

International virtual journal
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MACHINES
TECHNOLOGIES
MATERIALS

YEAR VIII **Issue 3 / 2014** **ISSN 1313-0226**



Published by
Scientific technical
Union of Mechanical Engineering



MACHINES, TECHNOLOGIES, MATERIALS

INTERNATIONAL VIRTUAL JOURNAL

PUBLISHER

SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING

108, Rakovski Str., 1000 Sofia, Bulgaria

tel. (+359 2) 987 72 90,

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ISSN 1313-0226

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DESIGN OF SIMULATOR FOR THE ENGINE CHARACTERISTICS

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Abstract: Various experiments are performed for detecting engine characteristics. In these experiments some values are kept constant; for example, engine power, torque and fuel consumption is measured as the values, depending on these motor characteristics are obtained by making a calculation. In this study, the simulator program is designed for analysis and synthesis of engine's characteristics. The program, according to data obtained and entered the engine curve to be drawn (numerical or graphical), to examine the changes interactively based on input parameters, calculations are done for the value cannot be measured, and many other features. Thus, in order to obtain characteristics of the engine or in the expression-related issues provides great convenience for understanding and education.

Keywords: Engine characteristics, simulator.

I. Introduce

Engines, is the most important factor determining the performance of the vehicle. If you do a good design, vehicle performance will increase in the same proportion. Engine parts are tested both in the design phase and terms of service. Sometimes it can be tested only a part [3]. Besides these motors are also tested to determine the characteristics. The tests in this group sees the engine as a whole. The tests in this group sees the engine as a whole. Next to the determination of the characteristic in the engine, the energy distribution is also occurs [4].

The main objective in the design is increased of engine power and improved to the economy. also to develop the characteristics by use of modern technologies and to reveal environmentally friendly products [5].

Analysis of motor parameters is one of the major areas in terms of vehicle performance. All design elements reliability and service life, specific fuel consumption, thermal efficiency, engine power and emissions emitted into the environment is very important. Determination of these properties is important in the design of the motor characteristic [6].

First data is obtained in all engine test. After performing with these data account can be achieved the other properties. To make calculation the data of complex engine is very difficult with classical methods. Many variable conditions and parameters should determined for the effects result. It requires a very detailed calculations. Because some of these characteristics (performance and economic relations ones) are inversely proportional. In Figure 1, it can be seen an engine connected to braking power and test systems. Table 2 shows the calculated equations [7].

Some of the values measured in an engine test installations are: Engine Speed, torque, fuel consumption, air consumption,

temperature (exhaust gas temperature, engine coolant temperature, oil temperature) and cooling water flow.

Here are some of the values that can be calculated; average effective pressure, engine power, specific fuel consumption, effective efficiency, excess air coefficient, mechanical efficiency, thermal efficiency, such as volumetric efficiency.

Table.1 Specification of the test engine [1]

Engine Type	FORD 6.0 LT T/C Intercooling DI
Stroke	4
Cylinder	6
Cylinder diameter (mm)	104.77
Piston stroke (mm)	114.9
compression ratio	16.5/1
Max. engine power (kW)	136 (2400 rpm)
Max speed (rpm)	2750-2780
Idle speed (rpm)	665-685
Engine volume (lt)	5.947
Injection timing (°CA)	20
Ignition order	1-5-3-6-2-4
Engine weight (kg)	500

Table 2. Used equations in designed programs .

Parameters	Equation
Effective Power	$P_e = \frac{F \cdot n}{13337} (kW)$
angular velocity	$\omega_e = \frac{2\pi n}{60} (rad / s)$
Moment	$M_e = \frac{P_e}{\omega_e} (Nm)$
mass fuel flow	$\dot{m}_f = \frac{\Delta v \cdot \rho_f \cdot 10^{-3}}{\Delta t} (kg / s)$
Specific Fuel Consumption	$b_e = \frac{\dot{m}_f \cdot 3600}{P_e} (kg / kWh)$
The total energy input per unit time fuel	$\dot{Q}_T = \dot{m}_f H_u (kW)$
Effective Efficiency	$\eta_e = \frac{P_e}{\dot{Q}_T}$
Theoretical amount of air	$\dot{m}_{H,t} = \rho_H Z V_h i_n (kg / s)$
The Actual amount of air	$\dot{m}_{H,r} = 7.182 d_H^2 (\Delta h_H)^{3/2} (kg / s)$
Volumetric efficiency	$\eta_v = \frac{\dot{m}_{H,r}}{\dot{m}_{H,t}}$
excess air coefficient	$\lambda = \frac{(\dot{m}_{H,r} / \dot{m}_f)}{h_{min}}$

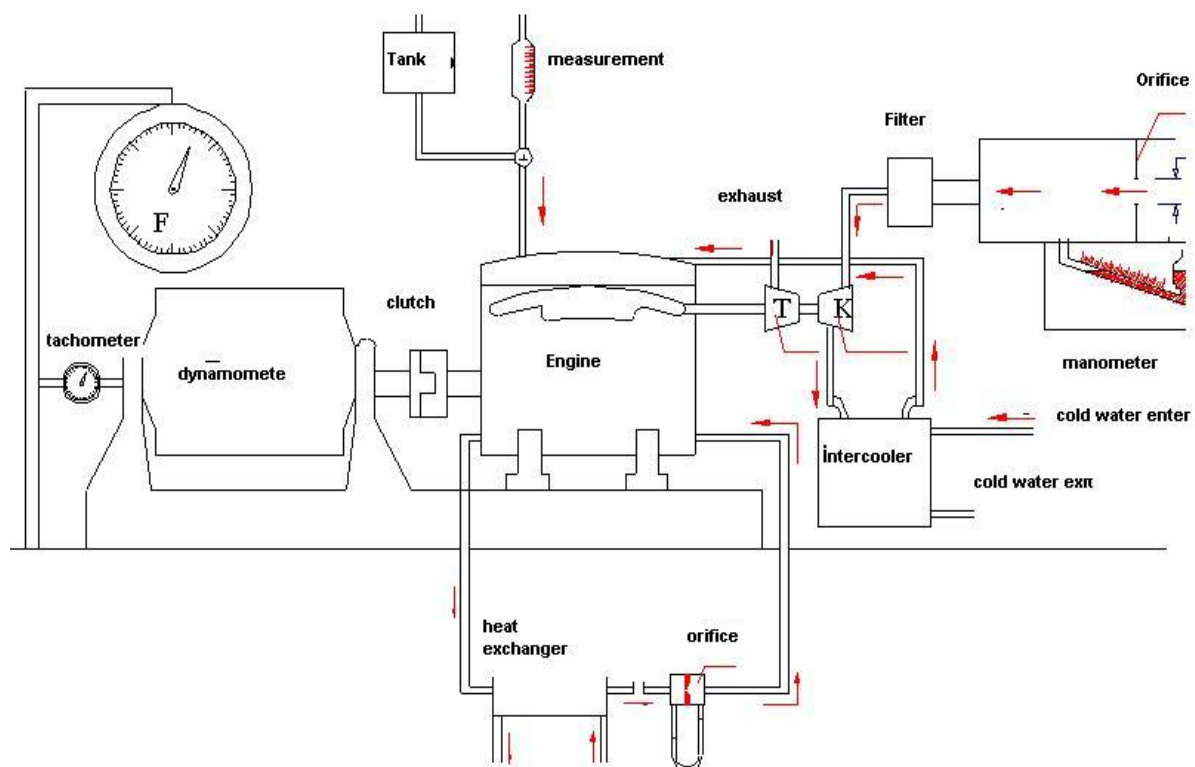


Fig. 2. Testing scheme [2]

II. Simulation

The simulation program is designed in Delphi. Example simulation screens is performed with this program, are given in Figure 2. In Figure 2a average effective pressure can be calculated.

Measured and calculated some input parameters (the number of engine strokes, engine power, engine speed and volume of stroke) after entering the average effective pressure, "pressure" can be seen in the display tab.

The screenshot shows the 'Pressure' tab of the software. The title bar indicates the file name 'Engine's Power and Efficiency ...', the date '11.05.2014', the time '14:53:48', and the user '© uzand >'. The main header features the text 'ENGINE'S POWER and EFFICIENCY' in large, stylized pink letters, flanked by two red target-like graphics. Below the header, there are four tabs: 'Pressure', 'Fuel', 'Power', and 'Efficiency'. The 'Pressure' tab is active. It contains a section for 'Average indicated pressure' with two radio buttons: 'Two-stroke engine' (selected) and 'Four-stroke engine'. Below this are three input fields: 'Engine power: (kW)', 'Max. engine speed: (d/dk)', and 'Stroke volume: (lt)'. A 'Calculate' button is positioned below these fields. At the bottom, there are two more input fields: 'Average indicated pressure (kg/cm²)' and 'Engine power (kW)' with a dropdown arrow. A 'Topic expression' link is visible in the bottom right corner.

Figure 2a. pressure tab

Figure 2b specific fuel consumption (g / kWh) and the amount of fuel injected per cycle (g) can be calculated.

The screenshot shows the 'Fuel' tab of the software. The title bar is the same as in Figure 2a. The main header is identical. The 'Fuel' tab is active. It contains two columns of input fields. The left column has 'BSFC', 'Combustion temperature (KCal/kg)', 'Influence degree', and 'BSFC (gr/kWh)'. The right column has 'The amount of injected fuel into the cylinder in each cycle', 'Engine brake horsepower (kW)', 'BSFC (gr/kWh)', 'Engine speed (rev/min)', 'Number of cylinders' (with a dropdown menu showing '4'), and 'Injected fuel per cycle (gr)'. There are 'Calculate' buttons in both columns. At the bottom right, there is an input field for 'Engine brake horsepower (kW)' with a dropdown arrow. A 'Topic expression' link is visible in the bottom left corner.

Figure 2b. Fuel tab

Indicated power of the engine, in Figure 2c, can be measured with the parameters entered.

Figure 2c. Engine Power tab

In Figure 2d mechanical efficiency, thermal efficiency and effective volumetric efficiency results can be calculated.

Figure 2d. Engine Efficiency tab

III. Conclusion

In this study, the simulation program is designed. Analysis and calculation of motor characteristics in this design can be made. With designed this Program, all calculations can be carried out with ease and high accuracy. By this program by associating appropriate sensors can be used in engine test stand. In addition, students in educational institutions comprehend the technical information in this topic and to perform analysis for efficiently used.

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SPECIFIC ASPECTS OF FUEL ASSESSMENT

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Abstract: We have tested typical samples of fuel (diesel, gasoline, technical gasoline and a mixture of unknown fuel). For fuel analysis we have used an analyzer IROX DIESE with an in-built infrared interferometer of Michelson's type. The results proved that within a wavemeter from 650 up to 1800 cm⁻¹ for each fuel there is a typical infrared spectrum. This spectrum can be compared with human fingerprints. It is possible to positively identify the majority of fuels with the usage of these spectra. Moreover in case of unknown mixture, it is possible to use these spectra for determination of their mutual ratio.

Keywords: OPERATING FLUIDS OF VEHICLE, DIESEL FUEL, FTIR, IROX DIESEL

1. Introduction

Basic fuel of diesel engines is diesel or kerosene. These fuels are mixtures of structurally different hydrocarbons – standard alkenes, isoalkenes, alkenes, naphthenics and aromatics with 12 up to 22 atoms of carbon in a molecule. Their boiling point is from 180° to 370°C and their mutual proportional representation arises from the quality of oil/petrol used and also from the applied technological processes. Fuel for diesel engines has to meet a number of qualitative criteria.

These criteria can be divided into several groups of physio-chemical characteristics, low-temperature characteristics, chemical composition, detonation behaviour, lubricity, parameters characterizing purity and other parameters [1].

For improving utility properties (depressants, detergents, lubricants, corrosion inhibitors, anti-foaming additives, bio-components in the form of methyl esters of fatty acids, etc.) there are other additives added into diesel.

Diesel qualitative parameter values and methods of their valuation are strictly defined by the standard ČSN EN 590 and is provided in the table 1 [2].

Strict refinery fuel quality checking nearly eliminates the possibility of selling of low-quality fuel which does not meet appropriate qualitative requirements. Fuel is stored in various storage places and transport tanks, which may be a source of undesirable contamination during distribution. This contamination can have a serious impact on engines.

Mechanical pollution by dust, abrasion and corrosive elements usually does not represent any serious problems because fuel is filtered before distribution to consumers, and fuel filtration is carried out at petrol stations. If the blow down system works well, even "usual" pollution by water should not represent any serious risk.

Pollution of fuel by heterogeneous carbide or organic fraction respectively could have an impact on the physical-chemical characteristics of fuels. Most frequently fuel is contaminated during transport in transport tanks where fluids are changed. This is usually minor mutual contamination of diesel fuel and motor petrol caused by technological negligence of a transporter. In the real life, it is possible to experience fuel pollution by completely different organic fraction than motor petrol or diesel fuel.

It is necessary to take into account the intentional admix of heterogeneous or "tax free" fraction in order to generate illegal profit or attempts to "improve" fuel by consumers [3].

Practical evaluation of physical-chemical characteristics of diesel by using classical methods is financially as well as operationally very demanding. Therefore there was an effort to develop an easier and faster method. One of them is a modern

instrumental method, which is based on the assessment of fuel infrared spectrum with the application of the Fourier's transformation (FTIR).

Table 1: General requirements and methods of assessment according to the ČSN EN 590 [2]

Quality	Limit values		Units	Method of testing
	min	max		
Cetane number	51		-	EN 15195
Cetane index	46		-	EN ISO 4264
Density (15 °C)	820	845	kg/m ³	EN ISO 12185
Polycyclic aromatic hydrocarbons	-	8	% (m/m)	EN 12916
Content of sulfur		10	mg/kg	EN ISO 20884
Content of oily acids methylesters	-	7	% (V/V)	EN 140078
Point of outburst	55			EN ISO 10370
Oxidative stability		25	g/m ³	EN ISO 12205
	20		h	EN 15751
Lubricity (60 °C) (wsd 1,4)	-	460	μm	EN ISO 12156
Viscosity (40 °C)	2	4,5	mm ² /s	EN ISO 3104
Content of ash				EN ISO 6245
Content of water	-	< 65	% (V/V)	EN ISO 12937
Total content of impurities	85	-	% (V/V)	EN 12662
Corrosive operation of copper	-	360	°C	EN ISO 2160
Distillation test				-
at 250° C it is distilled	-	< 65	% (V/V)	EN ISO 3405
at 350° C it is distilled	85	-	% (V/V)	
95 %(V/V)	-	360	°C	

2. Theoretical base of solution

The principle of infrared spectrometry is based on the Lambert-Beer law:

$$I = I_0 \cdot e^{-\varepsilon \cdot c \cdot l} \quad (1)$$

where: I_0 - incident radiation intensity; I - passing radiation intensity; ε_0 - molar absorb coefficient; l - absorb medium thickness; c - concentration of monitored substance.

The principle of infrared spectrometry is based on the infrared radiation absorption measurement in the range from 2.7 μm to 15.4 μm with the use of a spectrometer with Fourier's transformation. The result is spectral record [4]:

$$I(d) = \int_{-\infty}^{\infty} I(\tilde{\nu}) \cos(2\pi d \tilde{\nu}) d\tilde{\nu} \quad (2)$$

where: I – radiation intensity; d – trajectory difference of folded rays; $\tilde{\nu}$ – wave number ($1/\lambda$).

The interferometer principle, most frequently of Michelson's type, is shown in the Fig. 1.

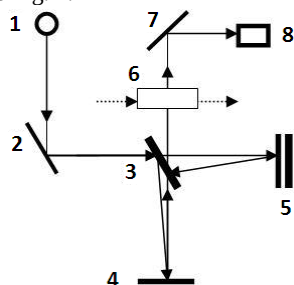


Fig. 1 Michelson type interferometer principle diagram [5]

where: 1 – infrared source; 2, 7 – mirror; 3 – ray divider (semi-permeable mirror); 4 – fixed mirror; 5 – moveable mirror; 6 – measuring cuvette; 8 – infrared detector

The light from infrared Source 1 is divided by Mirror 2 and Ray divider 3 into two equivalent rays. The first ray is reflected by a fixed Mirror 4 and the second ray is reflected by a Moveable mirror 5. Both rays are put together in a divider of ray 3 and then they are routed to Measuring cuvette 6, which is filled up by an unknown sample. Because a Moveable 5 mirror moves along a definite track, in each moment of a spectrometer activity other wave lengths are magnified and reduced. If the distances of mirrors 4 and 5 are identical, rays on the semi-permeable ray divider are added. If the distances are not identical, there is interference between both parts of ray. This variable light passes through cuvette 6, which is filled by an unknown sample and turns out over the Mirror 7 on the Infrared detector 8. The interference diagram (dependence incident radiation intensity in time) is consequently recalculated on spectrum with the use of Fourier's transformation.

3. Materials and methods

A lot of operating fluid samples were analysed at the Department of Combat and Special Vehicles. An extensive database was created from these analyses. Only for demonstration purpose in this paper there are presented results of 2 fuel samples. These are diesel (civilian diesel fuel and military diesel fuel F54). We have used IROX DIESEL analyser with an in-built infrared interferometer of Michelson's type for quality evaluation. Basic specification of IROX DIESEL you can see in the table 2.

Table 2: Technical data of IROX DIESEL [5]

Measuring Parameters	Range
Overall content of aromatic compounds [% v/v.]	0 – 60
Multi-kernel (PN) aromatic compounds [% vol.]	0 – 40
Cetane number	25 – 75
Cetane index	30 – 70
Additive for cetane number improve [ppm]	0 – 5000
Distillation characters [°C] (T85, T90, T95)	300 – 450
Bio-components content [% obj.] (ethyl-ester, methyl-ester)	0 – 40
Consistence [$\text{g}\cdot\text{cm}^{-3}$] $\pm 0,001 \text{ g}\cdot\text{cm}^{-3}$	0,5 – 1,999
Sample content for complex measuring [ml]	7,5

We have accomplished calibration of equipment with calibration fluid 99+ % n-hexane before the main measurement. The calibration library included 180 samples. The recorded evaluation of measured values was accomplished with the use of program MINIWIN 2.2.4.

4. Results and conclusion

The general measuring results are presented in the next graph (Figure 2).

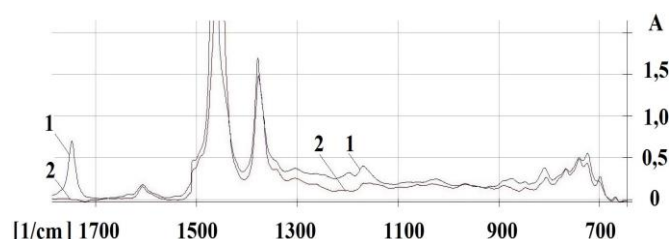


Fig. 2 Infrared spectrum (finger printer) of diesel fuel

1 – civilian diesel fuel, 2 – military diesel fuel (F54)

This spectrum in the extent of 650 to 1800 cm^{-1} is called “an area of fingerprint” in which a position (wavemeter) of lines represents characteristic groups contained in fuel. By these lines it is possible to identify positively and unmistakably the majority of mixtures. It becomes clear from Figures in this paper that for diesel there are typical wavemeter peaks 1377 cm^{-1} and 1377 cm^{-1} . Moreover, wavemeter 1747 cm^{-1} is typical for the contents of FAME, which is added into diesel.

5. Conclusion

In this paper the author deals with the evaluation of fuels. Samples of civilian diesel fuel and a military diesel fuel were analyzed and evaluated. For the evaluation an analyzer of Michelson's type was used with an in-built infrared interferometer. The results obtained proved that in the range of wavemeter 650 to 1800 cm^{-1} , there is a unique typical unmistakable infrared spectrum, which can be compared with human fingerprints. By the use of these spectra it is possible to identify unmistakably the majority of fuels. Moreover in case of unknown mixtures, it is possible by the use of these spectra fingerprints to analyse and state their mutual ratio.

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Acknowledgement

Presented work has been prepared with the support of the Ministry of Defence of the Czech Republic, Partial Project for Institutional Development, K-202, Department of Combat and Special Vehicles, University of Defence, Brno.

SOFTWARE APPLICATION FOR POSTAL ITEMS ROUTING AS PART OF POSTAL SYSTEMS' CRITICAL INFRASTRUCTURE

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Abstract: *Postal network is the most developed and complex logistical infrastructure in the world. The complexity is determined by the number of participants, which either require or perform postal services and by manipulating with a large number of postal items handling billions of them on daily basis globally. A basic request is that the shipment is transferred safely and on time to the recipient. A mass production, many sorting points in the supply chain and variety and stochasticity of delivery addresses are aggravating circumstances for this goal fulfillment. Accordingly, postal operators need the most advanced technological systems for sorting and processing. This paper proposes the concept of addressing based on the three levels of postal units and the software application created for the routing of postal items in the system of this kind.*

Keywords: POSTAL TECHNOLOGY, SHIPMENT, ROUTE, SOFTWARE

1. Introduction

Postal network is the most developed logistics infrastructure in the world. The complexity is determined by the number of participants that demand and offer postal services.

The most developed postal or courier operators in the world (DHL, FedEx, UPS, USPS etc.) work with their innovative and modern infrastructure, covering the largest part of the market. All their systems are kept in step with modern method of business, from receiving to delivery points. In this way, modern and efficient processing centers are equipped with the most efficient technological systems for sorting. By the same principle, the transport resources of new generation are the part of modern postal systems that base operations on efficiency and principles of sustainable development. From the users' point of view, the most important parameter of the quality of postal service is the safety of postal shipments. [4]

The parameter of safety refers to the shipment loss or damage. In order to improve this part of service, the concept of sorting, routing and transportation of postal shipments has a vital role. In this paper, the concept of addressing which is based on three levels of postal network is suggested, and beside this the software application for routing of the postal shipments in that systems is created.

2. The Concept of Addressing

The suggested concept of addressing is based on the numerical addressing coding system where an address is presented by four digits. It is suitable for the internal use in certain postal systems or as the main concept of addressing in smaller postal systems, because of its simplicity and its impossibility to divide territory into the smallest units of delivery.

Addresses include three observed levels of postal units. With the appropriate modifications, it is possible to adjust the software to any of the existing ways of addressing (Postal Address Code, standard postal number....)

The structure of address is the following:

A B C D

where:

- A – is ID number, assigned from the software (system) and it is virtual warehouse of addresses' storing,
- B – refers to the postal units of the first level,
- C – refers to the postal units of the second level,

- D – refers to the postal units of the third level.

This structure shows that the concept of addressing is suitable for smaller systems or the internal use, as previously said. The implementation on larger systems is possible by using new or existing ways of addressing, but with the change of address part in the software and logic of routing. By adding another character behind A, the adjustment is carried out to the particular postal system where business operation is based on four levels. By adding one more character, the needs of the five-level system are met etc.

3. Software For Routing Of The Postal Shipment

The usefulness of software tools in modern business is very important. The time of business operations is reduced, as well as necessary efforts and costs for accomplishing certain operations. The software proposed in this paper represents the plan how the shipments routing should function in postal system, and where it should be located in business information systems and interfaces.

The model with functionality is created for postal system, and it is organized in three levels because it has been noticed that the most postal companies operate in this way. An example for this way of functioning could be found in the "Post of Serbia", where its infrastructure is divided into executive units (units for offering services), postal centers and main postal centers. [2]

3.1 The levels of postal units included in the software model

The current levels in the model of postal system are: Postal units of the first level, Postal units of the second level and Postal units of the third level. The supremacy of units is determined respectively. The communication operates between the third and the second level, as well as between the second and the first level.

The first level includes big processing centers, in which all shipments arrive from a certain larger area. In these units these shipments are processed, sorted and dispatched to other units of the first level. The examples in the system of "Post of Serbia" are the main postal centers.

The second level refers to the centers, in which all shipments arrive from certain smaller area, which are dispatched from them to the superior units of the first level. The examples in the system of „Post of Serbia“ are the postal centers.

The third level are units in which the collection of mail is performed, as well as delivery on their territory, i.e. these units offer services to final users. The third level covers local areas where all shipments are dispatched to the superior unit of the second level. The examples in the system of „Post of Serbia“ are the units where postal services are offered to users.

3.2 Structure of interfaces

When the software run, a registration of unlimited number of users is enabled, which can be on administrator level or a common user, i.e. employee in postal system (Fig.1, Fig. 2).

A login window with a title bar. It contains two input fields: 'User' and 'Password'. Below the fields are two buttons: 'Login' and 'Close'.

Fig. 1 User login

Beside primary operations (shipment reception), administrator has a possibility to use so-called advanced options (Fig4). These options represent possibility of defining:

- new users,
- locations in postal systems,
- hierarchy,
- new addresses,
- new routes.

These options are not allowed to a common user (to employee

in postal system). Only access to the part of shipment reception is allowed.

This part (Fig. 3) enables filling in the primary data about sender and receiver, which are dispatched to the database and warehouse as following information. The fields that label identity numbers of the Post Office of sender and receiver have got a vital role, according to the explanations of the addressing concept. It is possible to add appropriate reference or comment with every shipment in the same field which is predicted for that purpose.

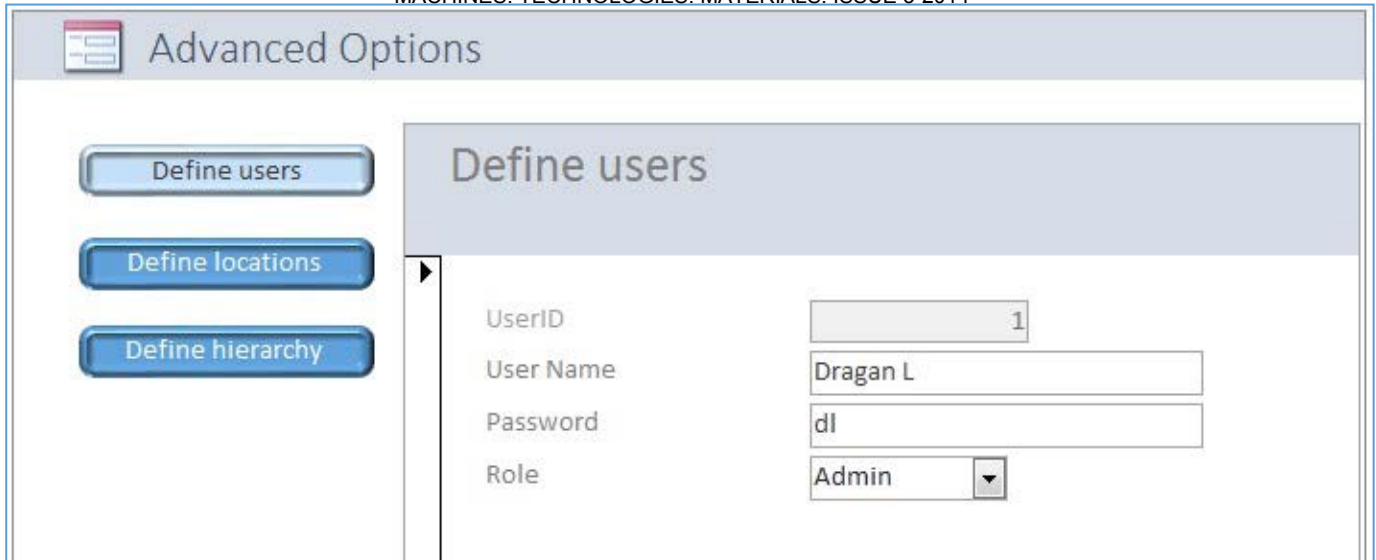
After filling in the addresses of sender and receiver's Post Office, it is possible to define the route where shipments should be sent to. In this part, unit of measure (package, bag and pallet) is defined, as well as its quantity and weight.

