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MEAN PRESSURE OF MECHANICAL LOSSES EQUATION FOR MARINE SLOW SPEED TWO-STROKE DIESEL ENGINE

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Abstract: During the engine experimental investigation usually was obtained engine effective power and rotational speed. In order to obtain engine mechanical efficiency and engine indicated power from experimental data, must be used equation for calculation of engine mean pressure of mechanical losses along with its proper coefficients. This equation gives correct values if engine mechanical efficiency and engine indicated power was obtained in the range $\pm 1.5\%$, when compared with experimentally obtained ones. For marine slow speed two-stroke diesel engine 6S50MC MAN B&W was analyzed this equation along with its coefficients during the whole range of engine loads. The mean pressure of mechanical losses equation, when obtained coefficients was applied, gives a percentage difference in the range $\pm 0.79\%$ for the engine mechanical efficiency and percentage difference in the range $\pm 0.85\%$ for the engine indicated power when compared with experimentally obtained values. For the higher engine loads presented equation is even more accurate and precise.

Keywords: TWO-STROKE DIESEL ENGINE, MEAN PRESSURE OF MECHANICAL LOSSES, MECHANICAL EFFICIENCY, INDICATED POWER

1. Introduction

Marine slow speed two-stroke diesel engines, compared to the other diesel engines, are characterized by their construction, dimensions and operating process. For a large number of engine components, the materials used in such engines cannot be of conventional type [1].

Development of numerical models for marine two-stroke diesel engine simulation is nowadays one of the goals for scientists [2] to be able to predict their operating parameters during the propulsion [3] or to get an insight into the details of in-cylinder processes [4] such as convective heat transfer [5].

To improve marine two-stroke diesel engine operating parameters and reduce their emissions, numerous investigations were performed in order to implement alternative fuel combustion [6], using bio-fuel blends for combustion [7] or using standard diesel fuels with some additives [8] in this type of engines.

For marine two-stroke diesel engines were also investigated some of the known techniques from automotive diesel engines for reducing nitrogen oxides (NO_x) emissions, as for example EGR (Exhaust Gas Recirculation) [9]. It is also important to know maximum NO_x reduction potential of two-stroke marine diesel engines [10] by using EGR. Along with nitrogen oxides, for marine slow speed two-stroke diesel engines was also investigated soot emission [11] and possibilities of soot emission reduction.

In this paper was investigated mean pressure of mechanical losses equation for calculating analyzed marine slow speed two-stroke diesel engine 6S50MC MAN B&W mechanical efficiency and indicated power. During the engine measurements, usually obtained parameters are engine effective power and rotational speed, for a wide range of engine loads. By using engine effective power, engine rotational speed and engine geometrical specifications along with the equation proposed in this paper can be calculated indicated engine power and engine mechanical efficiency. For the whole observed range of the engine loads, engine mechanical efficiency and indicated power calculated by proposed equation can deviate in the range of $\pm 1.5\%$ in comparison with values obtained during the experiment (usual deviation range of engine operating parameters calculation). For the analyzed engine was obtained measurement results of both effective and indicated engine power, for each observed engine load [12]. The calculated values were compared with experimentally obtained ones in order to analyze the accuracy and precision of the proposed equation for the mean pressure of mechanical losses calculation. Analyzed engine is used for propulsion on the chemical tanker, which specifications are presented in Table 1.

Table 1. Main characteristics and parameters of chemical tanker with analyzed propulsion engine

Dead weight tonnage	46000 DWT
Overall length	82.90 m
Max breadth	32.20 m
Design draft	12.00 m
Maximum draft	17.20 m
Guaranteed speed	15.5 knots

2. Marine two-stroke slow speed diesel engine main characteristics

Marine diesel engine analyzed in this paper is a slow speed turbocharged two-stroke engine with direct fuel injection 6S50MC MAN B&W. The main engine specifications are presented in Table 2.

Table 2. Specifications of marine slow speed two-stroke diesel engine 6S50MC MAN B&W [12]

Number of cylinders	6 in line
Cylinder bore	500 mm
Cylinder stroke	1910 mm
Firing order	1-5-3-4-2-6
Maximum continuous rating (MCR)	8580 kW
Engine speed at MCR	127 rpm
Maximum mean effective pressure	18 bar
Maximum combustion pressure	143 bar
Compression ratio	17.2
Crank mechanism ratio	0.436
Exhaust manifold volume	6.13 m ³
Inlet manifold volume (with intercooler)	7.179 m ³
Cumulative engine mass	232000 kg

Cross section of marine diesel engine 6S50MC MAN B&W is presented in Fig. 1. In Fig. 1 can be seen all housing and cylinder main elements. The engine was built in a diesel engine factory in Split, Croatia, according to the license MAN B&W.

3. Engine measurement results

The main operating data of the marine diesel engine 6S50MC MAN B&W were obtained by test-bed measurements in Shipyard Split, Croatia.

The ambient conditions during the measurements were:

- Ambient temperature 30 °C,
- Ambient pressure 1005 mbar,
- Relative humidity 50%.

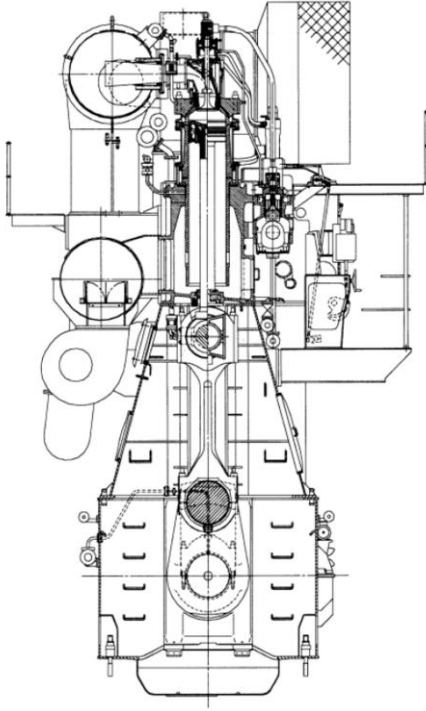


Fig. 1. Cross section of marine slow speed two-stroke diesel engine 6S50MC MAN B&W [13]

The engine measurements were performed with a standard marine diesel fuel, whose properties are:

- Density 844.7 kg/m³,
- Kinematic viscosity 3.03 mm²/s,
- Sulfur content 0.45%,
- Lower heating value 42.625 MJ/kg.

Engine load was presented in percentage of maximum continuous rating (MCR), Table 2. The measured values for the engine steady state operation at engine loads 25%, 50%, 75%, 93.5% and 100% of MCR was presented in Table 3.

Table 3. 6S50MC MAN B&W measured data [12]

Load (% of MCR)	Indicated power (kW)	Effective power (kW)	Rotational speed (rpm)	Fuel mass flow (kg/h)
25%	2401	2142	76.5	400.2
50%	4406	4099	96.0	713.5
75%	6580	6160	110.4	1054.5
93.5%	8170	7667	118.5	1317.3
100%	8656	8182	121.4	1429.1

4. The equation for the mean pressure of mechanical losses calculation

4.1. Mechanical efficiency according to experimental measurements

For the analyzed slow speed two-stroke marine diesel engine, during the measurements, Table 3, was obtained indicated and effective engine power. Engine indicated power was developed in the engine cylinders in comparison with engine effective power which is used for propulsion propeller drive. Therefore, engine effective power can be measured much easier at the engine crankshaft outlet. Measurements with obtained both indicated and effective engine powers for a range of engine loads are very rare.

If the indicated and effective engine power were obtained during the experimental measurements, it is easy to obtain engine power of mechanical losses and engine mechanical efficiency according to equations:

$$P_{ml} = P_{ind} - P_{eff} \quad (1)$$

where P_{ml} is power of engine mechanical losses, P_{ind} is measured engine indicated power and P_{eff} is measured engine effective power,

$$\eta_m = \frac{P_{eff}}{P_{ind}} = \frac{\eta_{eff}}{\eta_{ind}} \quad (2)$$

where η_m is engine mechanical efficiency, η_{eff} is engine effective efficiency and η_{ind} is engine indicated efficiency.

According to measured indicated and effective power, Table 3, and by using equation (2), was calculated engine real (experimentally obtained) mechanical efficiency. This real mechanical efficiency was compared with mechanical efficiency for the same engine obtained by using the equation for the mean pressure of mechanical losses, for each observed engine load.

4.2. Mechanical efficiency by using the equation for mean pressure of mechanical losses

Usually, during the experimental measurements of any engine was obtained only engine effective power (by using engine braking) and engine rotational speed. If not measured, engine indicated power can be calculated from engine mechanical efficiency, in order to get an insight into the engine mechanical losses and to determine the amount of energy transferred from the fuel to the engine pistons. It will be assumed that engine indicated power, for any observed engine load, is not known, so it will be calculated by using measured engine effective power and engine measured rotational speed along with known engine geometrical parameters.

Engine mechanical efficiency can also be defined as:

$$\eta_m = \frac{\eta_{eff}}{\eta_{ind}} = \frac{P_{me,eff}}{P_{me,ind}} = \frac{P_{me,eff}}{P_{me,eff} + P_{me,ml}} \quad (3)$$

where $p_{me,ind}$ is engine mean indicated pressure, $p_{me,eff}$ is engine mean effective pressure and $p_{me,ml}$ is engine mean pressure of mechanical losses.

At any engine load, mean effective pressure can be calculated by using an equation:

$$p_{me,eff} = \frac{P_{eff} \cdot \tau}{2 \cdot z \cdot n \cdot V_{op}} \quad (4)$$

where τ is engine stroke - analyzed engine is two-stroke engine so $\tau = 2$, z is number of engine cylinders, n is measured engine rotational speed and V_{op} is operating volume of one engine cylinder which can be calculated according to the equation:

$$V_{op} = \frac{D^2 \cdot \pi \cdot s}{4} \quad (5)$$

where D is cylinder bore and s is cylinder stroke.

Engine mean pressure of mechanical losses is not the real, measurable variable, it is just numerical auxiliary variable which allows calculation of engine mechanical efficiency, according to equation (3). Engine mean pressure of mechanical losses can be calculated according to few empirical equations. In any empirical equations all of the input and output variables must be in precisely defined measuring units, which has to be defined under the presented equation. One of the few empirical equations for engine mean pressure of mechanical losses calculation has the form:

$$p_{me,ml} = k_1 \cdot \left(1 + \frac{1}{z}\right) + \frac{3}{D} + k_2 \cdot p_{me,eff} + k_3 \cdot c_s \quad (6)$$

From the above equation (6), mean pressure of mechanical losses will be obtained in (MPa) if in the equation was put variables in following measuring units:

- Cylinder bore D in (mm),
- Number of engine cylinders z in (-),
- Engine mean effective pressure $p_{me,eff}$ in (MPa),
- Medium piston speed c_s in (m/s).

Coefficients k_1 , k_2 and k_3 are constants which are defined usually for the whole set of similar internal combustion engines. Based on the whole set of diesel engines for the road vehicles drive, these coefficients are:

$$k_1 = 0.06 \quad (7)$$

$$k_2 = 0.03 \quad (8)$$

$$k_3 = 0.015 \quad (9)$$

Medium piston speed c_s should be calculated by using an equation:

$$c_s = 2 \cdot s \cdot n \quad (10)$$

where s is cylinder stroke and n is engine rotational speed.

Equation (6) gives correct values for engine mean pressure of mechanical losses if engine mechanical efficiency and engine indicated power was obtained in the range $\pm 1.5\%$, when compared with experimentally obtained ones.

The main goal of this paper is to obtain correct coefficients k_1 , k_2 and k_3 for the analyzed slow speed two-stroke diesel engine. It is not a problem to obtain correct coefficients for one engine operating load, therefore the aim will be to obtain coefficients for all of the observed engine loads, within the recommended accuracy limits.

After the conducted mathematical analysis, for the marine slow speed two-stroke diesel engine was obtained the following coefficients:

$$k_1 = 0.0384 \quad (11)$$

$$k_2 = 0.018 \quad (12)$$

$$k_3 = 0.004 \quad (13)$$

The accuracy and precision of obtained coefficients for the equation (6) for marine slow speed diesel engine will be tested and compared with the experimentally obtained engine mechanical efficiency and engine indicated power for the complete range of engine loads.

5. Engine mechanical efficiency and indicated power calculated with developed equation - comparison with measurement results

The mean pressure of mechanical losses for marine slow speed two-stroke diesel engine was calculated by using equation (6) and coefficients obtained for the analyzed engine, equations (11), (12) and (13). Engine mean pressure of mechanical losses was calculated for each observed engine load, in order to present a proper analysis of obtained coefficients and to determine accuracy and precision of proposed equation.

The values for the mean pressure of mechanical losses continuously increase during the increase in engine load, Fig. 2. The lowest mean pressure of mechanical losses value was calculated at the lowest engine load 25% of MCR and amounts 0.0837 MPa, while the highest value was calculated at the highest engine load 100% of MCR and amounts 0.1141 MPa. The average value of mean pressure of mechanical losses for the complete range of engine loads is equal to 0.1023 MPa.

Accuracy and precision of mean pressure of mechanical losses values can be seen when this variable is used for calculation of engine mechanical efficiency and engine indicated power for each observed engine load.

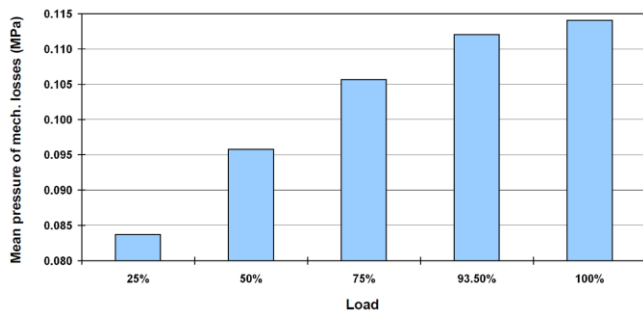


Fig. 2. Change in engine mean pressure of mechanical losses for analyzed loads

Marine two-stroke diesel engine mechanical efficiency obtained by experiment and by calculation was presented in Table 4. Experimentally obtained engine mechanical efficiency was calculated according to equation (2) by using measured indicated and measured effective engine power.

Calculated engine mechanical efficiency was obtained by using equation (3). The main parameters of equation (3) are engine mean effective pressure and mean pressure of mechanical losses. Both of these parameters were calculated for each observed engine load.

Table 4. Engine mechanical efficiency - experimental and calculated values

Load (% of MCR)	25%	50%	75%	93.5%	100%
Mechanical efficiency-experiment (%)	89.21	93.03	93.62	93.84	94.52
Mechanical efficiency-calculated (%)	89.92	92.24	93.37	93.90	94.03

Fig. 3 presents the percentage difference between calculated and experimentally obtained mechanical efficiency of the analyzed engine. Percentage difference for all of the observed loads is in the range from -0.79% up to +0.70%, which is within the target range of $\pm 1.5\%$. According to calculated engine mechanical efficiency, presented equation for the mean pressure of mechanical losses calculation gives a satisfactory accuracy and precision.

