \right) + \frac{a\sigma_r}{E} \left( \frac{V^2}{1-\nu} \right) = \frac{a\sigma_r V(\nu+2)}{E(1-\nu)} \text{ or}
\]

\[
\Delta u_r = \frac{2aFz\nu(\nu+2)}{E\pi r^2(1-\nu)}.
\]

Having used the reciprocal theorem we will define the dependence of mean displacements on force \( F \) distributed along the alveole length (in \( z \)-direction) applied inside the alveole. For this purpose let us define the radial displacements (see Fig. 5) of alveole from uniform pressure [14]:

\[
u = \frac{(1-\nu)q}{E}
\]

\[
\text{Fig. 5: Calculation model for definition of soil surface displacements upon action of force applied in alveola}
\]

3. Results and Discussion

Let us denote the mean radial displacements of lining from force \( F \) applied to inside the lining, \( \Delta \). In accordance with the reciprocal theorem it is possible to write down an expression:

\[
F\nu(a) = q\Delta
\]

\[
F \left( \frac{1 - 2\nu}{E} \right) q = q\Delta \Rightarrow F = \frac{\Delta E}{(1 - 2\nu)}
\]

For detection of the surface points’ displacement from force applied to the alveole internal contour, the reciprocal theorem is also used. Let us denote: \( U_z \) vertical displacement of soil surface, \( r = \sqrt{x^2 + z^2} \), \( \cos \theta = z/r \), \( \sin \theta = x/r \).

According to the reciprocal theorem we will get:

\[
F\nu_z = \frac{\Delta E}{(1 - 2\nu)} U_z,
\]

where from,

\[
u_z = \frac{2a z\nu(\nu+2)\Delta}{\pi r^2(1-\nu)(1-2\nu)}
\]

Figure 6 represents calculated subsidence’s profiles upon two pipelines (tunnels) penetration with use of the reciprocal theorem.
3.1. Comparison of subsidence’s troughs curves obtained by different methods and plaxis standard program complex: Together with known solutions numerical calculations with use of PLAXIS program complex have been performed. The calculation considered an elasto-plastic nonlinear performance of soil with account of draining and without it.

Typical values of volume loss for pipelines (tunnels) of diameters up to 6,6 m buried in marine clays are within the range from 2% to 3,5% depending on the penetration way [6]. This article uses the volume loss equal to 1%. Curves describing the soil subsidence upon two pipelines (tunnels) penetration are defined. Figure 7 represents displacements of soil layers and contour line scaled up to 100, obtained with use of PLAXIS program complex.

A curve of soil surfaces subsidence got on the basis of the function of Gauss errors is used for comparison of the results and the superposition method [15] is used for calculation of surface subsidence value upon penetration of two parallel pipelines (tunnels). The authors of the paper proposed to define the land surface subsidence by formula:

\[
S_l = S_{max A} \exp \left[ -\frac{(x + L/2)^2}{2l_A^2} \right] + S_{max B} \exp \left[ -\frac{(x - L/2)^2}{2l_B^2} \right] - S_{AB}
\]  

\[
S_l = S_{max A} \left\{ \exp \left[ -\frac{(x + L/2)^2}{2l^2} \right] + \exp \left[ -\frac{(x - L/2)^2}{2l^2} \right] \right\} a
\]

Where \( S_{AB} = 0 \) (without regard to reciprocity), \( L=2D \) distance between two pipelines (tunnels) (see Fig.8). Increase of the distance between the pipelines (tunnels) causes reduction of subsidence in the central part between the pipelines (tunnels). If the pipelines (tunnels) have equal diameters and soil losses, then \( S_{max A} = S_{max B} \) and \( l_A = l_B \).

pipeline (tunnels) and total subsidence upon penetration of two parallel pipelines (tunnels) with use of the function of Gauss errors and the superposition method. Figure 10 represents the comparison of subsidence troughs curves obtained by empiric, analytic and numerical methods upon penetration of two parallel pipelines (tunnels) at 1% coefficient of volume loss.
Total surface subsidence will be defined by expression: 

Figure 9 represents the curves of surfaced subsidence’s upon penetration of the left and right. It should be pointed out that the subsidence’s profile made by PLAXIS program complex coincides with the subsidence’s profile made on the basis of formulas of scientists Verruijt and Booker (1996). The subsidence’s profiles made by Loganathan and Paulo’s (1998), Park (2005) and Gauss function a little bit differ from the preceding results. Comparison of all profiles has shown that a curve obtained with use of the reciprocal theorem coincides with the results obtained by different methods, but differs upward from the data of field observations. The represented results show that the analytic and empiric methods sufficiently describe the soil surface subsidence’s. Nevertheless, it should be pointed out that the numerical methods enabling accounting of soils nonhomogenity are more suitable for complex ground conditions.

4. Conclusions

1. There is a comparison of different methods for determination of curves values and forms describing the soil surface subsidence’s upon penetration of underground pipelines (tunnels).

2. There is a new method for evaluation of the soil surface subsidence’s based on the reciprocal theorems. The method may be used for forecasting of the soil surface subsidence’s upon the pipelines designing.

3. Value of soil surface subsidence’s upon penetration of pipelines (tunnels) may be reduced or fully avoided, if pressure in the face and injection beyond the pipeline casing (tunnel lining) are controlled. Pressure shall not exceed the limit value.

4. As a rule, actual soil surface subsidence’s are smaller the forecasted ones, if the work process upon the pipelines (tunnels) penetration is dully observed.

5. If the pipelines (tunnels) are laid under the buildings of historical notability an instrumental monitoring in full-scale is required besides of the theoretical predictions.

5.References


RESEARCH RESULTS OF ENERGY EFFICIENT VENTILATION SYSTEM OF SHEEPFOLD

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Abstract: The article discusses the results of experimental studies of energy efficient ventilation system of sheepfold, using information-measuring system for remote registration of thermotechnical parameters of the ventilation systems.

They are given the results of testing of the experimental energy efficient ventilation system in the winter and summer periods.

KEY WORDS: ENERGY EFFICIENT VENTILATION SYSTEM. SHEEPFOLD. UNDERGROUND HEAT EXCHANGER. AIR CONDUIT. SOIL HEAT. TEMPERATURE SENSORS. SENSORS OF THE RELATIVE HUMIDITY AND TEMPERATURE. MASTERSCADA SYSTEM.

1 Introduction

The work addresses the problem of energy efficient ventilation systems in agricultural buildings, due to the effective use of low-grade soil heat.

There are a number of examples of the use of soil heat for heating and cooling of livestock buildings through underground air conduits and heat exchangers. They are allowed to save 50 to 75% of the costs for heating and cooling of the buildings. [1]

Consequently, energy efficient ventilation systems and efficient use of soil heat in them are perspective and relevant in modern conditions.

The work has been carried out at the Department of Energy Saving and Automation of Kazakh National Agrarian University.

2 Materials and methods

The experimental energy efficient ventilation system was built into the sheepfold for lambing in Almaty region. Plan and photograph of the sheepfold are presented in Figures 1 and 2.

For this sheepfold in accordance with an innovative patent of the RK number 26930 "The ventilation device" [2, 3] have been developed schemes and identified parameters of energy efficient ventilation system with heat soil.

Scheme of experimental energy efficient ventilation system for placing of the sheepfold is shown in Figure 3.
The device operates in the RS-485 network under the protocols OWEN, ModBus-RTU, ModBus-ASCII, DCON.

Controller OWEN PLC is used as the master network. Device is given with OPC driver and standard library WIN DLL, which are used for connecting the device to the SCADA-systems and controllers from other manufacturers. Configuring the device is carried out on a PC via the interface adapter RS-485 / RS-232 or RS-485 / USB (for example, OWEN ASZ-M or AS4, respectively) using the "Configurator M110" included the supply package.

Then all the data from all the sensors are transmitted to the programmable logic controller PLC OWEN 100-220. P-M. OWEN PLC controllers allow you to organize a gateway between devices with the protocol OWEN (RS-485) and industrial networks with protocols, Modbus TCP, DCON.

At the control center of station operator received a personal computer. To communicate through (CSD) GPRS-connection, it is installed Modbus OPC / DDE server to a PC.

OPC supports the work with a modem and allows you to work both in Master mode and in Slave mode. To transfer data to the computer modem operator is connected working in master mode, then the signals are transmitted to the processing and the computer modem operator is connected working in master mode.

3 Results of experimental studies

Testing of energy efficient ventilation system was carried out in two stages: winter and summer periods. Results of statistical processing of measurements are shown in Tables 1-4.

Table 1 - Results of statistical processing of measurements of air temperature in the heat exchanger-air conduit (in winter)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>temperature at entrance</th>
<th>temperature in the middle</th>
<th>temperature on the way out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of values n</td>
<td>72</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>Average value $X_{aver}$</td>
<td>-14.2597</td>
<td>-5.04028</td>
<td>5.625</td>
</tr>
<tr>
<td>Standard deviation $S$</td>
<td>1.645965</td>
<td>0.756504</td>
<td>0.211467</td>
</tr>
<tr>
<td>The standard deviation of the average $S_{aver} = S/\sqrt{n}$</td>
<td>0.193979</td>
<td>0.089155</td>
<td>0.024922</td>
</tr>
<tr>
<td>Student's t-test $(5% , n - 1)\tau$</td>
<td>1.993943</td>
<td>1.993943</td>
<td>1.993943</td>
</tr>
<tr>
<td>Confidence interval $CI = t \cdot S_{aver}$</td>
<td>-0.71299</td>
<td>-0.25201</td>
<td>0.28125</td>
</tr>
<tr>
<td>Relative error $\delta = \frac{CI}{X_{aver}}$</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 2 - Results of statistical processing of measurements of air temperature in the heat exchanger-air conduit (in summer)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>temperature at entrance</th>
<th>temperature in the middle</th>
<th>temperature on the way out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of values n</td>
<td>802</td>
<td>802</td>
<td>802</td>
</tr>
<tr>
<td>Average value $X_{aver}$</td>
<td>26.48999</td>
<td>20.52618</td>
<td>19.69433</td>
</tr>
<tr>
<td>Standard deviation $S$</td>
<td>2.496318</td>
<td>0.51628</td>
<td>0.530624</td>
</tr>
<tr>
<td>The standard deviation of the average $S_{aver} = S/\sqrt{n}$</td>
<td>0.088148</td>
<td>0.01823</td>
<td>0.018737</td>
</tr>
<tr>
<td>Student's t-test $(5% , n - 1)\tau$</td>
<td>1.96293</td>
<td>1.96293</td>
<td>1.96293</td>
</tr>
<tr>
<td>Confidence interval $CI = t \cdot S_{aver}$</td>
<td>1.324499</td>
<td>1.026309</td>
<td>0.984716</td>
</tr>
<tr>
<td>Relative error $\delta = \frac{CI}{X_{aver}}$</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 3 - Results of statistical processing of measurements of soil temperature (in winter)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>temperature at entrance</th>
<th>temperature in the middle</th>
<th>temperature on the way out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of values n</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Average value $X_{aver}$</td>
<td>15.1167</td>
<td>16.0875</td>
<td>16.6375</td>
</tr>
<tr>
<td>Standard deviation $S$</td>
<td>0.831273</td>
<td>1.536318</td>
<td>1.965089</td>
</tr>
<tr>
<td>The standard deviation of the average $S_{aver} = S/\sqrt{n}$</td>
<td>0.169683</td>
<td>0.3136</td>
<td>0.401122</td>
</tr>
<tr>
<td>Student's t-test $(5% , n - 1)\tau$</td>
<td>2.068658</td>
<td>2.068658</td>
<td>2.068658</td>
</tr>
<tr>
<td>Confidence interval $CI = t \cdot S_{aver}$</td>
<td>0.008484</td>
<td>0.01568</td>
<td>0.020056</td>
</tr>
<tr>
<td>Relative error $\delta = \frac{CI}{X_{aver}}$</td>
<td>0.000561</td>
<td>0.000975</td>
<td>0.001205</td>
</tr>
</tbody>
</table>