A 'Welcome!' screen with a title bar. It features four buttons stacked vertically: 'Main Menu' (green), 'Advanced Options' (blue), 'Switch User' (orange), and 'Exit' (red). At the bottom, it displays user information: 'Registered User', 'Dragan L', 'Position', and 'Admin'.

Fig. 2 Menu

The 'Main menu' interface is divided into two main sections. The top section, 'Mail Collection', contains input fields for 'Date', 'Sender's Name', 'Sender's Surname', 'Sender's Post Office Number', 'Recipient's Name', 'Recipient's Surname', 'Recipient's Post Office Number', 'Address of Recipient', and a 'Comment' text area. The bottom section, 'Route Calculation', features a large empty box for a map or route and a 'Route Calculation' button. Below this is a table titled 'Shipment Characteristics' with columns for 'Type of Shipment', 'Quantity', and 'Weight [kg]'. The table has a header row and several data rows, with the first data row highlighted in blue.

Fig. 3 Part of the shipment reception (Main menu)



Advanced Options

Define users

Define locations

Define hierarchy

Define users

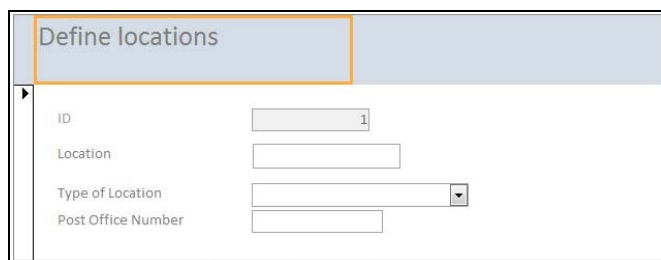
UserID: 1

User Name: Dragan L

Password: dl

Role: Admin

Fig. 4 Advanced options-define users



Define locations

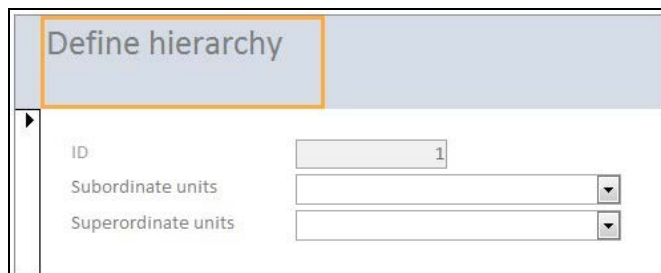
ID: 1

Location:

Type of Location:

Post Office Number:

Fig. 5 Advanced options-define locations



Define hierarchy

ID: 1

Subordinate units:

Superordinate units:

Fig. 6 Advanced options-define hierarchy

3.3 Numerical example

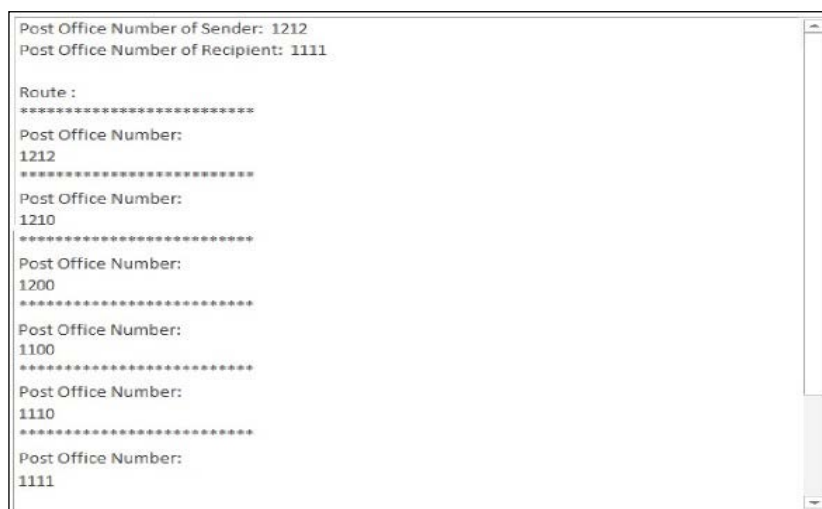
The package is dispatched from Novi Selo (1212) to Rudovci (1111). The numerical address code of these Post Offices are designed according to the concept proposed in this paper.

Analyzing the code starting from the last digit, we could say that Novo Selo (1212) is the second Postal unit of the third level, as the part of the first level Postal unit of the second level and the second Postal unit of the first level.

On the other hand Rudovci (1111) is the first Postal unit of the third level, the first Postal unit of the second level and the first Postal unit of the first level. The reception is carried out through the interface, which is shown in the Fig. 1. by filling in the appropriate information about the shipment. Beside the individual shipment, units of the enlargement, such as bags, pallets can be defined. After filling in the provided fields, the shipment reception is completed.

With the click on the option of defining route, we get required output of the software (Fig. 7).

The routing of postal shipment is important for the concept of traceability in the postal system. The definition of traceability concept according to the standard ISO 9001:2000 says that this is the ability to verify the history, location or application of an item by means of documented recorded identification. The possibility of identification of the previous and next location of the tracking unit is the result of the concept. [3] Beside traceability the concept application is accepted in the area of locating incorrect goods such as spoiled food and beverages, pharmacy products etc., in order to remove them all from distribution as soon as possible. [1] In order to achieve traceability through the business chain, internal and external traceability should be carried out in every chain. [2]



Post Office Number of Sender: 1212
Post Office Number of Recipient: 1111

Route :

Post Office Number:
1212

Post Office Number:
1210

Post Office Number:
1200

Post Office Number:
1100

Post Office Number:
1110

Post Office Number:
1111

Fig.7 Statement (defining) route, by which the postal shipment is dispatched

4. Conclusion

The modern business concept implies the orientation to the user as the main factor. In order to fulfill the needs and expectations of users the organizations should use modern concepts, information systems and adequate technology.

The concept of modern routing contributes to the improvement of total service quality. The main reason lies in the fact that this concept brings to higher safety in transfer of postal shipment, which is defined as one of the most important parameters for quality assessment by final users. Also, the use of critical postal infrastructure is optimized. One of the main problems and tasks of this concept is to determine the route, by which the shipment is transported.

The process of trace determination is the best to be done in the moment of receiving the shipment, i.e. when we create so-called source of information about shipment. This information is stored and if needed it is withdrawn from database.

The synergy of expectations that should be met in technology processes in postal companies and new available technologies results in the necessity for software that define and present the route. It is necessary that this software should be the component part of business information systems and interfaces. The proposed model of software, which is designed for collection of shipment and route definition, including the suggested way of addressing satisfies the internal needs of bigger or middle postal systems or overall needs of smaller systems. It is possible to adjust the suggested model to the new concepts of addressing applying the minimal changes in this software.

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AN OVERVIEW OF THE FUNCTIONALLY GRADED MATERIALS

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Abstract: The present work is motivated by the tremendous interest in the functionally graded materials (FGMs). The properties of FGMs change gradually with the position. The property gradient in FGMs is caused by a position-dependent chemical composition, NS OF FGMs microstructure or atomic order. The overall properties of FMGs are unique and different from any of the individual material that forms it. One unique characteristic of FGMs is the ability to tailor a material for specific application. There is a wide range of applications of FGMs and it is expected to increase. In this paper we will make a brief survey of the most distinguished properties and some of the applications of FGMs.

Keywords: FUNCTIONALLY GRADED MATERIALS, PROPERTIES OF FUNCTIONALLY GRADED MATERIALS, AREAS OF APPLICATIONS OF FUNCTIONALLY GRADED MATERIALS

1. Introduction

Nowadays, the functionally graded materials (FGMs) are of great fundamental and experimental interest [1-17]. This is mainly due to their importance for actual and potential applications as materials and devices. The main sphere of the FGMs usage - materials and devices operating in extreme conditions (large gradients of temperature, mechanical stress etc.). The evidence is the very big amount of literature on these materials. Today many countries have their own research programs on FGMs. There is a wide range of applications of FGMs and it is expected to increase. In this paper, an overview of some of the most promising properties of FGMs is presented. Here we will also

make a brief survey of several material and device applications based on the FGMs. The information presented in this study has been compiled from the available literature on the subject.

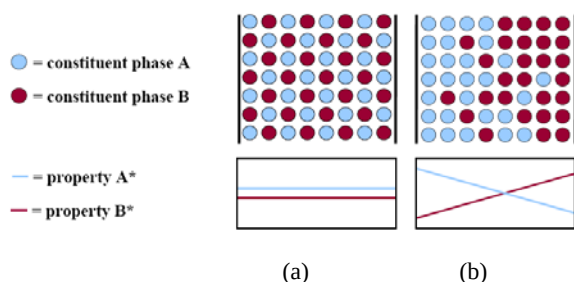


Fig. 1 Material of two phases. (a) constant composition and properties; (b) FGM – gradual change in composition and microstructure gives a gradient in properties [4].

2. Some Properties of FGMs

Functionally graded (or functional gradient) materials (FGMs) are an advanced, a novel and an artificial class of engineered materials characterized by variation in properties as the dimension varies. FGMs are a novel generation of materials having unique characteristics. FGMs occur in nature as bones, teeth etc. In a FGM the properties change gradually with the position. The property gradient in the material is caused by a position-dependent chemical composition, microstructure or atomic order. The overall properties of FMG are unique and different from any of the individual material that forms it. FGMs may be characterized by the variation in their composition and structure gradually over the volume, resulting in corresponding changes in their properties. FGMs are composites or single-phase materials, whose functional properties change uniformly at least in one dimension of the particle, film or a bulk sample. These materials can be designed for specific functions and applications. Various efforts and approaches based on the bulk (particulate processing), preform processing, layer processing and melt processing are used to fabricate the FGMs.

FGMs can be obtained by mechanically joining materials with very different physicochemical properties, for example, by

soldering glass and metal. As a rule, a change in the properties of an FGM is associated with a corresponding variation of the chemical composition or physical structure of the material. These materials can be produced by by-layer coating with materials of variable composition or by sintering (fusing, welding) of several plates or tablets of different composition. A gradient of material properties can be created by changing the degree of crosslinking (for polymers) or the degree of filling, and along the surface – for example, by changing the degree of modification. A smooth change of these characteristics leads to a smooth variation of the properties, and irregular changes correspond to an irregular form of dependence of the properties on the composition or structure.

There is a substantial difference between FGM and traditional composite material (CM). CM is a class of advanced material, made up of one or more materials combined in solid states with distinct physical and chemical properties. CM offers an excellent combination of properties which are different from the individual parent materials. Wood is a CM from nature. CM will fail under extreme working conditions through a process called delamination (separation of reinforcement from the matrix) [1]. To solve this problem, researchers in Japan in the mid 1980s, confronted with this challenge and came up with a novel material called FGM.

The gradation of properties in an FGM reduces the thermal stresses, residual stresses, and stress concentrations found in traditional composites. FGM may include more than two constituent phases (as CM) (see Fig. 1). FGMs are innovative composite materials whose composition and microstructure vary in space following a predetermined law. The gradual change in composition and microstructure gives place to a gradient of properties and performances [3].

FGM eliminates the sharp interfaces existing in CM which is where failure is initiated [5]. It replaces this sharp interface with a gradient interface which produces smooth transition from one material to the next. One unique characteristic of FGM is the ability to tailor a material for specific application. Such unique characteristics possess also graded semiconductor superlattices and graded quantum wells, which electronic structure may tailor for specific applications.

Depending upon the nature of gradient, the FGMs (composites) may be grouped into following types (see Fig. 2) [6].

- 1) Fraction gradient type (Fig. 2a)
- 2) Shape gradient type (Fig. 2b)
- 3) Orientation gradient type (Fig. 2c)
- 4) Size (of material) gradient type (Fig. 2d)

Depending on the number of directions the proprieties changed, we can discriminate as 1- dimensional, 2- dimensional or 3- dimensional FGMs.

A FGM's gradation in material properties allows the designer to tailor material response to meet design criteria. For example, the Space Shuttle utilizes ceramic tiles as thermal protection from heat generated during re-entry into the Earth's atmosphere. However, these tiles are prone to cracking at the tile / superstructure interface due to differences in thermal expansion coefficients. An FGM made of ceramic and metal can provide the thermal protection and load carrying capability in one material thus eliminating the problem of cracked tiles found on the Space Shuttle.

There are different methods for producing FGMs. FGMs can be divided into two broad groups namely: thin and bulk FGM. Thin FGM are relatively thin sections or thin surface coating, while the bulk FGM are volume of materials which require more labour intensive processes. Thin section or surface coating FGM are produced by physical or chemical vapour deposition (PVD/CVD), plasma spraying, self-propagating high-temperature synthesis (SHS) etc [7]. Bulk FGM is produced using powder metallurgy technique, centrifugal casting method, solid freeform technology etc [8].

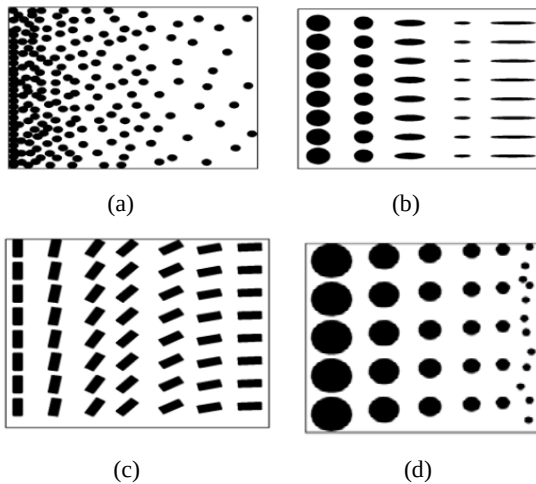


Fig. 2 Based on vividities of gradients, different types of functionally graded materials may be of (a) fraction gradient type, (b) shape gradient type, (c) orientation gradient type, and (d) size gradient type [6].

3. Some Applications of FGMs

FGMs find various applications in aerospace, automobile, medicine, sport, energy, sensors, optoelectronic etc. Owing to the importance of FGM applications, there are lots of research efforts at improving the material processing, fabrication processing and properties of the FGM. Some of the application areas of FGMs are highlighted below.

Aerospace

FGMs possess very high thermal gradient resistivity, which makes them suitable for thermal protection of space vehicles, for use in structures and materials for space plane body, rocket engine component and are promising in wider areas of aerospace industry [9]. Ceramic-metal FGMs are particularly suited for thermal barriers in space vehicles. They have the added advantage that the metal side can be bolted onto the airframe rather than bonded as are the ceramic tiles used in the Orbiter. Other possible uses include combustion chamber insulation in ramjet or scramjet engines

Medicine

FGMs have found a wide range of applications and mostly are used as medical implants, in dental [10] and orthopedic applications for teeth and bone replacement [11].

Defense

FGMs have the strong ability to inhibit crack propagation. This property makes them useful in defense applications, as a penetration

resistant materials used for armour plates and bullet-proof vests [12].

Energy

FGMs are used in energy industry as energy conversion devices and as thermoelectric converter for energy conservation. They also provide thermal barrier and are used as protective coating on turbine blades in gas turbine engine [1].

Optoelectronics

FGMs are used in optoelectronics as graded refractive index materials and in audio-video discs magnetic storage media. They are now used as nano, optoelectronic and thermoelectric materials also.

Other areas of application are: cutting tool insert coating, automobile engine components, nuclear reactor components, turbine blade, heat exchanger, tribology, sensors, fire retardant doors, etc [1]. The list is endless and more application is springing up as the processing technology, cost of production and properties of FGMs improve [1].

4. Examples of Some Materials for FGMs

The carbon nanotubes (CNT) reinforced functionally graded composite materials (FGCM) is expected to be the new generation material having a wide range of unexplored potential applications in various technological areas such as aerospace, defence, energy, automobile, medicine, structural and chemical industry. They can be used as gas adsorbents, templates, actuators, catalyst supports, probes, chemical sensors, nanopipes, nano-reactors etc. [13].

CNT reinforced metal matrix functional graded composites due to their unique combination of hardness, toughness and strength are universally used in cutting tools, drills, machining of wear resistant materials, mining and geothermal drilling. Some of the current and futuristic applications of FGM are listed as follows [13].

1) Commercial and industrial: pressure vessels, fuel tanks, cutting tool inserts, laptop cases, wind turbine blades, firefighting air bottles, MRI scanner cryogenic tubes, eyeglass frames, musical instruments, drilling motor shaft, X-ray tables, helmets.

2) Automobiles: (SiC-SiC) combustion chambers, (AlSiC) engine cylinder liners, (SiCw / Al-alloy) diesel engine pistons, (E-glass / epoxy) leaf springs, (Al-C) drive shafts, (Al-SiC) flywheels, racing car brakes, (SiCp / Al-alloy) shock absorbers.

3) Aerospace equipment and structures: (TiAl-SiC fibers) rocket nozzle, heat exchange panels, spacecraft truss structure, reflectors, solar panels, camera housing, turbine wheels (operating above 40,000 rpm), nose caps and leading edge of missiles and Space shuttle.

4) Submarine: (carbon and glass fibers) propulsion shaft, (graphite / epoxy) cylindrical pressure hull, (glass / epoxy) sonar domes, composite piping system, (Al-SiC) diving cylinders.

5) Biotechnology: the functional gradient nanohydroxyapatite reinforced polyvinyl alcohol (nanoHA / PVA) gel biocomposites can be prepared through a layer-by-layer casting method combining with freeze/thaw cycles technology. nanoHA / PVA gel biocomposites have been a promising and excellent artificial articular cartilage repair material. Compared to hydrogel-based materials such as poly (vinyl alcohol) (PVA), poly (lactic acid) and chitosan, nanoHA / PVA gel biocomposites possesses superior bioactivity and mechanical properties because of the nanoHA existence in the composites [14].

Some more applications of CNT in FGM having recent applications are the following [13]:

1) CNT reinforced functionally graded piezoelectric actuators.

2) As furnace liners and thermal shielding elements in microelectronics.

3) CNT reinforced functionally graded tools and dies for better thermal management, better wear resistance, reduce scrap, and improved process productivity.

4) CNT reinforced functionally graded polystyrene/calcium phosphate materials for bone replacement.

FGMs in optoelectronic devices

FGMs can be presented as a composition of several connected thin layers. Nowadays the graded materials are widely used for antireflective layers, fibers, GRIN lenses, GRIN lasers, peltier junctions, fuel cells and many other passive elements made from dielectrics, and also for sensors and energy applications. For example, the modulation of refractive index can be obtained in such components through the change in material composition. Another possibility is to apply concept of gradation in semiconductor active devices. In semiconductors the material function can describe energetic bandgap, refractive index, carrier concentration, carrier mobility, diffusion length, built-in electric field and another property which influence the parameters of optoelectronic devices.

In the paper [6] is presented a review of possible applications of $A_{III}-B_V$ group materials with graded composition for optoelectronic devices such as p-n diodes. By using FGM we can obtain higher sensitivity of detectors. It became possible to fabricate photonic devices which could operate in a wide spectral range (also voltage tuneable photodetectors). The important application area of usage of FGM is photovoltaics. Thin-layer photovoltaic cells made from FGM can overcome theoretical limit of 20% quantum efficiency specified for silicon homogenous elements. Moreover, gradation of composition and doping concentration in semiconductor materials makes possible to modify their electrical properties i.e. the modulation of built-in electric field and carrier concentration in FGM structures fabricated from $A_{III}B_V$ and $A_{III}N$ compounds.

High-efficient photodetector and solar cells

The fundamental limitation of the efficiency of homogenous silicon solar cells is the constant energetic band-gap width in bulk material. Because the high-energetic radiation is absorbed in a shallow layer under surface, it is necessary to form electric field in close vicinity to the surface. Generated carriers can effectively be separated in electric field; therefore the diffusion length of carriers should be longer than junction depth.

Another factor which decreases carrier generation efficiency is the difference of energetic band-gap and absorbed photons energy. By using materials with gradation of energetic band-gap, it is possible to match the absorption edge with band-gap, which improves generation efficiency. The appliance of cascade of junctions with different energetic band-gap width can be one of the solutions. Another way to overcome this limitation is the use of graded material. The idea of such device is shown in Fig. 3.

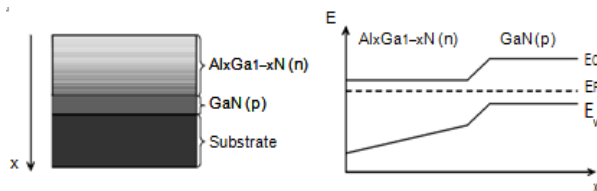


Fig. 3 Schematic structure of p-n photodiode with graded layer electric field, therefore the diffusion length of carriers should be longer than junction depth [14].

The article [15] describes the concept of creating ultrasonic waveguides based on uniform composition FGMs, such as an alloy Cu-Al-Mn by changing of mechanical properties generated by the gradient thermal treatment.

FGMs - alloys consisting of hard grains of carbides, nitrides and borides of transition metals (tungsten carbide, titanium carbide,

titanium carbonitride, titanium diboride, etc.) forming a continuous strong frame, and the metal binder (cobalt, nickel, titanium, aluminum, and etc.), the content of which varies continuously in volume of the material. As a result FGM materials possess properties as carbide or metal, i.e. have a high hardness and high toughness. Because of these properties, as well as high thermal stability, FGM alloys can be used effectively in the following areas: military equipment (body armor and protection of tanks and helicopters from a gunshot and shrapnel injury); metalworking (making cutters for machining difficult steels and alloys); mining (cutters for rock drilling); processing industry (facing grinders for grinding solids) etc. [16].

FGM based on Bi -Te for thermoelectric cooling mode with the maximum differential temperatures is presented in [17].

The emergence of functionally graded materials (FGMs) [1, 2] has revolutionized the aerospace and aircraft industry. The FGMs used initially as thermal barrier materials for aerospace structural applications and fusion reactors are now developed for general use as structural components in high temperature environments. FGMs are manufactured by combining metals and ceramics.

5. Final Remarks and Future Works on FGMs

This brief survey of some FGMs and their applications could enhance the common understanding of some modern and contemporary knowledge and materials.

In the literature, there has been a lot of research work and developments, that has been done by different investigators on the analysis of FGMs. Most of these works focus on 2D models. There is a need to develop 3D models to understand the full response to different loadings. There is also need to use higher order theories combined with no local stress analysis. In general, FGMs holds a good potential in many applications. Research work now should progress combining the modelling of FGMs with substantive experimental work.

Last but not at least, both experimental and theoretical studies of the FGMs are quite important and need to be developed in order to seek unknown and possible FGM properties for new potential FGMs applications. Future applications demand materials having extraordinary mechanical, electronic and thermal properties which can sustain different environment conditions and are easily available at reasonable prices.

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THEORY OF CUMULATIVE FUEL CONSUMPTION AND EXAMPLE FOR ITS APPLICATION

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Abstract: the theory of cumulative fuel consumption has been presented. The example of interurban bus research results have shown the way of getting to mathematical model of cumulative fuel consumption and the intensity of cumulative fuel consumption. The high value of presence quotients is not a case- similar values were obtained in various different cases.

KEY WORDS: FUECONSUMPTION, THEORY, APPLICATION

1. Introduction

The exploitative fuel consumption is described by the theory of cumulative fuel consumption. Its application enables the analysis of exploitative fuel consumption of both single vehicle as well as whole park machines, forecast of fuel consumption determination and also the comparison analysis of fuel consumption in vehicles powered by alternative sources of energy. This theory may also be one of elements of new tests' procedures defining fumes emission rules, which would count the exploitative conditions of vehicles. Such a theory has been presented. The example of interurban bus research results have shown the way of getting to mathematical model of cumulative fuel consumption and the intensity of cumulative fuel consumption.

2. Theory of cumulative fuel consumption.

The cumulative fuel consumption risen in relation to time t of engine exploitation may be determined as:

$$Q_{sp}(t) = \sum_{i=1}^{n(t)} v_i = n(t) \cdot \bar{v}(t) \quad (1)$$

Where: v_i - i -th quantum of consumed fuel (e.g. dose of fuel per one engine turn), $\bar{v}(t)$ - average amount of fuel quantum, consumed in relation to time t , $n(t)$ - number of fuel quanta consumed in relation to time t ,

$Q_{sp}(t)$ - cumulative fuel consumption in relation to time t .

To assign cumulative fuel consumption in relation to time t , it is necessary to know the average quanta amount of fuel given per one engine turn and the number of fuel doses. If the fuel quantum is determined through the dose of fuel given per one engine turn (it is randomly variable value) and the engine does number of turns in relation to time t , in which given fuel equals $n(t)$ then the cumulative fuel consumption is determined through product of average dose of fuel and its turns number.

Assuming that T_p is random variable indicating time between subsequent fuel doses, the distribution function of this variable is:

$$F_p(t) = P_p \{T_p < t\} \quad (2)$$

Where:

$P_p \{T_p < t\}$ - probability that T_p has lower values than t , t - Any time amount.

The density of random variable distribution, T_p is the derivative of distribution function:

$$\frac{dF_p(t)}{dt} = F_p'(t) = f_p(t) \quad (3)$$

The next assumption that $P_p \{t, t + \Delta t\}$ is a probability that in the time range Δt and thus, in time period $(t, t + \Delta t)$ the fuel will not be given, and that the fuel was not given in time period $(0, t)$, too.

Playing along with Baye's rule, it is got:

$$P_p \{t, t + \Delta t\} = \frac{P_p \{T_p \geq t + \Delta t\}}{P_p \{T_p \geq t\}} = \frac{R_p(t + \Delta t)}{R_p(t)} \quad (4)$$

Assuming that:

$$P_p \{T_p \geq t\} = 1 - P_p \{T_p < t\} = 1 - F_p(t) = R_p(t) \quad (5)$$

If $P_p^d \{t, t + \Delta t\} = 1 - P_p \{t, t + \Delta t\}$ is the probability of giving fuel dose in time range Δt , on the condition that such a giving has not taken place in time period $(0, t)$, then it is got:

$$P_p^d \{t, t + \Delta t\} = P_p \{t \leq T_p \leq t + \Delta t\} \quad (6)$$

$$P_p^d \{t, t + \Delta t\} = 1 - P_p \{t, t + \Delta t\} = 1 - \frac{R_p(t + \Delta t)}{R_p(t)} \quad (7)$$

Through division of both sides by Δt , there is acquired the expression:

$$\begin{aligned} \frac{P_p^d \{t, t + \Delta t\}}{\Delta t} &= \frac{1}{\Delta t} \left[1 - \frac{R_p(t + \Delta t)}{R_p(t)} \right] = \\ &= \frac{R_p(t) - R_p(t + \Delta t)}{\Delta t} \cdot \frac{1}{R_p(t)} \end{aligned} \quad (8)$$

Which limit when $\Delta t \rightarrow 0$ is :

$$\lim_{\Delta t \rightarrow 0} \frac{P_p^d(t, t + \Delta t)}{\Delta t} = \lim_{\Delta t \rightarrow 0} - \frac{R_p(t + \Delta t) - R_p(t)}{\Delta t} \cdot \frac{1}{R_p(t)} = - \frac{R_p'(t)}{R_p(t)} \quad (9)$$

The abovementioned limit shows the intensity of giving the fuel doses in moment t , which can be assigned as $\lambda_p(t)$.

$$\lambda_p(t) = - \frac{R_p'(t)}{R_p(t)} \quad (10)$$

The number of fuel quanta given to the engine in moment t is assigned by the paradigm:

$$n(t) = \int_0^t \lambda_p(t) dt = \int_0^t - \frac{R_p'(t)}{R_p(t)} dt = - \left[\ln R_p(t) + C \right]_0^t = \left[\ln \frac{1}{R_p(t)} - C \right]_0^t \quad (11)$$

According to the fact, that in the moment $t=0$ the fuel dose is not given to the engine and from the $R_p(t=0) = 1 - F_p(t=0) = 1 - 0 = 1$ definition, there is acquired the following relationship:

$$0 = \ln \frac{1}{R_p(t=0)} - C = \ln 1 - C = -C \quad (12)$$

From this relationship $C=0$ is acquired, hence the number of doses given in relation to time t is formulated with relationship:

$$n(t) = \ln \frac{1}{R_p(t)} \quad (13)$$

For the assignment of number of fuel doses, it is essential to know the random distribution variable T_p , and hence, the distribution of time range between subsequent fuel doses.