The largest deviations between calculated and experimentally obtained engine mechanical efficiency can be seen at the lower engine loads (25% and 50% of MCR), Fig. 3. For the higher engine loads (75%, 93.5% and 100% of MCR) percentage difference between calculated and experimentally obtained engine mechanical efficiency is in the range of $\pm 0.50\%$. This is an important conclusion because the majority of engine operation, during the ship navigation, will be on the higher engine loads. Therefore, presented equation for the mean pressure of mechanical losses calculation can be used with accuracy and precision much higher than expected ones, for the most of analyzed diesel engine operating time.

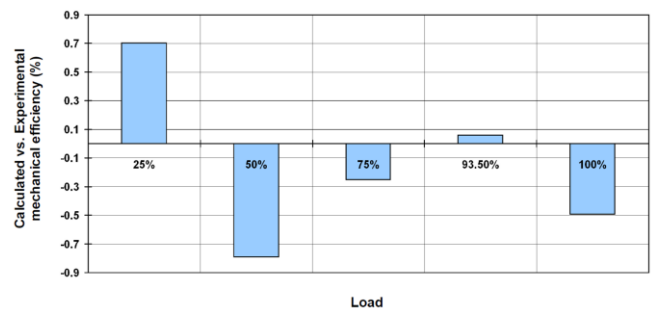


Fig. 3. Percentage difference between calculated and experimental engine mechanical efficiency for analyzed loads

Analyzed engine indicated power obtained by experiment and by calculation was presented in Table 5. Experimentally obtained engine indicated power was shown in Table 3, while calculated engine indicated power was obtained by using equation (2). In equation (2) engine effective power was obtained by experiment - Table 3, and engine mechanical efficiency was calculated by using equation (3) where was used the mean pressure of mechanical losses proposed equation and its coefficients.

The percentage difference between calculated and experimentally obtained indicated power of the analyzed engine is presented in Fig. 4. Percentage difference for all of the observed loads is in the range from -0.79% up to +0.85%, which is within the target range of $\pm 1.5\%$. It is concluded before that according to calculated engine mechanical efficiency, presented equation for the mean pressure of mechanical losses calculation gives a satisfactory accuracy and precision which is also valid for calculated engine indicated power.

Table 5. Engine indicated power - experimental and calculated values

Load (% of MCR)	25%	50%	75%	93.5%	100%
Indicated engine power-experiment (kW)	2401	4406	6580	8170	8656
Indicated engine power-calculated (kW)	2382.2	4443.7	6597.6	8164.9	8701.3

The largest deviations between calculated and experimentally obtained engine indicated power can be seen at the lower engine loads (25% and 50% of MCR), Fig. 4. For the higher engine loads (75%, 93.5% and 100% of MCR) percentage difference between calculated and experimentally obtained engine indicated power is in the range of $\pm 0.53\%$. Presented equation for the mean pressure of mechanical losses calculation can be used with accuracy and precision much higher than expected ones, for the most of marine two-stroke diesel engine operating time also from the viewpoint of calculated indicated power.

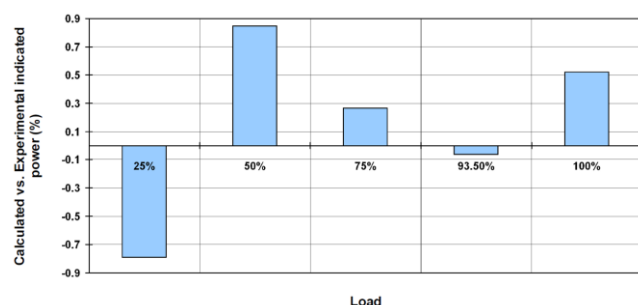


Fig. 4. Percentage difference between calculated and experimental engine indicated power for analyzed loads

6. Conclusions

During the internal combustion engine experimental investigation, by using engine braking, was obtained engine effective power (power transferred to power consumer) and engine rotational speed. By using only engine effective power cannot be known engine mechanical losses or the amount of energy transferred from fuel during combustion to engine pistons (indicated engine power).

In this paper was investigated empirical equation for calculating engine mean pressure of mechanical losses. This is not the real, measurable pressure, but auxiliary calculation variable, which can be used for calculation of engine mechanical efficiency and engine indicated power from measured engine effective power, measured engine rotational speed and known engine geometrical parameters.

The equation for the mean pressure of mechanical losses calculation gives correct values if engine mechanical efficiency and engine indicated power was obtained in the range $\pm 1.5\%$, when compared with experimentally obtained ones. This fact must be valid for the whole engine operating range (for all observed engine loads).

For the analyzed marine slow speed diesel engine, the equation for the mean pressure of mechanical losses calculation, when obtained coefficients was applied, gives a percentage difference in the range $\pm 0.79\%$ for engine mechanical efficiency and percentage difference in the range $\pm 0.85\%$ for the engine indicated power when compared with experimentally obtained values. For the higher analyzed engine loads presented equation for the mean pressure of mechanical losses calculation gives percentage difference for mechanical efficiency and engine indicated power in the range of

$\pm 0.53\%$, what is important fact because the majority of analyzed diesel engine operation can be expected on higher loads.

Presented equation for the mean pressure of mechanical losses calculation can be helpful to the ship crew for easy and fast analysis of the current engine parameters and mechanical losses.

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NUMERICAL SIMULATION ON THE VIBRATION OF A VEHICLE DRIVETRAIN WITH DUAL MASS FLYWHEEL

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Abstract: This paper describes the results of numerical simulations of a vehicle drivetrain model with dual mass flywheel. The differential equations of the model are given. The vehicle inertia, the tire torsional stiffness and the transmission gear ratios are taking into account. Numerical simulations with given mass, elastic and damping parameters are carried out. Natural frequencies of the system are determinate. Vibrational characteristics of the system are shown and analysed.

Keywords: DUAL MASS FLYWHEEL, TRANSMISSION, DRIVELINE, DYNAMICS, VIBRATION

1. Introduction

The Dual Mass Flywheel (DMF) is widely used in modern diesel or gasoline direct injection engines. Downsizing and downspeeding of engines, lowering friction in gearboxes and lightweighting of transmissions and drivelines cause increased vibration and noise. The periodic combustion cycles of a four-stroke engine create torque and speed fluctuations which cause torsional vibration to be passed down the drivetrain (Fig. 1). The resulting noise and vibration, such as gear rattle, body boom and load change vibration, results in a decrease in comfort [1].

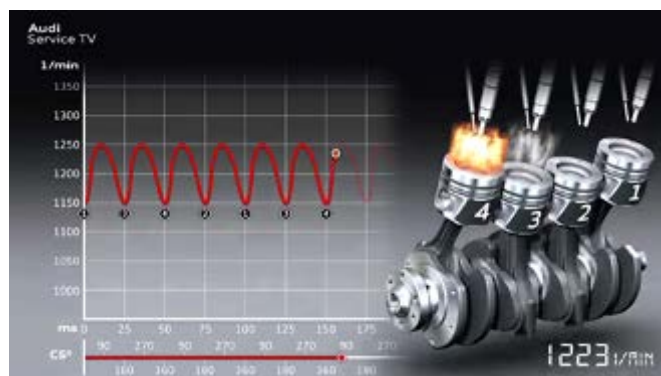


Fig. 1 Angular speed fluctuation of four-cylinder four-stroke engine [2]

The dual mass flywheel consist two masses free to rotate independently on a ball bearing. Two long coil springs lower the value of the natural frequency of the system (Fig. 2). Damping device is also present [3]. The secondary mass helps to increase the mass moment of inertia on the gearbox side. The total inertia of the DMF is the same as that of the rigid flywheel.



Fig. 2 Dual mass flywheel (DMF)[4]

As the DMF has an integral spring-damper system a rigid clutch driven disc without a torsion damper is normally used [1]. Owing to

the additional mass on the transmission input shaft, the vibration torque range, which is normally between 1200 min^{-1} and 2400 min^{-1} with original stiffer torsion dampers in the driven disc, is moved to a lower resonance speed range. This ensures excellent damping of engine vibration even at idle speeds [1]. Driving with less angular speed can reduce fuel consumption and CO_2 emissions [4, 5].

There are many books and research articles on DMF problems [4, 5, 6, 7, 8 and 9]. Their authors examine two or three degree of freedom engine-transmission model. But the system is more complicated because the vehicle mass should be reduced to the engine crankshaft and this is shown in [10, 11] but without mathematical description. The tire torsional stiffness has to be given an account too. Thus, the model whose scheme is given in source [12] most accurately reflects the essence of the real system. Unfortunately, the author does not present the mathematical description of this model, as well as numerical studies with specific values of the parameters. In textbook [13] a modal analysis of a vehicle drivetrain with and without dual mass flywheel is performed. In work [14] a dynamic model of friction self-excited vibration of a vehicle drivetrain with conventional damper in the driven clutch disc is created and numerical simulations are performed. In [15] dynamic model of a vehicle drivetrain with spring and friction damper in driven clutch disk is presented and test results for amplitude-frequency characteristics are shown. In work [16] a linear mechanical model of hybrid electric vehicle drivetrain is considered, a modal analysis is performed and the effect of the control of the drivetrain on the eigenvalues of the vibrational system is studied. In this regard, the purpose of this publication is to draw out the differential equations of dynamic drivetrain model with dual mass flywheel with taking into account of the vehicle inertia, the tire torsional stiffness and the transmission gear ratios and to carry out numerical simulations with given mass, elastic and damping parameters.

2. Dynamic Model

A front wheel drive vehicle with dual mass flywheel drivetrain and its kinematic scheme are shown in Fig. 3 and 4 respectively. The system mainly consists of engine, dual mass flywheel (DMF), gearbox, final drive, drive shafts, drive wheels, driven wheels and car body. The symbols used in kinematic scheme are:

- J_c – mass moment of inertia of the crankshaft;
- J_{f1} – mass moment of inertia of the primary mass of the flywheel;
- J_{f2} – mass moment of inertia of the secondary mass of the flywheel and clutch pressure disc;
- J_{g1} – mass moment of inertia of the clutch driven (friction) disc and primary shaft with drive gears of the gearbox;
- J_{g2} – mass moment of inertia of the secondary shaft with driven gears of the gearbox;
- J_0 – mass moment of inertia of the final gear and the differential;
- J_d – mass moment of inertia of the drive shafts;
- J_w – mass moment of inertia of the wheels;
- m – vehicle mass;

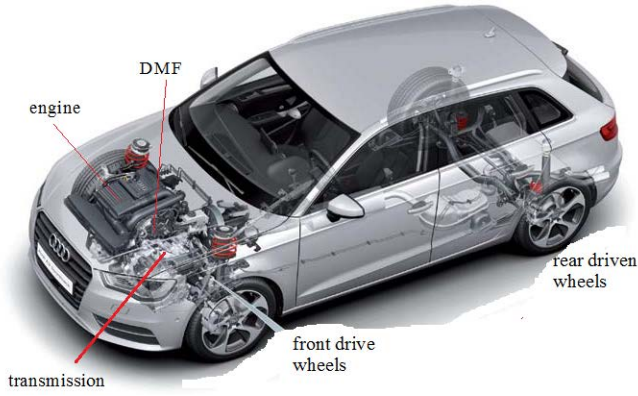


Fig. 3 Front wheel drive vehicle with DMF [17]

J_{g2} – mass moment of inertia of the secondary shaft of the gearbox;

J_0 – mass moment of inertia of the final gear and the differential;

J_d – mass moment of inertia of the drive shafts;

J_w – mass moment of inertia of the wheels;

m – vehicle mass;

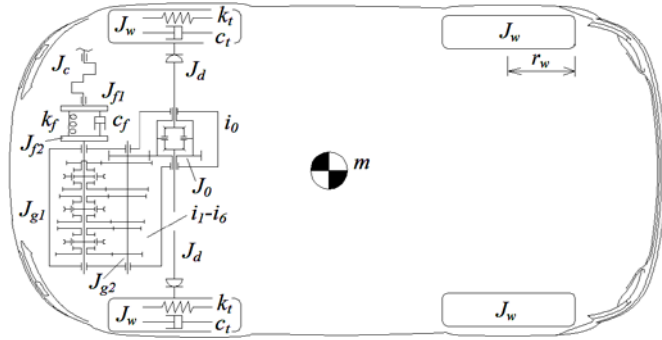


Fig. 4 Vehicle drivetrain kinematic scheme

i_{1-6} – gear ratios of the six speed gearbox;

i_0 – gear ratio of the final drive;

r_w – rolling radius of the wheels;

k_f, c_f – spring stiffness and damping of the dual mass flywheel;

k_t, c_t – tire torsional stiffness and damping of the drive wheels.

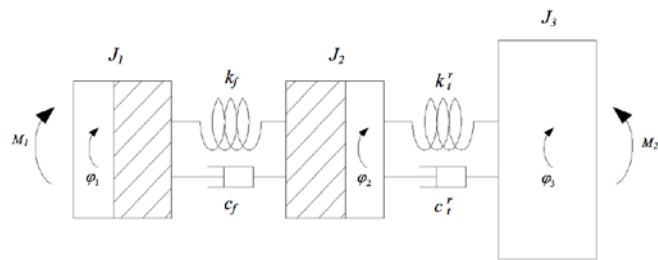


Fig. 5 Equivalent 3 DOF vehicle drivetrain dynamic model

The equivalent dynamic model shown in Fig. 5 has three degrees of freedom (3 DOF) and the vector of generalized coordinates is:

$$q = [\varphi_1 \quad \varphi_2 \quad \varphi_3]^T$$

The mass moments of inertia of the dynamic model are:

$$J_1 = J_c + J_{f1}$$

$$J_2 = J_{f2} + J_{g1} + J_{g2}^r + J_0^r + 2J_d^r + 2J_w^r$$

$$J_3 = 2J_w^r + J_v^r$$

J_1 – mass moment of inertia of the crankshaft and primary mass of the flywheel;

J_2 – mass moment of inertia of the secondary mass of the flywheel, clutch, gears and shafts of the gearbox and final drive, drive shafts and drive wheels;

J_3 – mass moment of inertia of the driven wheels and mass of the car body reduced to the engine crankshaft;

The mass moments of inertia reduced (referred) to the crankshaft are [18, 19]:

$$J_{g2}^r = \frac{J_{g2}}{i_{1-6}^2}$$

$$J_0^r = \frac{J_0}{i_{1-6}^2 \cdot i_0^2}$$

$$J_d^r = \frac{J_d}{i_{1-6}^2 \cdot i_0^2}$$

$$J_w^r = \frac{J_w}{i_{1-6}^2 \cdot i_0^2}$$

$$J_v^r = m \left(\frac{r_w}{i_{1-6} \cdot i_0} \right)^2$$

where superscript r means *reduced* or *referred* to the crankshaft;

J_v^r – reduced mass moment of inertia of translating mass of the vehicle to the crankshaft.