Table 4 - Results of statistical processing of measurements of soil temperature (in summer)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>temperature at entrance</th>
<th>temperature in the middle</th>
<th>temperature on the way out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of values n</td>
<td>147</td>
<td>147</td>
<td>147</td>
</tr>
<tr>
<td>Average value $X_{aver}$</td>
<td>16.11347</td>
<td>14.25299</td>
<td>12.68156</td>
</tr>
<tr>
<td>Standard deviation $S$</td>
<td>0.654286</td>
<td>0.618405</td>
<td>1.508083</td>
</tr>
<tr>
<td>The standard deviation of the average $S_{aver} = S/\sqrt{n}$</td>
<td>0.053965</td>
<td>0.051005</td>
<td>0.124385</td>
</tr>
<tr>
<td>Student's t-test $(5% , n - 1)\tau$</td>
<td>1.976346</td>
<td>1.976346</td>
<td>1.976346</td>
</tr>
<tr>
<td>Confidence interval $CI = t \cdot S_{aver}$</td>
<td>0.002698</td>
<td>0.00255</td>
<td>0.006219</td>
</tr>
<tr>
<td>Relative error $\delta = \frac{CI}{X_{aver}}$</td>
<td>0.000167</td>
<td>0.000179</td>
<td>0.00049</td>
</tr>
</tbody>
</table>

Figure 4 - Block scheme of information-measuring system
1 - sensors (of temperature, humidity, air flow rate); 2 - analog input modules (OWEN MY110-8A); 3 - programmable logic controller OWEN PLC 100-220; P-M; 4 - graphic operator terminal OWEN IP320; 5 - data acquisition module OWEN MSD200; 6 - Interface Converter USB / RS485 AC4; 7 - GSM / GPRS; 8 - Interface Converter USB / RS485 AC4; 9 - a personal computer.
During tests energy efficient ventilation system during the winter period found that the room temperature of the sheepfold ranged from +5.4 °C to +6.0 °C, on average +5.6 °C, with the number of measurements n = 72.

The relative humidity of the room of the sheepfold was in average 79.2% (for n = 72). The maximum and minimum value of relative humidity were respectively 93.4% and 64.1%. At the lowest outdoor temperature -18 °C (04.02.2014) supply air temperature reached 6 °C. Supply flow rate fluctuate depending on the outdoor temperature within 70-140 m3 / h. The maximum heat output of installation was 2.2 kW.

During tests energy efficient ventilation system in summer found that the room temperature of sheepfold ranged from +16.6 °C to +27.29 °C on average +22.3 °C, with the number of measurements n = 820.

The relative humidity of the room of sheepfold averaged 30.5% (for n = 820). Maximum and minimum value of relative humidity was respectively 58.88% and 10.37%. At the highest temperature of the outside air +33.4 °C supply air temperature reached +19.6 °C and humidity increased from 12% to 23%. Air flow rate was 140 m3/h. The cooling capacity of the installation was 2.6 kW.

**Conclusion**

In times of testing energy efficient ventilation system provided the required power saving mode and zootechnical parameters of the microclimate in the maternity ward of the sheepfold.

Energy efficient ventilation system has been adopted for economic use and recommended for implementation in the sheep farms.

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IMPROVING THE EFFICIENCY of off-line HEAT PUMP SYSTEM FOR HEATING RURAL HOUSE IN THE COLD DAYS

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Summary: This article presents methods and means of increasing an efficiency of heat pump system and hot water supply for residential houses on the base of using of the heat pumps «air-water», solar collector of energy and ground heat exchangers. The technological scheme of energy saving heat pump system of the rural house taking into account local climatic conditions is described. The study determines typical temperature parameters hybrid heat pump system’s elements at cold days in heating season. The expediency of use of solar energy and heat of ground for preliminary heating of the cold external air arriving to the thermal pump «air-water» is proved.

KEYWORDS: HEATING, THERMAL PUMP, AIR SOLAR COLLECTOR, SOIL HEAT EXCHANGER, WARMTH ACCUMULATION.

1. Introduction

Distinctive feature of agricultural objects of Republic of Kazakhstans is their rather small individual capacity and significant dispersion on extensive territory that creates the certain difficulties in construction of the effective centralized systems of heating and hot water supply (HHWS). At the same time local climatic conditions of this country favour to development of independent hybrid systems HHWS with use of renewed energy sources (RES), in particular, to energy of the Sun, a wind and heat of a ground. The last provides use of popular thermal pumps (TP) or their combination with other types of power sources. The choice of updating of TP depends on climatic conditions of the district and technical and economic indicators of the equipment. The solution of questions of a choice of TP type, scales and areas of their rational use in the different countries is far not equivalent. As a rule, geothermal TP «water-water» were extended in the northern countries, and in southern - TP «air-water». The price of the last for 30-40 % is cheaper than geothermal TP at comparability of capacity and quality of the equipment. This difference essentially increases at carrying out difficult earthwork, drilling of wells (by depth of 60-100 m) and a laying of geothermal probes [1].

In the majority of regions of Kazakhstan it is more preferable to use low-potential warmth of atmospheric air, that is to apply to HHWS of rural houses the thermal pumps «air-water» (TPAW). Wide circulation of TPAW is connected with relative simplicity of installation and low cost concerning other types of thermal pumps. Weakness of TPAW is reduction of thermal capacity at decrease in temperature of external air lower – 15 °C [2].

Considering that decrease in temperature of external air (below – 15 °C) in the major regions of Kazakhstan is observed rather short time (10-15 days of the winter period), arises practical interest to search of possibility of increase of overall performance of heat pump system of a heat supply (HPHS) of rural houses during this period of time taking into account use of local resources.

In this article it is offered some ways of increase of overall performance of HPHS of rural houses in cold days at the expense of preliminary heating of the external air arriving in TPAW, by means of the thermal blocks accumulating warmth of solar energy (in the afternoon) and soil air lines (at night).

2. Materials and research methods

2.1 Preconditions of use of solar energy and warmth of soil for HHWS of the rural house. The main indicator of overall performance of TP is the factor of transformation of the thermal pumps COP (coefficient of preformance) which is defined by the relation of capacity of received useful heat to the capacity spent for a drive of the compressor [1,2].

For calculation of COP the formula [1] is used:

$$\text{COP} = \frac{Q_h}{W},$$

where $Q_h$ – received useful heat, J;

$W$ - power consumption, J.

TPAW, as a rule, have optimum values $\text{COP} = 3,5 \ldots 4,0$ at temperature of external air $t=2 \text{ °C}$ [1]. With increase in temperature of a source of low-potential heat and reduction of temperature of heating factor COP increases and can reach 4, 5 and more values. Fall of temperature of air during winter time considerably reduces COP and leads to an inefficiency of use TPAW.

Key question on which efficiency of application of TP substantially depends, the question of temperature increase of a source of low-potential heat, that is the air arriving in TPAW is. Considering short duration of the coldest days in the southern and western regions of Kazakhstan (10-15 days) for achievement of the specified purpose in rural areas it is possible to find separate ways and means. For example, previously to pass cold external air through the adapted economic constructions, cellars, etc.

At a complete set of hybrid HPHS for rural houses of Kazakhstan, first of all, it is necessary to consider use of solar energy (especially in the afternoon). It gives essential reduction of consumption of electric energy TPAW with 25 to 15 % from the general development [3,4].

Irrespective of a geographical arrangement of the republic, resources of solar energy in the country are stable and accepted, thanks to favourable dry climatic conditions. The quantity of a sundial makes 2200-3000 hours in a year, and energy of sunlight of 1300-1800 kWh on metre a year. Total day radiation under various conditions on the republic makes 3,8-5,2 kWh/sq.m. Average monthly temperature of external air, for example, in Almaty area during winter time does not decrease below –11 °C. In some cases this temperature can decrease to –25 °C (in a current of 3-5 days).

In rural areas of the majority of regions of Kazakhstan and attractive use of warmth of soil as its temperature, on depth of 1,3-1,5 metres, practically do not change and keeps in limits 7-10 °C heat is available. When laying soil air lines on this depth and the admission through them cold external air from the subsequent giving in TPAW it is possible to increase in addition efficiency of its work in cold days.

Considering stated in this article one of ways of increase of efficiency of TPS of the rural house at the expense of preliminary heating of the external cold air arriving in TPAW, in the heat exchangers accumulating solar heat and warmth of soil is offered.

2.2 Block diagramme of the HHWS hybrid system. Widespread devices for transformation solar energy in thermal are concentrating and directly absorbing a solar stream - solar collectors and absorbers or panels. As solar
collectors serves гелиосистема, including a transparent roof from the metal plate established under it with the wavy profile which outer side is painted by a selective absorbing covering.

For increase of efficiency of use of solar radiation гелиосистема it can be supplied with the heatheat-sink design accumulating warmth of solar energy. Use of the accumulators charged in the minimum power consumption and discharged in the maximum requirement, essentially increases reliability and overall performance of HPHS. By means of such set of heliosystem the heat-carrier temperature in primary contour of solar absorbers and in a contour of the evaporator of the thermal pump during the winter period can be raised to 3 ... 7 wasps in relation to temperature of external air.

Heliothermal pump installation can work in two modes - summer and winter. In the summer period (April-October) hot water supply of a house becomes covered completely by the warmth received from solar collectors. The thermal pump as the additional power source, can work in cloudy days and, if necessary, at night. During the winter period thermal loading for heating of a house becomes covered by heatpump installation which uses as a source of low-potential energy warmth of external air warmed-up with solar absorbers and a heatheat-sink design.

We developed the hybrid HPS of the rural house consisting of air solar collectors, the soil heat exchanger and the warmth accumulator which can be used for preliminary heating of the cold external air arriving in evaporator TPAW.

In the picture 1 the block diagramme of saving HPS of the rural house which includes evaporator TPAW (1), the compressor (2), the condenser (3), a throttle dilator (4), system of heating (5), the circulating pump (6), an inclined solar collector (7), a vertical solar collector (8), the heataccumulator (9), soil the heat exchanger (10), a heated room (11) and thermal point (12) is presented.

From picture 1 follows that basic elements for preliminary heating of the external air arriving in a contour of evaporator TPAW, are: the air solar collectors integrated into a roof and the southern facade of thermal point, the soil heat exchanger (air line) and the warmth accumulator.

For effective use of the RES thermal resources the system of collecting low-potential heat takes place indoors which is attached to a heated building as thermal point (TP).

The arrangement of TP minimises quantity of air lines and reduces heatlosses at transformation of thermal energy. As TP can serves utility rooms, garages, etc.

The experimental module of thermal point given in the picture 2, includes a room in the area 25 sq.m and height of 2,2 m which is divided by the horizontal heatisolated ceiling into two parts: top and bottom, reported among themselves ventilating hatches.

During the winter period thermal loading for heating of a house as thermal point (TP) can work in cloudy days and, if necessary, at night. The heat-carrier temperature in primary contour of solar absorbers and in a contour of the evaporator TPAW during the winter period can be raised to 3 ... 7 wasps in relation to temperature of external air.

In the lower part of thermal point external block TPAW of the rural house, as is shown in the picture 4.

Picture 2 - The experimental module of thermal point attached to the rural house

The top part of thermal point contains a transparent roof from cellular polycarbonate in thickness δ = 10,0 mm, and under it the absorbing plate with the wavy profile "П" of a figurative form is established.

Feature of thermal point is that all elements of system of collecting low-potential heat are built in TP and through it automatic control of consumed warmth in heating systems depending on change of temperature of external air is carried out.

In a roof and the southern facade of TP the inclined and vertical air solar collectors consisting of a tight, heatisolated metal or wooden frame and a black metal plate, absorbing warmth take place. From above this frame is blocked by a transparent covering: glass or two-layer cellular polycarbonate. Properly sized square of a collector should be not less than 1,0 sq.m. The relation of length of a collector to its width should be in a range 5:1 ... 3:1.