The amount of particular fuel quanta v_i is random and can be described by two dimensional static distribution of density $f(v, t)$.

The average amount of fuel quanta given to the engine in time $(0, t)$ can be assigned as:

$$\bar{v}(t) = \int_{v_{\min}}^{v_{\max}} \int_0^t v \cdot t \cdot f(v, t) dv dt \quad (14)$$

Values $v_{\max}$ and $v_{\min}$ determine the maximum and minimum values of fuel quanta, which are related with dosage quality of a given engine.

According to the abovementioned determinations, the following relationship indicating cumulative fuel consumptions can be written:

$$Q_{sp}(t) = \bar{v}(t) \cdot n(t) = \bar{v}(t) \ln \frac{1}{R_p(t)} = \bar{v}(t) \ln \frac{1}{1 - F_p(t)} \quad (15)$$

During engine exploitation, the $\bar{v}(t)$ and $R_p(t)$ are unknown. Both amounts may be assigned in exploitation studies from histogram built of measured values and matching it to one of known statistic distribution. Such studies have not been made yet, that is why the value $F_p(t)$ has been assumed on the basis of the following conditions:

- Intervals between giving the particular fuel doses have static distribution of the same kind. It may be assumed that, these intervals can be described by the use of Poisson's type distribution of distribution function

$$F(t) = 1 - e^{-\lambda t}$$

- The accumulation is not performed, which means that in time range $dt \rightarrow 0$ only one dose of fuel is given.

Taking into consideration the fact that engine elements indulge in degradation, the amount of fuel dose can be described by time function. In the first approximation, it can be assumed that the value of this amount is a certain constant multiplied by quotient reliant on time. It can be described as:

$$\bar{v}(t) = \bar{v} \cdot t^a$$

On the basis of the abovementioned assumptions, and taking into consideration already described relationship indicating cumulative fuel consumption, the following relationship can be written:

$$Q_{sp}(t) = \bar{v}(t) \cdot n(t) = \bar{v}(t) \cdot \ln \frac{1}{1 - F(t)} = \bar{v} t^a \cdot \ln \frac{1}{1 - (1 - e^{-\lambda t})} = \bar{v} t^a \cdot \ln \frac{1}{\exp(-\lambda t)} = \bar{v} t^a \cdot \ln \exp(\lambda t) = \bar{v} t^a \lambda t \quad (16)$$

From the assumption that $\bar{v} \equiv \text{const}$, and $\lambda \equiv \text{const}$, the relationship is received: $\bar{v} \cdot \lambda = c = \text{const}$ (17)

Hence the simple relationship of cumulative consumption in a time function:

$$Q_{sp}(t) = c \cdot t^a \cdot t = c t^{a+1} \quad (18)$$

The intensity of cumulative fuel consumption is assigned by the derivative of the abovementioned expression:

$$\frac{dQ_{sp}}{dt} = c(a+1)t^a \quad (19)$$

For assigning of mathematical model of cumulative fuel consumption, it is necessary to know the a and c quotients of the equation (22):

After logarithmic calculation of both sides of this equation, the first degree polynomial is received:

$$\ln Q_{sp}(t) = \ln(c t^{a+1}) = \ln c + (a+1) \ln t$$

Substituting:

$$\ln Q_{sp}(t) = y; \quad \ln c = b_0; \quad (a+1) = b_1; \quad \ln t = x;$$

The lineal equation is received:

$$y = b_0 + b_1 x \quad (20)$$

Studies of cumulative fuel consumption are made in discrete way after several exploitation periods. After researches, two data vectors are received:

$$Q_{sp} = [Q_{sp}(t_1), Q_{sp}(t_2), Q_{sp}(t_3), \dots, Q_{sp}(t_i), \dots, Q_{sp}(t_j)]^T \quad (28)$$

$$T = [t_1, t_2, t_3, \dots, t_i, \dots, t_j]^T \quad (21)$$

Assuming further that:

$$X = \begin{bmatrix} 1 & \ln t_1 \\ 1 & \ln t_2 \\ 1 & \ln t_3 \\ \vdots & \vdots \\ 1 & \ln t_j \end{bmatrix} \quad (22)$$

b_0 and b_1 constants may be assigned by e.g. the use of the smallest squares method, with using the relationship:

$$\begin{bmatrix} b_0 \\ b_1 \end{bmatrix} = \mathbf{b} = (\mathbf{X}^T \mathbf{X})^{-1} \mathbf{X}^T \mathbf{Y} \quad (23)$$

Assigned in this way, the model values of cumulative fuel consumption may differ from the measured values. It is essential to evaluate those variations e.g. with the use of variation analysis.

3. Example of cumulative fuel consumption application.

The example of cumulative fuel consumption application has been presented with the use of mileage data and exploitative fuel consumption in the interurban bus. The received results are presented in the table 1.

Table 3.1. Measurement and model calculation results of cumulative fuel consumption and intensity of cumulative fuel consumption for interurban bus.

Year	Month	Mileage	Cumula- ted fuel consump- tion	Cumula- ted fuel consump- tion (model)	Deviation		Intensity of cumu- li- ted fuel consump- tion
1	2	3	4	5	6		7
		km	dm ³	dm ³	dm ³	%	dm ³ /km
2008	3	8 475	2 398	2 566	-168	-6,55	0,296
	4	22 119	6 473	6 564	-91	-1,39	0,291
	5	30 352	8 902	8 948	-46	-0,52	0,289
	6	40 360	11 942	11 828	114	0,96	0,287
	7	50 178	14 917	14 639	278	1,9	0,286
	8	56 079	16 724	16 322	402	2,46	0,285
	9	61 310	18 268	17 811	457	2,56	0,284
	10	71 338	21 065	20 659	406	1,97	0,284
	11	80 732	23 604	23 319	285	1,22	0,283
	12	91 266	26 610	26 294	316	1,2	0,282
2009	1	100 275	29 145	28 833	312	1,08	0,282
	2	109 375	32 043	31 393	650	2,07	0,281
	3	119 139	34 675	34 134	541	1,59	0,281
	4	129 620	37 495	37 071	424	1,14	0,28
	5	144 326	41 513	41 185	328	0,8	0,279
	6	155 790	44 560	44 385	175	0,39	0,279
	7	166 083	47 359	47 254	105	0,22	0,279
	8	176 856	50 349	50 253	96	0,19	0,278
	9	187 697	53 189	53 267	-78	-0,15	0,278
	10	197 834	55 895	56 083	-188	-0,33	0,278
	11	208 124	58 639	58 937	-298	-0,51	0,277
	12	217 564	61 316	61 553	-237	-0,39	0,277
2010	1	220 896	62 313	62 476	-163	-0,26	0,277
	2	231 005	65 277	65 274	3	0,01	0,277
	3	243 371	68 552	68 693	-141	-0,21	0,276
	4	254 045	71 345	71 642	-297	-0,41	0,276
	5	264 875	74 263	74 631	-368	-0,49	0,276
	6	276 369	77 356	77 800	-444	-0,57	0,276
	7	283 886	79 555	79 871	-316	-0,4	0,275
	8	295 767	83 092	83 143	-51	-0,06	0,275
	9	310 180	87 450	87 108	342	0,39	0,275
	10	322 336	90 727	90 449	278	0,31	0,275
	11	334 192	93 800	93 705	95	0,1	0,275
	12	345 974	96 928	96 938	-10	-0,01	0,274
2011	1	357 589	100 183	100 123	60	0,06	0,274
	2	370 388	103 633	103 631	2	0,01	0,274
	3	382 100	106 701	106 838	-137	-0,13	0,274
	4	383 657	107 094	107 264	-170	-0,16	0,274
	5	383 657	107 094	107 264	-170	-0,16	0,274

	6	393 544	109 723	109 970	-247	-0,22	0,274
	7	401 939	112 063	112 267	-204	-0,18	0,273
	8	405 952	113 172	113 364	-192	-0,17	0,273
	9	414 268	115 413	115 637	-224	-0,19	0,273
	10	424 574	118 126	118 453	-327	-0,28	0,273
	11	434 051	120 631	121 041	-410	-0,34	0,273
	12	443 657	123 253	123 663	-410	-0,33	0,273
2012	1	451 783	125 532	125 881	-349	-0,28	0,273
	2	459 481	127 679	127 980	-301	-0,24	0,273
	3	467 009	129 764	130 033	-269	-0,21	0,273
	4	473 923	131 494	131 917	-423	-0,32	0,273
	5	475 807	132 118	132 431	-313	-0,24	0,273
	6	481 673	133 716	134 029	-313	-0,23	0,272
	7	487 251	135 290	135 549	-259	-0,19	0,272
	8	492 990	136 853	137 112	-259	-0,19	0,272
	9	501 186	139 149	139 343	-194	-0,14	0,272
	10	511 135	141 744	142 051	-307	-0,22	0,272
	11	522 669	144 704	145 188	-484	-0,33	0,272
	12	536 734	148 365	149 013	-648	-0,43	0,272
2013	1	546 919	151 240	151 781	-541	-0,36	0,272
	2	552 672	152 851	153 344	-493	-0,32	0,272
	3	560 556	154 914	155 485	-571	-0,37	0,272
	4	569 504	157 131	157 915	-784	-0,5	0,271
	5	579 744	159 705	160 694	-989	-0,62	0,271

Having bus mileage and fuel consumption related to this mileage at the disposal, quotients b_0 and b_1 of the equation (31) were assigned. In the calculations the 3rd column (table 1) of mileage presented in $\ln(\text{km})$ with vector of value 1 create matrix $\mathbf{X}$, whereas the 4th column (table 1) of fuel consumption presented in $\ln(\text{dm}^3)$ creates matrix $\mathbf{Y}$.

The values of model prediction quotients are included in table 3.2.

Table 3.2. The values of model prediction quotients

Regression statistics	
R multiple	0,999913
R square	0,999825
Matched square R	0,999823
Standard mistake	0,01179
Observations	64

The model matching quotients to measured values are very high (close to unity). The low variations of values measured during exploitation to values assigned on the basis of model (column 6 table 1) are the result of that fact. Besides the first result, the percentage variation fluctuates in range of 3%. The graphic illustration of analyzed data is presented in fig. 3.1

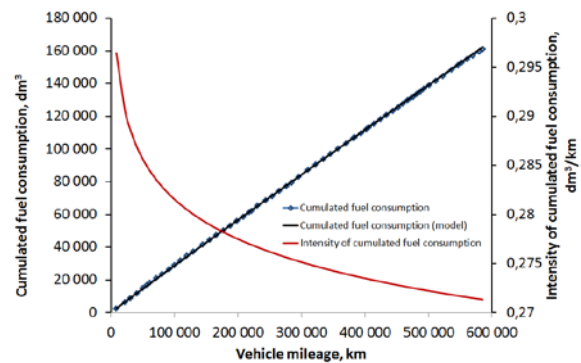


Fig. 3.2. Graphic illustration of measurement results and cumulative fuel consumption calculations and its intensity of the researched bus.

4. Conclusions

The theory of cumulative fuel consumption has been presented. The example of interurban bus research results have shown the way of getting to mathematical model of cumulative fuel consumption and the intensity of cumulative fuel consumption. The high value of prescience quotients is not a case- similar values were obtained in various different cases. Conversance of mathematical model of cumulative fuel consumption allows to carry out comprehensive analysis of this significant exploitative parameter.

5. Literature

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THE USING OF SOLVER SOFTWARE AND VEHICLE ROUTING FOR THE TRAVELING SALESMAN PROBLEM

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Abstract: The traveling salesman problem (TSP) is one of the most studied problems in management science. Optimal approaches to solving traveling salesman problems are based on mathematical programming. But in reality, most TSP problems are not solved optimally. When the problem is so large that an optimal solution is impossible to obtain, or when approximate solutions are good enough, heuristics are applied. Two commonly used heuristics for the traveling salesman problem are the **nearest neighbor procedure** and the **Clark and Wright savings heuristic**.

In this paper will be present using of the solver software and principles of TSP for optimal solution of vehicle routing for domestic bottled water and different juices in the different parts of the Republic of Macedonia.

Key Words: TSP, NNP, CWSH, routing

1. Introduction

Logistic system of a company contains a fixed number of places where raw materials, materials, semi-finished and finished products remain appropriate time, whether they are in undergoing treatment or in the warehouse. The link between fixed locations is provided by the transportation system. Transport provides goods to move between various fixed points which bridges the space between buyer and supplier. For efficient and economical operation of the logistic system it is necessary to have knowledge of the transport system. The role of transport is especially important today in terms of globalization, when companies are geographically dispersed or are distant from the sources of supply, causing dependence of transport whose task is to connect companies with sources of supply on the one hand and consumption on the other.

The goal of most transportation problems is to minimize the total cost of providing the service. It includes capital expenses for the vehicle, mileage and distance or personal expenses. But other goals may also come into play. In [6], [7] and [8] vehicle routing problem is solved using different optimization methods as dynamic optimization, linear optimization, graph theory, game theory. For optimization criterion is chosen transport costs [6, 8] or fuel consumption [7].

Problems of Routing and Scheduling are commonly displayed in graphical networks. Using networks to describe these problems take precedence over allowing decision makers to visualize the problem under study. The given picture below, which consists of five circles called nodes from which four nodes (2-5) represent the locations of delivery, and the fifth node (1) represents a node of the store or warehouse, where the tour begins or ends of vehicles.

Whit bonding of these nodes is obtained line segments called arcs. They can mark time, cost or distance required to pass from one node to another. Arches can be direct or indirect. Indirect arcs are represented by simple line segments.

Direct arcs are displayed in brackets. These brackets represent the direction of the drive in case of problems in routing (e.g., one-way streets) or preferential treatment in case of problems in the schedule (where a pick-up or delivered quantity must prevail over the other).

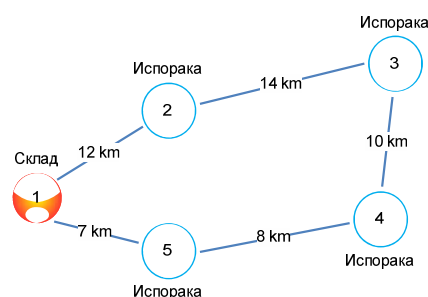


Figure1. Routing Network Example

From the image can be seen the simple routing of the single vehicle. Road that the vehicle passes is called the tour, and that is the direction $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5 \rightarrow 1$ or when arches are indirect, $1 \rightarrow 5 \rightarrow 4 \rightarrow 3 \rightarrow 2 \rightarrow 1$. The total length of either of the two tours is 51 km. The feasibility depends on the type of problem, but in general, it implicates: The tour must include all nodes; node must be visited only once, tour must start and end in the store or warehouse. In the simplest case, you should start with a network of nodes that must be visited by a vehicle. Nodes can be visited in any order, no priority, travel expenses between two nodes is also irrelevant to the driving direction. In addition, the bearing capacity of the vehicle is not taken into account. The performance for the problem of single-vehicle road or tour where each node is visited only once and routing begins and ends at the warehouse. The tour is being created in order to minimize the total cost of the overall tour. The simplest case is known as the Traveling Salesman Problem (TSP). Traveling Salesman Problem (TSP) is one of the most studied problems in management science. Optimal achievements to solve traveling salesman problems are based on mathematical programming. But in reality, most of TSP problems cannot be solved optimally. When the problem is real big and complex, then an optimal solution is impossible to obtain, in these cases programming techniques and principles are applying. Two techniques are generally used for TSP problems including: Nearest neighbor procedure and Clark and Wright savings heuristic.

Nearest neighbor procedure (NNP) builds a tour only in accordance with the cost or driving distance from the last visited node to the nearest node in the network. In this case, the technique is simple, but it has the disadvantage of having nearsightedness or inaccuracy, which is evident from the following example. The procedure is outlined in the following: Start with the top node of the tour (warehouse or storage node), finding the closest node to the last node added to the tour, a return to step 2. Whilst all nodes are added, connecting the first and last nodes to create a complete tour.

The table below provides the complete distance matrix for symmetric six-node network shown in the figure below.

Table1. Distance matrix for symmetric six-node network

Од јазол	До јазол (дистинација во километри)	1	2	3	4	5	6
1	-	-	5.4	2.8	10.5	8.2	4.1
2	5.4	-	5.0	9.5	5.0	8.5	-
3	2.8	5.0	-	7.8	6.0	3.6	-
4	10.5	9.5	7.8	-	5.0	9.5	-
5	8.2	5.0	6.0	5.0	-	9.2	-
6	4.1	8.5	3.6	9.5	9.2	-	-

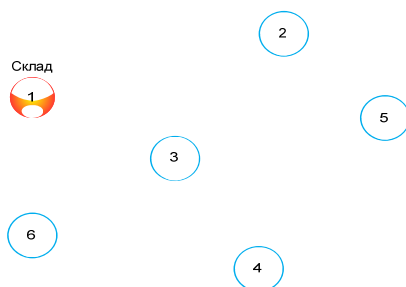


Figure2. Traveling Salesman Problem

According to the picture, the solution is determined as follows: Beginning at the initial node (node 1) and it is examined and considered the distances between one node and every other node. The created complete tour is $1 \rightarrow 3 \rightarrow 6 \rightarrow 2 \rightarrow 5 \rightarrow 4 \rightarrow 1$. The length of the tour amounted is 35,4 km.

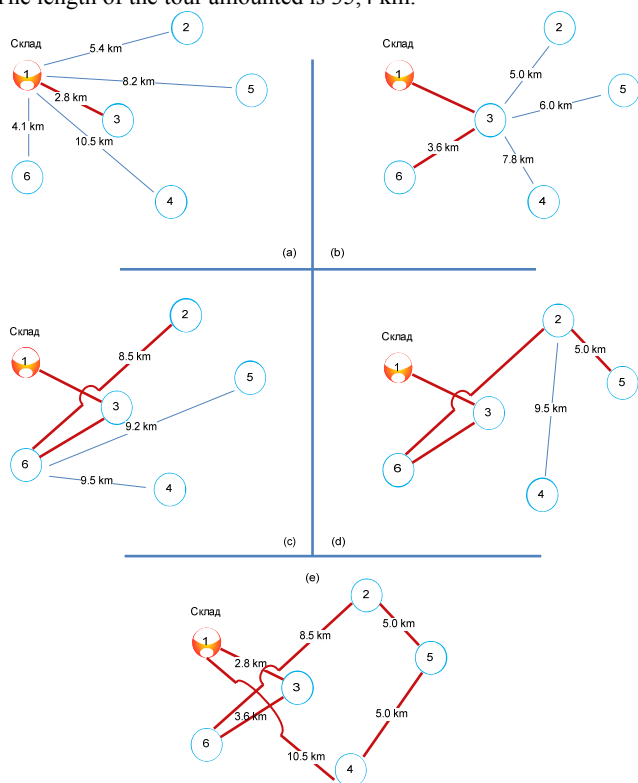


Figure 3. Nearest neighbor Procedure

However, the question is whether this represents the best tour or driving route? Consider again the network and try to find a better tour. Such as $1 \rightarrow 2 \rightarrow 5 \rightarrow 4 \rightarrow 3 \rightarrow 6 \rightarrow 1$? The total length of this tour is 30.9 vs. 35.4 km to Nearest neighbor-constructed tour. This results in limitations of the technique and the principle or the application of this technique does not guarantee optimality. In this small network, it would be possible to re-label all possible tours. However, a number of problems with 100 to 200 nodes, re-labeling or renumbering every possible combination would be impossible. Before leaving this technique (NNP), it is necessary to note that, in practice, the techniques are applied to denote repetition by every possible initial node to node, resolving

the problem, and then selects the lowest cost tour as a final solution. For example, if you repeat the procedure using the node 6 as the starting node, the tour will result in another length or $6 \rightarrow 3 \rightarrow 1 \rightarrow 2 \rightarrow 4 \rightarrow 5 \rightarrow 6$ and a length of 31,3 km.

Clark and Wright savings heuristic procedure is one of the best known techniques and methods to solve TSP problems. It begins with the selection of a node as the starting node and marking the node first then it is assumed, for the moment, there are available $n-1$ cars, where n is the number of nodes. In other words, if we have 6 nodes in the network, then there are 5 available vehicles. Each vehicle travels from the warehouse or from the starting node to another node and returns to the starting node. But this is not practically possible solution because the purpose of TSP-problem is to find a tour in which all the nodes will be visited by a vehicle, rather than two separate vehicles, as shown in the picture. To reduce the number of vehicles required, it is necessary to combine $n-1$ tours originally specified.

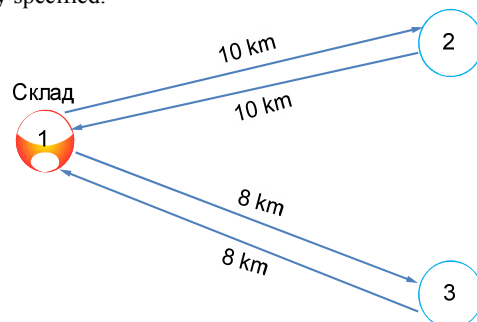


Figure4. Initial C&W Network Configuration: Three-Node Problem

The key to Clark and Wright savings heuristic procedure is to calculate savings. "Savings" is a measure of how much the driving range or cost can be reduced with "hooking up" - hanging a pair of nodes (in the case of the picture above nodes 2 and 3) and to create a tour $1 \rightarrow 2 \rightarrow 3 \rightarrow 1$, which can be marked for one vehicle. "Saving" is calculated as follows: By connecting nodes 2 and 3, add 5 km (distance from node 2 to node 3), but save 10 km of road from node 2 to node 1 and 8 km route from node 3 to node 1, total distance or length of tour $1 \rightarrow 2 \rightarrow 3 \rightarrow 1$ is 23 km. "Saving" which is obtained with the new configuration is 13 km. For a network with n nodes, calculate savings for each possible pair of nodes, and the amount of savings reaches Descending savings, so tours are constructed by linking the different possible pairs of nodes until a complete routing is obtained. The exhibit S & W savings heuristic procedure is as follows: Select any node as the starting node (node 1) Calculation of savings, S_{ij} for linking the nodes i, j , and $S_{ij} = c_{1i} + c_{1j} - c_{ij}$ for $i, j = \text{nodes } 2, 3, \dots, n$, where c_{ij} = cost of driving from nodes $i \rightarrow j$. Order of the savings from the biggest to the smallest, Starting at the top of the list of most sub-tour by connecting the appropriate node s and j . Stop when full tour is formed. As a demonstration of this procedure a TSP-problem is used, the network shown in the image below. It is assumed that there is one vehicle for each node (excluding the starting node) in the network. Full drawn lines show arches in use when starting with S & W savings heuristic procedure. Dashed lines show the arches that can be used, but are not currently used.

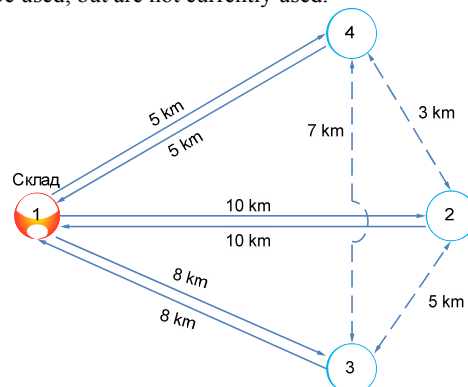


Figure 5. S & W savings heuristic procedure.

The next row of the savings for each pair of nodes is still connected. In order to save, the couples [2,3], [2, 4] and [3, 4]. The first step in the specification of a couple is to connect nodes with the highest savings, which are nodes 2 and 3. The resulting path is shown in Figure (a) below. Processing the future top savings, nodes 2 and 4 are connected according to Figure (b) below. The tour is now complete, as the last pair of nodes, 3 and 4 cannot be merged without disruption of the tour. The complete tour is $1 \rightarrow 4 \rightarrow 2 \rightarrow 3 \rightarrow 1$, which has a total length of tour of 21 km. The total savings obtained for the configuration "one vehicle per node" which is shown in the picture is 25 km.

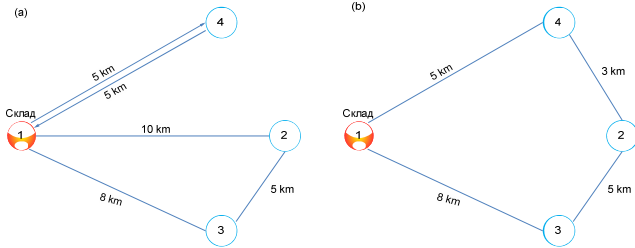


Figure 6. (a) 2-3 node connection, (b) 2-4 node connection

In general, because S & W savings heuristic procedure takes into account the cost when construct the tour; achieve better quality solutions compared to the nearest neighbor procedure (NNP). However, both procedures can easily be adjusted to suit the problems with direct arcs.

2. Traveling Salesman Problem (TSP)

When the problem is real big and complex, and it is a transportation of juices or carbonated mineral water, energy drinks Gorska - Koding - Skopje, then an optimal solution is impossible to obtain or when sufficient or sufficiently accurate approximate solutions are apply, than programming principles and techniques are used. Generally are used for solving TSP problems and the technique is: Nearest neighbor procedure.