For the generalized coordinates can be written:

$$\varphi_1 = \varphi_c = \varphi_{f1}$$

$$\varphi_2 = \varphi_{f2} = \varphi_{g1} = \varphi_{g2} \cdot i_{1-6} = \varphi_0 \cdot i_{1-6} \cdot i_0 = \varphi_w \cdot i_{1-6} \cdot i_0$$

$$\varphi_3 = \varphi_w \cdot i_{1-6} \cdot i_0 = \frac{S \cdot i_{1-6} \cdot i_0}{r_w}$$

where S is the driving distance, m .

$$k_t^r = \frac{k_t}{i_{1-6}^2 \cdot i_0^2}; \quad c_t^r = \frac{c_t}{i_{1-6}^2 \cdot i_0^2}$$

where k_t^r, c_t^r – tire torsional stiffness and damping reduced to the engine crankshaft.

The differential equations of the model are:

$$J_1 \ddot{\varphi}_1 + k_f (\varphi_1 - \varphi_2) + c_f (\dot{\varphi}_1 - \dot{\varphi}_2) = M_1$$

$$J_2 \ddot{\varphi}_2 - k_f (\varphi_1 - \varphi_2) + k_t^r (\varphi_2 - \varphi_3) - c_f (\dot{\varphi}_1 - \dot{\varphi}_2) + c_t^r (\dot{\varphi}_2 - \dot{\varphi}_3) = 0$$

$$J_3 \ddot{\varphi}_3 - k_t^r (\varphi_2 - \varphi_3) - c_t^r (\dot{\varphi}_2 - \dot{\varphi}_3) = -M_2$$

The excited moment from the engine is:

$$M_1 = M_o + M \sin \omega t$$

And

$$M_2 = \frac{M_R}{i_{1-6} \cdot i_0}$$

where M_R is resistive moment acted on the vehicle. It includes rolling resistance, road inclines and aerodynamic drag.

3. Numerical Simulation

The numerical simulations are performed in program field of MATLAB. The parameters of the model are taken from different literature sources [13, 14, 19 and 20]. The actual values of the parameters are given in Table 1. Some of the parameters are reduced (referred) according to the formulas given above to the engine crankshaft for the accurate conduction of the simulations.

Table 1: Parameters of the dynamic model

Parameter	Value	Dimension
J_c	0,045	kg.m ²
J_{f1}	0,115	kg.m ²
J_{f2}	0,115	kg.m ²
J_{g1}	0,004	kg.m ²
J_{g2}	0,004	kg.m ²
J_0	0,003	kg.m ²
J_d	0,015	kg.m ²
J_w	0,850	kg.m ²
m	1765	kg
i_{1-6}	3,615; 1,947; 1,281; 0,973; 0,778; 0,646	-
i_0	4,056	-
r_w	0,316	m
k_f	600	Nm/rad
c_f	100	Nms/rad
k_t	35000	Nm/rad
c_t	50	Nms/rad

Natural frequencies of the system when 1st gear is engaged:

$$\omega_1 = 0 \text{ - rotation of the system}$$

$$\omega_2 = 15,3 \text{ Hz}$$

$$\omega_3 = 4,2 \text{ Hz}$$

Natural frequencies of the system when 6th gear is engaged:

$$\omega_1 = 0 \text{ - rotation of the system}$$

$$\omega_2 = 19,9 \text{ Hz}$$

$$\omega_3 = 9,12 \text{ Hz}$$

In overcritical operating conditions ($\omega_{ex} > \omega_{nat}$), it must be ensured that the minimum excitation frequency will in all operating points will remain to a sufficient degree above the natural frequency and the excitation frequency from the engine is [21]:

$$\omega_{ex} = \frac{z}{2} \cdot \frac{n}{60}$$

where z is the number of cylinders;

n – engine speed, min⁻¹.

For 4-cylinder engine on idle speed - 900 min⁻¹:

$$\omega_{ex} = \frac{4}{2} \cdot \frac{900}{60} = 30 \text{ Hz}$$

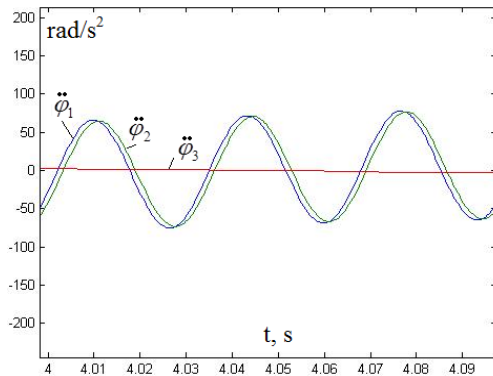


Fig. 7 Angular acceleration of the first (blue), second (green) and third (red) mass of the model on idle speed - 900 min⁻¹ on 1st gear

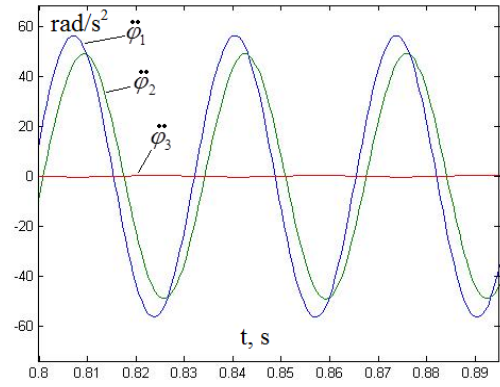


Fig. 8 Angular acceleration of the first (blue), second (green) and third (red) mass of the model on idle speed - 900 min⁻¹ on 6th gear

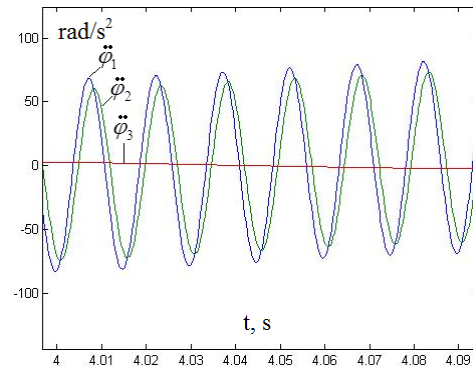


Fig. 9 Angular acceleration of the first (blue), second (green) and third (red) mass of the model, 2000 min⁻¹ on 1st gear

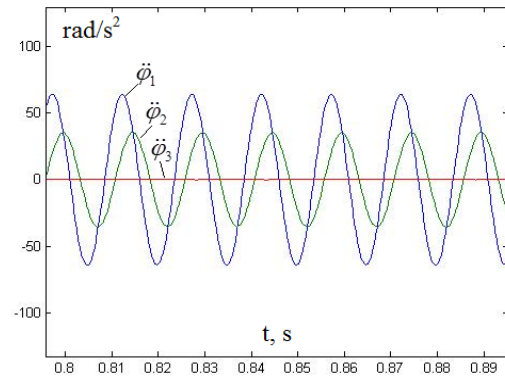


Fig. 10 Angular acceleration of the first (blue), second (green) and third (red) mass of the model, 2000 min⁻¹ on 6th gear

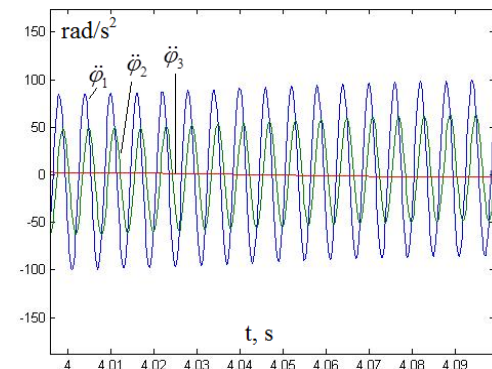


Fig. 11 Angular acceleration of the first (blue), second (green) and third (red) mass of the model, 5000 min⁻¹ on 1st gear

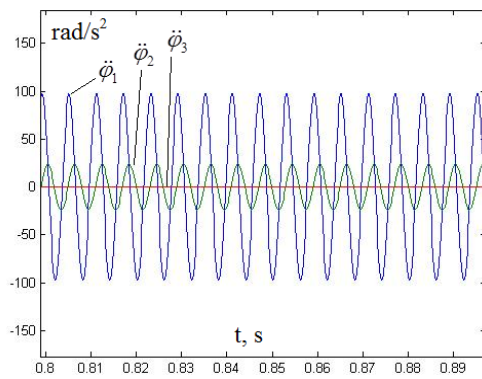


Fig. 12 Angular acceleration of the first (blue), second (green) and third (red line) mass of the model, 5000 min^{-1} on 6th gear

Analysis of the results for excited vibration shown in Fig. 7 to Fig. 12 indicates that the system effectively lowers the acceleration of the vehicle body (third mass of the model) and allows driving the vehicle on low engine angular speed. The acceleration of the second mass is less when the higher gear is engaged. Acceleration decrease when increase the angular speed of the engine.

4. Conclusion

The considered model enable to study the vibration in vehicle drivetrain and fluctuation in linear movement of the vehicles with dual mass flywheel. The shown consideration for reduction of all parameters to the engine crankshaft allows to be studied the vibration on various gears in vehicle gearbox. The numerical experiments with given parameters show good damping of acceleration of the third mass (vehicle) in all speed range of the engine and for all gears of the gearbox. The acceleration of the second mass (transmission) decreased with increase the angular speed and with engagement of the higher gear in the gearbox.

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ERGONOMIC ASPECTS WHEN DESIGNING LUMINAIRES BASED ON LED LAMPS.

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Annotation: Some initial information is given for the competent design of household LED lighting fixtures

KEYWORDS: LED LAMP, VISUAL PERCEPTION, COLOR TEMPERATURE, MELANOPSIN

Introduction

Fixtures based on LEDs lamps are of interest now, as the direction of actively developing lighting systems and devices.

When designing LED luminaires, tasks are set for matching ergonomic studies to reduce the contrast of the light pattern, eliminate the light drop and uniformity of the illuminated space.

It should be noted the current trend in designing fixtures-reducing size, weight, saving materials.

Fundamentals

The starting points for creating a good living environment lighting: parameters are formed as a result of studying the visually perceptible space, taking into account human physiology.

Lighting by LED emitters performs the following tasks:

- operational (allows you to read, recognize visual information of all kinds, navigate in space)
- psychological (creates favorable incentives, comfort, entertainment and mood)
- provides and creates prerequisites for greater safety of work and leisure
- hygienic (stimulates the maintenance of cleanliness)

The main factors of visual perception:

- maximum improvement of perception of visual information for performance of work.
- provision of an appropriate level of performance of tasks:
- maximum work safety assurance
- provision of necessary level of visual comfort.

Level of required illumination is determined by the following parameters:

- the smallest object size of view, in mm (from 0.15 to 5)
 - the scope of visual work: (from the 1st to the 9th)
 - contrast of the object of view with the background (small, medium, large)
 - characteristics of the background (dark, medium, light)
- Dependence of the visual system on the surrounding space
- Perception in the work area allows you to determine the characteristics of the reliability of human performance.

The quality of lighting of any premises should be evaluated complex, according to the requirements and various lighting factors.

Artificial lighting is divided into:

- general,
- local,
- combined and special (with specific technical characteristics: scattered, directional, reflected)

The color of light, or the spectral composition of the light flux, affects the appearance of the illuminated object. Because of the brilliance in direct lighting, the reading efficiency, after 3 hours is reduced by 80%, with a system of reflected light and no glare, the reduction is -10%.

Calculation of the required number of luminaires of general lighting in the premises is made by the formula (the height of the suspension of luminaries -1000mm above the illuminated surface)

$$n = \frac{1 \times b \times E_m \times k}{\Phi}$$

where "n" is the number of fixtures, pcs.; "k"-coefficient for the color and tone of walls, floor and ceiling (1,5-2,5); "1" - length of the room, m; "b" - width of the room, m; "Em" - illumination given, lx; "Φ"-light stream of light sources of one lamp, lm. The level of illumination depends on the height of the suspension and decreases in proportion to the square of its change:

The number of lamps must be increased in proportion to the square of the height change.

For local illumination of the workplace in combination with general lighting should be at least -20% of the workplace illumination.

Optimal lighting is designed according to

Project parameters	Distance value Contrast The property of the illuminated surface Dynamics and time Color Specifications Physiological - enables a person to see, work, create
Performance characteristics	Age of the person Restriction of sight Visual adaptation Perception of colors Depth of field
Lighting characteristics	Levels of illumination Distribution of brightness Spectral composition-color rendition (the accuracy of the perception of the color of the object depending on the color of light) The absence of zones of glare (glare) Flicker (light pulsation) The distribution of the shadow and the direction of light (light flux)
Specificity of the consumer situation	Influence of the human pose Visual field limitation Technical requirements for railroad cars - safety during operation Recycling Ecological compatibility Accuracy of visual work: -negated -very high -medium

*With age, sensitivity decreases: the need for a person in the illumination of 30 years of age is 2 times, for a 40-year-old at 3, and for a 50-year-old is 6 times greater than for a ten-year-old.

Advantages when using LED lights:

- there is no flicker of light.
- small size and weight.
- high light output with low power consumption.
- fast turning lights on and off - instant.
- increased stability to vibrations and impacts to other external influences.
- white light of high quality, color rendering index in the range of 80-95.

- optimal radiation pattern depending on the purpose of illumination with the possibility of creating scattered light or directional light.
- absence in the radiation spectrum of the infrared component and low heat generation, lack of heating of surrounding objects and surfaces.
- warranty guarantee with any humidity and ambient temperature from -50 to +50 ° C.
- simplified the supply and management of electricity.
- miniature sizes of radiating elements allow to widely embed LEDs in bearing structures and elements of lighting systems.
- the maintenance and operation of the luminaire is simplified.
- automatic control of the luminous flux and the process of switching on the luminaire is possible.
- color temperature control can be provided by electronic sensors and logic systems). Comfort is provided in use, high consumer qualities are formed.
- LED lights have a very high efficiency, reaching 75% or more, which allows you to significantly (in 4-5 times) reduce power, load on the network. The costs associated with the cost of consumed electricity are reduced.

Such technological and design solutions are appropriate.

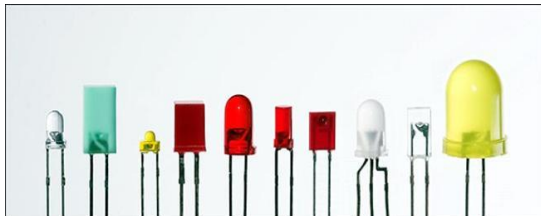


Fig.1, LEDs produced in a very wide range of colors - up to IR and UV ranges.