In the lower part of thermal point external block TPAW of the Toshiba Estia brand (HWS-803XWHM3-E) is attached to the general wall heated a room. The hydroblock (HWS-803H-E) of the thermal pump is connected to a heat-insulated floor and the heating devices bringing and taking-away pipelines. Management of modes of heating is carried out from the panel (HWS-AMS11E).

The offered design of the soil heat exchanger has the fan which takes away used in a contour of evaporator TPAW the heatcarrier (air) and discharges it through the pipes of the soil heat exchanger laid in a trench. Soil the heat exchanger is given in the picture 2 also represents the heat exchanger executed from two-layer goffered polyethylene, external diameter of a pipe of 110 mm, laid in a trench depth of 1,6 m and in the length of 66 m on perimetre of the rural house.

Picture 3 – General view of the soil heat exchanger

The heat-carrier (air) circulating in the soil heat exchanger selects warmth from soil and submits it to the heat exchanger of evaporator TPAW.

Regulation of the direction of circulation of the heat-carrier fulfilled in a contour of the evaporator, is carried out by means of a box with the cut-out air pipes, the thermal pump established on the external block, as is shown in the picture 4.
From picture 4 it is visible that on the open end of a box there is a rotary latch by means of which the adjustable suction of the air filled in TPAW is made. In case of a negative difference of the air temperatures, evaporator TPAW fulfilled in a contour, and the external air, the fulfilled air is circulated through pipes of the soil heat exchanger. Otherwise, when the temperature of external air is lower fulfilled, the last will circulate on a vicious circle, i.e. through air solar collectors.

For the purpose of the accounting of an expense of the heat-carrier on submitting pipelines of primary and distributive contours flowmeters CTВ-15 are established.

The heatheat-sink design is formed in TP in the form of a hole in volume not less than 5 m³. As heatheat-sink weight nonfreezing liquids (antifreeze, antifreeze, etc.) or firm materials (magnesite, t alc chloride, chamotte, etc.), possessing a high thermal capacity can be applied. The heatheat-sink design is reported on a contour of circulation by the solar water collectors established along the edges by a transparent roof, solar energy accumulating warmth.

In TP the external block TPAW using air, warmed up by the warmth utilised by system of collecting low-potential power sources takes place.

2.3 Principle of work of heatpump system. Hybrid HPS of the rural house works as follows. In the coldest days of the heating period, before receipt in evaporator TPAW, external cold air passes through vertical and inclined air solar collectors, it is warmed up and arrives in TP. Further the heated-up external air arrives in the evaporator of external block TPAW. Warmth thermotransformation to higher temperature level occurs by warmth transfer from the warm low-potential heat-carrier to a coolant circulating in a contour of the evaporator. Further the coolant evaporates, pairs of coolant are compressed in compressor TPAW, and its warmth is transferred circulating via the condenser of the thermal pump to water of system of heating. Water of system of heating heats up in the thermal pump to some temperature defined by conditions of economic work TPAW and by means of the circulating pump moves in heating system (in a heat-insulated floor or heating devices).

Cooled in a contour of evaporator TPAW the heat-carrier (air) by means of the fan moves in the soil heat exchanger. Passing through the goffered pipes laid in a trench of the soil heat exchanger cooled air, takes away warmth of soil on depth of a nonfreezing layer of earth and again comes back back to TP. It allows to circulate the most part of air in an internal contour (TP, TPAW and the soil heat exchanger) without external cooling.

Accumulation of warmth occurs in TP where the heatheat-sink weight (9) specified in the picture 1 takes place. At night, the warmth accumulated in a warm and heat-sink design warms up external air before its giving in a contour of evaporator TPAW.

3 Results and discussion

We carried out natural tests and the main are defined temperature characteristics in knots and elements HPS of the rural house in climatic conditions of Almaty area of the Republic of Kazakhstan.

During experiences temperatures were measured: external air, thermal point (at height of 1 m from a floor) and in a soil air line. Measurements were carried out according to a technique [5].

In the picture 5 dynamics of change of temperatures in the HPHS various elements of the rural house (Kargala’s settlement of Almaty area) during cold time is shown (on December 8, 2014).

Picture 5 – Dynamics of change of temperatures in elements HPHS of the rural house during cold time

Daily change of temperature of external air it is provided by dark blue colour (schedule 1). The temperature in a soil air line (depth of 1.6 m), shown by violet colour (schedule 2), practically did not change and was near +6 °C.

Air temperature in thermal point, at its heating by air solar collectors (during the period from 700 to 1800 hours), was measured at height of 1 metre from a floor (schedule 3). Despite a sunset (approximately in 1800 hours) warm air in TP keeps approximately till 2000 o’clock.

The TP air intended for TPAW, periodically passed heating in a soil air line by run by the special fan. At work of air solar collectors (from 700 to 1800 o’clock) soil air lines are disconnected and collect heat from surrounding soil.

In the picture 5 red colour (schedule 4) gave a resultant the average air temperature, arriving in evaporator TPAW. This temperature develops at the expense of preliminary heating of cold external air in thermal point which is in turn warmed up by air solar collectors and a soil air line.

In the considered technological scheme of HPS of the rural house, in cold days of winter, there is a preliminary heating of the external air arriving in TPAW. It allows to support factor of transformation COP in effective limits of 3-4 units. At more high temperatures of external air (higher than -5 °C) the soil air line is disconnected from the scheme. Air solar collectors become more active in the afternoon that allows to minimise operating time TPAW.

If the temperature of external air is lower, than the temperature of the heat-carrier fulfilled in evaporator TPAW, soil the heat exchanger works in the closed mode. Thus, the fulfilled heat-carrier is banished through the integrated systems of air solar collectors and soil air lines, is warmed up and moves in TPAW. Such way of heating of a low-potential source of warmth is much more effective.

Conclusion

The offered technological scheme of an independent heat supply of the rural house of the settlement of Kargaly of Almaty area allows to increase factor of transformation of heat COP of the thermal pump «air-water» with 2-2,5 to 3,5-4 at temperature of external air during the winter period from – 14 °C to – 20 °C. Thus, use of solar energy reduces in the afternoon electricity consumption TPAW approximately for 15-18 %.


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THE PROVIDING OF THE POWER SAVING CONTROL OF ONE OUTPUT VALUE WITH TWO CONTROLLING CHANNELS HAVING DIFFERENT EFFECTIVENESS AND COST OF THE CONTROLLING RESOURCE

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Abstract: Controlling of objects with the feedback negative loop is widely used in industry, intelligent technologies, robotics and transport systems. A negative feedback loop by comparing of the prescribed value of the output value with measured value of it generates a control signal, which adjusts the output value of the object. Typically, the number of controlled output values is equal to the number of feedback channels acting on the object, but in some cases, the number of the channel can be more. This situation is especially frequent in transportation systems. In the problem of the design of regulators, they pay the most attention to ensuring the required static and dynamic control accuracy, but recently the attention to the conservation of the resource manager increased. This saves fuel or energy costs, which is especially important, for example, in space technology. The task of saving resources in the control of an object with an excess amount of control channels was not previously considered in the literature. In this paper, the problem is investigated by numerical optimization with simulation. In some cases, the cost of resource of the control by the different channels may vary. At the same time the cheaper resources can have the worst quality of the control, for example, it can has a discrete form or (and) less speed and so on. In this paper, we study such state of the problem and give its solution. It is shown that for a suitable choice of the cost function one can preserve rather high quality of the control, while ensuring saving of the controlling resources. Resource saving can reach in some cases 96%, which is illustrated by an example.

Keywords: CONTROL, ACCURACY, POWER SAVING, REGULATORS, TRANSPORT SYSTEMS, AUTOMATION, ROBOTICS

1. Introduction

In the tasks of transport controlling, as in other tasks of automation, the issues of reaching the required dynamic and static accuracy are most important, especially when external disturbances act. That is why the negative feedback loops are used there.

Among the specific tasks of feedback control is the task of saving the controlling resource (energy, power etc.) [1–4]. Also the important task is to improve the quality of control by use of an excess amount of channels of influence on the object [5–10].

To the best of our knowledge, the joint solution of these problems has not been suggested in literature till now. However, such a situation in which it is necessary to ensure both high precision of the control and to make economy of resources, while the number of the channel of influence on the controlled value increases, often takes place in transport system. An example is the problem of controlling the spacecraft, in which it is equally important both to ensure high precision and to look for fuel economy. A characteristic feature of such a problem can be fundamental difference in the methods of control of various channels, which leads to different costs of different controlling resources with the different efficiency of each of these resources.

Indeed, for example, when moving on water surface one can use various types of thrust: a) an Archimedes screw; b) a reactive method based on the water jet ejection; d) an air propeller, and so on. The strength of each of the impacts will be different, as well as the cost of such impacts. It is obvious that this analogy can be extended to other types of transport systems, including space transportation, in which we know the distribution of impacts at different stages.

In this paper, we investigate the method of modeling and numerical optimization of the possibility of solving the considered problem using simple mathematical models of the impact of the object. In the model elements of various effectiveness are used, which is done by introducing discrete control, using different speed in different channels, as well as by introducing the derivative element at the output of the discrete element, which significantly complicates the management on such a channel.

2. Statement of the problem and solution method

Suppose we have choice between two kinds of impact to the output value of the object y(t). Also suppose that the first channel is faster and has higher cost of the control action, while the second channel, respectively, has lower speed and lower cost of control action to the object. Additionally we can suppose discreteness of action through the second channel. It is required to design the regulator, providing high static accuracy and sufficient dynamic accuracy of the control. In addition it is necessary to look for possible reduction of the cost of controlling resources in accordance with its given specific cost.

To solve this problem we propose to use numerical simulation and optimization program VisSim, for example, VisSim 6.0. In this case, the simulation of the two channel working demands using two different models, the output signals of which are added (common part of the models can be connected at the output of the adder). When simulating the disturbance it can be set equal to zero, and unit step can be used as the control action applied to the system input. These assumptions are quite acceptable for linear systems with feedback, but in this case there is non-linearity. The influence of this non-linearity will be developed in the fact that with increasing magnitude of the input action the relative magnitude of the non-linearity step will decrease, that is, the effect of non-linearity will weaken, and alternatively with a decrease in the magnitude the non-linearity will increase. Therefore, it is necessary to choose a value of the test step signal, which is the smallest one among the possible ones, that is, the effect of non-linearity reaches its maximum.

Let the step of nonlinearity be of 0.2 units, i.e. 20% of the used input unit step jump. This makes this type of nonlinearity quite noticeable when the task is being resolved.

The cost of function is proposed to be formed on the basis of the integral of the modulus of the error multiplied by the time since the beginning of the transient process. In it we propose to introduce the cost of controlling resources invested in the form of a square on the control action with a weighting factor, as suggested in our previous papers [5–7]. An additional peculiarity of our optimization task is different weighting coefficients for the different control channels.
3. The results of the regulator optimization

Let us consider the equation of the object in the following operator form:

\[ Y(s) = W_1(s)U_1(s) + W_2(s)U_2(s). \]  

(1)

Here, \( U_1, U_2 \) are input signals, \( Y \) is output signal, \( W_1, W_2 \) are related transfer functions, \( s \) is Laplace transform operator.

The equation of the regulator in common form is:

\[ U_1(s) = (p_1 + s d_1)E(s). \]  

(2)

\[ U_2(s) = (p_2 + s d_2)E(s). \]  

(3)

\[ E(s) = [V(s) - Y(s)]. \]  

(4)

Here \( E \) is error of control, \( V \) is the prescribed value of the output signal, \( p_1, p_2, d_1, d_2 \) are unknown coefficients which must be found with the help of numerical optimization.

Fig. 1 illustrates a structure for modeling and optimizing a regulator having two control channels.