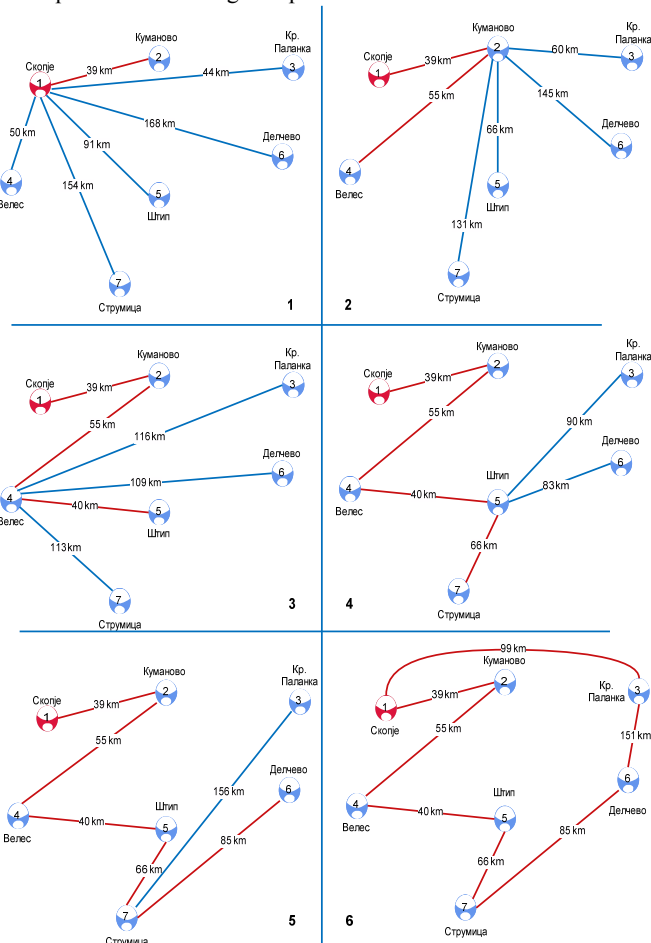


Figure 7. Regional distribution network in Eastern part of Macedonia using the TSP

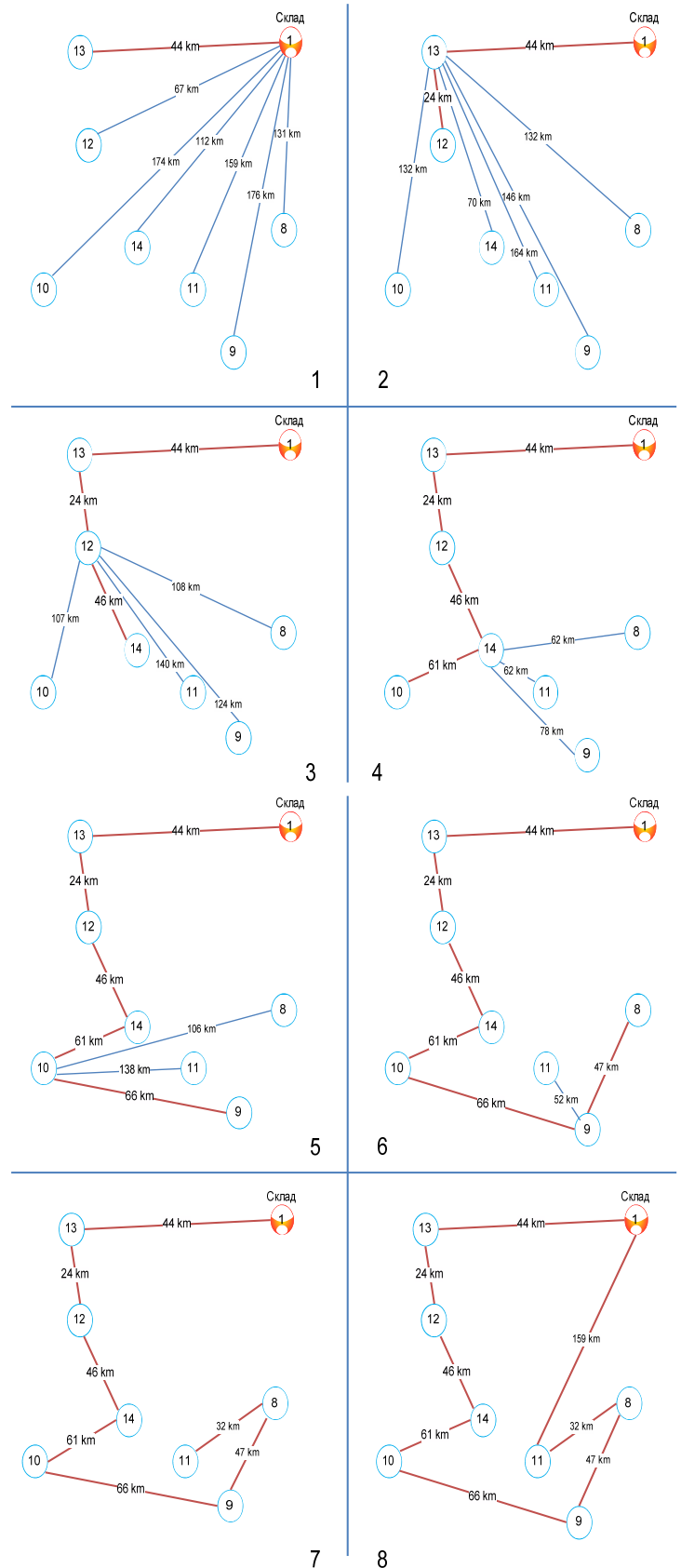


Figure 8. Regional distribution network of Western part of Macedonia with TSP

Conclusion

Reviewing the solutions of vehicle routing above picture you can create a complete tour $1 \rightarrow 2 \rightarrow 4 \rightarrow 5 \rightarrow 7 \rightarrow 6 \rightarrow 3 \rightarrow 1$ whose length is 535 km. Because this method does not always give the optimal value of the tour, we will again consider the network and try to find a better tour, such as $1 \rightarrow 4 \rightarrow 6 \rightarrow 7 \rightarrow 5 \rightarrow 3 \rightarrow 2 \rightarrow 1$. Total length of this tour is 461 km, versus the previous 535

km, or 48 km difference. Reviewing the solutions of vehicle routing as in picture 45, we can create a complete tour $1 \rightarrow 13 \rightarrow 12 \rightarrow 14 \rightarrow 10 \rightarrow 8 \rightarrow 9 \rightarrow 11 \rightarrow 1$ whose length is 479 km. Because this method does not always give the optimal value of the tour, we will again consider the network and try to find a better tour, such as $1 \rightarrow 13 \rightarrow 12 \rightarrow 14 \rightarrow 10 \rightarrow 9 \rightarrow 11 \rightarrow 8 \rightarrow 1$. The total length of this tour is 456 km, versus the previous 479 km, or difference 23 km.

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THE INTELLIGENT TRANSPORT SYSTEMS – RISKS AND BENEFITS

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Abstract: Effective deployment of ITS technologies depends in part on the knowledge of which technologies will most effectively address the issues of congestion and safety. Thus, it is important to understand the benefits or risks of both existing and emerging technologies. Based on documented experience locally and throughout the country, ITS deployments in urban areas have the potential to offer the following benefits:

- Arterial management systems can potentially reduce delays with the implementation of advanced control systems and traveler information dissemination.
- Freeway management systems can reduce the occurrence of crashes, increase capacity, and decrease overall travel times.
- Freight management systems reduce costs to motor carriers with the implementation of the commercial vehicle information systems and networks.
- Transit management systems may reduce travel times and increased reliability with automatic vehicle location and transit signal priority implementation.
- Incident management systems potentially reduce incident duration and offer numerous other benefits.

There is a wide range of benefits that can be obtained from ITS deployments. For example, fuel consumption, travel time, and delay can be reduced. ITS deployments can also result in higher travel speeds, improved traffic flow, and more satisfied travelers for all modes.

Keywords: ITS, RISKS, BENEFITS, DEPLOYMENTS

1. Introduction

The use of information technology is implemented and expanded in almost all areas and fields of human labor, so any transport not an exception. Intelligent Transport Systems (ITS) is the application of information technology in the transport sector. Intelligent Transportation Systems are defined as:

“Application of advanced sensors, computers, electronics and communication technologies and management strategies - in an integrated manner - to increase the safety and efficiency of surface transportation system”

This system can help transportation planners and operators. Accordingly tackles congestion, pollution, poor accessibility, may also help to reduce travel time, provide reliable, safe and convenient transport while reducing energy consumption and protecting the environment and working environment.



Figure 1. Intelligent Transport System

1.1 Intelligent Transport System

Most cases occur is creating problems with crowds and delays in road traffic. Therefore, it is necessary to find ways to manage traffic more efficient ways of existing roads. In all this, ITS can contribute to solving these problems. In the 60s of last century to optimize the traffic in the cities were designed computer control systems. More recently emerging and developed a range of sophisticated products and systems, which appears in a wide range of systems for commercial transport services for freight and public transport, the occurrence of ITS in our vehicles and informing the passengers in them. They extend to all modes of transport such as road, rail, water and air. Of course you need full coordination to exploit the full potential of ITS in the transport network both national and European level.

It must be mentioned that the existence of ITS software and hardware (architecture) allows a systematic basis for expansion of all possible systems and applications to be interoperable.



Figure 2. Application of Intelligent Transport System

2. Possible long-term problems and risks

The biggest change in the development of road safety is a change of focus and philosophy of integrated traffic system and traffic parameters of the process. Vehicle safety, internal passive occupant safety and road improvements in the existing environment, with specific targets risk groups (young drivers) and risk behaviors (drunk driving, speeding) - and prudent levels sanctions - are activities and synergies in integrated access systems. The development of intelligent transportation systems (ITS) suggests that road transport will become increasingly dependent structured by new and additional requirements for vehicle safety and driver / operator.



Figure 3a. Some examples of Intelligent Transport System

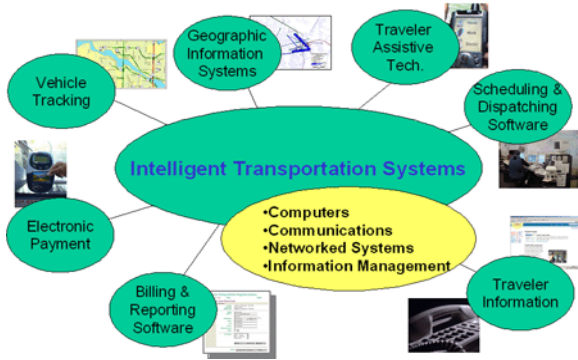


Figure 3b. Some examples of Intelligent Transport System

Intelligent Transport Systems ITS is widely known as Supervisory Control and Data Acquisition (SCADA) systems, which are designed for operations and safety. These systems are now connected to the internet and use available commercial technologies that introduce new security risks and threats.

In June 2010, anti-virus Security Company announced the first detection of the virus (malware) that attacks SCADA systems. The virus called Stuxnet was discovered and initially 14 systems internationally.

Brisbane City Council and Department of Transport and Main Roads stressed the need for implementation of secure information technology with full protection against malicious attacks on the system. According to the Brisbane City Council and Department of Transport and Main Roads was established high susceptibility of attacks on road systems in Brisbane, Australia. "The systems for traffic management of critical infrastructure in Brisbane were obviously not as secure as they should, and they were vulnerable to targeted attacks." The report presented by the Brisbane City Council and Department of Transport and Main Roads showed that the sensitivity of the system lies largely in the use of common information technology and internet connectivity.

Just like Australia in Brisbane and Israel learned this lesson the cruel way when virus was used to access and closing the network of cameras on a major arterial tunnels in Haifa. Consequently it was disabled and paralyzed highway in periods of two hours.

Also in Germany there are doubts about the abuse with changes in light of lights so drivers can create confusion, delays, congestion or causing accidents and incidents. With the introduction of ITS vehicle is expected to have a very positive safety improvements, which may contribute drivers to change their ways of taking along not intended for system engineers and implementers design. Identified downsides and unintended effects of ITS include:

- *Risk and taking along satisfactorily.* ITS can change the perception and the perception of risk drivers from driving, bringing up taking along risky driving, if their level of risk sensitivity is lower than their preferred level of risk. Drivers can also engage in the risky driving desire for compensation of reduced mobility (at low speed driving). According to US Federal Highway Administration Speed Management Information, accelerating too fast and driving under the circumstances given the speed limits are a factor of nearly a third of all fatal accidents. In 2011 there were 32,367 deaths on the roads, of which 9944 were associated with accelerated drive, which means a decrease of 5 % from the previous year. Driving too fast is a problem with the safety of all roads. Although much of the public concern and is associated with premature focused driving, almost half of the fatal cases are due to this.

- *Excessive confidence.* Drivers can take much greater responsibility for driving certain of the existing system and can leave you indifferent to accountability system without it being designed for such an undertaking. Excessive trust in ITS can create problems when the system is active while, so when driving a vehicle without ITS staffed, or if the system gives up and the driver should re-gain control.

- *Subtract attention.* ITS can overwhelm the driver to drivers if they wish to pursue more information in long periods of time. The National Highway Traffic Safety Administration reported that in 2010 drivers were the cause of 18 % of the total fatal accidents, killing 3092 people and themselves accidents resulted in 416 000 people injured. Forty percent of American teens say most were in cars or vehicles when the driver used a cell phone, GPS and other devices, putting people in danger. According to research at Virginia Tech Transportation Institute⁶, shown that text messages generate 23 times more likely to crash than driving without such activities. Eleven percent of drivers aged 18 to 20 years who participated in a car accident and survived, admitted that the accident had been accepted or sent emails or texts, monitoring, commands etc.

In [9] and [10] is presented experiment of observation and analysis of the movement of means of transport in real time through the application of GPRS. A method for controlling the movement of a road train with minimum fuel consumption is experimented with optimization of technical and operational parameters.

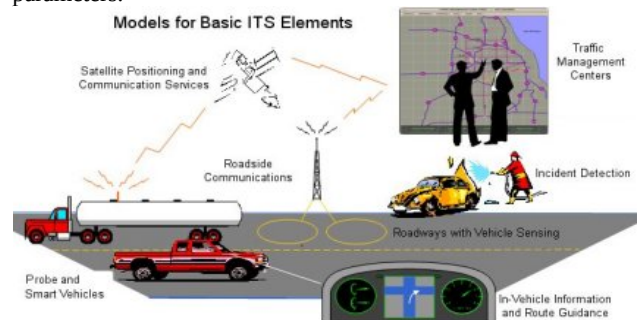


Figure 4. Models for Basic Intelligent Transport System Elements

The biggest risk serious deficiency can be detected in the overall application failed because ITDZ assessment of the full implications of its integration into existing or additional components. At the same time it is possible to ascertain that no valid technical application which is effectively impossible to apply due to organizational reasons. And to work for government, public administration or provider of ITS, ITS architecture helps in the long run to get the best value for the investment and effort invested in this whole effort. Risk and lack of ITS architecture that can create "islands of technology". However, the time when their boundaries will merge as a result of the need for expansion or connection will appear incompatibility.

Conclusion

The goal of intelligent transportation systems (ITS) is to improve the efficiency and safety of the transportation system. Effective scheduling of ITS technologies depends in part on the knowledge that the technologies most effectively answering questions about congestion and safety. In addition, it is important to understand the benefits from both, existing and emerging technologies.

The problems and risks must be disclosed by users of intelligent transportation systems (ITS), in order to make a real assessment of their resolve and overcome. After the assessment, you will surely get the desired result, i.e. the correct technical solution for removing them.

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IMPROVED ADHESION STRENGTH, CORROSION AND WEAR PERFORMANCE OF PLASMA-SPRAYED COATINGS DERIVED FROM PVD FILM-COATED POWDERS — CONCEPT AND PRACTICE

Повышение адгезионной прочности, коррозионной стойкости и износостойкости плазменных покрытий, полученных из порошков покрытых PVD пленками – концепция и практика

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Abstract. Technique and equipment for plasma spraying of wear-resistant and corrosion-resistant coatings with enhanced adhesive strength was developed. Ceramic powders coated metal thin films were used for plasma spraying. Optimal conditions for deposition of the metal films on the particles of alumina powder (40...63 μm fraction) by PVD process were obtained. Deposition of two-layer films on the powder particles was carried out. The first layer was titanium and the second layer was aluminum or copper. The titanium as adhesively-active element capable of wet alumina is necessary for increase the adhesion strength vacuum films as well as plasma sprayed coatings.

A special plasma-spray gun with external arc working in a mode of laminar plasma argon jet generation was designed. Such regime provides melting of the refractory ceramic core, saving metal films as well as localization of thermal effects during spraying process. The results of testing coated specimens confirmed that the developed technique improves the physical and mechanical properties of the plasma sprayed composite coatings. The sprayed composite coatings were compared with coatings sprayed using pure alumina powders in terms of adhesion, wear and corrosion properties. The shear adhesion strength increases up to about 1.9 times, the wear resistance increases about 5 to 7 times, the corrosion resistance increases about 2.5 to 5 times.

The shear adhesion strength was measured at tension of coated specimen at room temperature by developed adhesion testing technique. The substrate was flat and dog-bone-shaped. The substrate with rectangular cross-section was partially coated with plasma-sprayed coating. The specimens were tested in uniaxial tension under displacement control. The tensile specimens were loaded to adhesion delamination of the coating. Sprayed coating was detached as a result of shear interface stresses.

Keywords: alumina powder, plasma-sprayed coating, PVD, adhesion strength, tensile test, cracking, delamination, wear resistance, corrosion resistance

Introduction

The application of plasma-sprayed coatings of metals and metal alloys on a substrate are very limited, especially in solving problems concerning corrosion–wear resistance. One way to improve the functional properties and extending the application of plasma-sprayed coatings is the use of plated (coated with a thin film) ceramic powders. Currently, thin film on powders are made of expensive scarce metals (Co, Ni, Mo) generally by means of electroless deposition or CVD method [1]. These techniques do not provide good adhesion of the metal film to a ceramic particle, which leads to coagulation and blowing of the film during the deposition process, and consequently to a degradation of plasma-sprayed coating properties. Accomplishment of good adhesion of the metal film to the ceramic particle is possible by physical vapor deposition (PVD) of the bond layer of chemically active metals.

Some studies of sputtering processes of metal films on powders by PVD techniques for specific applications are presented in papers [2-4]. So, Schmid G. et al. deposit titanium films on the particles of glass powder with 2...70 μm fraction by magnetron sputtering method [2]. The authors develop an original device for mixing the powder in vacuum. Xu Z., Yu X. and Shen Z. studied the sputtering process of aluminum, silver, copper, cobalt, and nickel on powder of 40...200 μm fraction [3]. The sputtering of aluminum films with a thickness of 10...1000nm on glass powder of 35...230 μm fraction carried out also by magnetron sputtering [4]. Magnetron sputtering process is due to their physical-technological characteristics does not allow forming films with high condensation rate and good adhesion strength to a particle. It restricts the use of the resulting coated powder for plasma spraying.

The PVD is the most perspective procedure in the view of a technological and design features for sputtering films on powders of different fractions. The procedure allow to control the sputtering parameters and the film properties due to the presence of highly ionized component in products of cathode erosion. Also the

procedure allows to obtain high quality films from various metals, alloys and superhard compounds by direct synthesis without by-product yield and with the high adhesion to the treated surface [5].

The article is aimed to describe the technique of increasing the adhesion strength, wear-resistant and corrosion-resistant of the plasma-sprayed coatings by the spraying of the ceramic powder plated with two-layer metal PVD films.

Experimental

Alumina powder of – 63 + 40 μm fraction selected as the initial. The powder has good operating ability, high chemical resistance, commercially available and established for plasma spraying.

The particles of Al₂O₃ powder were coated with several layers. A first layer was titanium, a second one was copper or aluminum (in text these plated powders are designated as Al₂O₃/Ti/Cu or Al₂O₃/Ti/Al correspondingly). The use of titanium as an underlayer is to ensure bond between the alumina core and top metal film. Titanium as a reactive element to wet the alumina is able to form a transition layer, as well as to reduce residual stresses in the film, due to practically identical thermal expansion coefficient of titanium (~85·10⁻⁷ °C⁻¹) and aluminum oxide (~78...81·10⁻⁷ °C⁻¹). Aluminum when alloyed with titanium film forms a row of intermetallic compounds with the release of additional heat. It improves the melt of refractory alumina during deposition process. Copper, as a bonding material, contributes to reduced porosity and correspondingly increase the cohesive strength and corrosion resistance of plasma-sprayed coatings.

Plating was applied using a PVD equipment with a special device of drum type for mixing the powder (Fig. 1). Principles of the sputtering method, equipment and processes that occur in plating powder according to the technique have been discussed in detail in previous work [6].

Metallographic and SEM analysis of the surface morphology and films structure performed for evaluation the impact of process variables of plating on the uniformity and thickness of the metal films on ceramic powders. Morphology and cross section of coated powder are shown in Fig. 2.

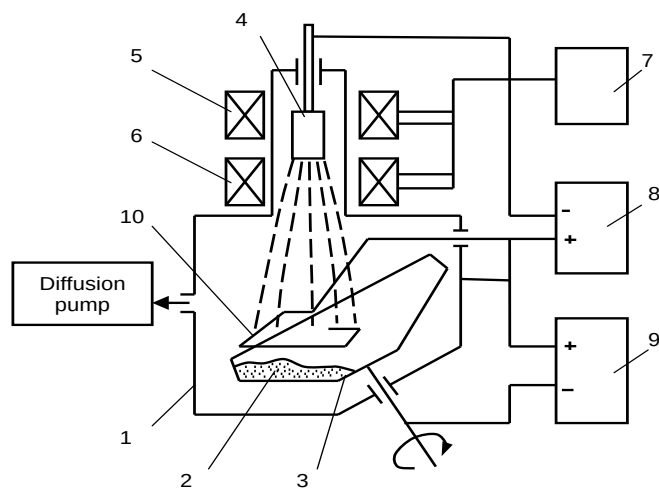


Fig. 1. Sketch of the PVD equipment for plating powders (1–vacuum chamber; 2–powder for plating; 3–boot drum; 4–cathode; 5–stabilizing coils; 6–focusing coils; 7–stabilizing power supply and focusing coils; 8–power supply to the evaporator; 9–high voltage power supply)

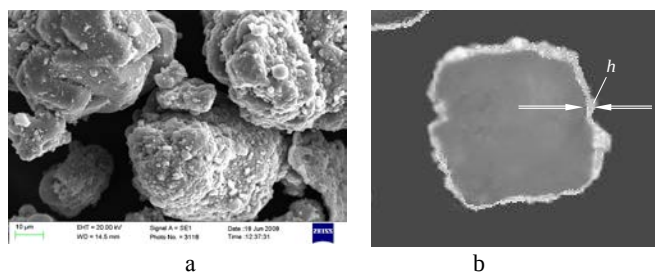


Fig. 2. Morphology and cross section of coated ($\text{Al}_2\text{O}_3/\text{Ti}/\text{Al}$) particle

On the basis of metallographic analysis of plated powders can be concluded the films on the particles have a dense, uniform distribution, sufficiently smooth topography and fully cover the surface of the powder particles.

The plasma-sprayed coating derived from plated powders was applied using a plasma-spray gun, with partially imposition of arc and additional cooling of plasma jet by concentric flow of protective gas. Argon used as the plasma and protective gas. Operating current is set within 80...100 A, voltage 50...60 V, the gas flow rate of 2...3 L/min at 2 mm diameter nozzle. Plasma jet formed with laminar character and extended the expiration high temperature area due to equipment design and operating conditions. This provides favorable conditions for the preservation of the metal film and the melt of the coated refractory ceramic core of the powder during spraying process. The coating sprayed on flat specimens from low carbon steel. Plasma-sprayed TiNi and NiAl coatings have high mechanical properties and adhesion strength to the low carbon steel substrate.

According to [7] as a result of deformation and crystallization, alumina particles have fragmented shapes even under favorable conditions of spraying due to high deposition rate and particle cooling. It is obvious that the presence of microcracks in the ceramic coatings leads decrease in their mechanical properties, primarily cohesion strength. In this case, the situation changes due to metal film having a good adhesive bond to the surface of the ceramic particles.

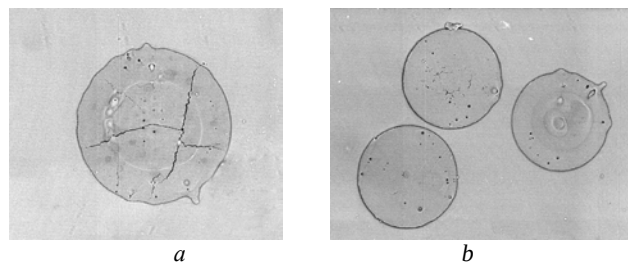


Fig. 3. The shapes of a fragmented disk splat of the pure alumina (a) and disk splats of the coated alumina without cracking (b)

The splats plated particles of coated alumina has an regular surface geometry with presence of insignificant valleys that can be connected to physicochemical interactions between a ceramic core of the particle and a metal film, and also influence of shock and presence of residual gases (Fig 3). The shape of these splats plays a crucial role in determining the mechanical and physical properties of the coatings.

Application plated powders leads to the formation of around ceramic particles areas with high cohesive bonds, which promotes the formation of a dense sprayed coating with good adhesion to the substrate, high corrosive and mechanical characteristics.

Structure of the two-layer plasma-sprayed coating with top coat obtained during deposition of plated Al_2O_3 powder is shown on Fig. 4.

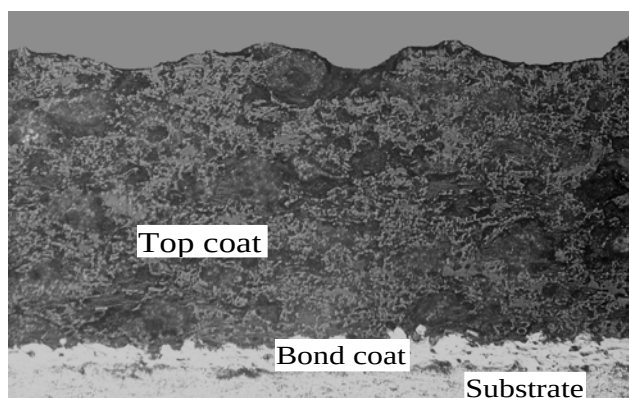


Fig. 4. Structure of plasma-sprayed coating obtained by spraying $\text{Al}_2\text{O}_3/\text{Ti}/\text{Al}$ powder on the NiTi bond coat (20 μm thick)

The technique for determining adhesion strength of the top ceramic coat has been developed. Substrate (2 mm thick) of low-alloy steel was used for testing. Plasma-sprayed NiTi coating (20 μm thick) has been used as bond coat for improved adhesion strength of top Al_2O_3 coat. The coating was symmetrically sprayed on the both side of the substrate. A thick (300 μm) layer of Al_2O_3 was coated onto bond coat. Tests were performed by standard tensile-testing machine. Strain gauges are used for measuring strains during loading of the specimens. Elastic characteristics of the coating determined by a technique developed earlier [8, 9].

First uncoated specimens (pure substrate) were used for determination of mechanic properties of the low-alloy steel. Than specimens with plasma-sprayed coating were tested. After testing specimens with only NiTi bond coat the specimens with top coat/bond coat were expanded. Stress-strain curves of all tested specimens have been recorded. After tensile testing adhesion strength of top coat was calculated.

A schematic sketch of the specimen with top coat/bond coat system before testing has been showed on Fig 5. The specimen after testing with detached top Al_2O_3 coat was showed on Fig.6. Cracking of the top coat with the subsequent delamination occurs at testing specimen with plasma-sprayed coating from plated alumina (Fig. 7).

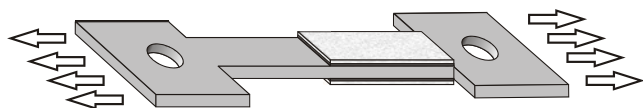
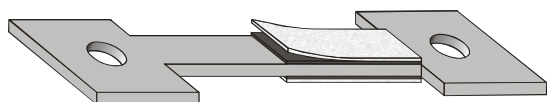


Fig. 5. Schematic sketch of the dog-bone-shaped specimen with top coat/bond coat system before testing



a

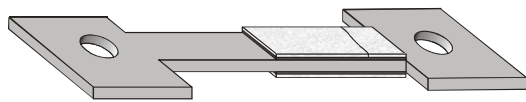


b

Fig. 6. Delamination of top alumina plasma-sprayed coating after testing of tensile specimen (a photo of specimen – a, schematic sketch – b)



a



b

Fig. 7. Cracking of top $\text{Al}_2\text{O}_3/\text{Ti}/\text{Al}$ plasma-sprayed coating after testing of tensile specimen (a photo of specimen – a, schematic sketch – b)

Top coat delamination happens as a result of influence of shear stresses in top coat/bond coat interface. The shear stresses have been determined according to the dependencies derived in [10]. Calculated critical shear stresses characterizing the shear adhesive strength of the top coating are shown in the table.