They can be either monochrome or multicolored (when several crystals of x colors are concentrated in one body), for example, RGB.

One of the drawbacks of these LEDs is the low scattering angle of the light flux: usually not more than 60°.



Fig.2, SMD LED

In addition to LEDs, SMD LEDs are also available. This includes super bright white and color LEDs with a power of about 0.1 W in a surface mount case. The dimensions of the housings are usually standard for any SMD type elements: 0603, 0805, 1210, etc., where the marking denotes length and width in hundredths of an inch or in millimeters. In this case, there are both varieties with a convex lens, and without it. Clearly classifying all the variety of LEDs is difficult, because rarely those or other LEDs are produced for some specific purposes. Nevertheless, the main directions of their application - indication and lighting - remain the same for the time being, and the classification given here is suitable for creating a general idea of the types of LEDs.

Specificity and design features of fixtures:

As a rule, the design of the luminaire consists of a support base, a fixing element, a rod, a bracket, a reflector. Also, the lamp is equipped with a diffuser of light or diffuser.

Achievement of uniformly illuminated space is achieved. The problems of reducing the contrast of the light pattern are solved, and the difference in the illumination is eliminated.

The luminaire provides the possibility of using in a complex spatial situation-placement and illumination in hard-to-reach places.

When designing, it is envisaged that the luminaire can be easily mounted and adjusted for operation.

The envelope of the radiating element is of small size (its size is a multiple of the design of the lamp). Weight devices are relatively small, there is a significant savings in materials (while reducing the cost of the lamp).



Fig.3, Waterproof version of LED for bathroom

No deposits are formed, maintenance and care (removal of dust, insects, other contaminants) are facilitated.

The electrical safety is easily ensured. The risk of injuries and life threatening effects is reduced (the work of the light system is ensured by a low current and voltage strength-usually designed for safe voltages of 12 ÷ 24V).

The mechanical durability of the LEDs is large. Their service life is up to 50000 hours. Therefore, a long service life allows you to increase the period between repair and maintenance.



Fig.4, Demonstration of formation on the example of LEAD

Influence of modern lamps on health and human vision:

The negative effects of blue LEDs on humans are noted. The blue spectrum, when viewed, causes overstrain of the visual area of the brain in a matter of minutes.

There are risks of disability in sight at working age. When working with color information, there is also a danger to health. It has been shown to have a negative effect on the retina of the eye; for example, blue light abruptly suppresses the production of melatonin in humans, there is a risk of blindness. With LED light, a large proportion of blue falls on the retina of the eye, than in sunlight with the same illumination of the retina. In sunlight, the ratio of the various components of its spectrum is adequate and does not lead to unnecessary intensity of the human eye.

With a large dose of blue in the spectrum of lighting, the so-called Melanopsin forms a signal to reduce the diameter of the pupil. This reduces the energy illumination of the retina, protecting it from exposure to a large dose of blue light. Melanopsin has 2 peaks of maximum photosensitivity - at 460 nm and 480 nm. The dose of blue light that gets on the retina depends on the pupil ø, which decreases depending on the amplitude at 480nm, the LED has a dip of 480nm. With LED lighting, this ratio is not respected, since there is a dip in the spectrum of such a light source. With a large

dose of blue in the spectrum, melanopsin does not form a signal to reduce the diameter of the pupil. Thus, most of the blue light of the LED hits the retina of the eye.

Comparison of TRI-R technology with filters in a conventional LED:

The newest LEDs of Sun Like emit purple, and the light is not blue, which then passes through a layer of phosphorus with three light filters - for blue. Interlayer technology is called TRI-R. The principle of technology - purple crystals 420 nm, which are painted with red, blue and green phosphors. In the white light spectrum of LEDs (TRI-R technology), the dip at 480 nm is eliminated and there is no excess dose of blue. The spectrum is close to solar.

Advantages of LED lamps using TRI-R technology:

- lighting is optimal in magnitude, close to the calculated
- the spectrum is close to solar
- the lack of pulsation in time and noise from the ballast (ballast)
- uniform distribution of lighting of the working area in accordance with the design
- high manufacturability and structural variability

Prospects for the development and expansion of the use of LEDs:

Designers create conceptual models (Fig.11), prototypes of future systems. The appearance of the lamp is developed in both traditional and retro style(Fig.6), classical or the latest avant-garde trends. Formed not stylized eclectic forms, but the most rational solutions from the structural and aesthetic side.



Fig.6



Fig.7, Design models of non-traditional forms are created, with new consumer functions.

The possibility of dynamic editing is provided. Providing rotation, shearing and moving in space.

A separate class of luminaires with autonomous power supply (energy sources with solar panels and batteries)

When manufacturing, progressive production processes -3D printers and other modern technologies can be used. They allow the integration of light-emitting diodes into various materials (such as

polycarbonate, polyethylene, epoxy compositions and others) electrical elements.

LED systems are now actively developing in landscape (Fig.8) architecture. In the design of the lighting system in this case, it is easy to take into account various weather factors, difficult weather conditions. The ventilation of the lighting system is simplified.

Low accumulation of moisture in the luminaire (there is a slight formation of condensation).



Fig.8, Fashionable and conceptual form of a landscape lamp

The experience of architectural application proves the perspective of light sources on light-emitting diodes. They allow you to get a light spot of any shape with minimal loss. There are solutions that allow using a single LED illuminator to highlight light columns, bridges and similar architectural elements.(Fig.9)



Fig.9, Formation of a light image in the interior

Based on LEDs, you can create light sources with a small beam angle of $5 \div 10^\circ$.

Technologies on light-emitting diodes allow to pass from static illumination of architectural elements of buildings to dynamic and colorful color representations, to reveal features of architectural objects (Fig.10).To ensure comfortable lighting in various areas and appearance.

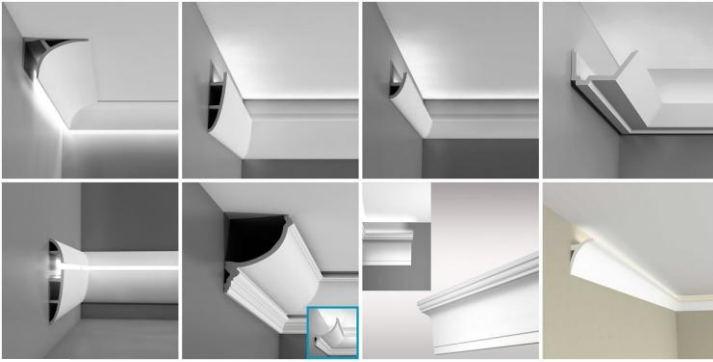


Fig.10

The use of light-emitting diodes for illumination of pools and in premises with high humidity has widely spread.

The main models of luminaires based on LEDs

Fixtures are developed practically for all household needs: floor, table, suspended, wall, portable, for exterior, landscape use, souvenir and others.

Performed in designs for lighting paintings, equipment, highlighting exhibits.

Dynamic lighting using LEDs influences the visual estimation of interiors, the perception of dimensions, details, and its color solution. LED lighting fixtures help to harmonize physiological processes in a person, provide vital modes rhythmically, "around the clock".



Fig.11, Forms of LED lighting fixtures in retro or parametrizm style

There are models for building graphical interfaces, other information carriers and systems (visual communications and other information tools).

The so-called "Art objects" based on LED systems stand out as a separate consumer niche of household lamps.



Fig.12 Forms of LED lamps are simple and geometric

They are designed to perform decorative equipment, functions of symbolic indexing of space or creation of the necessary imaginative atmosphere and toys.

Used LEDs of different designs, creating almost all the colors of the rainbow.

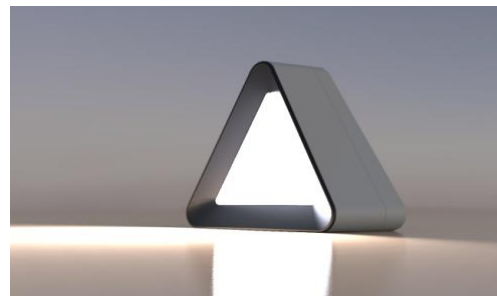


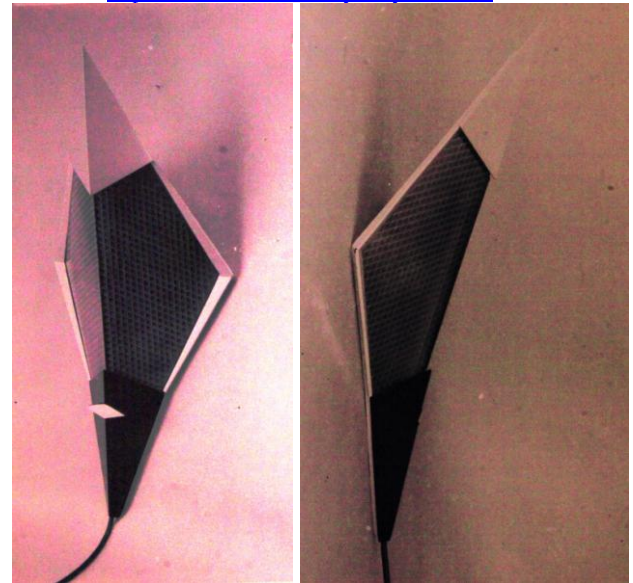
Fig.13, A typical example of the shaping of a lamp based on LED



List of sources used:

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<http://finelighting.ru/svetilniki/lampy/svetodiodnye/svetovoj-potok-kratkaya-xarakteristika-osobennosti.html>
<http://ledno.ru/svetodiody/vidy-led.html>



As an illustration of the appearance of the luminaire on the LEDs, the "Danko" system is presented, (overall size - 750mm x 280mm, Material of construction - plastic).



Fig14, Wide possibilities of shaping



Conclusion

Based on the results outlined above.

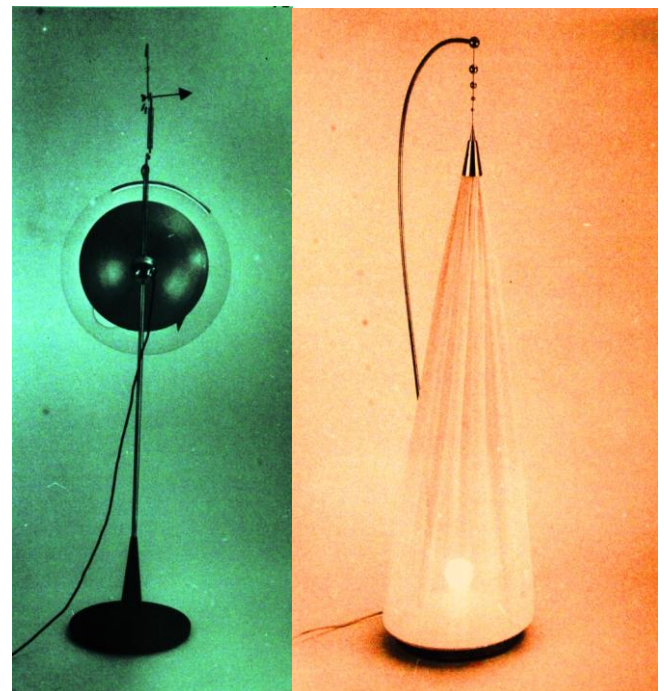
It is necessary to take into account socio-cultural factors, styles of basic aesthetic trends. It is possible to carry out synthesis of modern art and the latest technologies; there are the most extensive opportunities for creating a form. Such technological and design solutions are suitable for providing comfort when using LED, and their high consumer qualities are formed. I believe powerful LEDs will soon replace outdated light sources.

There is a tendency: designers develop "disposable" models of fixtures using LEDs.

The cost of replacing the LED element and repair is comparable to the production of the entire product and may exceed the cost of the lamp itself. This contributes to the marketing appeal. It is easier and cheaper to design LEDs.

Thus, they reflect the latest trends. Optimization contributes to improving consumer properties and quality of household products based on LEDs.

Now the technologies of LED lamps are actively developing, so final standards and standards have not been developed yet.

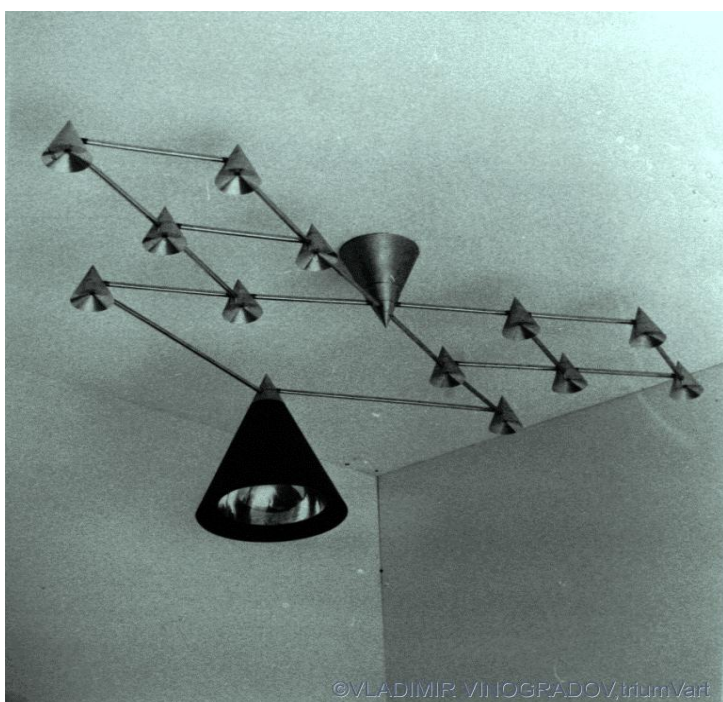


The "Eol" system is presented,
 Lamp for comfort in the living room
 (overall size -1800mm x Ø600mm,
 Material of execution - steel chromeplated).

The "Shaherezada" system is presented, Floor lamp for creating a cozy atmosphere in the home
 (overall size -1600mm x Ø350mm, material of the lampshade-Silk, base -Cu).



The "Malevich" system is presented, for changing the position of the luminaire suspension in a dwelling (overall size -* Ø270mm x1000mm, Material of execution - steel chromeplated).



As an illustration of the appearance of the luminaire on the LEDs, the "Galaxy" system is presented, (overall size -2000mm x1000mm, Material of execution - steel chromeplated).

A feature of this model is the function of changing the location of the LED modules (conical shape). The lighting system has a shaped star structure and is easily transformed. The central reflector can be lowered down for local illumination-an additional function for providing effective and comfortable illumination of space.