**Example 1.** Let the transfer functions in (1) be given by the relations:

\[ s^2 + 1 \]

\[ 1 \]

(5)

\[ 4s + 1 \]

\[ 1 \]

(6)

In addition, we introduce a non-linear element, namely, quantizing device with the quantization step 0.2 units.

We especially recommend using of the energy-efficient control algorithms for objects containing integrator. Therefore, such an object is selected as an example of it. The integrator common for the two channels is described with symbol \( \frac{1}{s} \). Two different control channels are presented by links between the bus with the marks of the controlling signal, respectively, \( u_1 \) and \( u_2 \), and the inputs of the adder marked with the symbol \( \Sigma \). Two control signals, \( u_1 \) and \( u_2 \), are formed by two different regulators having proportional and derivative links. In proportional links coefficients are set by the variables \( p_1 \) and \( p_2 \), and in derivative links coefficients are given by the variable \( d_1 \) and \( d_2 \). Derivative links are represented by block \( \text{derivative} \). The circuit for the cost function calculating contains linearly rising signal generator and rectifier \( \text{abs} \), connected to the bus of the error signal \( e \). These two signals are multiplied by the block \( \text{abs} \) and integrated by the block \( \frac{1}{s} \).

The result of optimizing is shown in the form of values of the found coefficients as well as value of the energy cost. Also as a result of the optimization, transient processes in the system are calculated and plotted, which is shown on Fig. 2 and Fig. 3.

**Fig. 2.** Transient process in the system by Fig. 1
Also in the project there is a unit for calculation of energy consumption. It performs the squaring of each of the controlling signals, calculates the sum of these squares and integrates the result. Wherein different weights are used corresponding to the energy costs, namely 0.5 and 0.01. In addition, there is a block for the optimization containing four elements, denoted by the symbol \texttt{parameterUnknown}. This block carries out the search procedure for the required controller gains which provide the minimum of the positive value in the input to the unit \texttt{cost} in the end of the transient process.

The resulting transient process of the output value (see. Fig. 2) meets the requirements as it ends with prescribed value, equal to unit value. Overshoot is almost nonexistent. The graphs in the Fig. 3 show the form of control signals that serve to illustrate how the saving energy option operates with these signals. In this example, which is illustrated in Fig. 1–3, an option for power saving was not included because the connection between the output of power costs calculating unit and input of the unit \texttt{cost} was absent.

**Example 2.** Fig. 4–5 shows similar results when using power saving features. By comparing this result with the result of Example 1, we conclude that the quality of the transient process is almost not affected, only the speed decreased slightly (by 2.5 times), overshoot does not appear, static error does not occur. Energy cost savings amounted to about 96% because of the decreased value of 2.24 to a value of 0.0822. By comparing Fig. 5 and Fig. 3 it can be seen that by introduction of value of the relative contribution of the energy costs of the control signal into the cost function, the relative value of the second channel increased in comparison with the previous result. If earlier this signal was almost half of this of the first channel, then now it has become almost twice as much as the signal in the first channel, which is the channel with greater cost of the control resource.

**Example 3.** Let introduce into the object model derivative link between the output of the nonlinear element and the input of the transfer function. In this case, the second channel can carry out only pulse control, because if the signal at input of the nonlinear device is changed within the same quantization step, the output signal of the nonlinear element is not changed, and the output signal of the derivative link which is connected to this non-linear element, will be zero. Such a channel is not very suitable for the control, but it can also work as an object contained in the integrator. Derivative and integrating link of partially mutually compensate their action, but it weakens the desired effect of integration, which is important for energy savings in the controlling process. We solve the problem in these changed conditions by using a modified structure. Numerical optimization results are shown in Fig. 6 and 7.

The use of the value of the total energy expenditure in the cost function leads to the use of the second channel with less expensive energy source, but this, on the other hand, causes slight oscillation.
Thus the cost of controlling resources flow turns to be about 0.92 units.

**Example 4.** To compare these results, let us exclude terms equal to energy consumption from the cost function. The cost of energy consumption in this case is 2.53 units. It is more than 2.5 times greater. But the quality control markedly increases, as is shown in the graphs transient processes in Fig. 8 and 9.

Thus in this example, in the considered structure of the object model with the selected regulator structure, the reduction of the cost of controlling resource can be achieved only with the significant deterioration in the quality of controlling, and vice versa, improving the quality of transient processes can be achieved by increasing the cost of the controlling resource.

![Fig. 8. Transient process in the system by Example 4](image)

**Example 5.** Let us introduce the nonlinear element “dead zone” with the width of the dead zone of 0.2 units into the regulator of the second channel, as shown in Fig. 10. The resulting transient processes are shown in Fig. 11 and 12.

It is evident that although the duration of the transient processes increased slightly (in 1.5 times) compared to the previous result shown in Fig. 10, yet there are no oscillations, steady-state error is decreasing to zero, and thus the cost of the controlling resource is only slightly different from the result obtained with the structure shown in Fig. 7, namely 1.029 comparatively 0.92 units. Therefore, the introduction of an element with dead zone allows us to combine the requirement of cost savings of controlling resource with removal of self-oscillation.

![Fig. 9. Controlling signals in the system by Example 4](image)

**Fig. 10.** The structure of the regulator with the use of the element “dead zone” and results of the optimization (coefficients and resource costs) using the objective function, which does not include the cost of the resource

Varying the width of the dead zone leads to different results, which can also be assessed as successful. Namely, when the width of the dead band is 0.4 unit, energy cost is 1.15 units, the duration of the transition process is about 3 seconds, the process is similar to the process shown in Fig. 13. When the width of the dead zone is of 0.3 units, energy costs is 1.044 units, the transient process is virtually the same.
Conclusion

This paper has confirmed the possibility of dual channel control of single output value of the object while ensuring cost-saving of the controlling resource. Also the paper has proposed the method recommendations for the solving of this task. It has been shown that even with very limited possibilities of alternative control channel with lower cost of the controlling resource in this channel one can provide an effective combination of two types of impact with high-quality astatic control without overshoot and inexpensively control resources.

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References


RESEARCH OF POSSIBILITY OF ELECTROMECHANICAL TURNING MECHANISM CREATING FOR TRACKED VEHICLE AS FIRST STEP TO HYBRID TRANSMISSION

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Introduction
The need for a hybrid transmission for a vehicle has recently acquired great importance due to economic and environmental problems.

The possibility of a significant reduction in fuel consumption and emission of toxic gases when the engine is only achieved when using a hybrid transmission in which the excess energy during the engine and the alternator while driving coasting stored in batteries and used during acceleration or when a sharp increase in the resistance movement for various reasons. Such solutions are already used in many mass-produced vehicles, among other Toyota Prius and Honda Civic, as well as in the vehicles by “big three” of the USA.

Work on the use of hybrid transmissions for military vehicles have been conducted for a long time, but in Ukraine the development and application of hybrid transmissions for the army is taking place very slow.

Materials research.
Estimation of the required drive power electromechanical mechanism for turning on the example of a tracked vehicle multipurpose tractor MT-LB.

Consider a uniform rotation of the machine of mass \( m \) with a relatively large and constant speed \( V_C \) in the horizontal section area (Fig. 1). Assuming that the longitudinal component \( F_X \) of the centrifugal force \( F_C \) does not change the diagrams of normal loads on the track and does not cause changes in the steering force, and considering only the effect of shear force \( F_Y \), we can calculate the displacement \( \chi \) of the poles of turn \( O_1, O_2 \) and normal reactions of soil \( N_1 \) and \( N_2 \). The indices 1 and 2, respectively, for lagging and outpacing boards.

Centrifugal force and its transversal constituent are determined as:

\[
F_C = m\omega^2 R_C = \frac{G}{g} \left( \frac{V_C}{R_2 - \frac{B}{2}} \right)^2
\]

The shear force \( F_Y \) causes displacement of the poles of turn on a size \( \chi \), because it must be balanced against the transversal forces acting on the lower branches of caterpillars in the plane of the bearing surface

\[
F_Y = 2\chi\mu \frac{G}{L} \Rightarrow \chi = \frac{F_Y L}{2\mu G}
\]

Then the longitudinal component of the centrifugal force will be determined as

\[
F_X = F_Y \tan \psi = F_Y \frac{\chi}{R_2 - \frac{B}{2}} = \frac{F_Y^2 L}{2\mu G \left( R_2 - \frac{B}{2} \right)}
\]
If using $S_1$ and $S_2$ to identify lateral soil reaction per unit length of the bearing surface of a corresponding caterpillar, then

$$S_1 = \mu \frac{N_1}{L}, \quad S_2 = \mu \frac{N_2}{L} \Rightarrow S_1 + S_2 = \frac{\mu}{L} (N_1 + N_2).$$

The moment of resistance to turning is determined by the following expression

$$M_C = \int_0^L \left( S_1 + S_2 \right) x dx = \mu \frac{G L}{4} \left( \frac{L}{4} + \chi^2 \right) = \mu \frac{G L}{4} \left[ 1 + \left( \frac{2 \chi}{L} \right)^2 \right].$$

From the equations of the moments relative to the poles of the turn we will get traction and braking respectively on the outpacing and the lagging caterpillars

$$P_2 = R_2 + \frac{M_C}{B} - \frac{F_Y X}{B} + \frac{F_X}{2}, \quad P_1 = R_1 - \frac{M_C}{B} + \frac{F_Y X}{B} + \frac{F_X}{2}.$$ 

Accordingly, the resistance force will be equal to $R_{f_2} = f N_2$ and $R_{f_1} = f N_1$.

The redistribution of loads between the caterpillars (Fig. 2) will be equal to $N_2 = \frac{G}{2} + F_Y \frac{h_C}{B}$ and $N_1 = \frac{G}{2} - F_Y \frac{h_C}{B}$.

Then, the expressions for the required thrust forces will have a look

$$P_2 = f \left( \frac{G}{2} + F_Y \frac{h_C}{B} \right) + \mu \frac{G L}{4B} \left[ 1 - \left( \frac{2 \chi}{L} \right)^2 \right] + \frac{F_X}{2} ; \quad P_1 = f \left( \frac{G}{2} - F_Y \frac{h_C}{B} \right) - \mu \frac{G L}{4B} \left[ 1 - \left( \frac{2 \chi}{L} \right)^2 \right] + \frac{F_X}{2}.$$ 

With the increase of rate of movement the constituents $F_X$ and $F_Y$ increase, and tractive forces diminish, i.e. the turn of caterpillar machine is facilitated. Displacement of poles of turn increases at the same time. When it arrives at a size $\chi = \frac{L}{2}$ there is "skidding" of caterpillar machine and trajectory of motion distorted.

The maximum speed of a caterpillar on the condition of the complete skidding $v_C \geq \sqrt{\mu_{max} g \left( \frac{R_2 - B}{2} \right)}$; on the condition of the partial skidding $\sqrt{\mu g \left( \frac{R_2 - B}{2} \right)} \leq v_C < \sqrt{\mu_{max} g \left( \frac{R_2 - B}{2} \right)}$; on the condition of motion without skidding $v_C < \sqrt{\mu g \left( \frac{R_2 - B}{2} \right)}$. Here $\mu = \frac{\mu_{max}}{a + (1-a) R_2 / B}$, $a=0.85$.

The results and real fixed radiuses of turn for the different coefficients of resistance to rotation are brought around to the charts presented on fig. 3-5.

![Fig. 2 – Dependence of speed on the radius of turn at the $\mu_{max}=0.8$](image)

![Fig. 1 – Dependence of speed on the radius of turn at the $\mu_{max}=0.6$](image)

<table>
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<th>$N_0$</th>
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<th>$v_{1}$</th>
<th>$r_2$</th>
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<th>$F_Y$, N</th>
<th>$\chi$, m</th>
<th>$\mu$</th>
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<td>77,48</td>
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Table 1 – Calculation parameters of tracked vehicle multipurpose tractor MT-LB in a turn
For determination of expenses of power we will be set by next basic data:
\[ m = 10000 \text{ kg}; \quad B = 2.5 \text{ m}; \quad L = 3.7 \text{ m}; \quad f = 0.08; \quad \mu_{\text{max}} = 0.8. \]

Speeds and radiuses of turn, provided by the regular transmission of a tracked vehicle multipurpose tractor MT-LB in the mode of maximal power, are driven to the table.