Table. Adhesion strength of plasma-sprayed top coat

Top coat	Shear adhesion strength, MPa
Pure Al_2O_3	29
$\text{Al}_2\text{O}_3/\text{Ti}/\text{Al}$	47
$\text{Al}_2\text{O}_3/\text{Ti}/\text{Cu}$	55

Testing of the coatings in corrosive medium was conducted by polarization resistance, which has been successfully used for corrosion studies of different materials in liquid environments. This method relies on measuring changes in polarization current between the two electrodes of the same metal and a coating upon application of the same polarization less than 20 mV.

Time dependences of the polarization resistance of plasma-sprayed coatings obtained during tests in 10 % H_2SO_4 and HNO_3 are shown in Figs. 8 and 9.

The polarization resistance for all types of coatings in 10 % H_2SO_4 reaches a steady value after 60...80 min (Fig. 8). This stable value can serve as a corrosion resistance criterion in comparison tests. A significant increase R_p (about 50 %) observed when replacing aluminum in copper for plated powders due to the greater stability of the copper in the sulfuric acid. To significantly improve the R_p and accordingly reduce corrosion causes an increase in coating thickness. This is due to lower amount of related voids

and consistent with published test results on the protective ability of other types of coatings [11].

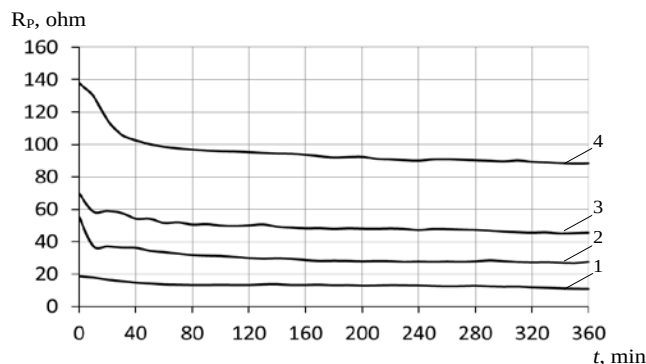


Fig. 8. The polarization resistance time dependence in the 10 % H_2SO_4 for the coating spraying from Al_2O_3 powder: 1 – pure (non-plated) powder (thickness of plasma-sprayed coating 120 μm); 2 – plated Ti and Al (thickness of plasma-sprayed coating 120 μm); 3 – plated Ti and Cu (thickness of plasma-sprayed coating 120 μm); 4 – plated Ti and Cu (thickness of plasma-sprayed coating 200 μm)

Plated powder based coatings at the initial time showed a decrease in polarization resistance in comparison with non-plated alumina in 10 % HNO_3 environment (Fig. 9).

The polarization resistance R_p for the plated powder based coatings in 10 % HNO_3 R_p increased and exceeded the value for pure alumina after 5 hours due to the ability of titanium to passivation in nitric acid. At the same time, more stable values for the polarization resistance were observed in titanium/copper system.

The results of studies of the influence of the bond coat material and its thickness on the corrosion resistance showed a slight deviation in the values of R_p when tested in 10 % H_2SO_4 . So, after stabilization of the polarization resistance of coatings with a bond coat thickness of 15 μm was 40...45 ohm regardless of the material used for bond coat (NiTi or NiAl), a slight increase was observed R_p with increasing thickness of the bond coat up to 50...60 ohm. Here, such values can be achieved also by increasing the thickness of the top coat.

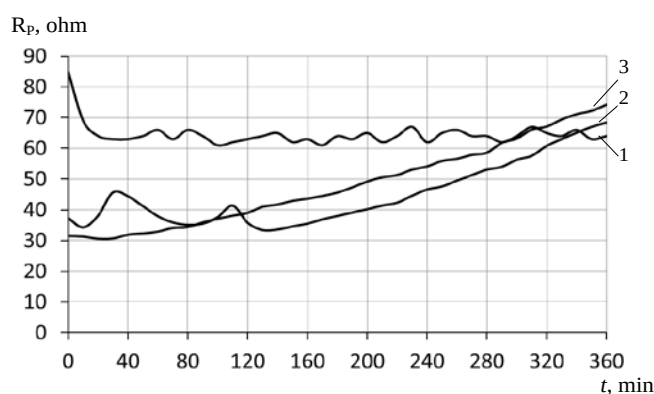


Fig. 9. The polarization resistance time dependence in the 10 % HNO_3 for the coating spraying from Al_2O_3 powder: 1 – the pure (non-plated) powder; 2 – plated Ti and Al; 3 – plated Ti and Cu.

Wear resistance of the coatings was investigated on the finger friction machine, using the pair of friction: a fixed specimen (the coating surface) – sliding rider (medium-carbon steel 1045). Wear was determined gravimetrically. According to the experimental conditions the mean free path of the sliding rider – 40 mm, peak speed – 0.1 m/s, loading – 10.6 N at a nominal contact area (10 mm^2). The results of wear-resistant tests of the plasma-sprayed coatings from plated alumina powder and pure alumina powder are shown in Fig. 10.

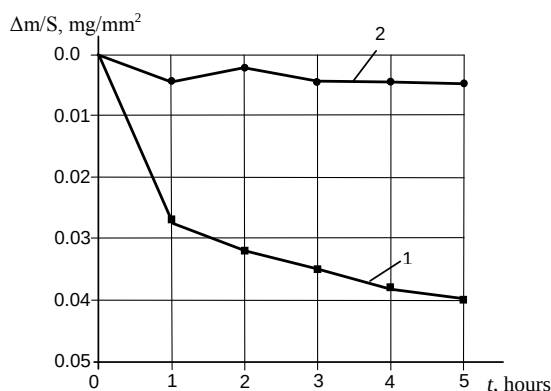


Fig. 10. Wear kinetics of the coatings obtained by plasma spraying of plated powder by titanium and aluminum (2) and pure alumina powder (1)

During the first hour of the friction materials takes place reseating that is accompanied by weight loss, and then wear stabilizes. Stable low wear observed for specimens with the coating based on plated alumina by titanium and aluminum (curve 2). Wear of the coatings based on pure alumina powder is 7...8 times higher (curve 1). Furthermore, in the second case rider wear 4...5 times larger than the first due to the high level of coating microhardness ($H_{\mu} = 14,6$ GPa) and the abrasive effect of the products of the wear.

Thus, the experimental data (Fig. 10) indicate that the plasma spraying of alumina powder plated by titanium and aluminum are formed the wear resistant coating with high cohesion and adhesion strength. These coating show high corrosion resistance in 10% HNO_3 .

Conclusion

Comparing properties of the different coatings with each other, it was found that the plated alumina powders obviously improved not only the adhesion strength of the plasma-sprayed coatings, but also the corrosion and wear performance. The above results may be explained to an increase in the real contact and in the bonding strength between the lamellae of the coatings.

Application of the ceramic powder of alumina plated by thin PVD films of such metals as titanium, aluminum and copper for the plasma spraying of protective coatings, provides formation of dense sprayed coatings with low porosity (2...6 %). Tensile tests of the specimens with two-layer coatings have shown that the shear adhesion strength of top coat (the coating spraying from plated alumina powder) to the sprayed metal NiTi bond coat increase on up to about 1.9 times as compared with the top coat derived from pure alumina powder.

The lowest porosity and best corrosion resistance in sulfuric acid solution has the coating based on alumina powder plated by two-layer (titanium/copper) PVD film. Increase of the polarization resistance in 2...3 times more dependent on the thickness of the top coat than to the material and bond coat thickness. It is associated with a decrease in top coat amount bonding pores. Plating of alumina powder for spraying by titanium and aluminum provides increased wear-resistant of the plasma-sprayed coatings on 7...8 times.

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INFLUENCE OF INTERNAL COMBUSTION CATALYST TO SHORTEN THE IGNITION DELAY

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Abstract: The paper presents a discussion of the combustion processes in the engine piston, in terms of ignition delay. The problem of the physical and chemical ignition delay is discussed and equations which allow the calculation of ignition delay based on the theory of combustion processes are presented. The paper proposes the use of a catalytic coating in the combustion space in order to shorten the ignition delay. The results of studies made on single diesel engine are displayed. Studies have confirmed a significant effect of the catalyst on the combustion process and shortening the ignition delay. Internal combustion catalyst used as a coating made of ZrO₂ activated Pt and Rh deposited on engine valves, caused a shortening of ignition delay of about 1 - 3 degrees of crankshaft rotation.

KEY WORDS: INTERNAL CATALYST, IGNITATION, PISTON ENGINE

1. Introduction

Ignition delay, lasting only a few milliseconds, is a fragment in the diesel engine working cycle. Nevertheless, this delay is responsible for conditioning the effectiveness and ecological effects of engine work [1]. If the delay period lasts too long- the combustion goes rapidly (loud engine work) and less effective (the toxic components of fumes as well as the fuel consumption are increased). There is known the directly proportional correlation between lasting time of ignition delay period and deterioration of fumes quality, especially when the intensity of incompletely combusted hydrocarbons is concerned (among them mutagenic and carcinogenic multi annular aromatic hydrocarbons), in the exhaust gases in diesel engines [1].

Delay period is longer in diesel engines where the time is counted from the moment of fuel injection and the combustible mixture must be properly prepared during this period.

Physical processes appearing in the cylinder after the fuel injection beginning, are necessary for air- fuel mixture preparation and for the pre ignition chemical reactions initiation. The time interval between the moment of fuel injection and the beginning of chemical chain reaction initiation which causes self ignition is called *time of physical ignition delay*.

For the physical processes appearing in diesel engines during time of physical ignition delay belong primarily:

- Fuel flow breakup into single drops
- Heating and vapourization of single drops
- Diffusion going in on the limits of fuel and air steams (formation of flammable gas mixture).

The impact on lasting time of chemical and physical ignition delay also have any modification of fuel that feed the engine [1]. Huang, Ren, Jiang, et.al [2] studied the lasting time of ignition period in ZS engine fed by fuel mixtures of diesel type- DMM (Diesel-dimethoxymethane). Those researches indicate the impact of fuel-air mixture on the ignition delay time, especially during the phase of diffusion processes going on [2].

Considering the abovementioned facts, the ignition delay time in injection engines is conditioned by the sum of physical and chemi-

cal ignition delay times [3]. It seems impossible to state the clear limit between the ending of physical ignition delay and the beginning of chemical ignition delay. That is why the ignition delay has to be treated as a resultant of normalized physical- chemical processes in which the all transformations- both physical and chemical appear simultaneously. Thus the ignition delay period is the sum of physical and chemical ignition delay[11]:

$$\tau_i = \tau_f + \tau_{ch} \quad (1.1)$$

The impact on the ignition delay period have various factors which are, primarily, closely related to chemical properties of fuel and the composition of inflammable fuel mixture [1].

On the basics of empirical data and the analysis of kinetic relations Semenow introduced the model for ignition delay period which for fuels coming out from oil is following:

$$\tau_i = const \left(\frac{T}{p} \right)^{0,5} e^{\frac{E_a}{RT}} \quad (1.2)$$

Where: p- mixture pressure, T- mixture temperature, E_a - activation energy, R -universal gas constant.

After logarithmic calculations of the model, it is visible, that together with the growth of pressure and temperature (exponential function) the delay period decreases [1].

Kavaradze, Zeilinger and Zitzeler [4] made engine researches concerning measurement of ignition time due to the used fuel type, introducing for the first time paradigms for ignition delay of natural fuel and of several synthetic fuel variants.

Thanks to applied research methodology, the results of those researches suggested the validity of the chain theory of ignition. According to the authors of those studies, the presented empirical paradigms can be used for engine fed by particular fuel working stimulation and for prediction of its ecological effects.

For diesel engine with direct fuel injection, which works with the use of classic diesel oil, the suggested paradigm goes as follows:

$$\tau_i = 0,55 p^{-1,3} \exp\left(\frac{4400}{T}\right) \quad (1.3)$$

Where: p and T relates to pressure and temperature in the cylinder during the moment of fuel injection.

Due to the fact that in present diesel engines the recirculation of fumes is used, for the paradigm (1) there has been added empirically assigned K factor. The value of this factor is determined according to recirculation ratio. Thus the paradigm is:

$$\tau_i = 0,55 K p^{-1,3} \exp\left(\frac{4400}{T}\right) \quad (1.4)$$

$$\text{Where: } K = 0,9 z^{0,09} \text{ for } z = 5 - 40\% \quad (1.5)$$

From the abovementioned paradigm it follows that the temperature in the cylinder during the fuel injection moment is inversely proportional to lasting time of ignition delay. The higher the temperature is, the shorter ignition delay time is. Because this relation decreases exponentially, thus even slight prevailing temperature increase in the cylinder during injection should result in noticeable effects of shortening ignition delay.

William and Schmidt [5], while analyzing parameters of ignition initiation during the researches concerning catalytic oxidation of higher alkenes with the use of rhodium as an active factor, noticed that introduction of even small amount of catalyst in reactor simulating the prevailing engine conditions (with certain limits concerning the actual engine conditions, for the case of reactor constructed by the authors the adiabatic processes are present) results in high efficiency in limiting those compound emission. One of the authors' suggestion is the thesis that the active factor introduced into combustion space causes the beginning of complicated chain reactions causing, at the same time, the shortening of chemical ignition time delay and therefore, the lasting time of adverse processes producing toxic, organic carbon compound is minimized.

According to literature [1,4,5,6] it is possible to conclude that the modification of engine combustion space based on introduction of active factor (catalyst), may, with high probability, cause the shortening of chemical ignition delay through declining activation energy of pre ignition reactions.

2. Internal combustion catalyst

The notion of internal combustion catalyst is understood by the authors as the fragment or entirety of walls creating the combustion space of internal combustion engine or the element of this space- e.g. valve, glow pug, which were covered with ceramic coating that composes catalytic substance media which is also soaked with this substance and activated. Internal catalysts, known in literature, were made through activation (ion implantation) of the wall surface combustion space or through introduction of catalytic active material such as platinum tube or wire into this space.

Trials of using internal catalyst, which were described in literature, indicated its positive influence on the combustion process. However, it should be emphasized that the basis of the effectiveness of the catalysis process is the large amplification of the catalytic space and relatively high catalyst temperature. For platinum, high effectiveness is noticed over the temperature of 500K.

In literature, the presented solutions are characterized by relatively low catalyst temperature and low amplification of space.

The offered solution based on using the ceramic coating as media, according to coating property, causes quick obtainment of higher coating temperature, and thus higher effectiveness of the catalyst working.

The catalyst placed inside combustion space may work in several combustion stages:

- in the phase of preparing inflammable mixture- cracking processes of injected fuel,
- in the pre fiery phase= shortening ignition delay,
- in the combustion period- the increase of combustion speed
- in the afterburner period- combustion of hydroxides in the boundary layer, afterburning of CO and NO_x reduction.

According to its kind, size and catalyst placement as well as load and rotary speed of engine, the effectiveness of catalyst working may change in the particular stages. Is should be expected, however, that the adverse working may appear in e.g. NO_x increase or fumes smokes increase.

Offered by the authors, internal catalyst of combustion is made in the form of ceramic coating deposited on the element surface or combustion chamber wall. After depositing, the coating is polished in order to obtain even gage and then it is activated by precious metals with catalytic properties- in this case rhodium and platinum. After depositing of precious metals the coating faces calcinations and reduction processes. It may be predicted, that the most beneficially is making the active coating on the surface of piston combustion chamber. From the technical points, according to the present negative experiences connected with incommensurate durability of coating made on pistons, it has been decided to make the coating on the surface of valve mushrooms.

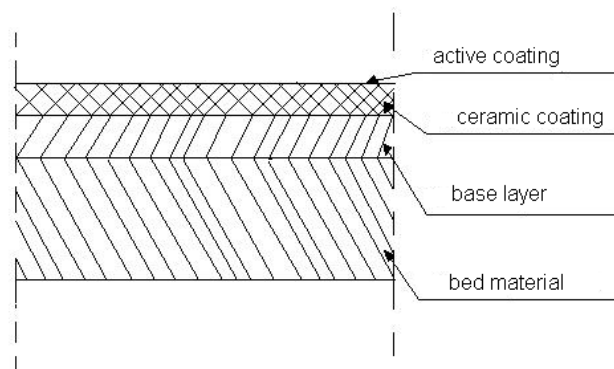


Fig . 2.1. Scheme of internal combustion catalyst.

Where from the above: active coating, ceramic coating, base layer, bed material.

As it has been mentioned, the necessary condition of catalyst working is possibly large surface on which the catalytic material is deposited and its high temperature over 250°C.

In the case of internal combustion catalyst, according to the present experiences, it has been decided to use the coating made of zirconium oxide, partially stabilized by yttrium (PSZ), as the media. Yttrium stabilization prevents the adverse changes in the structure and the yttrium participation is of 8-20% of weight.

Ceramic media of catalyst should be characterized by fine bed adhesiveness, temperature shock resistance, aggressive environment (chemical and gas corrosion) resistance and the catalytic activation sensibility (large surface amplification, porosity).

3. Research location and measurement methods.

For the purpose of engine research, the portion of valves with ceramic covering and platinum active coating and with ceramic covering and platinum and rhodium activation. The gage of ceramic coating was of 0,3 mm. The coating was deposited with $ZrO_2 8Y_2O_3$ on the base of $MCrAlY$ with the gage of 100 μm .

The valves were mounted to stationary single cylinder SB3.1 engine made based on SW680 engine elements.

The engine was loaded with rotational current Hennan-Froude brake which provides the stability of rotations and full range of load.

For the measurement of fumes components URAS 10E no 3.200418.2 analyzer, 4-gas Infralift 4000 and Infralift T4393/2238 analyzers, as well as the NO_x CLD type by Pierburg Co. analyzer in the final phase of researches were assigned.

The usage of fuel was measured by volumetric meter with the compliance of fuel density.

For the measurement of air usage, the system including reservoirs equalizing the air ripple and the double flange ISO system with the measurement of clypeal pressure, were used.

The measurements of combustion pressure and fuel injection of engine were made with the support of piezo quartz sensors ALV QP500, which were mounted in the fuel system before injector and in the engine head cooling adapter with the direct access to combustion space. Ambient parameters were measured by the support of the system- barometer, hygrometer and thermometer with continuous trace. Before each measure session the engine was examined and regulated in detail. The scheme of research location is presented in fig. no 3.1 its view and elements are visible in the fig. no 3.2.

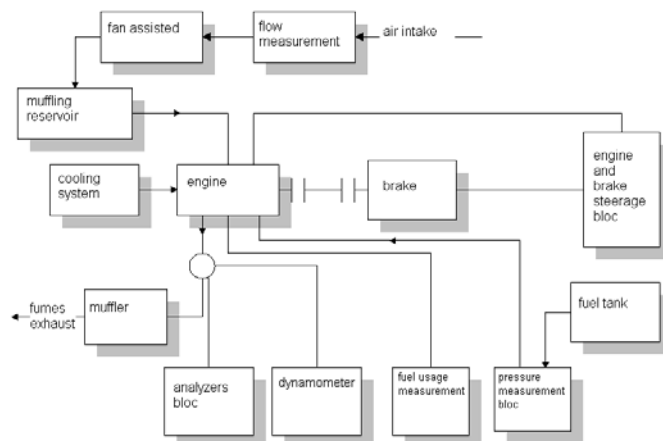


Fig. 3.1 Scheme of research location



Fig. 3.2. General view on the research location.

About the diagram accuracy, concerning the changes of indicated pressure and its position towards reference point i.e. external turn, several measurement aspects are deciding. Among them there are: sensor calibration methodology (static and/or dynamic), whole measurement line calibration, the location of pressure sensor in the combustion chamber, type of signal filtration, the frequency of sampling, accuracy of defined location of external piston turn (GMP).

In the presented studies, sensor calibration has been made with accuracy of $\pm 0,01$ MPa, but for the whole measurement line calibration the amplifier, oscilloscope and 18 bits measurement computer card were applied. For those devices the accuracy of $\pm 0,01$ MPa for the measurement extend of 0÷5 MPa and $\pm 0,03$ MPa for measurement extend of 0÷10 MPa were used. This diversity results from transformation of measurement impulses on the pressure value during different signals amplification in the amplifier and oscilloscope.

The measurements of pressure in the combustion chamber were carried out for:

- Different conditions of engine working: three different speeds (1200, 1400 and 1600 rotations/minute) with different loads and three different angles of the beginning of fuel squeezing 20, 23 and 27 °OWK,
- Different construction modifications: "basic" condition-engine in standard version (from producer), ceramic in the combustion chamber and platinum as catalyst, ceramic activated by platinum and rhodium.

4. Research results

Disposing of actual pressure processes it was possible to indicate the values of angles of the combustion beginning – table 4.1.

Table 4.1. Angles of combustion beginning for different conditions of engine working

Angle of the beginning of fuel squeezing °OWK before GMP	Combustion beginning, °OWK before GMP					
	1200 rot/min		1400 rot/min		1600 rot/min	
	Basic condition	with catalyst	Basic condition	with catalyst	Basic condition	with catalyst
-20	- 1,10	- 4,70	- 3,40	- 4,20	- 2,30	- 5,60
- 23	- 3,24	- 4,96	- 4,19	- 4,58	- 2,86	- 3,82
- 27	- 11,00	- 11,8	- 11,2	- 11,2	- 9,5	- 11,0

From the data presented in the table above, it follows that in the case of external catalyst using, the combustion process begins earlier than in the engine of basic condition.

The combustion beginning is also a function of engine rotation speed and together with its increase, the combustion beginning moves towards external turn (GMP).

In the table 4.2 there were correlated values of pressures increase in the combustion phase for different conditions of engine working.

Table 4.2. Preassure increase $dp/d\alpha$ in the combustion phase for different conditions of engine working.

Angle of the injection timing [°CA]	$dp/d\alpha$, MPa/°OWK					
	1200 min ⁻¹		1400 min ⁻¹		1600 min ⁻¹	
	Basic condition	with catalyst	Basic condition	with catalyst	Basic condition	with catalyst
-20	0,43	0,43	0,33	0,33	0,25	0,32
- 23	0,29	0,47	0,20	0,47	0,31	0,35
- 27	0,64	0,36	0,84	0,75	0,57	0,64

The abovementioned research material indicates that, for the angles of squeezing beginnings of 20 and 23 degrees before the external turn the value $dp/d\alpha$ are higher for the engine working conditions with internal catalyst than those for the basic conditions. Only for 27 degrees angle and the speed of 1200 and 1400 rotations/minute diverse relationship was observed. The lack of clear tendency may be explained by the chance of angle optimum in the squeezing

beginning for the engine with catalyst and thus, it is necessary to work out further researches towards optimizing engine regulations.

5. Conclusions

From what has been presented it follows that the use of internal combustion catalyst shortens the ignition delay of about 1 to 3 degrees of crankshaft rotation. Shortening of ignition delay essentially influences the improvements of engine working parameters, especially in the aspect of using fuels with variable composition and properties like biofuels. The use of internal catalyst decreases engine sensitivity to fuel properties, which allows to use fuels of lower quality that usually show increased angle of ignition delay, without adverse impact on combustion process and harmful fumes components emission.

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INDICATED PRESSURE OF INTERNAL COMBUSTION ENGINE

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Abstract: the contribution deals with problems of measurement indicated pressure of internal combustion engine. Indicated pressure measurement allows better monitoring of change state quantities during implementation working cycle of internal combustion engine. Measurement is realized with the mobile unit on the vehicle under the specified mode, the real conditions of transport, as well as on brake bench in the laboratory. By analysing the results of experiments can be more precisely to quantify efficiency of power transmission and energy flows in the drive mechanism of the vehicle.

Keywords: INDICATED POWER, MEAN INDICATED PRESSURE, INDICATOR DIAGRAM, BRAKE TEST BENCH, SPARK PLUG

1. Introduction

To complexly assess work, economy and adverse ecological impact of conventional piston combustion engines, various parameters and their dependence – characteristics are used. Based on their values the combustion engines are qualitatively ranked. Main parameters are: mean effective pressure, mean indicated pressure of a cycle, indicated and effective engine power as well as engine losses power, specific consumptions of operating materials, specific engine efficiency and produced emissions (of gases, noise and vibrations). [5] For a closer classification and evaluation of combustion engines characteristics in practice, comparative characteristics are used. They describe also other properties and values needed for mutual comparability of engines regardless their size, power, construction, operating principle, etc.

Theoretical – ideal cycles, are reversible processes according to which the ideal engine works. To be closer to reality, open theoretical cycles are solved, i.e., the replacement of a cylinder charge is considered. Real work cycle describes real processes taking place in the engine cylinder.

2. Detection of indicated power P_i

We usually work with an indicator diagram, i.e. the dependence of pressure change on an instantaneous value of a cylinder volume – Fig. 1. If this change is evaluated in dependence on the angle of rotation of a crankshaft or on time, we speak of a developed indicator diagram – Fig. 4b.

The processes connected with energy transformation are frequently assessed according to their power outputs.

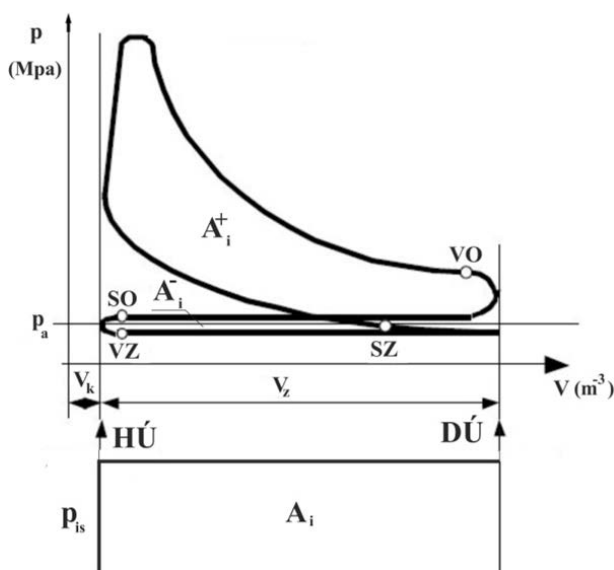


Fig. 1 Indicator diagram.

Indicated engine output P_i is obtained from work cycles in the combustion engine regardless of losses. The indicated power output is experimentally collected from measurements of an indicator diagram or by the cylinders shut down.

An area closed by the indicator diagram A_i (given by difference $A_i^+ - A_i^-$) – Fig. 1 is proportional to the work of one work cycle ($J \cdot \text{cyk}^{-1}$). Positive area of indicator diagram A_i^+ present the work received during the expansion stroke. Negative area A_i^- presents the work consumed to replace the capacity of the cylinders. [4]

The indicator diagram area is replaced by a rectangle area with an identical basic side (corresponding to V_z (m^3)). The mean indicated pressure thus represents an imaginary constant mean value of pressure acting on the piston; when within one stroke, the work equal to the quantity of indicated work performed in the duration of one stroke, would be done. The mean indicated pressure (p_a) is defined by the relation:

$$p_{is} = A_i / V_z \quad (1)$$

Fig. 1 presents the indicated work A_{il} of one cylinder of the internal combustion engine area that can be determined by multiplying the values of mean indicated pressure p_{is} and stroke volume V_z :

$$A_{is} = p_{is} \cdot V_z \quad (2)$$

Indicated power of one cylinder:

$$P_{il} = A_{il} / t_l \quad (3)$$

The duration of one cycle internal combustion engine:

$$t_l = 1 / (2 \cdot n) \cdot z \quad (4)$$

P_i (W) is given by the indicated work of a cycle, number of cylinders i and by the cycle duration t (s), depending on a number of engine revolutions n (s^{-1}) and strokes z per cycle (two-stroke $z = 2$, four-stroke $z = 4$). The resultant relation for a four-stroke engine is of P_i :

$$P_i = (p_{is} \cdot V_{z1} \cdot 2 \cdot n \cdot i) / z \quad (5)$$

3. Measurement of indicated power P_i in brake test bench

Measurements indicated pressure of combustion engine of road vehicle was released in selected driving modes on brake test bench, with using the measuring equipment Kibox to go – Fig. 3. The main goal of a series of experimental measurements was to determine the energy terms during the operation of a road vehicle.