Design this model (only 5 models)

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MICROSTRUCTURAL EVOLUTION AND MECHANICAL PROPERTIES OF ALUMINUM IN THE PROCESS "PRESSING-DRAWING"

ЭВОЛЮЦИЯ МИКРОСТРУКТУРЫ И МЕХАНИЧЕСКИХ СВОЙСТВ АЛЮМИНИЯ В ПРОЦЕССЕ «ПРЕССОВАНИЕ-ВОЛОЧЕНИЕ»

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Abstract: The aim of this work is to study the influence of the combined process of "pressing-drawing" on the microstructure and mechanical properties of aluminium wire. Analysis of the results of the research has shown that the proposed combined method of deformation "pressing-drawing" has a significant advantage over the existing technology of production of aluminium wire. This method of deformation due to combination of two ways: by severe plastic deformation in equal channel step die and the process of drawing through a drawing die, allows obtaining aluminium wire with ultrafine-grained structure and a high level of mechanical properties, required size and shape of the cross section at a small number of cycles of deformation. Also would like to mention that this method of deformation in implementing it in production does not require significant economic investments, and substantial refitting of existing drawing mills.

KEYWORDS: PRESSING-DRAWING; COMBINED PROCESS; ALUMINIUM WIRE; MICROSTRUCTURE.

1. Introduction

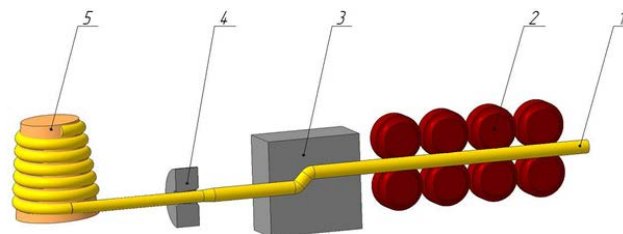
The contemporary level of electronic technology development has led to the appearance of devices that often have moving parts and / or work in difficult conditions. Therefore, interest in the problems of forming physical and mechanical properties of functional conductor materials has recently grown abroad in connection with the need to stabilize the properties of current conductors and increase their reliability, including in heavily loaded cable systems, motor and generators windings and low-current computer networks [1-2]. The increased interest of researchers in such materials has greatly increased in recent decades in connection with the use of severe plastic deformation (SPD) methods to obtain bulk materials with fine grains characterized by high physical and mechanical properties [3-4].

Nowadays, the mechanical properties of bulk nanostructured materials generate particular interest. It is known that they are characterized by an increase in the yield point by 2-5 times compared with the corresponding values on SPD at coarse-crystalline state [5-6]. The paradox of SPD, consisting in the simultaneous growth of strength and plasticity as the degree of SPD increases, low-temperature and highspeed superplasticity, deviations from the Hall-Petch law to the higher values of the yield point [7-9].

The SPD method is free from disadvantages of other methods of obtaining such materials, such as the method of compacting powders obtained previously by various methods, and the method of depositing gas atoms on a substrate or electric deposition of atoms from an electrolyte solution. When the materials are compacted or deposited, impurities and pores flow into the boundaries of their grains, influencing the properties of the obtained materials. Among the SPD methods, the ECAP method is especially noteworthy [10-12].

A polycrystalline sample of a macroscopic volume subjected to ECAP retains its shape after multiple extrusions through a curved channel. As a rule, ultrafine-grained or nanocrystalline materials, obtained at the output, have nonequilibrium grain boundaries and a considerable density of lattice defects [13]. These features of the microstructure formed in the SPD process underlie the mechanical properties of the materials. However, the ECAP has a disadvantage – the impossibility of processing products of relatively large length due to loss of stability by a pressing punch. On the basis of a comprehensive analysis of the existing schemes of plastic structure formation and also taking into account the promising directions of their development [14-15], a new combined "pressing-drawing" process using an equal-channel step matrix (Figure 1) was proposed. It enables to obtain a wire with an ultrafine-grained

structure and increased level of mechanical properties, required dimensions and shape of the cross section at insignificant number of deformation cycles.



1 – wire; 2 – pushing device; 3 - equal channel step matrix; 4 – calibrating drawing tool; 5 - winding drum

Fig. 1. Scheme of the combined process of "pressing-drawing"

The gist of the proposed deformation method consists in the following. Preliminary sharpened end of the wire is set to equal-channel step die and then subsequently in the finishing die. At its core, process setting metal does not differ from the setting of the wire in a drawing die at a standard process of drawing. After the end of the workpiece exits the die it is fixed by means of gripping tongs and is wound on a drum drawing machine. In this case, the process of drawing the workpiece through an equal channel step die and a caliber die is realized by the application to the end of the workpiece stretching force. The external load is applied to the drawing metal and on the surface of the contact metal - tool contact stresses arise. Unlike other methods of material forming, the implementation of which cannot be carried out without the presence of the contact friction forces at drawing on metal-tool, directed against metal movement, are negative phenomena of the process, which undoubtedly involves the use of technology lubricants that reduce friction.

To determine the effects of a new combined method of deformation "pressing-drawing" on the changes in the microstructure and mechanical properties of aluminum wire laboratory experiment was carried out at an industrial drawing machine - I/550 M. For the first cycle of deformation before the draw plate with working diameter of 7 mm equal channel step die with channel diameter is 7 mm and the angle of the junction of channels equal to 135° was fixed. The die was placed in a container for lubrication.

The initial diameter of the wire was 7.0 mm. After the process of pressing-drawing wire diameter has been 6.0 mm. All compression was carried out only in the drawing die, after exiting the workpiece from the equal channel step die wire diameter stayed

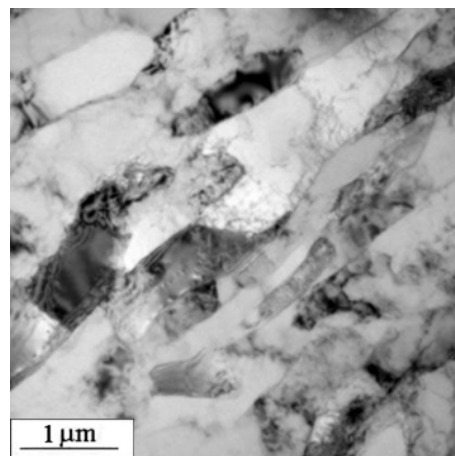
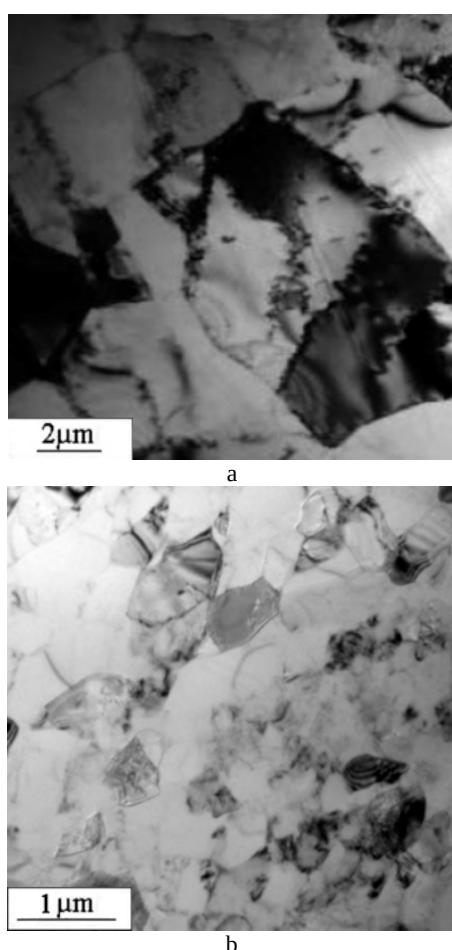
unchanged at 7.0 mm. The experiment was duplicated four times. In this case after each experiment wire diameter was measured and cut templates for production of microsections in the transverse and longitudinal direction.

In order to identify the advantages of the proposed technology in comparison with the current technology of drawing three passes annealed wire of aluminum for each technology were carried out. I.e. clean drawing wire rod was carried out diameter of 7.0 mm in the drawing die on diameter 6.0 mm, equal channel angular drawing and combined process of "pressing-drawing". In this case also, after each experiment wire diameter was measured and cut templates for production of microsections in the transverse and longitudinal direction. As a lubricant chips of soap were used.

2. Results and discussion

Preparation microsections for metallographic investigations carried out by the standard method, for the study a scanning electron microscope JEOL JSM 5910 was used.

The results of the study of the microstructure of aluminum before and after the third cycle of deformation are shown in Fig. 2.



a – the initial structure, b – by the proposed ECAP-D technology, transverse direction, c – at existing technology of drawing, transverse direction

Fig. 2. Structure of wire of aluminum

Having conducted metallographic analysis of the deformed samples it can be concluded that the cold deformation when drawing at the current technology with a moderate and high total compression leads to the formation of a distinct textured structure. However, even as a result of substantial compressions produced wire in drawing process, not all grains are crushed and are deployed in the direction of the axis of deformation. As shown by metallographic analysis of the samples, resulting in uneven allocation of the deformation over the cross section in the central part of the longitudinal sectional of the wire area of large grains is retained, resulting in an inadequate level of the plastic properties of the finished wire, in particular elongation. Thus from figure 3c it is shown that in this case deformation leads to insignificant of grain refinement in the transverse direction, in the longitudinal direction grains are elongated and somewhat refined with the formation a visible axial texture. Also it should be noted that in the longitudinal direction of the deformed samples the texture is pronounced and has striated character. The appearance of texture of drawing leads to anisotropy of the material properties in the longitudinal and transverse directions, which may adversely affect the operation parameters of the finished product. To reduce the appearance of axial deformation texture it is necessary to carry out recrystallization annealing of obtained wire with correctly chosen heat treatment parameters.

When using the proposed technology of deformation, i.e. combined process of "pressing-drawing", as shown in Figure 3b, already in three passes change of the initial microstructure was a significant, at the same time significantly in the less degree texture expressed and anisotropy, respectively. The proposed combined technology "pressing-drawing" eliminates the disadvantages of drawing process. In the first stage of drawing to a 30-40% breakdown cellular structure is formed. The local increase in internal stress field causes the formation of stable microcracks. Intensive disclosure of stable microdefect leads to stress relaxation that during subsequent deformation opens previously blocked the Frank-Read sources. Simultaneously cellular structure being improved fibrous structure is arisen and texture is formed. To achieve ultra-fine grain structure only by the uniform flow of dislocations is impossible: the accumulation of plastic deformation and dislocation density growth there is disproportionately rapid increase detents and obstacles hindering their progress through the crystal. Dislocation flow gradually depletes the level of internal stress increases. This continues until cracks begin to appear, brittle fracture of the sample occurs. To avoid this, and the energy delivered to the sample is not accumulated in the material mainly in the form of elastic distortions, and continue to dissipate, equal channel step die will be applicable, where the shear deformation

are and large-borders will be formed as a result of conditions for continuation of the plastic deformation at large strains creates.

Results of mechanical studies are presented in Tab. 1. The strength characteristics of aluminum represented by the values of tensile yield σ_T and yield strength σ_b ; plastic characteristics represented by values of percentage reduction and elongation of samples before destruction.

Table 1 - Results of mechanical testing of wire samples

Designation processing technology	Yield strength σ_b , MPa	Tensile yield σ_T , MPa	Percentage of elongation δ_5 , %	Percentage reduction ψ_5 , %
Annealing	115	120	18,0	60,0
Classic drawing	203	198	15,5	44,0
ECAP-D Technology	316	312	16,0	49,0

The greatest change in the yield strength and tensile strength values (as changes in the microhardness) during the pressing-drawing occurs after the first pass. At subsequent passes, this increase occurs more uniformly. The values of tensile strength and yield increase for three passes from 115 to 316 MPa (absolute increase is 201 MPa) and from 120 to 312 MPa (absolute increase is 192 MPa), respectively.

As is known, the characteristic that most fully reflects the ability of the material to plastic deformation is a percentage reduction in the area of neck. Percentage reduction in the aluminum is changed from 60 to 49%.

From the analysis of carried out mechanical tests of samples by different technologies, we can conclude that the best mechanical characteristics there has a treated wire by the combined technology of "pressing-drawing". An increase in the yield strength and tensile strength values are observed and also index of the hardness, with the preservation of plasticity.

3. Conclusion

Based on this research we can conclude that the proposed combined method of deformation "pressing-drawing" has a significant advantage compared to previously known methods of producing a metal with subultrafine structure, because this method of deformation due to the combining two ways: severe plastic deformation in the equal channel step die and drawing process through a drawing die, allows to obtain the workpieces (aluminum wire) of required dimensions and shape cross section, having subultrafine structure at insignificant number of cycles and also removes restrictions on the length of the initial workpiece, and hence allows to obtain finished products length of up to several tens of meters.

Also would like to note that this method of deformation when introducing it into production does not require significant economic investment and can be implemented in industrial enterprises of the country for the production of wire so that it does not require retrofitting of existing drawing mills. Because for implementation of this combined process only the addition requires in construction equipment, equal channel step die, intended for drawing through it the material.

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DEPENDENCE OF THE ACTIVE POWER OF THE SERIAL RESONANT BRIDGE CONVERTER FROM THE PHASE DIFFERENCE AND THE DUTY CYCLE

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Abstract: Serial resonant bridge converter commonly used in process of induction heating on metal materials. In these applications during the heating process, the converter load equivalent electrical parameters are changed. This contributes to the transferred power from the converter to the induction device to change. In this paper with mathematical analysis are determined the quantities from which depends the active power of the resonant converter. Derived is an equation that gives the dependence of the active power from the phase angle between the voltage and current the converter as and from the duty cycle. This equation can be used in control methods to maintain maximum converter power transfer.

Keywords: ACTIVE POWER, RESONANT CONVERTER, EQUATION

1. Introduction

In power converters of interest is that the power transferred from the converter on the load to be maximal. Often due to the change in the parameters of the output circuit of the converter, this power is not always maximal [1], [2], [3]. To maintain maximum transferred power from the converter to the load is needed knowledge of the parameters that affect the power. Independent of the type of process controlled by the converter, motor drive or induction device, etc., causes leading to a reduction in the transferred power are related to increasing the phase difference between the voltage and the current of the converter as well the deviation of duty cycle of value 0.5. The change in the phase difference is caused by the change of parameters (inductance, resistance, and capacitance) of the output circuit of the converter. To changing the duty cycle on the output voltage of the converter comes as a result of the need to change the effective value of the output voltage, with target to controlling the output power of the converter. The change on the phase difference leads to an increase in reactive power and a reduction in the active power of the converter. Reduction of the duty cycle from 0.5 increases the harmonic distortion of the output voltage and current of the converter. Both reasons reduced the output active power and efficiency of the converter [4], [5], [6] [7].

In this paper with mathematical analysis are determines the quantities from which depends the active power of the resonant converter. Derived is an equation which gives the dependence of the active power from the phase angle between the voltage and current the converter as and from the duty cycle.