Determination of minimum radiuses of turn on the condition of the complete skidding for all transmissions of slow row, and also the calculation of necessary twisting moments and angulators on managing elements we conduct on a next algorithm: radiuses of turn, corresponding to the border of beginning of skidding of machine for each of certain on a table speeds we find on a formula

\[ V_C < \sqrt{\frac{\mu g (R^*_2 - \frac{B}{2})}{2}}. \]

Where \( \mu = \frac{\mu_{\text{max}}}{a + \frac{(1 - a) R^*_2}{B}} \), \( a = 0.85. \)

Conducting a substitution and transformations, we will get

\[ V^2_C = \frac{\mu_{\text{max}} g (R^*_2 - \frac{B}{2})}{a \frac{(1 - a) R^*_2}{B}}, \]

from where

\[ R^*_2 = \frac{\mu_{\text{max}} g - (1 - a) v^2_C}{\mu_{\text{max}} g - a v^2_C}. \]

Further we find the radiuses of turn \( R^{**}_2 \), corresponding to beginning of the complete skidding of machine for each of certain on a previous step speeds (see a table.). We determine the angulator of turn of machine corps of relatively vertical axis \( \omega_C \) and check it for exceeding \( 1.5 \text{ s}^{-1} \), that corresponds to the maximally possible horizontal accelerations for a crew. If necessary we increase a radius to the value at that speed \( \omega_C = 1.5 \text{ s}^{-1} \). Taken on for further calculations values we add to the table.

Was counted the values of linear speeds of outpacing \( V^*_2 \) and lagging \( V^*_1 \) sides which added to the table.

The size of centrifugal force arising up at a turn with the calculated descriptions

\[ F_Y = m \frac{v^2_C}{R^*_2 - \frac{B}{2}}. \]

Relative displacement of poles of turn \( \chi_0 \) under the action of force of inertia we find on a formula

\[ \chi_0 = \frac{F_Y}{\mu g}. \]

If the got values more unit, then we accept their \( \chi_0 = 1 \) and we count the coefficient of resistance to the turn on a formula

\[ \mu = \frac{F_Y}{mg}. \]

We find normal reactions under outpacing \( Q^*_2 \) and lagging \( Q^*_1 \) sides.

The coefficient of moment of resistance to the turn we find from the condition of absence of central forces defiat even distribution of pressure on length of tracks \( K = 1 + \chi^2_0 \). Longitudinal constituent of inertia force

\[ F_X = F_Y \frac{\chi_0 L}{2(R^*_2 - \frac{B}{2})}. \]

Tractive forces on outpacing \( P^*_2 \) and lagging \( P^*_1 \) to the sides, necessary for realization of turn machines with the set speed and radius on the prospected soil make:

\[ P^*_2 = \mu L \frac{mgK}{4B} + \frac{F_Y L}{2B} \chi_0 + \frac{F_X}{2}; \quad P^*_1 = - \mu L \frac{mgK}{4B} - \frac{F_Y L}{2B} \chi_0 - \frac{F_X}{2}. \]

Twisting moments on the sunny cog-wheels of resumptive planetary rows taking into account streamline of power on sides (fig. 6):

\[ M_{\Sigma 2} = \frac{M_{\text{Bl2}}}{i^M \eta^M_{\Sigma}}, \quad M_{\text{Bl2}} = \frac{P^*_2 R_{\text{BK}}}{i_{\text{Bl2}} \eta_{\text{cycl2}} \eta_{\text{Bl1}}}; \quad M_{\Sigma 1} = \frac{M_{\text{Bl1}}}{i^M \eta^M_{\Sigma}}, \quad M_{\text{Bl1}} = \frac{P^*_1 R_{\text{BK}} \eta_{\text{cycl}} \eta_{\text{Bl1}}}{i_{\text{Bl1}} \eta_{\text{cycl}} \eta_{\text{Bl1}}} \text{ for the mode of traction from an engine and} \]

\[ M_{\Sigma 2} = \frac{M_{\text{Bl2}}}{i^M \eta^M_{\Sigma}}, \quad M_{\text{Bl2}} = \frac{P^*_2 R_{\text{BK}} \eta_{\text{cycl2}} \eta_{\text{Bl1}}}{i_{\text{Bl1}} \eta_{\text{cycl}} \eta_{\text{Bl1}}} \text{ for the mode of braking by a lagging side and recuperation of power.} \]
The angulators of corona gear-wheels of resumptive planetary rows we determine for all transmissions in the mode of rectilineal motion:

\[ \omega_{\pi} = \frac{V_C}{R_{BK}} \cdot i_{\Pi} \cdot \frac{k_0}{k} \]

where \( k_0 \) = 1,415 – kinematics transmission relation of resumptive planetary row in direction from an epicycle to lever of planetary row at a shut-down sunny cog-wheel.

The angulators of sunny cog-wheels of resumptive planetary rows we determine for all transmissions in the mode of turn with before certain linear speeds on outpacing and lagging to the sides:

\[ \omega_{\Pi}^2 = \frac{V_2}{R_{BK}} \cdot i_{\Pi} \]

or \( \omega_{\Pi}^1 = \frac{V_1}{R_{BK}} \cdot i_{\Pi} \)

\[ \omega_{\Sigma}^2 = -2,41 \omega_{\Pi} \Sigma + 3,41 \omega_{\Pi}^2 \]

\[ \omega_{\Sigma}^1 = -2,41 \omega_{\Pi} \Sigma + 3,41 \omega_{\Pi}^1 \]

Power on the sunny cog-wheels of resumptive planetary rows

\[ N_{\Sigma} = \omega_{\Sigma} N_{\Sigma} \]

Table 2 – Geometrical, kinematics and power descriptions of turn of a tracked vehicle multipurpose tractor MT-LB

<table>
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<th>№ transmission</th>
<th>( V_{c1} ) m/s</th>
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Here:

\( R_{BK} = 0,265 \) – radius of driving-wheel;

\( i_{\Pi} \) = 6 – transmission relation of side reducing gear;

\( i_{KL} = 3,41 \) – power transmission relation of resumptive planetary row in direction from a sunny cog-wheel to lever of planetary row:

\( \eta_{\Pi} = 0,95 - 0,018 \) – output-input ratio caterpillar mover accordingly

for outpacing and lagging sides; \( \eta_{Pi} = 0,98 \) – output-input ratio side transmission;

\( \eta_{KL} = 0,9 \) – output-input ratio resumptive planetary row.
Choice of electric motors for the electromechanic of double-flux mechanism of turn of caterpillar machine

1. Engines of direct-current.
   Basic advantage of these engines, that determined their general use on the stage of development of electric drives, is lightness of the smooth adjusting of speed in wide limits. Therefore with development of semiconductor industry and appearance of relatively inexpensive transformers of frequency the percent of their use diminishes constantly. Wherein it maybe direct-current re-engined by drives on the basis of asynchronous engines with a shortcircuited rotor. The basic lacks of engine of direct-current (not high reliability, complication of service and exploitation) are conditioned by the presence of collector knot.

2. Synchronous engines.
   Basic advantage of synchronous engines is that they can work with the power-factor of cosφ=1. Their feature also is constancy of speed of rotation at the change of moment of loading on a billow. At all dignities of synchronous engine basic defects limiting their application are complication of construction, presence of causative agent, high price, starting complication.

3. Asynchronous engines.
   On structural principle asynchronous engines are subdivided into engines with a shortcircuited and phase rotor. Thus the most used electric motors are asynchronous with a shortcircuited rotor. A so wideuse is conditioned by simplicity of their construction, service and exploitation, high reliability, relatively low cost. The lacks of such engines are a large starting current, relatively small starting moment, and for the smooth adjusting of speed the transformer of frequency is needed. For reduction of starting currents of asynchronous engine with a shortcircuited rotor the device of the smooth starting or transformer of frequency can be used.

From three considered types of electric motors evidently, that used synchronous electric motors as an electromechanic it is impossible without the additional box of transmission. The basic lacks of engine of direct-current is not high reliability, complication of service and exploitation, high cost, therefore using this type of electric motor as an electromechanic is not recommended. An asynchronous electric motor has three basic advantages: smooth adjusting of speed in wide limits by means of transformer of frequency; simplicity of construction, service and exploitation; high reliability and low cost. It was therefore made decision to choose an asynchronous electric motor as an electromechanic of turn mechanism.

Conclusions
1. The got calculation power necessary for realization of turn with the accepted parameters shows that for the second, one third of transmissions and transmission of back-draught applying an electromechanic without the complete processing of transmission and setting of powerful electric motors and generator is impossible.
2. Realization of turn on fourth, fifth and sixth transmissions due to the single motorized drive of mechanism of turn maybe without the cardinal processing of transmission of machine, because requires setting of one or two electric motors total power to 10-12 kW.
3. At an attempt on all transmissions to realize only the electromechanic of mechanisms of turn thrown away opportunity the use of mechanical drive on a low gear that must provide if necessary the protracted work of machine in heavy travelling terms.
4. In connection with the stated the combined drive of mechanisms of turn that would allow on more subzero transmissions to use a mechanical drive with the fixed radiuses of turn and on higher transmissions is offered is an electromechanic with the smooth adjusting of radius of turn. In addition, an offer technical solution will allow to use the electromechanic of mechanisms of turn for the brief increase of power in the modes of rectilineal motion due to the power accumulated in storage batteries, that will promote descriptions of mobility of machine substantially.
METHOD AND RESULTS OF EXPERIMENTAL RESEARCHES OF AUTOMATED INSTALLATION FOR DEFINITION OF EGG GEOMETRICAL PARAMETERS BASED ON VISION SYSTEM

Abstract: A methodology and results of experimental researches of the automated installation for determination of geometric parameters of eggs, based on vision systems, using software LabVIEW and Vision Assistant, is considered in the paper. The installation provides improved performance and accuracy of the measurement of geometrical dimensions and determination of the form coefficients of the eggs. The principle of operation of the automated installation is based on non-contact method of measuring large and small diameter, area and perimeter of the eggs, as well as calculation of the values of form coefficients and comparing them with the fluctuation limits of the measured parameters. The basic technical parameters of the automated installation are accuracy of geometric parameters determination, image processing time and performance. Experimental researches were carried out by three stages: an estimation of geometrical parameters measurement accuracy; determination of measurement productivity of eggs geometrical parameters; determination of productivity of eggs division into two categories (relevant and irrelevant to the form requirements of the standard). The obtained experimental results give reason to consider that the measurement accuracy of the linear dimensions of eggs, using the automated installation, meets the technological requirements. Automated installation enhances 4.5 times the labour productivity, spent on measurement of parameters of eggs. The accuracy of separation of eggs into categories, based on the their form using the automated installation, depends on the time, which operator needs for the correct reaction on the signal of the virtual instrument indicator and is equal to 15% at productivity 1,800 eggs per hour and 5.0% at productivity 1200 eggs per hour.