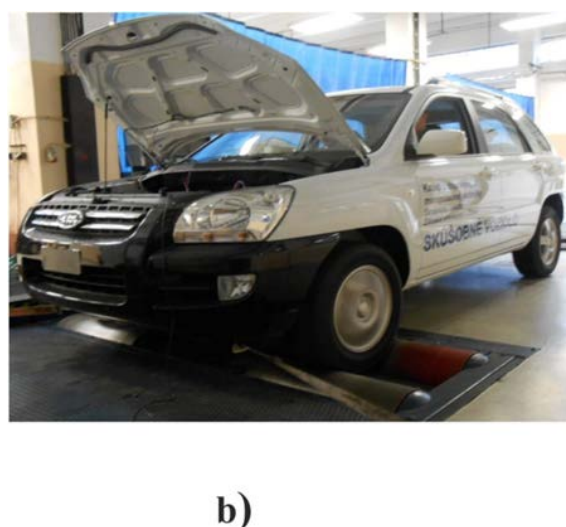
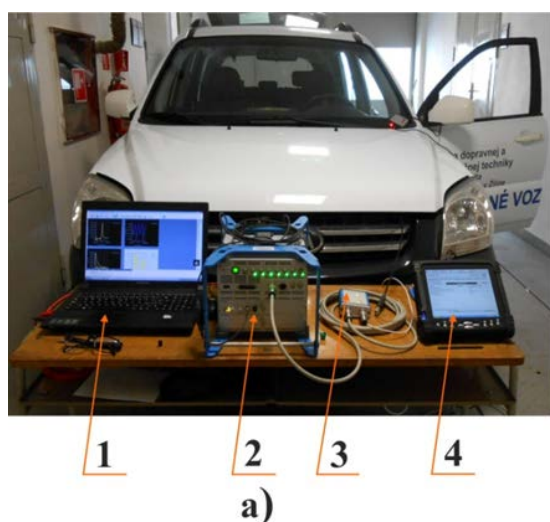


Fig. 2 a) Measuring equipment Kibox To Go: 1 – PC, 2 – Kibox To Go, 3 – converter, 4 – serial diagnostic, b) Vehicle on the brake test bench.

For the measurement was used Kia Sportage vehicle with a displacement of 2.0 l, power of 104 kW at 6000 rpm and torque 184 Nm at 4500 rpm. Brake test bench simulated load 1500N - 2000N. The measurement was realised on road vehicle with third speed gear. During the measurement rpm were change in range of 1000 – 5000 min⁻¹.

Indicated power of the individual measurements was determined from the indicator diagrams. For the measurement of indicated pressure was used special spark plug with pressure sensor – Fig. 3.

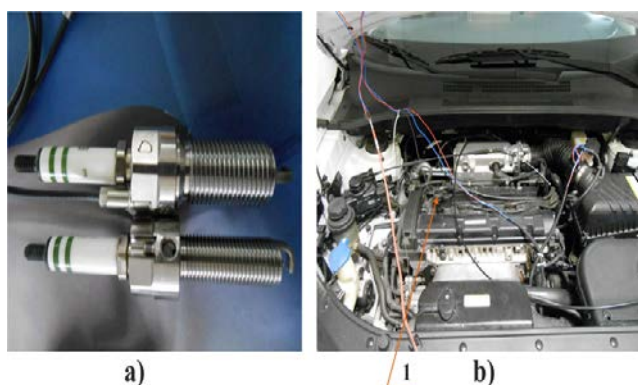


Fig. 3 a) spark plug, b) position of spark plug (1).

Measuring equipment make digital data recording of rpm of combustion engine, pressure of positive and negative area of indicator diagram, cycle count and the displacement in the dependence of crank angle.

In rpm range of 1000 – 5000 min⁻¹ was made record of one hundred cycles of combustion engine. Fig. 4 shows the real indicator diagram and developed indicator diagram from real measurement.

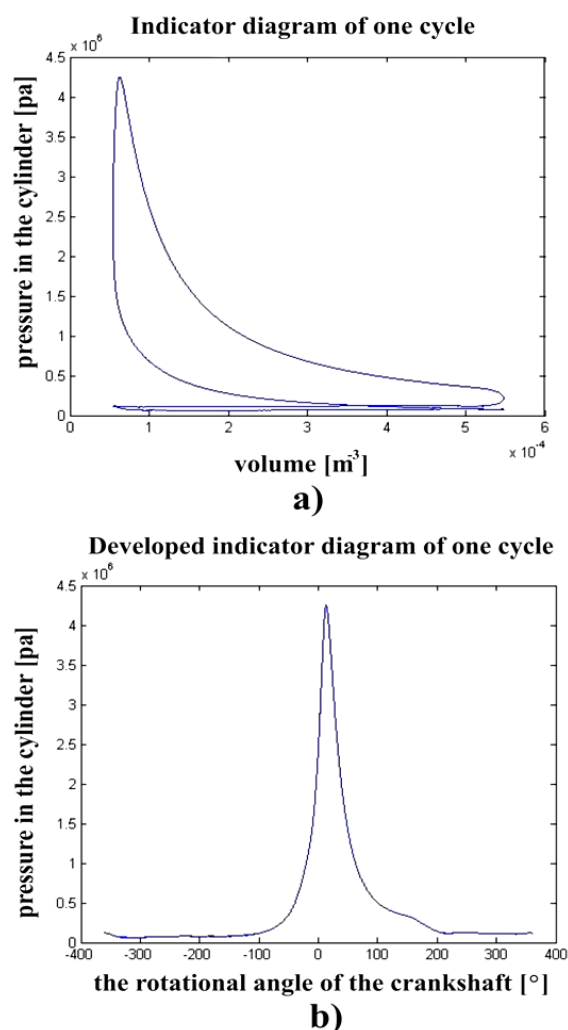


Fig. 1 Real diagrams – a) indicator diagram, b) developed indicator diagram.

The results of the measurements are graphics dependencies monitored parameters during the selected driving regimes of a road vehicle. In the tables 1, 2 are shown the values of the monitored operation parameters of a road vehicle.

Table 1: Measured values, third speed gear, load 1500 N

n (min ⁻¹)	p ₁ ⁺ (Pa)	p ₂ ⁻ (Pa)	p _{is} (Pa)	P _{il} (W)	P _{im} (W)	A _{i1} (J)
1000	719001	-20019	685990	2760	11040	34431
2000	753160	-34796	718360	5704,9	22820	35842
3000	778690	-49254	729430	9301,8	33720	36394
4000	823720	-63913	759800	12560	50239	37910
5000	842740	-84043	758700	15552	62208	37854

Table 2: Measured values, third speed gear, load 2000 N

n (min ⁻¹)	p ₁ ⁺ (Pa)	p ₂ ⁻ (Pa)	p _{is} (Pa)	P _{i1} (W)	P _{im} (W)	A _{i1} (J)
1000	925001	-11519	913452	4885	19540	45851
2000	958750	-26254	932500	8558,1	34232	46526
3000	981610	-41542	940070	12108	48433	46904
4000	999940	-54380	945560	14500	57998	47102
5000	1036900	-88720	948220	19682	78728	47310

n – rpm, p_1^+ – pressure of positive area of indicator, p_2^- – pressure of negative area of indicator, p_{is} – indicated pressure, P_{i1} – indicated power of one cylinder of the combustion engine, P_{im} – indicated power of the combustion engine, A_{i1} – indicated power

The indicated power of one cylinder and combustion engine was calculated from measured values in tables 1, 2 by using calculation formula 4. Figure 5 shows a comparison the changes in magnitude of pressure in positive p_1^+ and negative p_2^- area of the indicator diagram and indicated pressure depending on the rpm with various loads.

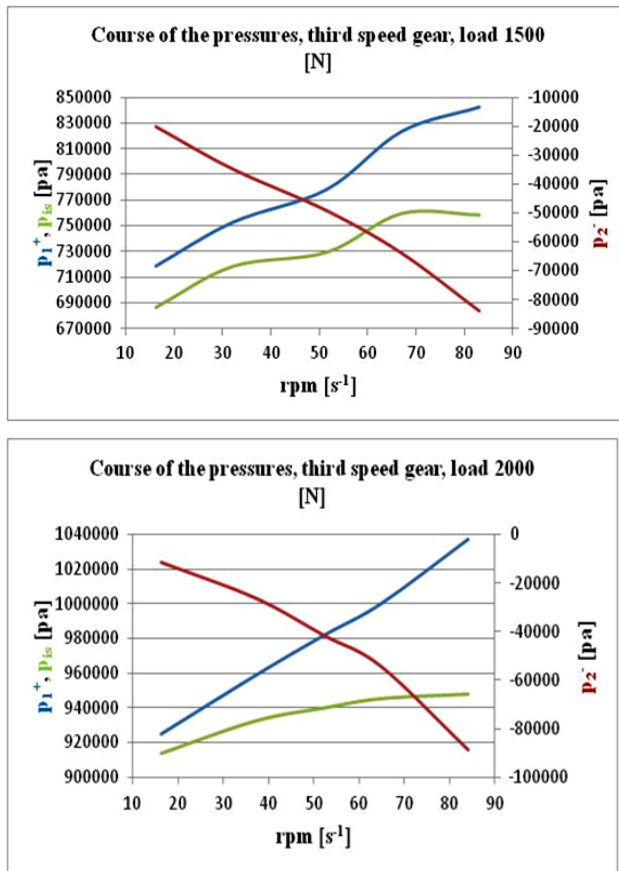


Fig. 5 The course of the pressures, third speed gear, load 1500 and 2000 [N], p_1^+ – positive pressure of the indicator diagram, p_2^- – negative pressure of the indicator diagram, p_{is} – indicated mean effective pressure

The change of load involves a change of a size of the individual pressures. The increasing of the load caused the growth of the individual pressures. The pressure in the cylinder and indicated mean effective pressure increasing too. Pressure dissipation increases with the increasing rpm of the combustion engine and with the increasing load due to increase in losses. Fig. 6 shows comparisons of changes of the indicated power P_{i1} of one cylinder and the entire P_{im} combustion engine with various loads.

By the measurement of mean indicated pressure is possible to identify power of accessory equipment of the combustion engine. It is no-load measurement. Indicated power equal the sum of effective power and losses power according to formula (5):

$$P_i = P_e + P_l \quad (5)$$

In this measurement $P_e = 0$ and $P_i = P_l$. Indicated power in this case equal to losses power of accessory equipment of the combustion engine. Table 3 show the measured values of indicated parameters. The courses of indicated parameters are shown in Fig. 7.

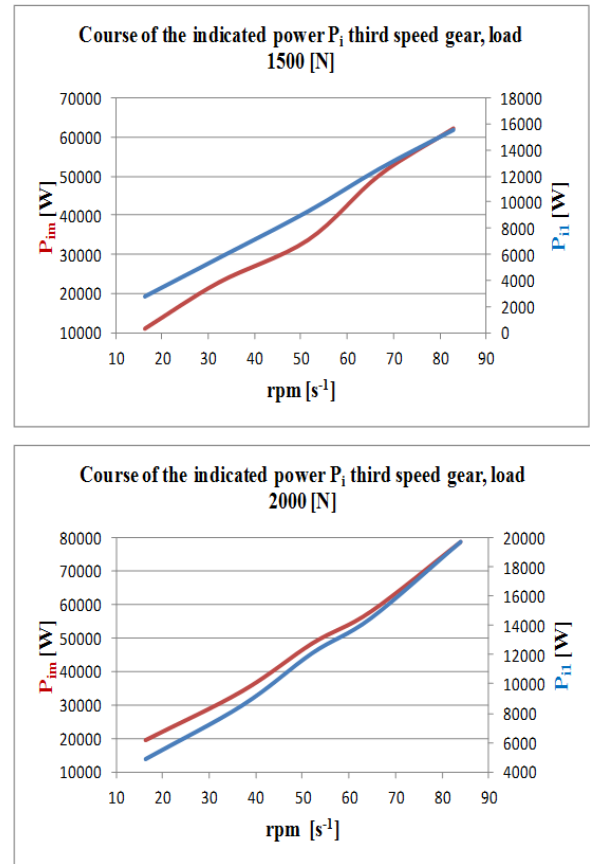
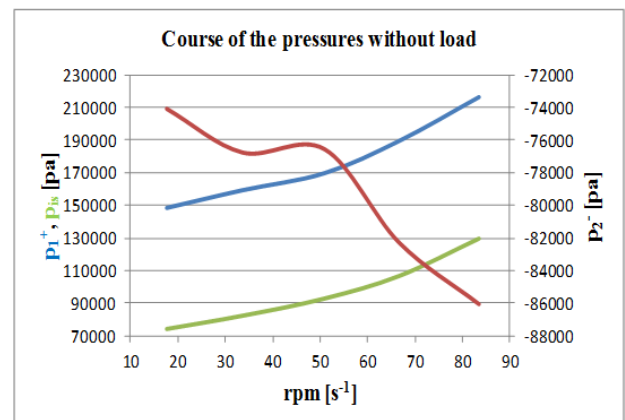


Fig. 6 The course of the indicated power, third speed gear, load 1500 and 2000 [N], P_{i1} – indicated power of one cylinder of the combustion engine, P_{im} – indicated power of the combustion engine.

Table 3: Indicated parameters in no-load measurement

n (min ⁻¹)	p ₁ ⁺ (Pa)	p ₂ ⁻ (Pa)	p _{is} (Pa)	P _{i1} (W)	P _{im} (W)	A _{i1} (J)
1000	148160	-74091	74071	324,7348	1298,9	3695,7
2000	158970	-76770	82204	684,5862	2738,3	4101,5
3000	169430	-76571	92856	1171,4	4685,8	4632,9
4000	189160	-82304	106800	1762,3	7049,3	5381,3
5000	215950	-86069	129880	2682,8	10731	6480,1



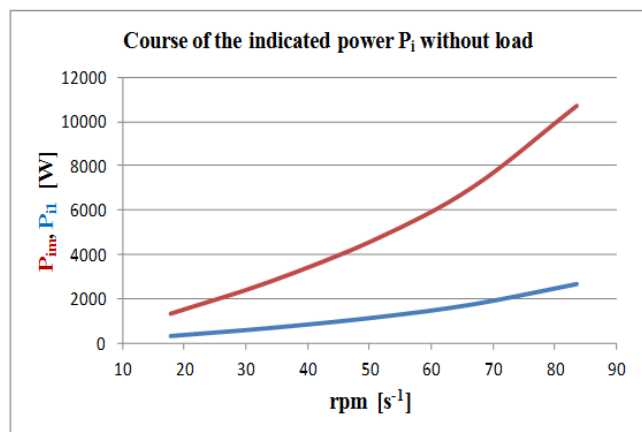


Fig. 7 Courses of indicated parameters in no-load measurement.

In series of experiment was made another measurement of indicated pressure during downhill driving. The power in this case equal to power that could be accumulated. Indicator diagram of downhill driving is shown in Fig. 8.

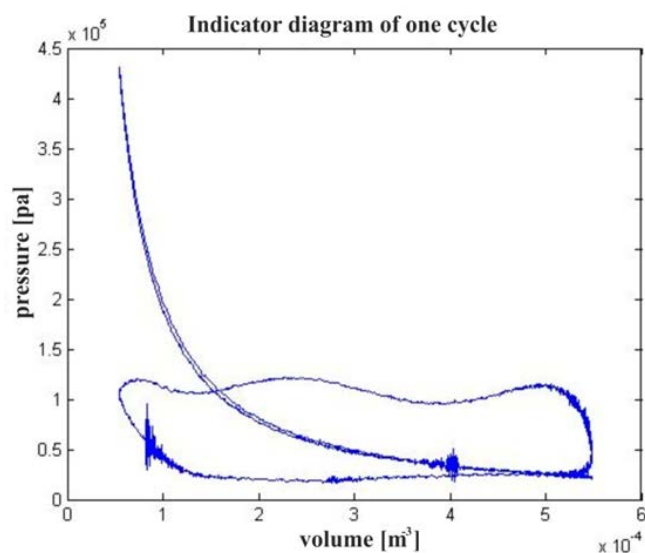


Fig. 8 Indicator diagram of downhill driving.

Conclusion

Measuring apparatus Kibox to go, that was used during a series of experimental measurements, offers a wide range of use. Apparatus allows the measurement of the pressures in the cylinder, measurement of the heat release, identification the beginning and end of combustion, TDC (top dead centre) identification, sensing the rotational angle of the crankshaft and others.

In addressing the issue of energy consumption of road vehicles is planned a series of measurements during the operation of a road vehicle in real traffic.

Acknowledgement

This contribution was created within the framework of the projects ITMS: 26110230107 supported by the Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic for EU Structural Funds.

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SIMULATIONS OF NONCONVENTIONAL DESIGNS WITH REGARD TO COMPRESSION ABILITY FOR USE IN STIRLING ENGINE

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Abstract: This paper deals with comparing three types of non-conventional mechanisms of Stirling engines [1]. It is a wobble yoke mechanism, a special type of wobble yoke mechanism and mechanism with ring. The mechanism with a ring was designed as another possible mechanism for structural design of wobble plate in projekt Nonconventional engine FIK –Stirling [2]. The aim is to compare the relative movement of two consecutive pistons in the Stirling engine system and thus evaluate the course compression that arises in one interconnected system of this engine. The paper deals with the dynamic simulation of these mechanisms. The dynamic simulations were made in Autodesk Inventor software.

Keywords: WOBBLE YOKE, MECHANISM, SIMULATION, DESIGN

1. Introduction

There is no need to use only the standard types of mechanisms, such as the Stirling engine in design of heat engines. Non-conventional mechanisms of heat engines replace in some areas of energetics and transport the classic crank mechanisms [3] [4]. Indisputable advantage of crank mechanism is its relative design simplicity. Amount of experiences with mathematical modeling and dynamic calculations of crank mechanism allows its optimization on the operating conditions [5]. Engines with non-conventional mechanisms may have several advantages when used in practice, but the design calculation model is often more difficult. Mechanisms of transforming linear reciprocating motion to rotary motion can be investigated in several aspects. These aspects are the suitability of the mechanism for given type of heat engine, advantage in terms of design size and location of individual components, etc.

In the power engineering industry, these unconventional mechanisms displace or completely replace the traditional conventional mechanisms.

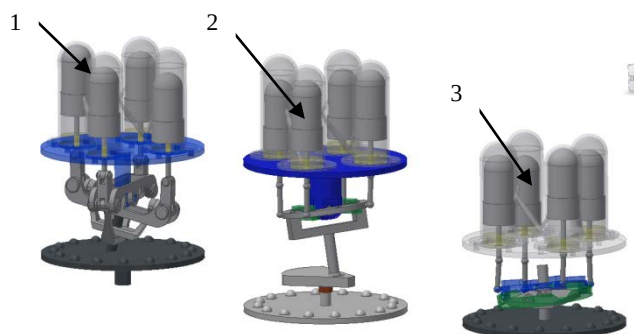


Fig.1 Virtual models of the nonconventional designs:
1-Whispergen- wobble yoke, 2-wobble yoke, 3- mechanism with ring

2. Description of the compared mechanisms

Models have been proposed for the design of Stirling engine with a double-acting piston. In the design of each compared types of mechanisms were specified the initial conditions. The models have the same strokes, the same length of connecting rods or ball joint segments (used in a mechanism with ring, and a wobble yoke), because the task was to compare the relative motion of the pistons one interconnected part and to show course of the these strokes per time unit. The initial conditions were determined with a view to achieving comparable graphically results.

Wobble yoke system:

The mechanism (details Fig.2, Fig.3) is designed so that the wobble plate 4 is allowed to circulate through the universal joint 7. The cross is attached to the fixed part 3 and the wobbleboard 4. Transformation of energy is further mediated through a ball joint 5 which is eccentrically attached to the output shaft.

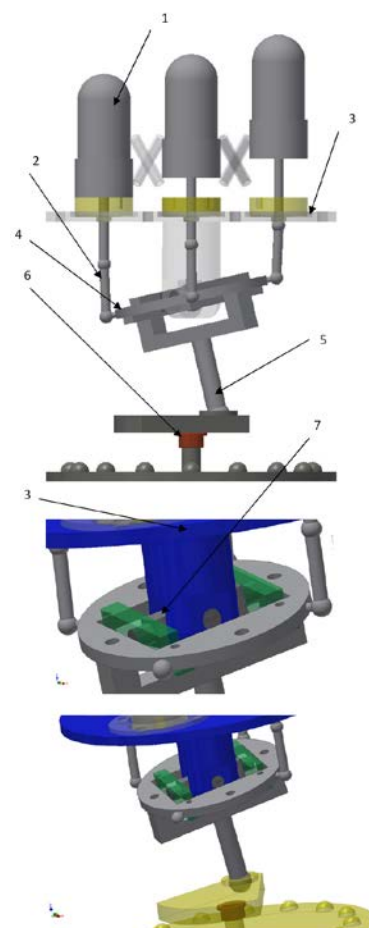


Fig.2 Model of wobble yoke: (general view- up, details of wobble board mechanism- down): 1- piston, 2- ball joint segment, 3- handle cylinders (fixed part), 4- wobble board, 5- shaft with ball joint, 6- bearing flywheel (fixed part), 7- cross joint

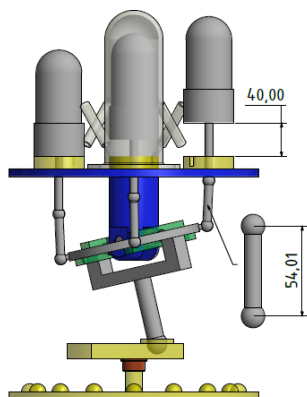


Fig.3 Model of wobble yoke mechanism- stroke and length of ball joint segment

Whispergen system:

This system (Fig.4, Fig.5) is designed so that each pair of opposite piston 1 is attached to its own joint mechanism (this is a universal joints 5), thus the whole mechanism is a double universal joint. Joint pins are attached to the fixed part 2 and the swinging arm 6. Transformation of the rocking motion to rotary motion is provided by swing arms (Fig. 4 position 6) fixed to the connecting segment (Fig. 4 position 7 and 8). Reciprocating motion of the pistons is transmitted through the connecting rods 3 and universal joints on the eccentric shaft which is fixed component part of the output shaft 4.

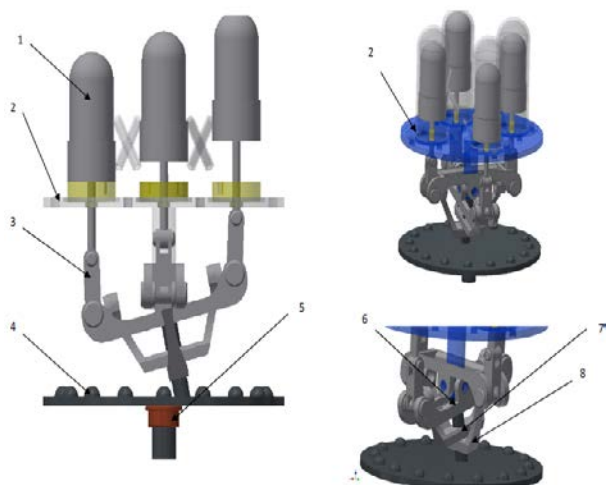


Fig.4 Model of whispergen wobble yoke mechanism: (general view-right side, details of wobble board mechanism-left side): 1- piston, 2- handle cylinders (fixed part), 3- rod, 4- shaft with flywheel, 5- bearing flywheel (fixed part), 6- swing arm, 7- upper connecting segment, 8- lower connecting segment

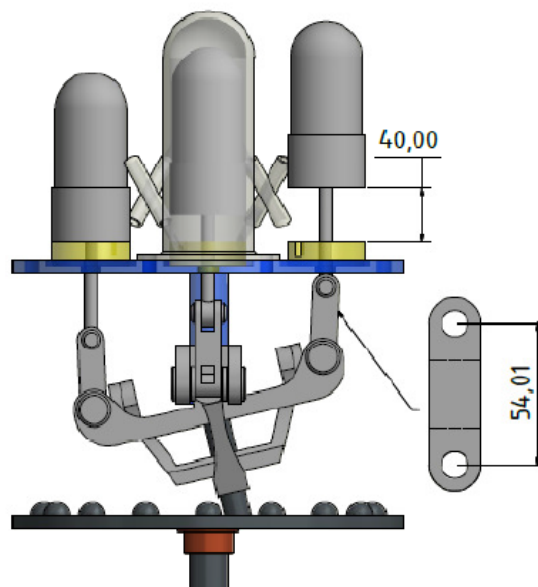


Fig.5 Virtual model of wobble yoke-whispergen mechanism- stroke and length of rod

Mechanism with ring:

This mechanism was designed as another possibility in case the mechanism of floating plate. In that case serves against concurrent rotational movement of a wobble board 3 along with crankshaft ring 4 (shown in green), the axis of the pins must intersect point (intersection of the axes) crankshaft. Ring pins are fixed to the fixed plate 6 and on the wobbling plate 2, thereby allowing the board to perform a rocking motion, which is transformed into rotary motion by means of a cranked shaft 5.

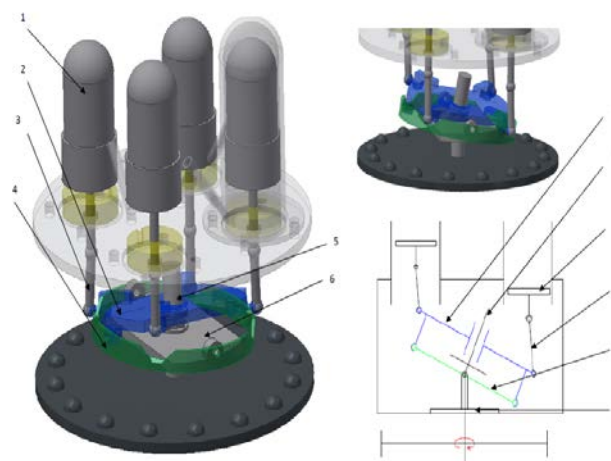


Fig. 6 Design of mechanism with ring (general view right side, details of mechanism and scheme- left side): 1-piston, 2-wobble plate, 3- ball joint segment, 4- ring, 5- shaft, 6-fixed plate

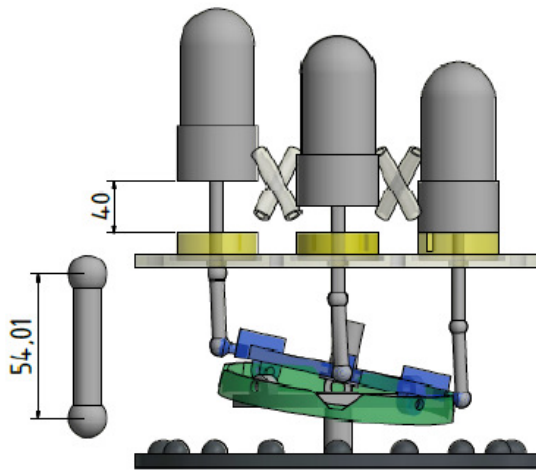


Fig.7 Virtual model of mechanism with ring- stroke and length of ball joint segment

Virtual models used in the simulations were simplified, but these models are sufficient to evaluate the desired issue. Dimensional images with parameters such as the length of piston stroke and connecting rod, ball joint etc. were generated using the CAD software.