2. Impact on Phase Difference and Duty Cycle at Serial Resonant Bridge Converter

Serial the resonant converter is normally used in the devices for induction heating [1], [2]. In Fig. 1 is shown the electrical scheme of this converter with output load: $R = 0.24 \Omega$, $C = 26.6 \mu F$ and $L = 26.5 \mu H$ [8]. In Fig. 2 are shown the output voltage and current waveforms in the more usual above-resonance mode of operation. In induction heating/melting and similar applications the heated workpiece equivalent electrical parameters are part of the resonant circuit. As the work-piece temperature increases, its equivalent resistance and inductance change, thus changing the circuit resonant frequency. Consequently, the deviation of the switching frequency from the resonant one is also changed, which results in undesired change of output power.

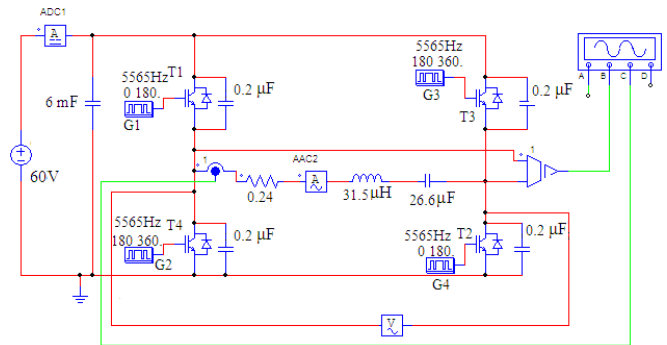


Fig. 1 Serial resonant bridge converter topology in mode of induction device.

The typical R and L change during metal-piece induction melting is in the range of 50%. These real values are used as an example in the following examination giving the values for the resonant frequency $\omega_0 = 37665 \text{ rad/s}$, $f_0 = 5998 \text{ Hz}$ [9], [10].

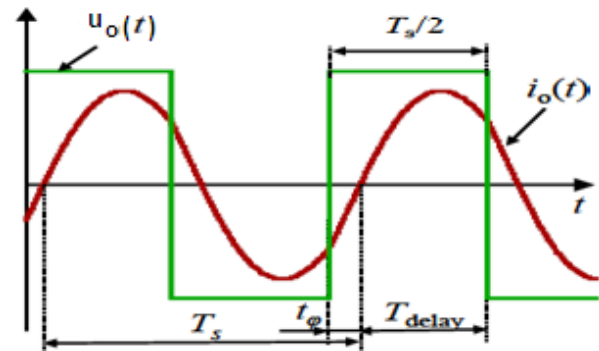


Fig. 2 Output voltage and current waveforms in above-resonance mode.

The mode of induction heating changes the value of the resistance and inductance of the resonant circuit of the converter. This leads to a change in the phase difference between the current and the voltage of the converter and the change of the output power.

In Table I are given the values on the switching frequency f_{sw} , output voltage U_o , output current I_o , output power P_o and phase difference ϕ for change on the resistance and the inductance for 20 %, i.e.: change on R from 0.24Ω on 0.29Ω , and change on L from $26.5 \mu H$ on $31.5 \mu H$.

To visualize this rather strange dependence, Fig. 3 gives Power-Sim simulation results of steady state for several values of the switching frequency below and above resonance [9].

Table I: Values of the output converter parameters for changes of resistance and inductance for 20%

L [μH]	R [Ω]	ϕ [°]	f_{sw} [kHz]	I_o [A]	U_o [V]	P_o [kVA]
26,5	0,24	5,00	6.27	208	56	10,7
31,5	0,29	31,34	6.27	145	56	6,16

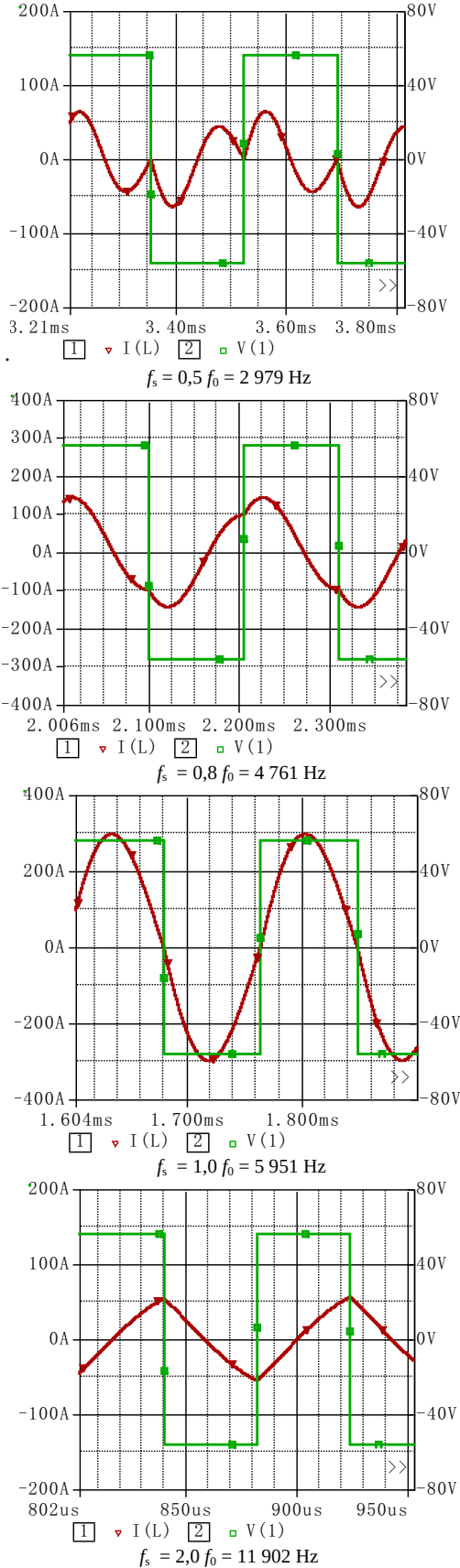


Fig. 3 Steady state voltage and current waveforms below and above resonance ($R = 0.24 \Omega$, $L = 26.5 \mu H$, $C = 26.6 \mu F$ and $Q = 4$).

From Table I can be seen that the change in the inductance and the resistance for 20 %, changes the phase angle for 16 % and reduces the output power for 42 %.

The current waveform for $f_s = 0.5 \cdot f_0$ shows that is very much distorted deep below resonance, the first harmonic is no longer dominant, which reflects to the amount of active power transferred to the load. This explains why below-resonance mode of power control was less desirable. The first diagram in the Fig. 3 for $f_s = 0.5$ f_0 shows that phase difference gets zero values every time the switching period T_s is multiple of the resonant one T_0 , in this case $T_s = 2 T_0$.

The general conclusion from Fig. 3 is that when switching frequency f_s is different from resonant frequency f_0 the harmonic distortion of the output current are increased.

In Table II are given the values on output voltage U_o , output current I_{out} , output power P_{out} for change on convertor duty cycle.

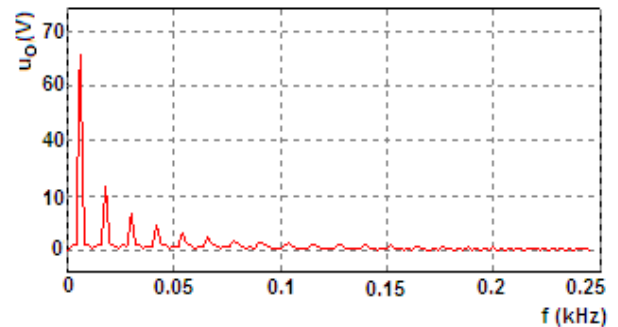
Table II: Values of the output converter parameters for changes of the duty cycle

L [μH]	R [Ω]	ϕ [°]	f_s [kHz]	D	I_o [A]	U_o [V]	P_o [kVA]
26,5	0,24	5,00	6.27	0.5	208	56	10,7
26,5	0,24	5,00	6.27	0.4	187	56	8,5
26,5	0,24	5,00	6.27	0.3	125	56	3,8
26,5	0,24	5,00	6.27	0.2	43	56	0,45

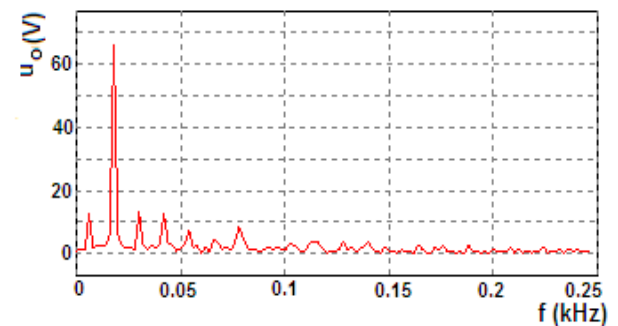
From Table II can be seen that the change on the duty cycle D significantly reduces the output power P_o . Changing the duty cycle to 0.1 from optimal value 0.5 causes a change on the power for 21 %. Larger changes in the duty cycle D causes significant changes on the power P_o .

Also, the change in the duty cycle causes an increase in the harmonic distortion of the output voltage. In the Fig. 4 is shown harmonic specter for the output voltage of the converter for duty cycle 0.5 and 0.2.

From Fig. 4a can be see that for duty cycle 0.5 the first harmonic (on frequency 6.027 kHz) has the highest value and for duty cycle 0.2, the highest value has third harmonic, Fig. 4b.



a)



b)

Fig.4 Harmonic specter of the output converter voltage: a) for duty cycle 0.5 and b) for duty cycle 0.2.

The general conclusion from Fig. 4 is that for less duty cycle $D < 0.5$ the harmonic distortion of the output voltage increases.

3. Determination on the active power from phase difference and duty cycle

The output active power of the serial resonant converter is determine as [2], [3]:

$$P_o = U_o I_o PF \quad (1)$$

In (1) U_o is the effective value on the output voltage, I_o is effective value on the output current, and PF is power factor of the converter.

In a converter that generates a voltage with a square waveform at the output, the power factor of the converter is defined as:

$$PF = DF_u \cdot DF_i \cdot DPF \quad (2)$$

In (2) DF_u is a voltage distortion factor and is defined as the ratio of the effective value of the fundamental voltage harmonic U_1 and the effective value of the total voltage U_o , ie:

$$DF_u = \frac{U_1}{U_o} = \frac{1}{\sqrt{1 + THDV^2}} \quad (3)$$

In (3) THDV is a total harmonic distortion of the voltage and is defined as a square root of the ratio of the sum of squares to the effective values of the higher harmonics of the voltage and the square of the effective value of the fundamental harmonic of the voltage U_1 , ie:

$$THDV = \sqrt{\frac{|U_3|^2 + |U_5|^2 + |U_7|^2 + |U_9|^2 + |U_{11}|^2 + \dots}{|U_1|^2}} \quad (4)$$

The second term in (2), DF_i is a current distortion factor and is defined as the ratio of the effective value of the fundamental current harmonic I_1 and the effective value of the total current I_o , ie:

$$DF_i = \frac{I_1}{I_o} = \frac{1}{\sqrt{1 + THDI^2}} \quad (5)$$

In (5) THDI is a total harmonic distortion of current and is defined as the square root of the ratio of the sum of squares to the effective values of the higher harmonics of current and the square of the effective value of the fundamental current harmonic, ie:

$$THDI = \sqrt{\frac{|I_3|^2 + |I_5|^2 + |I_7|^2 + |I_9|^2 + |I_{11}|^2 + \dots}{|I_1|^2}} \quad (6)$$

The third term in (2), $DPF = \cos \varphi$ is the displacement factor.

For frequencies close to the resonance, the current is with the sinusoidal waveform, so that the current distortion factor $DF_i = 1$. Based on the above and (1), the power factor in a resonant converter with a square waveform of the output voltage and operating frequencies close to the resonance, is given as:

$$PF = DF_u \cos \varphi = \frac{U_1}{U_o} \cos \varphi \quad (7)$$

In a bridge resonant converter with a square waveform on the output voltage, when the duty cycle is $D = 0.5$, the voltage distortion factor is $DF_u = 0.90$ [2]. With this (7) gets the form:

$$PF = 0.9 \cos \varphi \quad (8)$$

The effective value of the fundamental voltage harmonic U_1 in a bridge resonant converter with a square waveform of the output voltage and the duty cycle factor D is given with [2]:

$$U_1 = \frac{4U_{DC}}{\pi\sqrt{2}} \sin(D\pi) \quad (9)$$

Replacing (9) in (7) for the power factor is obtained:

$$PF = \frac{1}{U_o} \frac{4U_{DC}}{\pi\sqrt{2}} \sin(D\pi) \cos \varphi \quad (10)$$

When the (10) is replaced in (1) the power gets the form:

$$\begin{aligned} P_o &= \frac{I_o U_o}{U_o} \frac{4U_{DC}}{\pi\sqrt{2}} \sin(D\pi) \cos \varphi = \\ &= I_o \frac{4U_{DC}}{\pi\sqrt{2}} \sin(D\pi) \cos \varphi \end{aligned} \quad (11)$$

The equation (11) gives the dependence of the output power of a bridge resonant converter from the output current I_o , the voltage of DC source U_{DC} , the phase difference φ and the duty cycle D .

From (11) can be concluded that the output power of the converter can be controlled with control of the phase difference and with duty cycle D . However, control of the output power with changing the duty cycle D is limited of the increase of the harmonics which comes with a decrease on duty cycle.

When $D < 0.5$ the harmonic distortion increases and the voltage distortion factor $DF_u < 0.90$. For illustration of this, in Fig. 5 is shown the dependence of the voltage distortion factor $DF_u = U_1/U_o$ from duty cycle D .

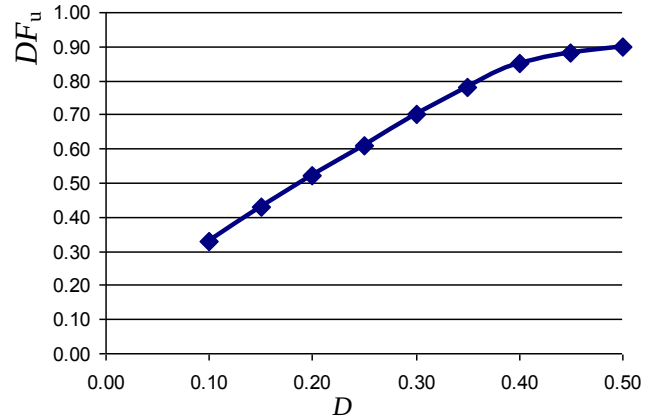


Fig. 5. Dependence of the voltage distortion factor DF_u from duty cycle D .

From Fig. 5 can be noted that to 20 % (value 0.4) decrease of the duty cycle, the voltage distortion factor are decreased to 0.85. With this, the power factor will fall below 0.85, the active power will decrease, and therefore the efficiency will decrease. Therefore, in practice when adjusting the output power of the resonant converter by adjusting the duty cycle, it should go with its change in small range below 0.5.