KEY WORDS: AUTOMATED DEVICE, GEOMETRICAL PARAMETERS OF EGGS, VISION SYSTEM, LABVIEW

1. Introduction

The estimation of quality of eggs is the first necessary step for process control and successful incubation. Hatching eggs should be selected carefully, taking into account that any deviation from the norm adversely affected on the output and quality of young growth. Unsuitable for incubation by the external features of the whole eggs are considered eggs which have big and small masses, or irregular shape (completely round, excessively long, flattened) and defects of the shell. At present, the quality control of hatching eggs is carried out manually according to the analysis of the control sample batch of eggs. For definition of parameters of the control batch of eggs is used mechanical measuring devices (scales, calipers) and appliances (indeksomer, a device for determining the thickness of the shell). The measurement results are recorded manually or entered into the computer with the subsequent calculation of eggs parameters. With the purpose to increase the productivity of eggs geometrical parameters process measurement at the Kazakh National Agrarian University are developed an express method and analysis of geometrical parameters of eggs within the framework of a research plan under target program MES "Target development of university science focused on innovative result" [1]. The automated installation consists of a chamber, a computer with specially developed software, a support and a working surface for placement of the object. The program for preparation and eggs image processing is developed in “LabVIEW” environment. The program includes a block diagram and a virtual instrument, which displays on the monitor the values of the measured geometrical parameters (large and small diameter, area, perimeter, and the coefficients of the form) of examined eggs. The installation automatically determines the eggs geometric parameters and compares the size and shape values with the given values of these parameters in accordance with standard and generates a signal of the correct size and shape. Studies have shown that the automatic device provides improved performance of eggs parameter evaluation and separation into categories, based on the size of eggs with simultaneous rejection of eggs with irregular shape.

2. Materials and methods of research of object using vision systems

2.1. The information on object of researches. Object of research is stationary installation for definition of geometrical parameters of eggs. The stationary automated installation allows determination of the following eggs parameters: large diameter (D), small diameter (d), perimeter (L), area of longitudinal section (S), an index of the form K1 (K1 = (d/D)·100 %), shape factor K2 (K2=L²/S) [1]. The basic technical parameters of the installation are accuracy of definition of geometrical parameters, image processing time and performance. Schema of the stationary installation is shown in Figure 1.

Fig. 1 - Schema of the installation
1- working surface; 2 - egg – the object of study; 3- image capturing device (camcorder, camera, webcam); 4 - personal computer with software.

2.2. Installation principle of operation. Egg is set on a work surface in the control zone gripping device that captures the object of study, and transmits the acquired digital images to a PC, where by means of the special software "STZ Egg" the eggs
geometrical parameters are determined. Software "STZ Egg" provides photos capture of the working surface with egg, followed by extraction of the eggs image and determination of its parameters. In Microsoft Office Excel the egg data parameters are transformed in the form of a table by which the database is formed. The solution developed in LabView program, provides a comfortable working environment for an operator with initial computer skills. The following skills are required to work with the automated installation: Windows applications 7, 8, 8.1; MS OFFICE, OpenOffice, LibreOffice; LabView, Vision Builder, VisionAssistant and VisionDevelopment.

2.3 Preparation of installation for work. The stationary automated installation is mounted on a smooth, evenly lit surface (table). Webcam on a support is mounted in a vertical position perpendicular to the work surface at a height of 160 mm. In the control area on the working surface of the table is inserted matt black cover. PC is connected to the power supply network and after that it is connected to a video capture device via USB-3.0. The distributive software "STZ Egg" includes: a software environment Labview; NI VisionAssistant; NI VisionDevelopment; the client part of the Windows application. To start the system is required to pass a panel Start menu Windows (XP, 7) programs, find the folder "STZ Egg" and run the executable file STZ Egg.exe. The program interface "STZ Egg" is shown in Figure 2 and consists of the following operating and display windows:

1. Main menu - contains functions for program start-up and closure, window turning, as well as the help function;
2. Start Button - starts the camera work and the program for identification and analysis of the geometric parameters of the studied eggs;
3. Start button calibration "Calibration" - starts calibration device; "Stop Calibration" - disables the calibration device;
4. Program (RUN) indicator and a progress indicator;
5. Start button calibration "Calibration" - starts calibration device;
6. Image window of analyzed object - in this window the image of the analyzed eggs is displayed in black - red color.
7. Table with data - in the given table values of geometrical parameters of each analyzed object are entered.
8. Area indicators. Indicators of the area with green color show, each egg to what category on the size is concerned.
9. Indicators of geometrical parameters - The current values of the geometric parameters of the object are displayed: Large and small diameter, area, perimeter, shape index and shape factor.
10. Shape Factor variation range controller. It designates the allowable boundary value of the shape factor, depending on the requirements and chickens breed.
11. Exit button - sets the overall output of the system software.
12. Way of storage databases (DB) - specifies the place where analyzed objects data will be stored.
13. The delay controller. The period of time, in seconds, required to determine the parameters of one egg. The time can be set from 1.0 to 30.0 seconds depending on the task.
14. Indicators of aspect ratios - show compliance with the standard form of eggs from the values of the two coefficients characterizing the shape of eggs. Shape index, equal to the ratio of small to large-diameter as a percentage (the permissible limits for hatching eggs provides the industry standard) and the value of the shape factor equal to the ratio of the square perimeter of the area, which is recommended by the results of research as informative.

2.4 Installation operating procedure. After checking the working capacity of the program, it is necessary to calibrate the system for determination of the geometric parameters. The calibration procedure provides, translation of values of geometrical parameters from the digital form, specified in pixels, in metric system (millimeters). The sizes of the special standard are included in a database (a square of white color in the sizes 70x70 mm). In order to calibrate the system it is necessary to run a calibration program by press button "Calibration" on the panel.

Further it is necessary to adjust height of installation webcam using a support to the moment when the green color indicator "System is calibrated" is turned on. The next step is as follow: press the button "Stop Calibration" and enter the value of the allowable range of changes in the shape factor of the controller range. Minimum and maximum value of the shape factor is equal to the ratio of the square perimeter of the image eggs to its area, determined in accordance with the requirements of the standard and with the researches results. The time required to determine the parameters of one egg in seconds, taking into account the time it takes to install and remove the eggs from the working surface is entered in the delay area. The time necessary for determination the parameters of a single egg on the automated installation is 960 milliseconds. The delay time can be varied from 1.0 to 30.0 seconds. In the storage database (DB), by pressing the function button to open (as a folder) opens conductor. Select a local drive "C" and save the data in the format Excel. Next, set the following egg and again using the Start button starts the system. If the egg has an irregular shape, the shape factor indicator lights up in red that indicates that the egg misses in a predetermined allowable range of the shape factor and the egg shape is unusual. At the same time the area indicators irrespective of the eggs shape factor determines egg category by the size (weight). Figure 3 shows relevant indicators.

If the egg has the correct form, the shape factor indicator remains green that indicates that the egg is in the acceptable range
of values of the form factor and its shape corresponds to the standard (Fig. 4).

After the research it is necessary to shut down the system by pressing the "Stop" button, wait for theRUN indicator to turn off, and then click Exit and confirm the output (YES) or cancel (No).

3. Methodology and results of experimental researches

The basic technical parameters of the automated installation are accuracy of geometric parameters determination, image processing time and performance. Experimental researches were carried out by three stages.

1. An estimation of geometrical parameters measurement accuracy;
2. Determination of measurement productivity of eggs geometrical parameters;
3. Determination of productivity of eggs division into two categories (relevant and irrelevant to the form requirements of the standard).

3.1. Estimation of geometrical parameters measurement accuracy. The geometrical parameters measurement accuracy depends on the following factors: resolution of the camera; calibration accuracy (procedure of converting a digital image in pixels, in the metric system in millimeters); location of the object on the working surface toward to the camera. Selected webcam has three variants of CCD resolution. High resolution - 1280 x 960 pixels, average - 960 x 720 pixels and low – 640 x 480 pixels. Analysis of the image quality on the screen showed that the clear contour lines are obtained at high and medium resolution setting. Therefore, for the experimental setup "STZ Egg" high resolution (1280 x 960) is chosen.

To verify the effect of the object location on the eggs geometrical parameters measurement accuracy series of tests were performed with eggs located at different angles toward the camera.

1 position. Egg is disposed horizontally toward webcam, the large diameter is located at the abscissa axis, and the small diameter along the vertical axis. Such egg arrangement is standard in determining of eggs parameters. However, during operation the operator can place the egg with some deviations from strict predetermined position, whereby, during the measurement some additional random errors can be appeared. Eggs location for this first position is shown in Figure 5.

For comparative assessment of the accuracy of determination the geometric dimensions by the experimental installation, large and small diameters of the same eggs were identified using an electronic caliper with an accuracy of 0.01 mm. ten times repeatedly. Fig. 6 shows the procedure for measuring large and small diameters using an electronic caliper.

3.2. Comparative assessment of the automated installation performance. The purpose of this experiment is a comparative evaluation of the performance of the two methods of determination the geometric parameters of the eggs, the manual method for measuring large and small diameter using electronic calipers and entering data into the computer and the evaluation of large and small diameter, area and perimeter as well as the values of the index and the shape factor using automated experimental installation. The experiment was conducted in a research laboratory in KazNAU. To determine the performance of a manual method of measuring large and small diameter of eggs using an electronic caliper, it was performed timekeeping of the time spent by three different operators to measure and to enter the results obtained in prepared in advance table in the computer. The process of measuring the size of the eggs using an electronic caliper is shown in Fig. 7.

<table>
<thead>
<tr>
<th></th>
<th>D</th>
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<td>0</td>
<td>59.50</td>
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<td>σ</td>
<td>0.012</td>
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<td>45</td>
<td>59.42</td>
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<td>σ</td>
<td>0.0482</td>
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<td>90</td>
<td>59.15</td>
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<td>164.82</td>
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<tr>
<td>σ</td>
<td>0.055</td>
<td>0.042</td>
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<td>135</td>
<td>59.43</td>
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<td>σ</td>
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As a result of statistical processing of the measurement of the large and small diameters the following results were obtained. The average value of a large diameter (D) is equal to 58.53 mm. The standard deviation (σ) is equal to 0.23 mm. The average value of a small diameter (d) is equal to 44.45 mm. The standard deviation (σ) is equal to 0.19 mm. The shape index (K1) is equal to 75.85% respectively. The values of the area and perimeter were not measured by an alternative method of measurement due to the absence of appropriate certified measuring tool.

The comparison between values of the large and small diameters measured by the automated installation and the same value measured by the caliper shows that the absolute value of differences for a large diameter is not more than 0.97 mm., while for the small diameter it is not more than 0.45 mm. The relative value of differences when measuring large diameter is 1.66% and it is 1.01% of small diameter. The obtained values of differences between the certified method of determining the size of the eggs and the values obtained from the automated installation gives a reason to believe that the accuracy of determination the linear dimensions of eggs on the automated installation meets the technological requirements for determining the size of the eggs.
The experiment used 60 eggs into two categories: 1 - egg with shape corresponding to the standard; 2 - irregularly shaped eggs. 14 out of 60 eggs had non-standard for incubation shape (23.3%). Then eggs were mixed and three experts independently and manually separated the eggs into two categories by its shape. The same were preliminary divided by the value of the shape factor which were obtained on the experimental installation. It can measure parameters of both white and brown eggs.

The specific amount of time for measurement of large and small diameters and to input data to a computer was, respectively, 12.2; 14.2; 14.4 seconds. It is assumed that the average duration of the manual method of determining the size of the eggs using an electronic caliper equal to 13.6 seconds. Thus, the performance of the parameter measurement of eggs using an electronic caliper is an average of 265 eggs per hour.

It is known that the time for determining the size of the eggs on the automated installation can be set from one to 30 seconds per egg. Before the experiment, it was checked how long it takes for an untrained operator to measure parameters of eggs on the automated installation. The program developer spent no more than two seconds to define the parameters of one egg, and the students involved as operators spent three seconds.

The experiment on an automated installation was also carried out in 3 stages: using 10 eggs, the elapsed time of 30 sec.; 30 eggs, the elapsed time of 150 sec.; and 60 eggs, the elapsed time of 180 seconds.