3 Results

The simulations were made in Autodesk Inventor. Simulations were set for one revolution. It means that the graphs show the course for one working cycle of one pair of pistons. The relative movement of the pistons was compared.

Setting of dynamic simulation parameters:

- angular velocity of the shaft 10 deg. sec^{-1}
- simulation time- 36 sec

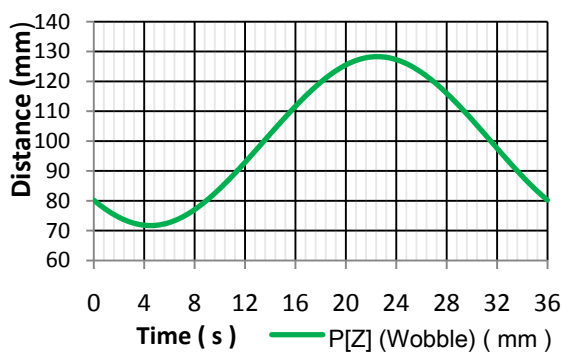


Fig.8 Course of the relative movement - Wobble yoke system

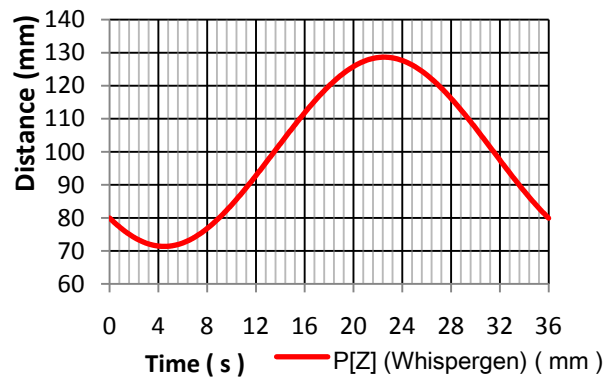


Fig.9 Course of the relative movement- Whispergen system

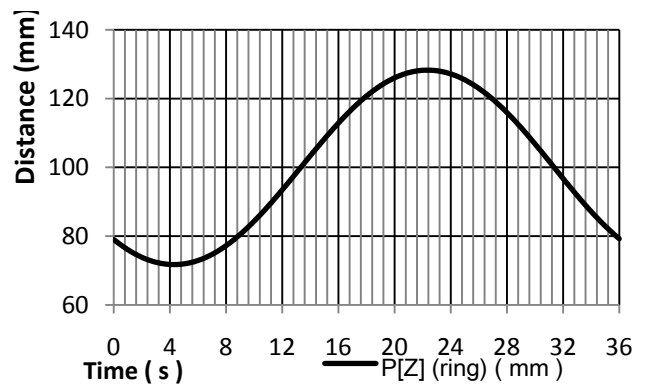


Fig. 10 Representation during the relative movement - Mechanism with ring

4 Conclusion

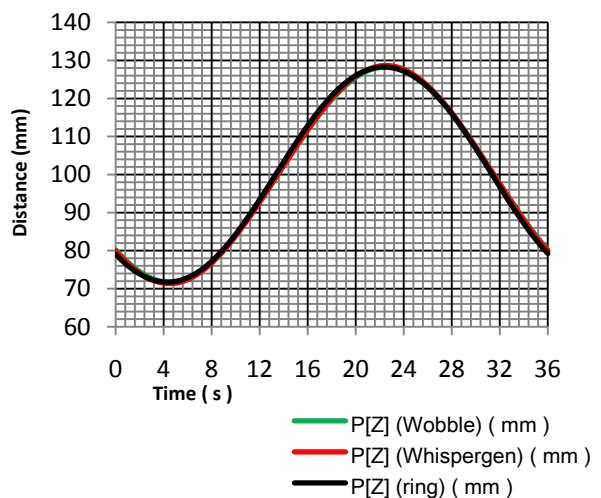


Fig.11 The comparison of relative movement courses

The resulting graphs were imported from Autodesk Inventor to Microsoft Excel. Fig. 11 shows the course of all three types of

engines. It can be seen only small deviations in courses of compression, transfer and expansion stroke. Models of wobble yoke and whispergen-wobble yoke have the same course. The mechanism with ring slightly deviates from them. From this comparison it can be said that the model with ring, which has been constructed so far only in virtual form, is suitable as an unconventional mechanism for Stirling engine design. Since the deviations of the piston movement courses are negligible, we can conclude that all three types of monitored models are in terms of heat transfer, respectively thermodynamics equivalent.

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Acknowledgement

This contribution was created within the framework of the project VEGA 1/0482/11 Stirling engine with non-conventional FIK mechanism, which is supported by the Ministry of Education of Slovak Republic and within the framework of the project ITMS 26110230117 Support of education quality and human resource development in the field of technical research and development in the area of modern knowledge society.

IMPACT OF RAILWAY INFRASTRUCTURE PARAMETERS ON SAFETY OF GOODS TRANSPORTATION BY RAILWAYS

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Abstract: *It is important to load and fix goods in railway wagons in well done way to reduce the number of accidents on the railway. The bad way of loading and fixing of the goods in the railway wagons can bring a very dangerous results as a damage of the transported goods or accident of the train. This paper deals with the analysis of the railway infrastructure parameters which affect the well done way of loading and fixing of goods in railway wagons.*

Keywords: LOAD, FIXING, GOODS, RAILWAY INFRASTRUCTURE, PARAMETERS, SAFETY

1. Introduction

The basic rules for loading and fixing of goods in railway transport are Regulations UIC. Their application ensures operational safety and avoids damaging of transported goods and wagons. Consigner of sent goods is responsible for the observance of the rules. If the provisions of regulation directives are not respected, railway operators are entitled to not accept the shipment for transportation. Rules of regulations are valid for international as well as for national transportation. They are the higher legal standard than the operator's transport rules and the lower legal standard than laws. Operator's transport rules have to accept loading and fixing rules of regulations. Therefore their knowledge and application is a prerequisite to make good contract of goods transportation and safety transport. Railway operators may also use their own, supplemented and modified rules (examples of loading), which in their entirety may or may not be mandatory for all railway undertakings.

2. Loading regulations

Loading regulations were issued by the International Union of Railways (UIC) and are applied since the 1st January 1999. They were issued in UIC official languages - French, German and English but there are also national translations. For example holder and the main responsibility of loading rules in Slovakia is Railway Cargo Company of Slovakia, Inc. About 20 changes were received till today and range of rules is about 350 pages.

Loading directions consist of three volumes:

- Volume 1: Principles - contains binding principles that must be followed by fixing and loading of goods.
- Volume 2: Goods - provides methods for loading different types of goods which correspond with principles of Volume 1 or which have been developed on the basis of practical tests.
- Volume 3: Line category - contains information about the railway lines of UIC stakeholders. They are currently published on the website of the UIC (LOCA).

3. Rules of loading and fixing of goods

Nature of the goods, the technical characteristics of the wagon and used railway line must be taken into account at the time of loading. The railway operations may not be endangered by:

- bad stowage of goods,
- bad location of goods gravity center,
- the effect of wind, ice and snow on the loading ramp or goods etc.

Therefore the goods must be stably stored and fixed against raising, falling, sliding, rolling off and overturning not only in the longitudinal as well as in transverse direction. At once the goods may not be damaged by its mounting and fixing. There

are used walls, side walls, stanchions and integrated locking devices in wagons to fix goods. Side walls and stanchions are therefore fundamentally bring into the active position. If this is not possible, for example transported goods exceed the width of the wagon, the goods must be fixed with the consent of the sending railway undertaking by the special fixing devices. In this part of the direction there is loading and fixing of the goods dividing by the various kinds of goods:

- goods loaded freely and disordered,
- bulk goods,
- compact or rigid mounting,
- loading with mass displacement in the longitudinal direction,
- goods that can roll,
- goods that can be inverted,
- stacked goods,
- goods loaded on more than one vehicle,
- solid loading units,
- flexible loading units.

If a new way of goods loading is used it is necessary the security of loading proved:

- in the longitudinal direction of the wagon by the crash tests based on the corresponding table,
- in the transverse direction of wagon by the driving tests or by the tests on a test stand.

Safety of railway operation must be always guaranteed in each case.

4. Basic parameters

There are several parameters which could affect safety and quality of goods transportation by railway transport. They could be divided into two categories of parameters:

- track parameters,
- train parameters.

The basic track parameters are:

- number of the track lines,
- track speed limit,
- traffic signaling system,
- track leaning ratios,
- minimum curve radius,
- track resistance (slope, curvature, crossovers, tunnel).

The basic train parameters are:

- load capacity (per axle, per usual loading meter),
- maximum train weight,
- maximum train length (in meters, in number of the axles),
- train driver (driving style, driver skills),
- pull force of the locomotive engine (indicated, circumference of the drive wheels, at coupler, adhesion),

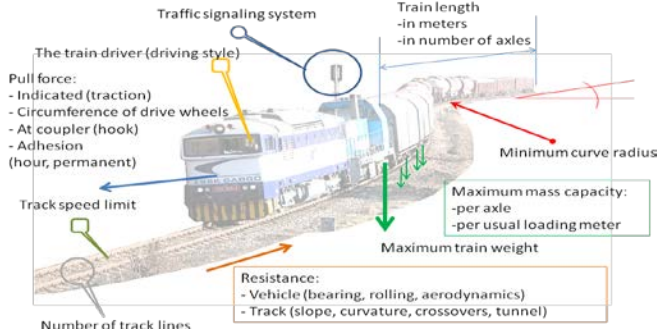


Fig. 1 The track and train parameters

5. Dependence of the observed indicators on changes of the railway infrastructure parameters

Description of the main parameters, which are necessary for the railway transportation:

- minimal transport time ($T_{\min}$):
 - maximum of the track speed limit ($V_{\max}$),
 - minimum of the track curve radius ($r_{\min}$),
- maximum capacity ($n_{\max}$):
 - number of the track rails (TR),
 - minimum of the track curve radius ($r_{\min}$),
 - maximum of the track speed limit ($V_{\max}$),
- maximum capacity of the transported wagon units per track relay (N_{wu}^T):
 - number of the track rails (TR),
 - minimum of the track curve radius ($r_{\min}$),
 - maximum of the track speed limit ($V_{\max}$),
 - maximum track mass capacity ($M^{\max}$),
 - maximum train length ($L_{tr}^{\max}$),
 - maximum number of axles ($N_{axle}^{\max/tr}$),
 - maximum train weight ($M_{tr}^{\max}$).

6. Relationship between transport time and infrastructure parameters

If we simplify the train drive just to a drive with a fixed speed and zero acceleration, then the travel time is proportional to the train passed distance and inversely proportional to its maximum speed.

$$T_{\min} = \frac{l}{V_{\max}} \quad (1)$$

Then we can calculate the travel time for each track section and the total travel time on the passed track by adding the partial travel times.

$$T_{\min}^T = \sum T_{\min}^i \quad (2)$$

In the curve ride with the radius r (m) by a fixed speed v ($m.s^{-1}$), we must add also the centripetal force to the tractive force acting in the same direction as the curve tangent (Majerčák, J. et al. 2008). The centripetal force is directed into the curve center and it makes the trajectory curvature. Then the dimension of the centripetal force is:

$$P = \frac{m.v^2}{r} \text{ [N]} \quad (3)$$

This force causes the vehicle response, which is equal to the size of the centripetal force but has the opposite direction – centrifugal force. This force is reflected at the railway vehicle on its wheel flange and gives the vehicle curvilinear movement. The centrifugal force and the vehicle weight together make the resultant into three typical aspects:

- resultant cuts the drive plane in the middle of rails – the equivalence is stabilized,
- resultant cuts the tangent point between the vehicle wheel and head of the rail – the equivalence is labile,
- resultant cuts the drive plane in general out of the rail track – the turnover of the vehicle:
 - inside the curve – the track camber is abnormally high,
 - from the outside of the track – the camber is abnormally low.

For the smooth curve ride and also the stabilized vehicle ride position we must eliminate the negatives of the centrifugal force effect:

$$\sin \alpha = \frac{P}{s} \quad (4)$$

The dimensions of the superelevation can be figured out of the resultant of the vehicle gravity and the centrifugal force which is perpendicular to the drive plane and axis of it. The pressure on the rails is the same.

The resultant R consists from centrifugal force P and the gravity force ($G=m.g$) which acts on the ride plane.

$$\tan \alpha = \frac{v^2}{g.r} \quad (5)$$

The angle α can be described also from the range of the liaison circles of the wheel set and the superelevation

$$\sin \alpha = \frac{P}{s} \quad (6)$$

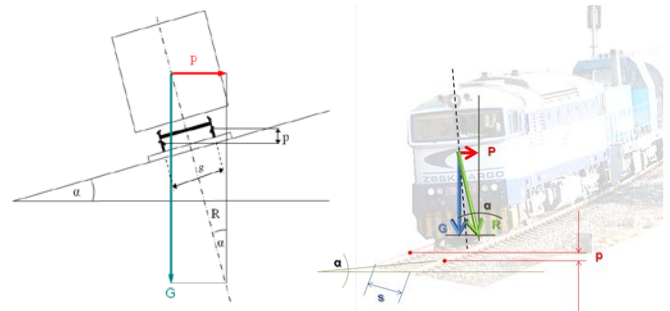


Fig. 2 The superelevation of the track in the curve (left: ideal situation; right: common situation)

Because the dimensions of angle α are too small, it can be written with the sufficient accuracy $\sin \alpha \approx \tan \alpha$ and then

$$\frac{p}{s} = \frac{v^2}{g \cdot r} \quad (7)$$

from this situation, the superelevation is

$$p_i = \frac{s \cdot v^2}{g \cdot r} \quad (8)$$

For the railway needs better suits the using of the superelevation in mm and the speed in $km \cdot h^{-1}$.

We can describe this superelevation as theoretical and we mark it p_t . The theoretical superelevation is used for the ideal situation – all the trains travel at the same speed. Generally the trains don't ride at the same speed, however, so this equation must be transformed (slower trains can damage the lower rail in the curve superelevation). The transformation is made multiplying with $\frac{2}{3}$.

This superelevation can be denoted as normal and sign it p_n .

$$p_n = \frac{2}{3} \cdot \frac{s \cdot v^2}{g \cdot r} = \frac{2}{3} \cdot \frac{s \cdot \frac{3,6^2}{9,81 \cdot r}}{g \cdot r} = \frac{2 \cdot s \cdot v^2}{381,41 \cdot r} \quad (9)$$

The superelevation of the curve rails can be stated by each country on its own decision. That's why we can count the maximum speed in the curve ride in the general conditions

$$p_n^{\max} = \frac{2 \cdot s \cdot v^2}{381,41 \cdot r_{\min}} \Rightarrow v_{\max}^T = \sqrt{\frac{381,41 \cdot r_{\min} \cdot p_n^{\max}}{2 \cdot s}} = 13,81 \cdot \sqrt{\frac{r_{\min} \cdot p_n^{\max}}{s}} \quad (10)$$

Maximum (theoretical) volume of the capacity is proportional to the calculated time and inversely proportional to the occupation time of the track per one train.

$$n_{\max} = \frac{T}{t_{\text{occ}}} \quad (11)$$

The resulting track volume capacity is given by the volume of the capacity of the constraining section (it is the section with the lowest capacity)

$$n_{\max}^T = \min \{ p_{\max}^i \} \quad (12)$$

7. Comparative indexes

The logistics performance index (publish by World Bank) is composed by 6 pillars. The second one is infrastructure. The infrastructure means in this case – quality of infrastructure based on evaluation of the quality of trade and transport related to infrastructure in country. The quality of infrastructure shows situation in each country in ports, airports, roads, rails, warehousing/transloading facilities and telecommunications and IT. The global competitiveness index framework is based on three sub indexes – the basic requirements, the efficiency enhancers and the innovation and sophistication factors. Those three sub indexes can be split deeper into 12 pillars, 4 pillars are required for basic, 5 pillars for efficiency and 2 pillars for innovations. The second pillar in sub index basic requirements is infrastructure. The infrastructure pillar is calculate by ranking of quality of overall infrastructure, quality of roads, quality of railroad infrastructure, quality of port infrastructure, quality of air transport infrastructure, available airline seat kilometers, quality of electricity supply, mobile telephone subscriptions and fixed telephone lines. The Global innovation index is composed by two sub indexes (innovation input and innovation output). Innovation input is based on five indicators. The third one is infrastructure which consists from ICT, energy and general infrastructure. Three global comparative indexes which show competitiveness in different type cases use one very similar indicator – the infrastructure. This indicator is compiled three times but every time by different procedures. The result from this comparison is knowledge that infrastructure is very important

for each country for own development and international competitiveness.

8. Decisive infrastructure parameters

Every infrastructure is a system of components – energy supply network, communication network, system of safety devices and tracks (paths, roads, waterways, pipelines, airways). Each parameter from those main systems influences final product of transporters/carriers (Gogola, M. 2005). Carrier can offer services just in size which enable the infrastructure parameters in each country. Carrier's services are different for example in provided feeder systems, payment system possibilities, the highest measure/ volume/ size of one package (consignment), 24 day services, distribution system, delivery system, time of delivery etc. The resulted quality of performed service is directly depended on the real time situation on infrastructure, its current operation parameters and limits for different type of reasons.

The railway infrastructure parameters which are directly connected to quality of provided services are:

- Type of locomotive (pull forces of locomotive engine – indicated, circumference of the drive wheels, at coupler, max. adhesion forces), type and system of driving, driving style, drivers experiences;
- Number of track lines, track speed limits, traffic safety system, track leaning ratios, minimum curve radius, track resistance (slope, curvature, crossovers, tunnels);
- Loading capacity (per axle, per usual loading meter), maximum train weight, and maximum train length (in meters, in number of the axles).

More about infrastructure parameters can be found in (Kendra, M., Babin, M. 2012) and (Kendra, M., Babin, M., Barta, D. 2012).

9. Dependence between railway infrastructure parameters and quality of provided services

Dependence between railway infrastructure parameters and quality of provided services can be explained with following example. Consignee and also consignor expected high quality service – compliance of delivery time (on right time), right volume (mass/ pieces/ etc.), right place (door2door/ freight village/ etc.) and fair prices (Nedeliaková, E. et al. 2013). Fair prices depends on many factors – especially energy consumption, volume efficiency – unit costs. Delivery time is depending on traffic schedule, real time traffic management, train ride, operational problems, working (building) shutdowns and others. Right volume (mass...) is close depending to efficiency (economic, energetic) – but shipper requirements are usually not in conformity with carriers requirements (unit parameters) – feeder and delivery system problem. The efficiency problem is also closely connected to vehicle and track path (route) parameters (loading capacity – track/ vehicle, minimum curve radius, track leaning ratios, track speed limits etc.). Most of these parameters depend on right type locomotive (carrier's ownership) with well experienced driver. Conclusion for this part is knowledge that quality of transportation services is closely depended to infrastructure parameters, which means direct impact to country competitiveness in global market.



Fig. 3 Stress analysis

10. Conclusion

Loading of goods onto railway freight wagons and its fixing is a very important issue, which is directly related to protection of the transported goods, saving lives endangered by accidents, safety of operations and also the economic and commercial interests of the carriers. The proposed solution and additional information is useful for railway transportation and elsewhere as well. One of the most important areas of implementation is the transportation of dangerous goods (flammable, explosive etc.) and prevention of danger by clear information how to load and fix the goods. The result of LOADFIX project will be a powerful information tool based on universal international data warehouse. It will allow a structured approach to complex data on goods loading. It will provide structured and up-to-date info for managers, staff and the professional public. It is especially intended for the employees of the carriers who deal with the issue of how to load and secure the cargo safely and economically. The info will also be useful to the professionals who deal with the method of storage and fixing (safeguarding) of cargo in the vehicle as a part of their job, particularly the specialists and institutes dealing with transportation such as sales agents, staff of non-standard shipment services and security advisors. Furthermore, the data is especially to be used by the operations staff who carries out the activities connected with handover of shipments and cars from the carriers and the inspections of the vehicles and goods during transport – wagon master, transport workers, transport warehousemen. It mainly covers inspection of storage and securing of goods during loading and the subsequent care of the transported goods during transport.

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This paper is prepared with the support of the project EUREKA E!6726 LOADFIX and Ministry of Education, Science, Research and Sport of the Slovak Republic.

NON-DESTRUCTIVE TESTING OF SURFACE DEFECTS BY RAYLEIGH WAVE

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Abstract: *Transit of surface waves through defects in steel surfaces has been viewed in this paper. The form of registered signal is changing as result of complex wave processes in the area of defects. The received signals are digitized and phase-spectral analyses are have been made. If there is a defect in the surface of the samples it shifts the phase of the Rayleigh wave. The phase shift depends on the size of defects. The results obtained can be used for the creation of innovative technologies with improved resolution for testing of surface and subsurface defects in the practice of non-destructive testing.*

Keywords: NON-DESTRUCTIVE TESTING OF SURFACE DEFECTS, SURFACE WAVES, PHASE SIGNAL ANALYSIS

1. Introduction

A surface and subsurface discontinuity testing in elastic structures is a traditional problem in the practice of ultrasonic NDT. Usually, the method of reflection of a wave from defects has been used, because by using the method of transmission there is no significant alteration of the basic informative parameter – wave amplitude – it is in the range of 2 – 4%. The roughness after the mechanical processing further impedes interpretation of results [1, 2]. There is an admission in [1] issued on the base of experimental investigations that when the wave pass trough a cylindrical and spherical discontinuity, it disperses. The sources of dispersion are two: close to the surface and at the bottom of discontinuities.

Nowadays a digital transformation of signals is applied for creation innovative NDT technologies. Informative of NDT parameters increases in order to improve resolution and precision of measurement. The phase of wave is increasingly introduced as a parameter for evaluation of current situation of elastic structures when concrete problems are solved. [3].

Aim of this paper is to present theoretical and experimental investigation of Rayleigh wave signal change when pass trough surface and subsurface defects and to suggest additional diagnostic informative parametr for practical implementation in NDT.

2. Theoretical study of the problem and justification

The spreading of the surface wave in elastic body is presented in [1, 2]:

$$4.k^2.q.s - (k^2 + s^2)^2 = 0 \quad (1)$$

where $q^2 = k^2 - k_l^2$ и $s^2 = k^2 - k_t^2$. Here k , k_l и k_t are the wave numbers, respectively, on the surface, the longitudinal and transverse waves in the body. The energy density of the wave in the depth z is determined by the expression [1]:

$$\bar{E} = \frac{A^2 \rho \omega^4 c_t^2}{2c^4} [A_1 \exp(-2.q.z) - A_2 \exp(-(q+s).z) + A_3 \exp(-2.s.z)], \quad (2)$$

where , $A_1 = 4 + \eta^2 - 4.\eta^2.\xi^2$,

$$A_2 = 2\sqrt{1-\eta^2.\xi^2} \cdot (\sqrt{1-\eta^2} + \sqrt{1-\eta^2.\xi^2}) \cdot (2 + \eta^2 + 2\sqrt{1-\eta^2} \cdot \sqrt{1-\eta^2.\xi^2}) / (2 - \eta^2),$$

$A_3 = 4 \cdot (1 - \eta^2.\xi^2) \cdot (4 - 3.\eta^2) / (2 - \eta^2)^2$ are mathematical excretions, $\eta = k_t / k = c / c_t$, $\xi = k_l / k_t = c_t / c_l$. Here c , c_l and c_t are the speed of propagation, respectively, of the surface, longitudinal and transverse waves ($k = \omega / c$, ω is the angular frequency).

In fig. 1 a) is shown a dependence, calculated by (2) for the average density of wave energy from the relative depth z/λ of spreading in a sample of low carbon steel. The energy is unevenly distributed in the depth of the layer. For example, 90% of wave energy passes trough a layer with relative thickness $z/\lambda = 1$. The

entire wave energy is distributed in a layer with relative thickness $z/\lambda = 1.6$. In Fig. 1 b) numerical simulations are shown for the attenuation of the amplitude of the surface wave when cylindrical whole with diameter in the range 1 – 7 mm and depth 1 mm in the still sample is available. These results are obtained for wave width 10 mm. In the practice of non-destructive testing is accepted the uncertainty of attenuation of the probe-sample boundary is within 0 - 3 dB and that means the minimal detectable diameter of the cylindrical hole is 5 mm.

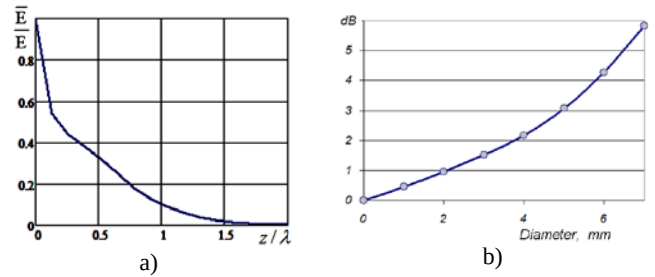


Fig. 1 Simulation study of: a) - average energy density of the wave in the relative depth z/λ ; b) - change the registered amplitude due to the presence of a cylindrical hole whit diameter in the range 1 – 7 mm.

3. Experimental study

Experimental studies of the surface of the signal wave passing through a rough-milled steel samples having a thickness 8 mm were carried out (see Fig. 2 a). Artificially discontinuities in the shape of cylindrical openings and channel-shaped are produced in some of the samples. The holes have a depth 1mm and diameter 2 mm, and end with a right cone with a central angle 120° (depth 0.6 mm). The total length of such discontinues are 1.6 mm. They are formed perpendicularly to the surface in one or two rows (depending on the number of holes, the maximum number in a row is 3) with distance $a = 4.5$ mm. The ultrasonic sensors are positioned symmetrically to the holes when experiments have been carried out. The channel has a width 3 mm and elliptic shape in cross-section, gradually changing depth from 0 to 0.3 mm and is disposed at an angle 30° in relation to the direction of wave propagation. A study in a section of a brake disc from a car with delaminated subsurface and visible cracks has been carried out. The defects are derived during normal operation of the part due to sudden temperature changes like heating and cooling. The surface deviations that were tested are described in Table. 1.

Table 1. List of tested discontinuities

Deviation №	Type of discontinuity
1	A cylindrical hole, 1 pc.
2	A cylindrical hole, 3 pc.
3	A cylindrical hole, 6 pc.
4	Channel with variable depth
5	Brake disc with delaminated subsurface and visible cracks

The experimental results were recorded by digital flaw detector of LECOEUR ELECTRONIQUE SARL, working with a PC via USB interface. The surface wave is excited and registered by

sensors with rectangular plate with width 10 mm, nominal frequency of 4 MHz and a real resonance frequency 3.81 MHz, determined by spectrum analysis of recorded signals by flaw. The velocity of the surface wave is measured 2923 m/s, which determines $\lambda = 0.77$ mm and layer thickness for distribution within 1.23 mm.

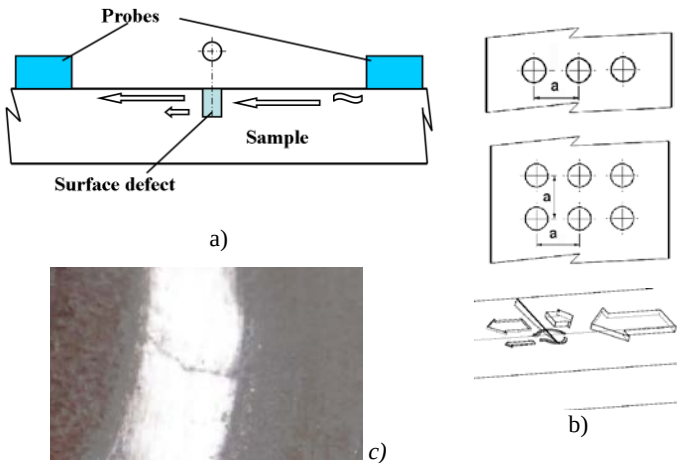


Fig. 2. Experimental setup; a) - scheme of the experimental study; b) samples with artificial discontinuities; c) - delaminated subsurface and visible cracks in the brake disc.