For greater power deviation from the nominal (due to change in resonant circuit resistance) is more practical to use a DC/DC converter in a DC power source that will supply the inverter. However, even considering that the DC/DC efficiency is about 0.9 and the efficiency of the resonant converter is about 0.9 the total efficiency will fall about 0.8.

In serial resonant converter, the output voltage is with square waveform and in such a case phase differences is [8], [10]:

$$\varphi = \arctg \left(\frac{\sin(\pi \frac{\omega_d}{\omega_s})}{e^{\frac{\pi \omega_0}{2Q \omega_s}} + \cos(\pi \frac{\omega_d}{\omega_s})} \right) \quad (12)$$

where:

$$\omega_d = \sqrt{\omega_0^2 - \left(\frac{R}{2L}\right)^2} \quad (13)$$

is damping frequency and with values for $R = 0.24 \Omega$, $C = 26,6 \mu F$ и $L = 26,5 \mu H$ has the value 37392 rad/s . When (12) is replaced in (11), for active power of converter is obtained:

$$P_o = I_o \frac{4U_{DC}}{\pi\sqrt{2}} \sin(D\pi) \cos \left(\arctg \left(\frac{\sin(\pi \frac{\omega_d}{\omega_s})}{e^{\frac{\pi \omega_0}{2Q\omega_s}} + \cos(\pi \frac{\omega_d}{\omega_s})} \right) \right) \quad (14)$$

Base on (14) in Table III are given data for the effective value on output current I_o , the voltage on DC supply U_{DC} , ratio on the switching and damping frequency f_s/f_d , the phase difference φ and calculate power P_o . These values are obtain with RLC parameters that are given above.

Table III: Data for f_s/f_d , U_{DC} , I_o , and P_o for $D = 0.5$, $D = 0.4$ and $D = 0.2$

f_s/f_d	U_{DC} [V]	φ [o]	$D= 0.5$		$D= 0.4$		$D= 0.2$	
			I_o [A]	P_o [kW]	I_o [A]	P_o [kW]	I_o [A]	P_o [kW]
0.1	60	-0.02	57	2.88	25	1.26	18	0.91
0.25	60	-0.06	33	1.67	23	1.16	32	1.62
0.3	60	-15.13	62	3.03	52	2.54	34	1.66
0.4	60	20.53	52	2.46	28	1.32	41	1.94
0.5	60	-0.06	42	2.13	41	2.07	41	2.07
0.6	60	-19.72	55	2.62	55	2.62	42	2
0.7	60	-32.56	62	2.64	76	3.24	57	2.43
0.8	60	-37.36	89	3.58	110	4.42	58	2.33
0.9	60	-29.32	157	6.93	155	6.83	47	2.07
1.0	60	0.19	211	10.7	186	9.41	43	2.18
1.1	60	31.10	169	7.32	174	7.54	42	1.82
1.2	60	43.88	129	4.71	128	4.67	33	1.2
1.3	60	47.70	86	2.93	90	3.06	29	0.99
1.4	60	48.17	76	2.57	73	2.46	28	0.95
1.5	60	47.31	62	2.13	62	2.12	26	0.89
1.6	60	45.90	55	1.94	53	1.86	24	0.85
1.7	60	44.29	46	1.67	47	1.70	26	0.94
1.8	60	42.63	41	1.53	44	1.63	23	0.86
1.9	60	40.99	40	1.53	37	1.41	19	0.73
2.0	60	39.42	35	1.37	36	1.40	18	0.7

In the Fig. 6 are shown waveforms of the output power in relation to the normalized circular frequency f_s/f_d obtained with equation (14) for three value of duty cycle: $D = 0.5$ (a), $D = 0.4$ (b) and $D = 0.2$ (c).

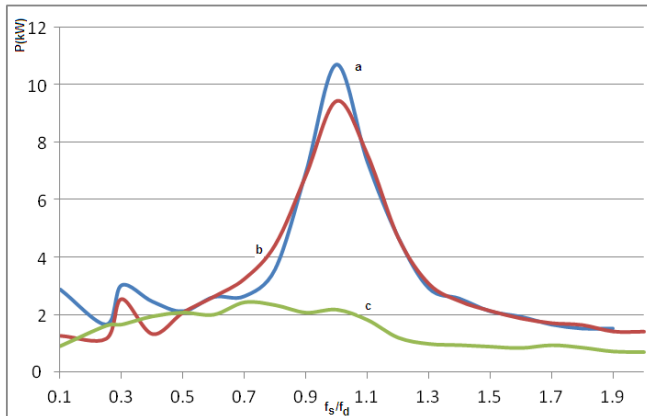


Fig. 6. Waveforms on the output power of the resonant converter for three value on duty cycle: $D = 0.5$, $D = 0.4$ and $D = 0.2$.

Calculating the output power with (14) the effective value on the

output current I_o is obtained with simulation on the circuit from Fig.1 in PowerSim program.

From Table III and Fig. 6 can be seen that: first, the output power is maximal for $f_s = f_d$ and duty cycle $D = 0.5$, second, the output power for $D = 0.4$ and $f_s = f_d$ is reduced for 15 % in ratio on the power for $D = 0.5$.

Also, can be noted that for frequencies larger than $f_s = 1.1 f_d$, the waveforms on the output power for $D = 0.4$ and $D = 0.5$ are almost the same.

The waveform on the output power for $D = 0.2$ shows that in this case is greatly reduced with maximum value for $f_s = 0.7 f_d$.

4. Conclusion

The serial resonant bridge converter have output voltage with square waveform and output current with sinusoidal form when switching frequency is same with the resonant frequency. When this converter operates in mode on induction device RL parameters are changed. This changes cause change on the phase difference between the output voltage and current. This cause change on transferred power from the converter to the output load. On the output power also can be influenced with changes on duty cycle.

To maintain a constant power transfer from the converter to the load, it is necessary to know the dependence of the power on the phase difference and duty cycle. In this paper, an exact equation is derived for the dependence of the output power of the converter from the phase difference and duty cycle. This equation can be used for development of an algorithm for the operation of the converter with constant power.

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USING THE PLANNING PROCESS TO CONSTRUCTION MANAGEMENT OF THE IRRIGATION INFRASTRUCTURE

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Abstract: The poor technical condition of the existing irrigation infrastructure in our country and “Common Strategy for Management and Development of Hydro melioration and Protection against Harmful Effects of Water”, which was prepared by a World Bank, give us reason to expect the financing of projects for the rehabilitation and modernization of irrigation systems. Analyzed good practice in this area shows that project management is essential to the qualitative and effective achievement of the main goal.

In the report, special attention has been paid to the process of planning certain priority projects for the rehabilitation and reconstruction of irrigation infrastructure at the construction stage and an analysis has been carried out for the different areas of management (time, costs, quality, human resources, communications, supplies and risks).

Keywords: CONSTRUCTION MANAGEMENT, IRRIGATION INFRASTRUCTURE, PLANNING PROCESS

1. Introduction

Lack of investment in irrigation infrastructure for more than two decades has contributed to a significant deterioration of its condition, which has reached a critical level to now. Thefts in the linear and basic facilities, strong depreciation of the intake and distribution network, water losses in irrigation systems amounting to 70-80% are one of the reasons for the development of a "Common Strategy for Management and Development of Hydro-melioration and Protection against Harmful Effects of Water ". It identifies as an important priority the rehabilitation and modernization of irrigation and drainage infrastructure in our country and the necessary capital expenditures for this are more than one billion euro [1].

For this reason, it was urgent to draw up a proposal from the team of World Bank staff and consultants for a framework, programming and prioritization of funding from the European Agricultural Fund for Agricultural Rural Development and the Rural Development Program (RDP). The main aim of this project is to contribute to improving the competitiveness of agriculture, together with promoting effective water consumption and increasing the environmental sustainability of irrigated areas [2].

Based on this project, the most favorable impacts are expected to be achieved within RDP Area 5A Increasing agricultural water efficiency, namely: Measure M4 Investments in tangible assets, Sub-measure 4.3 aimed at supporting investments in irrigation and drainage infrastructures [3]. For the purpose of programming and defining priority irrigation systems, it is recommended to use a multi-criteria assessment to allow the ranking of a list of rehabilitation and modernization projects for irrigation systems.

Beneficiaries of the Sub-measure 4.3 will be Regional Public Hydro- melioration Enterprises (it is expected that the Irrigation Systems Company will be restructured into such), Irrigation Associations (According to the Irrigation Associations law) and Municipalities, which there are at least one Irrigation Association on their territory and apply for financial support with the associations.

Good practices analyzed related to the construction of irrigation infrastructure show that project management in this area is essential to the qualitative and effective achievement of the ultimate goal. The project management process groups include planning processes, implementation processes, monitoring and control processes and completion processes. Interaction between the management processes is shown in Fig. 1.

The purpose of this report is to analyse the group of planning processes at the construction stage of certain rehabilitation and reconstruction projects for irrigation infrastructure for the

different areas of management (time, cost, quality, human resources, communications, supply and risk) [4].

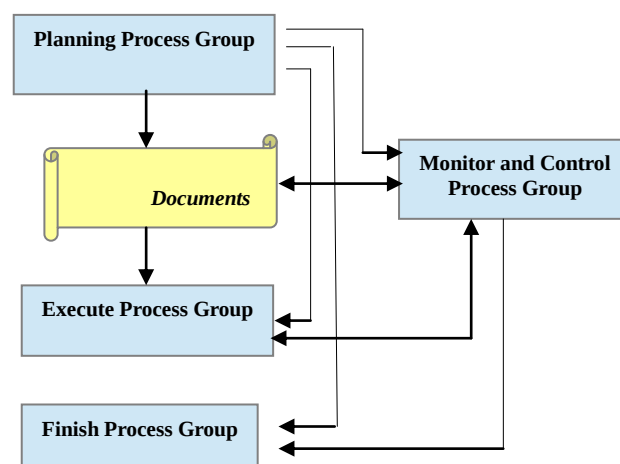


Fig. 1 Interaction between the management processes

2. Results and discussion

The planning process group at the irrigation infrastructure construction stage aims at establishing the overall scope of the activity, defining and refining the objectives and developing an action plan in each management area (Fig.2).

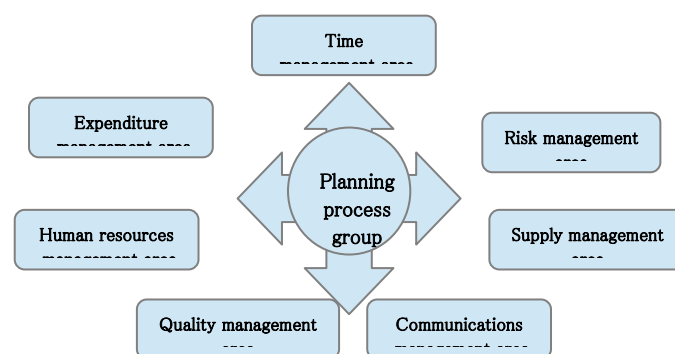


Fig. 2 The planning process group and each management area of the construction of irrigation systems

2.1 Planning in the time management area

The planning processes in the time management area for the irrigation infrastructure construction stage are mainly limited to:

- Definition and decomposition of the activities for the implementation of the construction stages of the site, including preparation of the construction site, main construction and finishing works
- Choosing the resources needed to implement the activities, including human resources, construction mechanization, materials
- Determination of the sequence of execution of individual works and elaboration of working calendar (linear or network model) with critical path analysis and certain time reserves for the respective types of works
- Assessment of the duration of the execution of the construction works and the optimization of the working schedule if necessary

Effective time planning will ensure consistency of costs and time for building the site; availability and coordination of resources used; possibility to predict contingencies; clarity for the execution of the site within the agreed deadline.

2.2 Planning in the expenditure management area

The planning processes in the expenditure management area are:

- Planning the financial means according to the budget envisaged for the implementation of the site during the design phase and the working calendar schedule
- The analysis and evaluation of the financial charts are the term of construction – an integrated and differential flowchart of cash funds.

The cost estimate is designed to be controlled over time, provide funding during site construction, resource allocation

Based on the preliminary planning of the funds for the individual decomposed activities for the construction stage of the site, the baseline framework of costs over time is established and approved.

2.3 Planning in the supply management area

Planning processes in the supply management area include:

- Preparation of a supply management plan – the plan provides a description of how the procurement processes will be managed – from supplier selection to the completion of the contractual relationship with them. Selected suppliers will need to equip irrigation systems with water meters, water level controllers, gates, management and control systems, pumps and the other.
- An outline of delivery work – the information contained in this process may include technical specifications of deliveries; quantity; requirements for: quality level; delivery and installation time; warranty terms; technical support during the operation of the site, etc.
- Delivery documents – these documents include a statement of the supply work, including and binding clauses of contracts with suppliers; technical capabilities of the selected suppliers, production capacity, etc.

The supply planning processes are closely related to the working calendar schedule. For this reason, the decisions made in the delivery of the supply management plan should be integrated with the schedule preparation processes.

2.4 Planning in the quality management area at the stage of construction of the irrigation infrastructure

Quality planning in the construction of the irrigation infrastructure is limited to ensuring the quality of the site construction works and the quality of the management process. For this purpose, it is necessary to have clear technical specifications for the implementation of the site, use of Bulgarian and European standards regarding building materials, experience of the construction company in building similar sites, use of skilled labor and modern construction machinery.

2.5 Planning in the human resources management area

The planning process in the human resources management area at the irrigation infrastructure construction stage involves the development of a human resources plan on the basis of which the posts, responsibilities and relationships between human resources are planned; their working hours, wages, needs, technical safety of work, etc.

2.6 Planning in the communications management area

The planning process in the area of communications involves the planning of communication channels and the process of exchange of information between participants in the construction process. The Communication Management Plan provides stakeholders' requirements for the type and manner of dissemination of the information; the deadlines and frequency of transmission of the requested information; restrictions on communication usually imposed by regulatory or company policies, etc.; a schedule for project team meetings, etc., which would improve communications.

2.7 Planning in the risk management area

The planning processes in the area of risk management are:

- Identifying possible sources of risk
- Analysis and assessment of possible consequences when the risk occurs
- Analyzing and assessing the possibilities for mitigating the effects of the risk development of a risk control and management plan

The planning processes in each area build up the project management plan and its documentation. During the implementation period, additional planning may be required due to the accumulation of additional information or the clarification of certain features. Significant changes that occurred during the implementation of the site triggered the need to review some of the planning processes and to gradually detail the project management plan. The update resulting from the approved changes during the construction of the sites may significantly affect parts of the project management plan. Updating these documents provides greater precision in terms of calendar planning; the spending of the funds for the implementation of the site; preventing risks or minimizing their impact, etc.