3.3. Determination of the performance of the separation of eggs into two categories. To evaluate the performance and accuracy of the selection of eggs for incubation, experiment was conducted in the following manner. The experiment used 60 eggs which were preliminary divided by the value of the shape factor into two categories: 1 - egg with shape corresponding to the requirements of the standard; 2 - irregularly shaped eggs. 14 out of 60 eggs had non-standard for incubation shape (23.3%). Then eggs were mixed and three experts independently and manually separated the eggs into two categories by its shape. The same procedure was carried out on the experimental installation. The operator set the egg on the work surface and following the shape factor indicator signal (Fig. 2) divided the eggs into two categories by its shape. If the indicator is green, the egg shape conforms to the standard, if it is red – it is irregularly shaped egg. This investigation produced the following results. During the manual selection, average time spent on the separation of 60 eggs was 196 seconds or 3.26 seconds per egg. The performance of sorting is 1100 eggs per hour. However, 8 irregularly shaped eggs were incorrectly assigned to the group of standard eggs and 13 eggs of standard form were separated to the category of non-standard eggs. The total number of incorrectly classified eggs was 21. The relative accuracy of the selection of eggs by its form using the manual method is 35%.

When separating eggs into categories based on the form on the automated installation two options selection were investigated. The first option includes a delay between the measurements of two seconds. The second option includes three seconds delay. In the first option of sorting time was 120 seconds, the number of operator errors was 9 eggs. Mistakes were made as a result of improper mechanical movement of eggs, when under operators own momentum an egg with regular shape was shifted into the container with non-standard eggs, or in opposite case. The separation accuracy of eggs by shape in that case is 15%. In the second option of sorting time was 180 seconds, the number of operator errors was 3 eggs. The separation accuracy of eggs by shape in that case is 5%.

5. Conclusion

As a result of the experimental investigation, the following results were obtained.

1. The values of large and small diameter of eggs, which are measured on an automated installation, do not differ from those, measured by electronic caliper. The absolute value of the differences is, for large diameter not more than 0.97 mm., and for the small diameter not more than 0.45 mm., thus giving reason to believe that the accuracy of the determination of linear dimensions of eggs on the automated installation meets the technological requirements and can be used to determine the eggs size.

2. The analysis of the results from the timekeeping show that the time for manual measurement of one egg is 13.6 seconds, while the same time on the automated installation is three seconds, thus the productivity of manual measurement is an average 256 eggs per hour, while the productivity of the automated installation – 1200 eggs per hour. Automated installation provides increased productivity spent on measurement of the eggs in 4.5 times. The installation also provides quantitative information for the size (area and perimeter) and shape (form factor) of eggs, which is not available for manual measurement.

3. The time required to determine the parameters of a single egg on the automated installation is 960 milliseconds. The technological capabilities of the automated installation allow bringing the performance of the process of determining the parameters of the eggs up to 3,600 eggs per hour.

4. The accuracy of the manual separation of eggs into categories by its form is about 35%, while the accuracy of the automated installation depends from the time needed for the operator’s correct reaction on the signal of the virtual instrument indicator and is equal to 15% at productivity 1,800 eggs per hour and 5.0% at productivity 1200 eggs per hour.

6. Literature

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STUDY OF THE DEVELOPMENT OF THE STRUCTURE OF THE NETWORK OF SOFIA SUBWAY

ИЗСЛЕДВАНЕ НА РАЗВИТИЕТО НА СТРУКТУРАТА НА МЕТРОМРЕЖАТА НА СОФИЙСКАЯ МЕТОПОЛИТЕН

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Abstract: The main issues are considered in this topic: study of the structure of metro system by using the Graph Theory. New indicators have been defined in the research such as a degree of routing, a connectivity of the route, average length per link (which takes into account the number of routes), intensity of the route, density of the route. The study includes network of Sofia subway and the plans for its future development. The methodology could be used to evaluate other existing metro networks as well as for preliminary analysis in the design of subway systems.

KEYWORDS: GRAPH THEORY, METRO NETWORK, SUBWAY, PASSENGERS, VERTEX, EDGES, CONNECTIVITY, STATION

1. Introduction

Metro systems are the main type of public transport in many cities around the world. The structure of the different metro lines depends on the size of the city, the location of the different regions, the density of the development and others. The structure of the metro network, the number of subway lines and subway routes are important for the volume of passenger flows and the overall organization of urban passenger transport. An analysis of metro networks features can be of substantial help for planners.

The object of the research is the network of Sofia’s subway. The operation of the Sofia’s subway started from 1998, the expansion continues to our own day. As of May 2015, the Sofia Metro consists of two interconnected lines, serving 34 stations, with a total route length of 38.6 km. In this context it is necessary to examine factors related to the structure of the metro network to assess the schemes of development and organization of transport.

The aim of the study is:
• To apply the Graph Theory for studying metro network;
• To examine the state and the structure of metro network with indicators defined by the Graph theory;
• Apply the model to the network study of the Sofia’s metro system and the future plans of development.

2. Methodological approach

The Graph Theory is inherently linked to transportation. A lot of researchers have used the Graph Theory to study the characteristics of transport networks. In [11] is explained the main Graph Theory concepts as well as various indicators have been introduced, such as traffic flow, network diameter, and other dimensionless ratios. The first introducing of three of the Graph Theory’s indicators directly linked to network design (circuits, degree of connectivity, and complexity) is made in [9]. In [12] is established a comprehensive series of new indicators, the line overlapping index, the circle availability, and network complexity. The main indices that represent the structural properties of a graph as such are beta index (a level of connectivity), alpha index (a measure of connectivity which evaluates the number of cycles in a graph), gamma index (connectivity), eta index (average length per link) and others, [12].

Some authors have used the Graph Theory to study metro networks. In [5] and [6] are used three indicators such as coverage, directness, and connectivity to assess the overall properties of networks. There are introduced new indicators such as tau (directness) and rho (connectivity). Authors have analysed 19 subway networks located around the world, [5, 8]. They are compared by using the annual numbers of boarding per capita as a performance indicator. In [6] has been adapted various concepts of the Graph Theory to describe characteristics of the State, Form and Structure of 33 metro systems. The complexity of metro systems and the impact of network size have been analysed and the implications on robustness have been discussed, [7]. It uses three indicators relevant to ridership: coverage, directness, and connectivity. This study used the Graph Theory as a mathematical method to transform networks into graphs, from which relevant properties (e.g., links, nodes) were collected. The authors analysed 19 subway–metro networks and developed three indicators to assess the overall properties of transit networks, linking them to ridership.

The Graph Theory and the Complex Network Theory are adopted to examine the connectivity, robustness and reliability of the Shanghai subway network of China, [16]. The subway network systems of four cities, i.e., Seoul, Tokyo, Boston and Beijing, are studied by using global and local efficiencies and the Graph Theory, [3]. The Complex Network Theory and the Graph Theory are adopted to analyse and calculate the vulnerability of metro network, [4].

All these studies indicate that the Graph Theory may be successfully used for examining the metro networks. In the papers, it has not been studied the effect of the number of routes in metro systems on their structure and the satisfaction of passengers.

2.1. A representation a metro network in a graph

In this research is used the methodology elaborated by authors in [13]. The model was applied to study and classify the 22 European metro systems.

The goal of a graph is to represent the structure of a network, [2, 15]. A graph is a symbolic representation of a network and of its connectivity. It implies an abstraction of the reality so it can be simplified as a set of linked nodes. The conversion of a real network into a planar graph is based on the following principles: every terminal and intersection point becomes a node; each connected node is then linked to a straight segment.

The metro network is presented in a graph. It is a set of vertexes (nodes) (\(V\)) connected by edges (links) (\(E\)). The vertex is a terminal or an intersection point of a graph. It is the abstraction of a location. The edges are a links between two stations. A link is the abstraction of a transport infrastructure which supports movements between nodes. Two types of vertexes (nodes) have been defined: transfer and end-vertexes. Transfer-vertexes are transfer stations, where it is possible to switch lines without exiting the system regardless of the nature of the transfer which could be a simple cross platform interchange or a longer walk. End-vertexes are the line terminals, where it is not possible to switch to another metro line. If a terminal actually hosts two lines, it is considered as a transfer-vertex. The ability to transfer is the determining factor to define the transfer-vertexes.
An example of a representation of a metro network in a graph is shown in Fig. 1. In Figure 1a is shown a real metro network, Figure 1b shows a presentation of a simple graph presented in the research. Edges are non-directional links. The edges are two types – single \( e_S \) and multiple \( e_M \).

\[
e = \frac{e_S + e_M}{2},
\]

where: \( e \) is the total number of edges; \( e_S \) is the total number of single-use edges; \( e_M \) is the total number of multiple-use edges. In order to define the total number of edges \( e_S \) and \( e_M \), each edge must be reported twice - the first time from node “i” to node “j”, secondly from node “j” to node “i”. This is the reason why in formula (1) the sum of the total number is divided by two.

A real metro network by www.metrosofia.com

**Fig.1. Sofia’s metro network representation in graph structure**

The single edge shows that vertices are connected. The multiple edges show that there is more than one specific line between two vertices. If two consecutive vertices are linked by two or more edges, this is considered as a single edge \( e_S =1 \) and a multiple one \( e_M =1 \). The total number of edges equals 2 in this case. If two consecutive vertices are linked by one edge, this is considered as a single edge \( e_S =1 \) if the total number of edges is \( e =1 \).

2.2. Indicators for study metro networks

In order to study the indicators it must be taken in to account the following clarifications:

- A metro line is an infrastructural track which connects a starting point with a finishing point and it has a definite number of stations.
- A metro route is an organization of trains’ movement between a starting station and a finishing station and it consists of one or more than one metro lines. In most European metro networks metro routes coincide with metro lines. In the case of Sofia metropolitan a metro route is consisted of two metro lines.

Fig. 2 shows the difference between metro line and metro route.

![Metro line and route](image)

**Fig.2. Sofia’s metro network with metro lines and metro routes**

2.2.1. Complexity (beta index)

The main network indicators which have been developed are complexity \( \beta \) and a degree of connectivity \( \gamma \), [5, 6, 12]. A state refers to the current development phase of a metro network. The complexity is expressed by the relationship between the number of links \( e \) divided by the number of nodes \( v \). The complexity \( \beta \) is determined by the formula, [6]:

\[
\beta = \frac{e}{v},
\]

where: \( v \) is the sum of the transfer-vertices \( v_T \) and the end-vertices \( v_E \); \( e \) is the number of edges.

\[
v = v_T + v_E
\]

A connected network with one cycle has a value of 1.

2.2.2. A degree of connectivity (gamma index)

The degree of connectivity \( \gamma \) calculates the ratio between the actual numbers of edges to the potential number of edges; that is if the network is 100% connected. The value of \( \gamma \) is between 0 and 1, where a value of 1 indicates a completely connected network. This indicator is a measure of the evaluation of a network in time. For planar graphs with \( v \geq 3 \), the degree of connectivity is calculated by the formula, [12]:

\[
\gamma = \frac{e}{3(v-2)}
\]

The structure of metro networks is a planar graph in most cases because there is not any connectivity between all peaks within the network. In these cases, the following formula has been used (4).

In non planar graphs the degree of connectivity \( \gamma \) is calculated as follows, [12]:

\[
\gamma = \frac{2e}{(v-1)}
\]

Metro networks which are consisted of nods connected completely have a non-planar graph. For example Warsaw metro network is linear and it is consisted of two nods and one edge. In this case, \( \gamma =1 \). It could be easily checked by using the formula (5) that a non-planar graph with 3, 4, and 5 nods \( \gamma =1 \) and in the case of number increase up to 6 then \( \gamma < 1 \).
The two indicators a complexity \( \beta \) and a degree of connectivity \( \gamma \) show the structural differences between two networks of an equal size.

### 2.2.4. Connectivity (rho)

The network structure is presented by connectivity \( \rho \). This indicator measures the intensity and the importance of connections (i.e., transfers) in a metro system. This indicator is the relationship between the net numbers of transfer possibilities divided by the number of the transfer stations. It is calculated by the formula, [5, 6]:

\[
\rho = \frac{\nu_T - e_M}{\nu_T}
\]  

(7)

where: \( \nu_T \) is the total number of transfers in the transfer vertices; \( e_M \) is the total number of multiple edges; \( \nu_T \) is the total number of transfer vertices in a metro network.