Series of experiments with laboratory samples have been organized and implemented and images of signals, taken at the same reference distance $L = 55$ mm between the probes, and at a constant adjustment of the flow detector scale have been received. The probes were removed from the samples and offset from the surface deviations after each measurement. The experiments have been organized so that (1) the signal level is approximately 80% of the height of the screen; (2) probes are pressed with a constant force to the samples and (3) sufficient contact lubrication in order to ensure a better comparability of results. A compensation for acoustic attenuation due to different deviations within 0-2 dB has been noticed. It is remarked that the attenuation of probe-sample boundary were significantly more. The images are compared by the photo overlay and using labels/markers that are part of the detector software.

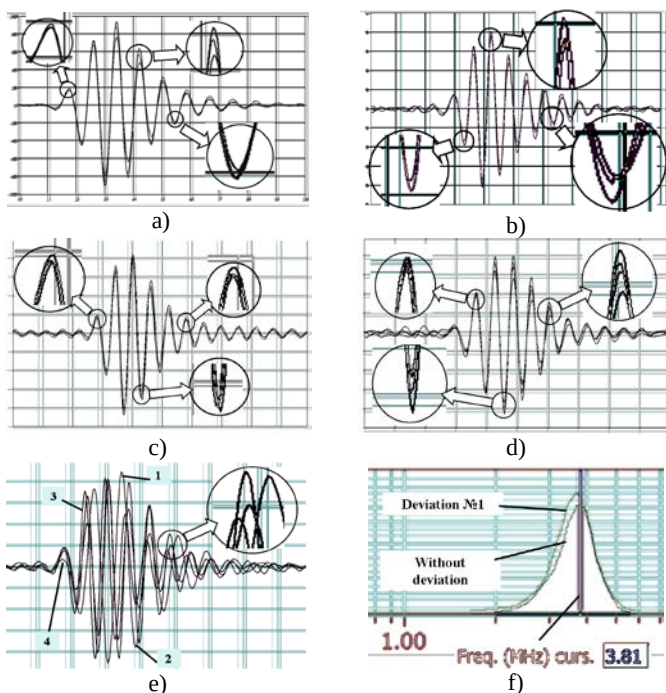


Fig. 3. Experimental results of the signal at a different deviation; a) - without deviation; b) - deviation № 1; c) - deviation e № 2; d) - deviation № 3; e) - comparison of the signals; f) - comparison of the spectra.

Some results of the comparison of the signals obtained when the waves propagate on surfaces without and with deviations № 1, 2 and 3 are shown in Fig. 3 a) - d). The signals were recorded at different distances between the probes and the deviations. There is no significant dispersion of signals from studies of identical discontinuities. The existing deviation is likely due to imperfections in the machining and different positioning. A comparison of the signals in the above is shown in Fig. 3 e). Here there is a significant deviation between signals recorded under different conditions. Here 1 refers to the wave without surface deviation and with 2, 3 and 4 - the deviations №, respectively, 1, 2 and 3. There is coincidence at the beginning of all the signals, however at the end of the signal there is some dissipation. This fact can be explained by interference of two waves: the first (main) passed through the discontinuity, it has a major share of the signal amplitude; and second: the scattered wave from the surface of discontinuity. When there is a deviation, then the signal is longer. This is an indication of an increase in the propagation path of the second wave as a result of the geometrical characteristics of the deviation. A comparison between the spectra of the signal from the sample without defect and signal from the sample with deviation № 1 is shown in Fig. 3 f). The spectra were obtained using the built-in the flaw detector software after digital filtering and maintaining a constant level of amplitude. There is a shift of the spectrum. A clear deviation in the resonant frequency of the wave can not be taken into account visually. Similar results were obtained by comparing the spectrum with other deviations.

A comparing the test result with deviation № 5 is shown in Fig. 4 a). There is increasing of duration for wave propagation through the deviation within a $0.088 \mu\text{s}$. Therefore, there is an increased equivalent length of the wave path (the calculated increase of the length is in the range 0.26 mm). In the Fig. 3 b) the images of the signals are superposed on each other by shifting, so to obtain complete coincidence of the beginning of the signal. Similar to the previous results, an increase of the duration of the signal is remarked (an increase in the duration of $0.037 \mu\text{s}$ is noticed, which corresponds to the extension of the path of the dispersed wave 0.109 mm). These facts can be explained again with dispersion of the surface wave from the wall of the discontinuity and interfering with the base wave.

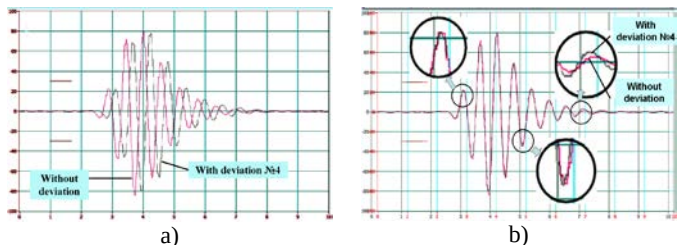


Fig. 4. Comparison between experimental results from a study of deviation 4 after positioning; a) - at the time; b) - at the signal beginning.

A study of surface and subsurface stratifications in the brake disc is shown in Fig. 5. Some rough unevenness in the surface are cleaned in advance. A significant dissipation of the waveform due to the influence of the roughness has been found. The measurements were carried out in reference distance between the probes 17 mm. A significant compensation (about 60 dB) of losses in the layer between surface and probes (in comparison with measurements with laboratory samples) has been made. There is good agreement in the beginning and some deviation at the end of the signals. There is some deviation in the signal spectrum because of surface cracks and stratifications.

It is appropriate an additional informative parameter for testing of discontinuity to be formulated on the base of experimental results obtained by study of signal change when the surface wave pass through artificial and natural discontinuities. The discontinuity causes partial wave dispersion. The scattered wave and the passed wave have equal speed. The both waves interfere and it changes the signal form. The registered signal carries information for both waves, including for the passed length of the scattered wave by its phase shift. Therefore, it is appropriate that the phase shift of the

surface wave after the discontinuities to be used as a further data parameter for testing.

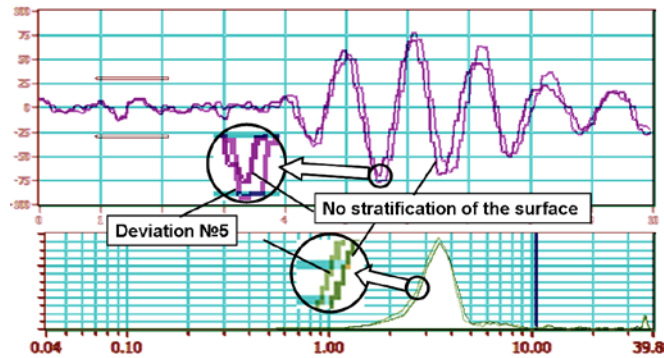


Fig. 5. Experimental results comparison in the study of unventilated car brake disc.

4. Modification of the phase of the wave if there is discontinuities

The obtained experimental data on wave signals are digitized using software. The number of points of sampling is within 126-256. In Fig. 6 a) is shown an example for the digitization of the registered signal wave. The digitized signals are processed by an algorithm, as shown in [3], in order to obtain the phase of the waves by means built-in the software MathCAD functions spectral analysis as directed in [4]. The specters are compared by superimposing of images by samples without and with surface deviations.

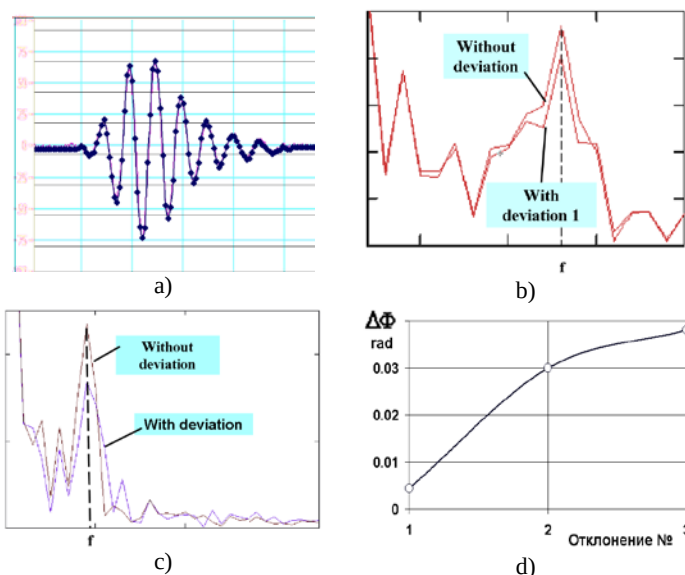


Fig. 6. Results of digital signal processing; a) – moment of digitization of the registered signal wave; b) – spectrum of the signal for deviation № 1; c) – spectrum of the signal for deviation № 5; d) – values of $\Delta\Phi$ for shift № 1, 2 и 3.

Comparisons of results for the unfiltered spectra, respectively, in the study of laboratory specimen of deviation № 1 and brake disc deviation № 5 are shown in Fig. 6 b) and c). The phase Φ_0 of the wave when discontinuities are missing and the phase Φ_1 when discontinuities are existing are calculated. The phase shift $\Delta\Phi$ is calculated as:

$$\Delta\Phi = \Phi_0 - \Phi_1 \quad (3)$$

Some results for $\Delta\Phi$ obtained for deviations № 1, 2 и 3 are shown in Fig. 6 d). The more number of holes is caused the greater difference $\Delta\Phi$ of phases. The most significant increase $\Delta\Phi$ between the signals from deviations № 1 and 2, although the greatest increase of reflecting surface is between deviations № 2 and 3. The numerical processing showed a phase shift of the signal from deviations № 4 and 5 within 0.014 rad and 0.013 rad.

There is a correlation between the phase difference and shape / size of the discontinuity. Therefore, it is appropriate to introduce phase shift as a further informative parameter for characterizing the size of discontinuities.

5. Conclusion

Spread of the Rayleigh surface wave in samples with artificial and natural discontinuities has been studied in this paper. Waveforms are analyzed and obtained the spectrum and phase of the recorded signals. Existence of discontinuities in the sample surfaces is a reason for phase shift of the signals. It has been found by experimental way that the phase shift depends on the overall size of discontinuities. Phase shift measurement of the signal ensures testing defects with smaller dimensions. Phase as an additional parameter to allow abnormal with smaller sizes. These results can be used for creating innovative non-destructive technologies with improved resolution for testing of surface and subsurface defects by surface waves.

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3-D CAD MODELING AND MODAL ANALYSIS OF LIGHT AIRCRAFT WING USING SOLID WORKS AND ANSYS SOFTWARES

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Abstract: The aim of this work is to extract modal parameters of a light aircraft wing. Modal parameters like natural frequencies, and mode shapes characterise the dynamic response of a structure and can be used for determining of the wing divergence and flutter. The CAD (Computer-Aided Design) model plays a pivot role in the design and development phases of an aircraft. Creating drawings, preparing reports of assembly and part drawings, preparing bill of materials, the aircraft design becomes easier and faster with the use of CAD system. CAD model has to be imported in FEM (Finite Element Method) software, and so it can do FE model, which have to be solved. In this work a light aircraft wing is modelled by SolidWorks software. After that the CAD model is imported in ANSYS Workbench. The FE model is generated and solved by using ANSYS Workbench. The first six natural frequencies and mode shapes are shown for the proposed light aircraft wing.

Keywords: AIRCRAFT, WING, CAD, SOLID WORKS, FEM, ANSYS

1. Introduction

Computer-Aided Design (CAD) has wide applicability in the design and development process of an aircraft. CAD is used in creation of 2_D or 3_D virtual models. The benefits of CAD models are increasing rapidly, ranging from shape visualization to its analysis, machining, layout designing and considerable cost reduction [4].

The Finite Element Analysis (FEA) is a computer simulation technique for solving problems of engineering analysis. It uses a numerical technique called Finite Element Method (FEM). The FEM is useful for problems with complicated geometries, loadings, and material properties where analytical solutions cannot be obtained.

The extensive use of CAD software in the design, combined with the great features of the FEA provides a good opportunity for the study of aircraft structures, in particular of airplane wings [5].

Vibration problems in aircraft structures often involve the excitation of structural resonance or modes of vibration. An example of a severe resonance-related problem during aircraft operation is flutter. Before an airplane is realised, flight flutter tests have to be performed to detect possible onset of flutter. The classical flight flutter testing is to expand the flight envelop of an airplane by performing a vibration test at constant flight conditions, curve-fit the data to estimate the resonance frequencies and damping ratios, and then to plot these frequencies and damping estimates against flight speed or Mach number. The damping values are then extrapolated in order to determine whether it is safe to proceed to the next flight test point. Flutter will occur when one of the damping values tends to become negative. Before starting the flight tests, ground vibration tests as well as numerical simulations and wind tunnel tests are used to get some prior insight into the problem [3, 6]. The first step in such investigation of flutter is to obtain the natural frequencies and modes of the structure.

Moreover, the frequency range is important in the study of loss of static aeroelastic stability of aircraft wing. The smallest eigenvalue of wing determines the critical air flow rate at which the action of the stationary lift the wing deforms due to the elasticity to structural failure.

This research is based on the FEA of the light aircraft wing FEM modeled by CAD. The first six natural frequencies and mode shapes are obtained.

2. CAD Model of the Wing

Complete wing of a light aircraft is modeled in SolidWorks 2012 software consisting of spars, ribs, wing fuselage attachments, skin panels, and wing skin (lower and upper). Control surfaces are not modeled. CAD model of the wing is shown in Figure 1. In the

Figure 1, the canvas skin is not shown, since it provides only the aerodynamic shape of the wing, but does not have a role in the modal and structural analysis. The airfoil is Clark Y. The chord length is 0.940 m, and the wing length is 5.200 m.

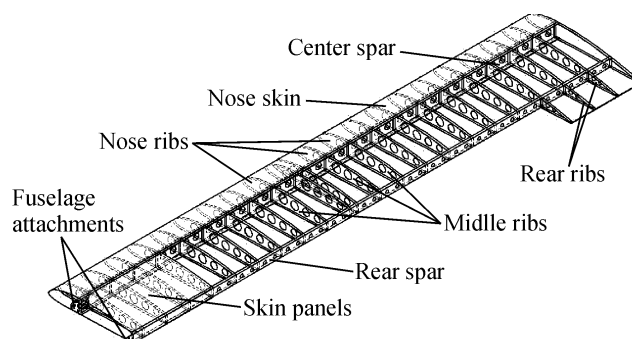


Fig.1 Solid Works model of the wing

2. FE Model of the Wing

The SolidWorks CAD model is imported in ANSYS Workbench 14. The FE wing model uses the patch conforming (tetrahedrons) mesh [2]. It has 196 610 nodes, and 94 986 elements. Size of the mesh is set manually to obtain the maximum thick mesh and taking into account the capabilities of the PC to solve the task. The option Advanced Size Function is used for shell models. The finite element mesh is shown in Figure 2.

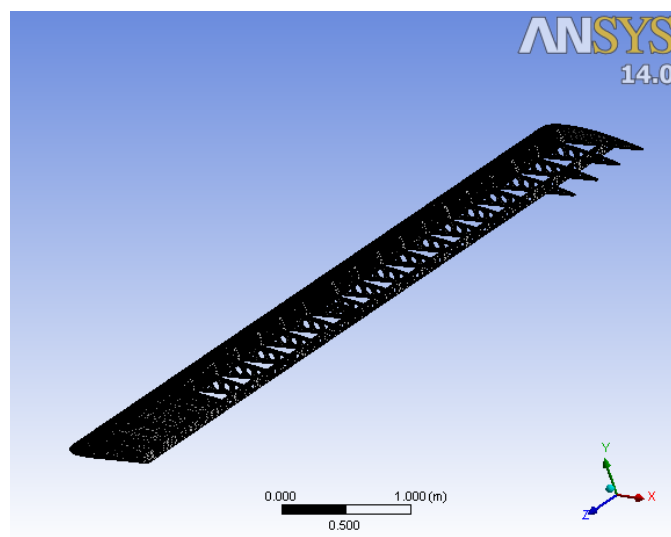


Fig.2 Finite element model of the wing

The wing is treated as a cantilevered beam, which is fixed at the fuselage attachment (all DOF), as it is shown in Figure 3.

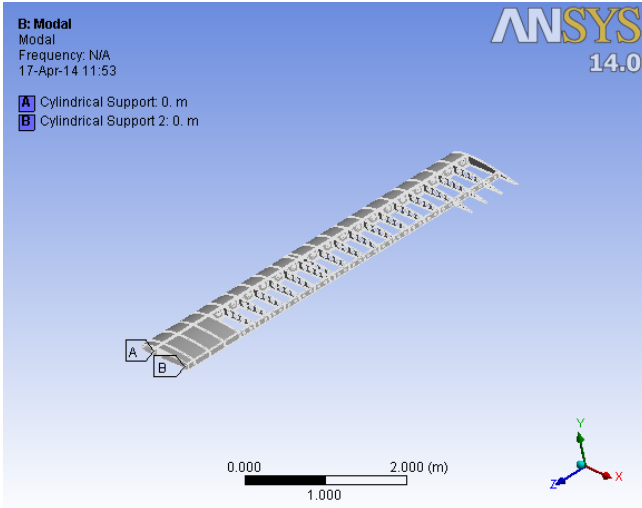


Fig.3 Finite element model applying boundary conditions

The material properties used in this study are:

Aluminum alloy with Young's modulus 2×10^{11} Pa, and Poisson's ratio 0.3.

To solve the problem the Block Lanczos method is used [1]. This method is very appropriate where there are complex models with a mixture of solids/shells/beams etc. Moreover, the modes in the frequency range can be easily extracted. The general equation of motion is

$$[M]\{\ddot{q}\} + [C]\{\dot{q}\} + [K]\{q\} = \{F(t)\}$$

where $[M]$, $[C]$, and $[K]$ are the mass, damping and stiffness matrixes respectively. It is assumed that the vibrations are free and the damping is ignored:

$$[M]\{\ddot{q}\} + [K]\{q\} = \{0\}$$

It is assumed that there is a harmonic motion, (i.e. $q = Q \sin(\omega t)$)

$$([K] - \omega^2 [M])\{q\} = \{0\}$$

The roots of this equation are ω_i^2 , the eigenvalues, where i ranges from 1 to number of DOF. Corresponding vectors are $\{q_i\}$, the eigenvectors. The square roots of the eigenvalues are ω_i , the structure's natural circular frequencies. Natural frequencies Ω_i are then calculated as $\Omega_i = \omega_i / (2\pi)$. It is the natural frequencies Ω_i that are input by the user and output by ANSYS. The eigenvectors $\{q_i\}$ represent the mode shapes – the shape assumed by the structure when vibrating at frequency of Ω_i .

3. Results and Discussion

The analysis is done in ANSYS Workbench 14 software. The first six natural frequencies and mode shapes are shown in Figures 4 – 9, and Table 1.

The presented results show that four frequencies (3.22 Hz, 11.32 Hz, 23.35 Hz, and 68.83 Hz) are typical bending oscillations. The frequency 34.22 Hz is typical twisting oscillations. The bending and twisting oscillations are connected at the frequency of 59.60 Hz.

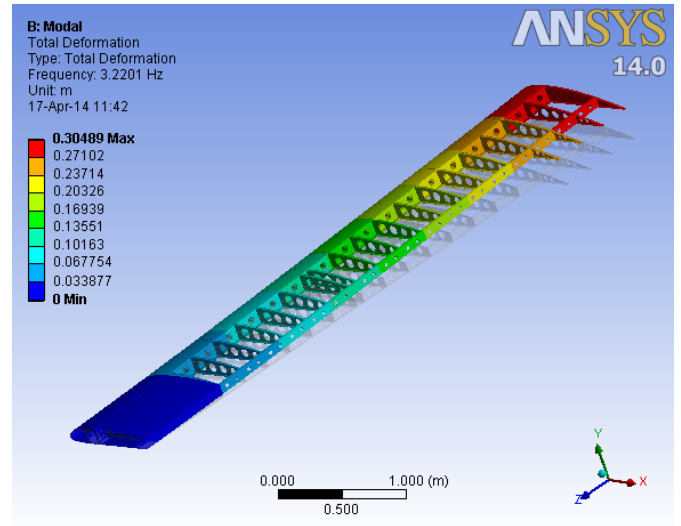


Fig.4 First vertical bending mode

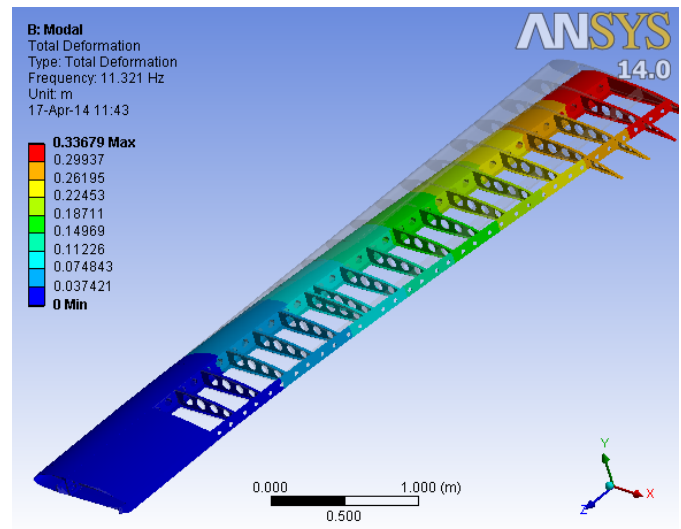


Fig.5 First horizontal bending mode

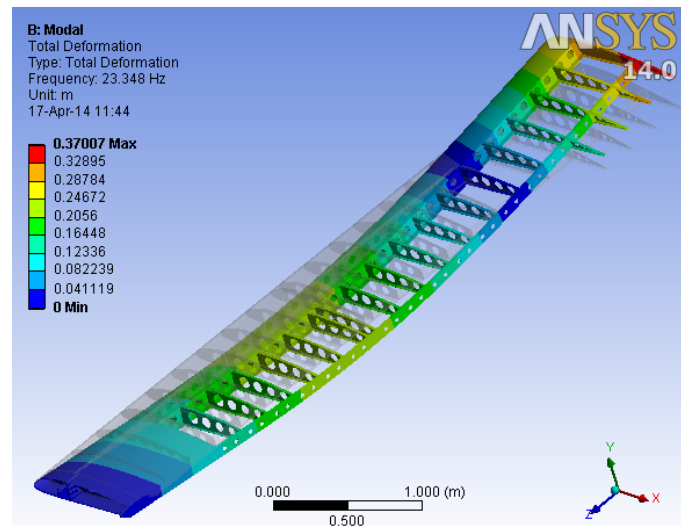


Fig.6 Second vertical bending mode

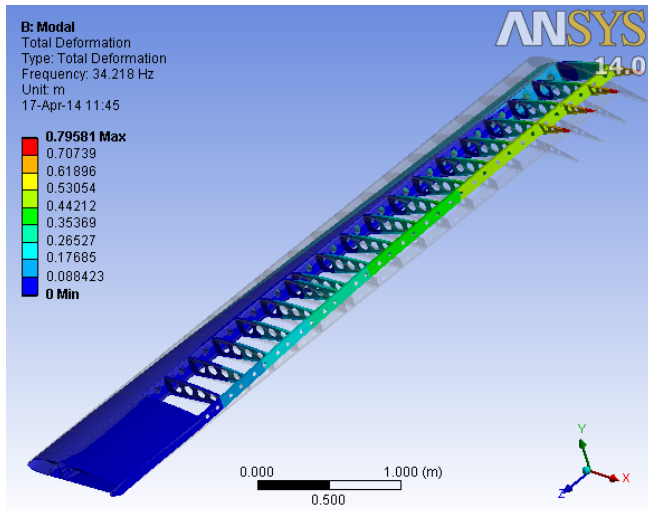


Fig.7 First twisting mode

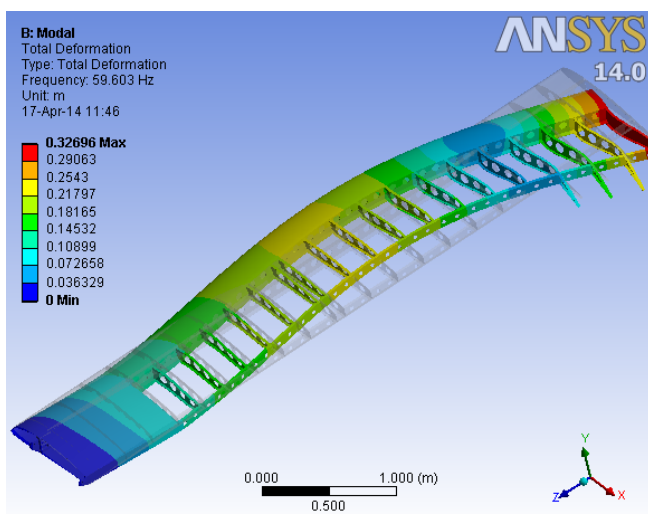


Fig.8 First vertical/horizontal bending mode

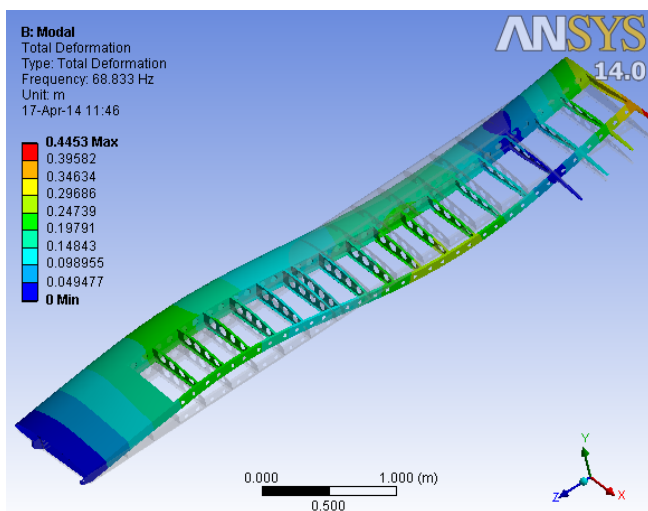


Fig.9 Third vertical bending mode

Table 1: Natural frequencies of light aircraft wing

	Natural frequencies, in [Hz]
First vertical bending mode	3.22
First horizontal bending mode	11.32
Second vertical bending mode	23.35
First twisting mode	34.22
First vertical/horizontal bending mode	59.60
Third vertical bending mode	68.83

In terms of the loss of static stability the lowest frequencies of 3.22 Hz (first vertical bending mode) and 34.22 Hz (first twisting mode) are of particular importance.

From the viewpoint of flutter the frequencies 3.22 Hz, 23.35 Hz, 59.60 Hz and 68.83 Hz (defining the vertical bending and vertical/horizontal bending modes) are very important.

3. Conclusion

CAD modeling of the light aircraft wing was done in SolidWorks. The model was imported in ANSYS, and modal analysis was made. The Block Lanczos method was used. The first six natural frequencies and corresponding modes were presented.

The future scope of work will be to perform the modal analysis of the same aircraft wing, but with a support structure. So we can see its influence on the modal parameters and how to avoid the loss of static stability and flutter because of support structure.

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