The total number of transfers in the transfer vertices is the sum of the number of metro lines going through a transfer station minus one. A transfer station sharing two transit lines offers one transfer possibility, another sharing three lines offers two possibilities, and so on.

This indicator calculates the total number of net transfer possibilities. The ratio indicates the average connectivity of each transfer node in the network. The advantage of this indicator is that it provides information about the stations where more transfers from one line to another could be done, i.e., it crosses more than two metro lines.

### 2.2.5. Indicators of routing

New indicators such as a degree of routing, connectivity of the route, average length per edge (which takes into account the number of routes), intensity of the route, density of the route have been introduced in this research. These new factors have great impact on the categorisation and the evaluation of a metro network based on their routes. The coefficients describing the routes in a metro network show the total transport satisfaction.

The degree of routing a subway network gives a greater degree of satisfaction of transport to passengers.

\[
g = \frac{i}{3(v - 2)}
\]  

(8)

where: \( g \) is the degree of routing; \( i \) is the total number of route arcs in the metro network; \( v \) is the total number of vertices in the metro network.

The total number of metro routes is a sum of the route edges \( i_S \) and the multiple routes edges \( i_M \).

The coefficient \( g \) considers the degree of connectivity of the routes in the transferring vertices of a metro network. The increase in the number of arcs of routes will cause an increase in the number of the vertices.

The coefficient of connectivity of the routes \( b \) is the ratio of the total number of arcs route \( i \) to the total number of vertices in a metro network. It takes into account the connectivity of the routes in the structure of the network.

\[
b = \frac{i}{v}
\]  

(9)

For the coefficients \( g \) and \( b \) and is valid the following:

\[
g \geq \gamma ; b \geq \beta
\]  

(10)

The total number of edges (routes) is equal to the sum of the single edges (routes) and the multiples edges (routes). In the matrices, one arc is passed twice for each of the both directions. When determining the total number of arcs, the sum is divided by two. This applies to \( e_S, e_M, i_S, i_M, e \) and \( i \). If the edges between two nodes pass through different infrastructures, multiple arc is not counted. They are accounted as single arcs.

The coefficient \( \eta \) for average length per edge, which takes into account the number of routes, determines the intensity of the routes in a metro network.

\[
a = \frac{L}{i}
\]  

(11)

where: \( L \) is the total length of the metro network, km

As the value of the coefficient is smaller, the more intense is an metro network of routes. A low coefficient indicates saturated routes metro network.

For the coefficients \( \eta \) and \( a \) is valid the following:

\[
a \leq \eta
\]  

(12)

The following relationship is valid for metro networks for which the graph arcs do not pass more than two lines:

\[
g = \gamma ; b = \beta ; a = \eta
\]  

(13)

The coefficient of density of the routes \( r \) shows what the density of multiple route arcs in a metro network is.

\[
r = \frac{i_M}{v}
\]  

(14)

where: \( i_M \) is the total number of multiple route arcs in a metro network.

### 3. Application. A study of the indicators for Sofia’s metro network

Those indicators by the graphs theory and introduced new indicators were examined for different schemes of development of the network of the Sofia subway.

In the paper have been developed variants of routes according to the possibilities of the infrastructure of the metro network. For each scheme have been studied the modification of coefficients in regard to the number of nodes, number of arcs and number of subway lines.

In Figures from 3 to 15 are shown schemes of the survey routes in the metro network. Figure 3 shows the scheme of the network of the Sofia’s subway from its opening in 1998 until 2012, when the subway system consists of a subway line (one subway route). Figure 4, 6,7,9, 10 show schemes with two subway routes for two subway lines (subway lines and subway routes do not match). Figure 4 displays matching of the subway routes with subway lines. Figure 8 shows three subway routes in two subway lines. In Fig. 5, 11, 12, 13, 14 and 15 are shown schemes with three subway lines and three subway routes. Figure 5 shows the scheme of matching of subway lines and subway routes. Figure 4, 6, 7 and 9 shows the existing subway routes in the period 2012 – 2015. The scheme of Fig.8 shows a variant of an organization with three subway routes for two subway lines. Schemes from Fig.9 to Fig.15 reports the planned phased of construction of the Sofia’s subway in its development until 2020.
Fig. 3. Variant scheme 0а, 0b, 0c. The end stations 2а, 2b and 2c are respectively for each of the variants 0а, 0b and 0c.

Fig. 4. Variant scheme 1.

Fig. 5. Variant scheme 2.

Fig. 6. Variant scheme 3.

Fig. 7. Variant scheme 4.

Fig. 8. Variant scheme 5.

Fig. 9. Variant scheme 6.

Fig. 10. Variant scheme 7.

Fig. 11. Variant scheme 8A.
Table 1 shows the indicators length of the metro network, number of subway lines, number of vertices, number of edges, number of routes for studied variant schemes.

Table 2 and 3 show the matrices with the values for the indicators by the graphs theory and innovation indicators for the variant scheme 5. The values seen the difference in the two approaches.

### Table 1. Indicators for variant schemes

<table>
<thead>
<tr>
<th>Variant scheme</th>
<th>Length of metro network, ( l ) km</th>
<th>Number of metro lines</th>
<th>Number of metro routes</th>
<th>Number of vertices, ( v )</th>
<th>Number of edges, ( e )</th>
<th>Multiple route arcs Im</th>
<th>Total number of route arcs</th>
</tr>
</thead>
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<td>1</td>
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<td>9.9</td>
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<td>1</td>
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### Table 2. A matrix of edges for the scheme 5

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<th>6</th>
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<th>( e_M )</th>
<th>( e )</th>
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### Table 3. A matrix of routes for the scheme 5

<table>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>( l_s )</th>
<th>( l_M )</th>
<th>( l )</th>
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<td></td>
<td>4</td>
<td>6</td>
<td>10</td>
</tr>
</tbody>
</table>

The number of arcs between two nodes in a metro system for the introduced new coefficients \((g, b, r, a, u)\) is the number of routes. For example, if three metro lines pass two nodes with
coefficients $\beta, \gamma, \eta, \rho$, the value for the number of multiple links is "2", while for the new coefficients is taken "3".

This specificity gives an idea of the intensity of routes between two nodes (stations) in a metro network. These new coefficients are always different from those from the Graph Theory where the number of multiple arcs between two nodes is more than two.

Table 4 shows the value of indicators by Graph theory and new indicators.

<table>
<thead>
<tr>
<th>Variant scheme / Indices</th>
<th>$\gamma$</th>
<th>$g$</th>
<th>$\beta$</th>
<th>$b$</th>
<th>$\rho$</th>
<th>$r$</th>
<th>$\eta$</th>
<th>$\alpha$</th>
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<td>6,50</td>
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<tr>
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<td>0,50</td>
<td>0,00</td>
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<td>8,10</td>
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<tr>
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<td>2,95</td>
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</tbody>
</table>

Figure 16 shows a comparison of the initial scheme of development of the metro. Since the three schemes (fig.3) differ only in their length the coefficients have identical values. These schemes include only one metro line.

The average length per edge $\eta$ and the coefficient $a$ for average length per edge, which takes into account the number of routes, grew by increasing the length of the network.

In figures 17, 19, 21 and 23 is shown a comparison of the variants of the development of the metro network with two subway route.

In figures 18, 20, 22 and 24 is shown a comparison of the variants of development of the metro network with three subway route.

In most schemes between the coefficients of "Graph Theory" and introduced new factors there is no difference. This is due to that in the Graph Theory for multiple edges is recorded "2" independently from of number of passing between two nodes arcs. The new indicators take into account of the exact number of arcs passing between any two nodes. Only in scheme 5 has the difference in the two types of indicators. The reason for this is the large number of routes in one line (more than 2).

The comparison of the schemes with two and three routes allows to observe the difference in indicators. The values of newly coefficients increase by increasing the number of routes on a subway line and the transportation satisfaction for passengers in the metro network is growed.

The number of arcs between two nodes in a metro system for the introduced new coefficients (g, b, r, a) is the number of routes. For example, if three metro lines pass two nodes with coefficients $\beta, \gamma, \eta, \rho$, the value for the number of multiple links is "2" (one single edge and one multiple edge), while for the new coefficients is taken "3" (the real number of passing routes). This specificity gives an idea of the intensity of routes between two nodes (stations) in a metro network. These new coefficients are always different from those from the Graph Theory where the number of multiple arcs between two nodes is more than two.

The coefficient "g" considers the degree of connectivity of the routes between nodes in a metro network. The value of this ratio for studying metro schemes is from 0 to 1.

The values of the coefficient "b" in the research are in the range between 0,5 and 2. The largest value has the scheme 5, fig.8. It has a large number of metro lines (routes) in an arc.

When the values of "g" and "b" are higher, then the network has more than two routes.

Complexity $\beta$ depends on the number of subway lines, transfer and end nodes. By increasing the complexity of metro network and crossings of metro lines, its value increases. For example: the variant scheme 8b (fig. 12) has $\beta = 1,83$. This index has a low value when the scheme is a linear structure such as variant 0a, 0b, 0c, fig.3.

The indicator of a degree of connectivity $\gamma$ shows to what extent metro lines have contact to each other. The highest degree of connectivity is $\gamma = 1$. This value clearly represents the linear structure of the metro network with only one line - variants 0a, 0b, 0c, fig.3.

Average length per link $\eta$ has a value greater than 1. Networks with a small number of arcs and small length of lines have a higher value of the coefficient. For example scheme 0a ($\eta = 0,5$), 0b ($\eta = 0,9$), 0c ($\eta = 9,9$). The coefficient "a" accounts for intensity of routes in a metro network. It has a value from 2,62 to 9,9. These two indices have a small difference. This is for schemes 5, 7, 9b.

The differences are due to the way of determining the indices total number of edges and total number of routes.

Connectivity $\rho$ depends on the metro network. This ratio shows the level of the average connectivity of each transfer node in a network. Connectivity is 0 in linear networks such as scheme 0a, 0b and 0c. In this case, there are no transfer nodes. With an increasing number of metro lines and complexity of the network, the value of the connection is increased. The results from the study have shown values of this coefficient from 0 to 2,33. The maximum value of this coefficient is for scheme 5, fig.8 ($\rho = 2,33$) because it has larger number of transfer units (3) and larger number of metro routes (3) compared to the other schemes in the study.

The coefficient "r" shows the density of multiple route arcs in a metro network. The more lines pass through an area, the greater is the coefficient value. For networks where there is no multiple route edges, $r = 0$.

The introduced new coefficients are important for assessing the routes in the metro network. Although it is quite simple Sofia’s metro network is connected in a way that has not been applied in metro networks in Europe, which gives the possibility of passage of several routes in a line. The connection of metro network thus allowing reducing the number of transferring, reduce operating
costs and also there is a possibility the same train composition to run on both metro lines.

The connection method the metro network in Sofia eliminating the need for separate depots for both lines and also reduces to a minimum of zero mileage of trains.
Conclusions

The study has shown the following results:

- The Graph Theory has been applied to characterise the metro network and to define the indicators of the state and the structure of a metro network.
- The new factors for study the metro network have been defined. These factors allow us to evaluate the stage of development of the examined systems.
- The new indicators take into account the routes in the metro network. In the study has been examined the change of these indicators.
- The variant schemes were tested by methodology which taken into account of the development of the metro network of Sofia’s metro, since the introduction of the first part of the first subway line to final planned development of the metro’s network.

Acknowledgement

This research is conducted in relation to the execution of a contract № 142ПД0019-04/2014 “A simulation modelling of technological processes in main metro stations of the Sofia’s subway”. The research has been funded by Technical University of Sofia, Bulgaria.

References