3. Conclusion

In line with the state of the irrigation systems and facilities, the priorities and measures formulated in the current programming period 2014-2020 under the Rural Development Programme as well as those developed by the World Bank and endorsed by the Council of Ministers in August 2016, a "Common Strategy for Management and Development of Hydro-melioration and Protection against Harmful Effects of Water" give us reason to expect the preparation, implementation and management of investment hydro-melioration projects concerning construction, reconstruction and modernization of irrigation systems and facilities. The restore of irrigation

infrastructure will not only increase the competitiveness of farms but shall also ensure effective, rational and environmentally sound management of available water resources.

For this reason, the beneficiaries of the selected priority projects for the reconstruction and modernization of irrigation systems and facilities need to focus on effective planning of the building construction stage in all areas of management, namely: time, cost, quality, human resources, communications, supplies and risk. All this will lead not only to the qualitative and timely implementation of the projects but also to the efficient spending of the financial resources under the Operational Programme.

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Thankfully

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BUSINESS CLIMATE AND PRECONDITIONS FOR REVIVING THE BULGARIAN INDUSTRY

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Abstract: *The inadequate economic policy in 90's brings to destruction of basic sectors of the Bulgarian industry. Bulgaria is one of European's countries mostly engaged with deindustrialization process. Nowadays we have to pay more attention to high technological sectors in industry which are based upon theoretical and practical knowledge that by its side is based of enormous investments in science. The condition of Bulgarian industry needs to focus urgently towards inculcating innovations and investments for increasing the enterprise competitiveness. The introducing innovations needs special attention nowadays because the rapidly speed of changes. The world had gone through the industrial time to the age of knowledge. In the fast developing global environment the strategic advantage can be brought by leaders of changes and the only way for that is by introducing innovations. An important role for the long term competitiveness of the Bulgarian economy has the increasing level of innovative enterprises which produce and inculcate new products and processes and the participation of the country in the global high technological manufacture. The reviving of the Bulgarian industry is connected with building new high-tech enterprises and a good example for that is Trakia economic zone (Plovdiv region, Bulgaria).*

Keywords: innovations, technology, crisis, economics, management, industry

1. Introduction

The crisis is a widely held view and its indications affect different aspects of the financial, social, spirit life of the nation. First of all when we talk about crisis it's important to accent not only to the consequences of its manifestation but also to the opportunities for overcoming. The careful analysis of the crisis nature in Bulgaria and the mass of its acts force to introducing the next limitations according the theme:

- as a small country with poor developed and strongly open economy, Bulgaria cannot be isolated by the world financial – economic crisis;

- the human resources – a factor for industrial growth and overcoming the crisis.

The Republic of Bulgaria is a small country in Southeastern Europe, located in the east part of the Balkan peninsular. Its uniqueness is hidden in the balanced combination of incredible nature, Black sea strip of wonderful beaches, beautiful mountains for summer and winter tourism, rivers and so on. But besides all these natural resources Bulgaria is a country with poorly developed economy and is far behind the economics of other countries in the European Union.

To receive a total explicit idea of the level of Bulgarian's economic development in accordance with the global standards and the vulnerable level toward outside economic treats it can be used the level of competitive power. According the macro-economic competitive power stranded on the World economic forum for 2008-2009 Bulgaria takes 76th place by 134 countries in this research and a last place in the EU. But Bulgaria takes better position and shows **a positive economic growth** according the data from the last World economic forum 2016-2017. According data of the same forum the index of internet web readiness Bulgaria is on 68th place from 134 countries. This means that in front our countries are all the participants and candidates in the EU, the countries of OPEC /organization of the petroleum exported countries/ but also around 30-35 poorly developed countries from Africa, South Asia, Latin America. In comparison in the World economic forum in 2016-2017 Bulgaria takes 57th place and proves **a better economic environment** in the country.

The aggregated index for competitive power is calculated based upon 85 analytical macro and micro economics indexes. According some of the micro ratio especially on the company's level Bulgaria is classified between 100th and 120th place of all 134 countries (incl. quality of business functioning, quality of company's management, technological level of manufacture, an assimilation speed for new

technologies, employee qualification and fluctuation etc.). This is a very serious reason for anxiety.

Bulgaria still poorly utilizes the advantages of the global process for raising the national competitive power, realizing an economic structural reorganization and modernization of the technical manufacture. This situation is determined by the action of different factors some of which are: decreasing the general economic potential of the country, the technical level of effectiveness of the national manufacture in times of reforms, the specification of the national economic development till 1989 and so on.

Especially in this moment of reorganization and reforms the world and Bulgaria meet the real global economic crisis that puts new records in all its acts. The current economic crisis is very important because it led the country till the edge of the economic shock, providing its citizens with new stress and unclear conditions. Nowadays subject is the decrease of the national domestic product, mass bankruptcies and unemployment, lowering the life level of the nation.

The global financial crisis worsens the conditions that were reached for labor market development in the first decade of 21 century. The country was hit hard by the crisis; it broke the relative balance of the stock markets, it led to commerce contraction and to investment restrictions. The decrease of investments, commerce and real economy reflected to the labor markets and a considerable shrinkage in labor search and unemployment enhancement. The economic and political leaders tried to fight with the challenges using packages of programs and restrictions. Their research is necessary to clear the adequacy, effectiveness and timeliness of the actions in the short and long run.

The negative crisis influences over the employment in a world scale and in Europe in private reflect over the employment decrease and raising the unemployment as well as in intensifying the structure misbalances standing out the instability of separate groups on the labor market – youths, middle-aged people, and lowly qualified workers.

In Europe the crisis measures a loss of more than 1.9 mln working places just for the end of first three months in 2011 that reflects to decrease of the employment with 1.3% yearly based. This is the biggest decrease in employment after 1995. The flowing down in GDP with 4.8% for the end of the second three-months in 2011 because of the manufacture and service compression leads to decrease of the number of employee as the number of man - hours.

In Europe the crisis from 2008 in its extent and depth has a different display. For some of Eastern European countries it's more considerable and brings back their economic and social

development with years, deletes their efforts and achievements from the transition period and the years of participation in EU. In countries like Bulgaria the crisis started later. The population of the country still remembers the big economic crisis of the 90s, **the high unemployment level, the mass poorness and insecurity, the various strata of society**. The most significant unemployment decrease is in Baltic countries, Spain and Ireland. The unemployment reduction corresponds with the strong compression of the economic activity. The most evident is the reduction in the countries with biggest decrease in the economic activity and the number of employed (Lithuania, Estonia, Latvia, Ireland and Spain). Totally for the EU-27 the unemployment reached 9.5% in January 2012 as it has a lot varieties in different countries: from two-digits for Latvia (22,9 %), Spain (18,8 %) and other 5 countries (Ireland, Slovakia, Hungary, Portugal and France) to the lowest levels in Holland (4,2%), Austria (5,2%) and round 10 countries with unemployment level between 6-9%, incl. Bulgaria (8,1%).

The Bulgarian crisis influenced summary at the next fields:

- Lowering the economic growth rate and limited market search;
- In the real sector – manufacture compression with strongest attitude in building, metallurgy, machine-building, chemical and textile industries;
- In the financial sector – instability and collapse in the stock exchange;
- In the bank sector – restrictions in crediting through compression of the mortgage and consumer credits, slowing down the temps of crediting the private sector, raising the interests.
- Decrease in investment exportation;
- Increase in unemployment;
- Raising the food prices, etc.

Prognosis

- As a whole in Europe the decrease in economic growth in 2014 is 1.9% in prognosis by the International Monetary Fund drop till 1.5% on average.
- In 2016 is expected bigger decrease in economic growth that will contribute to the Central and Eastern Europe. It's expected raising the inflation in short-term but slacken the pace in long-term because of the reduction in supply and demand.
- In Bulgaria the reduction of growth rates will be weaker but is expected decrease of revenues by taxes (VAT, corporation tax and others) that will reflect over budget expenses and budget surplus.
- It will decrease the money float by Bulgarian emigrants to Bulgaria.
- The treats for Bulgaria are connected with the existence of additional factors like corruption, weaknesses in the judgment system, bad infrastructure.
- The Bulgarian economic dependence of outside resources exposes it to risk, instability and more expensive outside resources.
- By one side is expected rise in service price but without better the quality.
- Enhancement of the deficit of budget balance that now is fulfilled by outside credits, euro funds etc.

Positive points of view by the crisis

- As a whole the stability of the financial system is based upon the currency board. This is a condition for stability of the bank system. The crisis forced banks to balance the crediting that is useful for the bank system. The crisis stimulated these

institutions to renovate the service packages and restructure their portfolio. This forces the bank competitiveness that is a positive for the whole system.

- The increased inflation by other side leads to convergence in price level with that in the EU.
- In the real sector positive effects are the lack of non-elastic companies and compressions of additional costs in stimulating the more effective labor.
- A positive tendency is the reduction in petrol prices and gas crisis that stimulates developing the opportunities of alternative energy sources.
- It's found new opportunities for stimulating the agriculture because of the price raising.

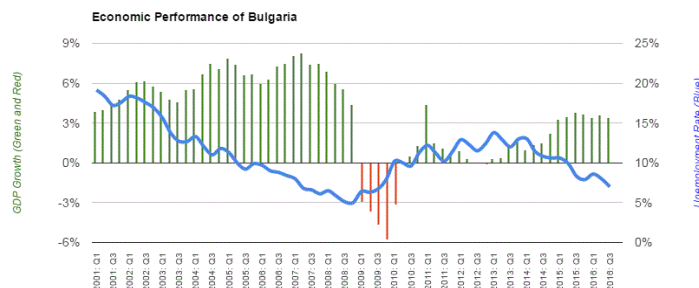


Fig. 1 Positive indicators for the Bulgarian economy: high GDP growth and falling unemployment

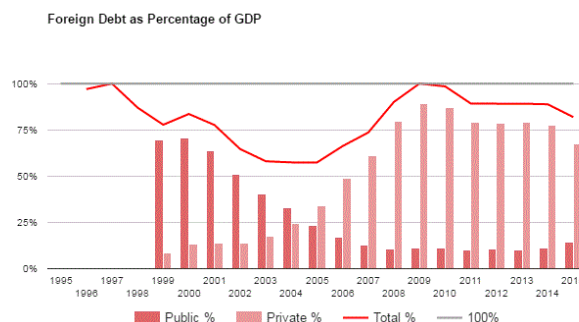


Fig. 2 Negative indicators for the Bulgarian economy: levels of foreign debt are at the same levels as during the last financial crisis, of 1996

2. Undertaken anti - crisis measures in macro and micro level till the end of 2017

- Decrease to minimum the cash bank ratio and increase of the credit resource;
- Changes in BNB in the regulations for capital adequacy and for the evaluation of client's solvent;
- Bank promotions for deposits, fund extraction that are not in the bank system – around 200 mln.lv.;
- A coordination between the system for prudential supervision of credit institutions and the one in EU;
- Force the activity of BNB for credit development for SMEs and enhancement of the sum for credit guarantee;
- When gathering euro funds to be provided bigger advance for financial compensations;
- Budget financing of projects in education, health care, ecology;
- Strengthen the financial supervision and control;
- Decrease in ministry expenses till 70% of the stipulated ones;

- Redistribution of the social dues as the country takes 12% of all the payments;
- Funds for unemployed, young families who would like to buy a house and raising the children additional payments;
- Creating conditions for temporary employment, temporary release and saving the working places;
- Creating stimulus for employers who hire released workers.

3. Propositions

- Preparing a plan of the EU for reinforcing the credit inflow in the region, broaden the range of anti-crisis measures of Central and Eastern Europe;
- Elaboration of new credit products, enhancement of the market transparency;
- Decrease of the insurance charge;
- Increase in the export crediting;
- Marking priority fields in the expenses in every ministry;
- Reducing the period for VAT refund;
- Increase the expenses for advertisement in tourism
- Increase in public investments, opening new working places;
- Improvement of the organization for structure funds absorption, fighting with the misappropriations;
- Accent over applying the legislation and especially the normative acts.

4. Conclusion

The review of the crisis effects over the labor markets and applied policies for reducing the negative effects give opportunity for the next generalizations:

1. In accordance with the crisis duration the labor market reacts with actions following short term and long term scenario. The short term scenario includes measurements for stable employment (flexible working time and labor organization, different training opportunities and social defense) and including unemployed people (programs for temporary employment, public-investment projects and training of unemployed). However these actions lose their meaning in long term crisis periods. In accordance with this the long term actions must begin in time.

2. The programs with long term impact are forced toward improving the competitiveness (through integrated education, technical help and support for the small and medium-sized enterprises); improving the services in the system for qualification and teaching; making better the forming, training and employment of the human capital and flexibility of the system for unemployed defense. The applying of such programs and policies leads to new quality of the human resources and their organization that will enable the faster after crisis economic reconstruction and abilities for reaching better development in long term periods.

3. On the background of the European practice, the Bulgarian labor market remains stable but this is as a consequence of the later crisis development in the country. The short term measures for minimizing the crisis effects over the labor market include a wide range of measurements and programs that are improved their effectiveness in the European practice. A matter of fact is their contribution to the retaining a moderate level of unemployment in Bulgaria in accordance with the EU.

4. Trakia Economic Zone (TEZ) is one of the biggest economic projects in Bulgaria, a public-private partnership that includes six major industrial zones in the region of Plovdiv.

Together the zones in TEZ have attracted over 1.2 billion euro of fixed- capital investments.

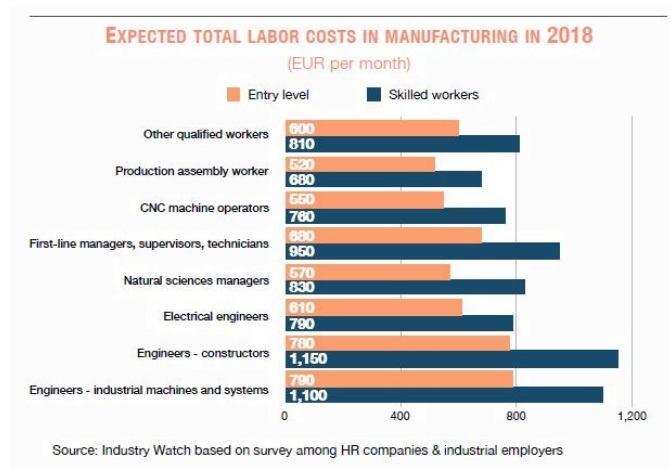


Fig. 3 Expected total labor costs in manufacturing in 2018

5. The elaboration of development programs is an obligation and responsibility not only to the government but also of the social partners, the civil community and the science potential of the country.

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QUALITY IMPROVEMENT OF CASTER SCHEDULING AT TRINECKE ZELEZARNY

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Abstract The paper analyzes melt shop and caster scheduling at special steel maker – Trinecke Zelezarny. The main optimization objectives of melt shop and caster scheduling are defined as: minimization of earliness and lateness of orders, maximization of tundish utilization, minimization of steel grade changes and minimization of mold width changes, minimization of stock, minimization of over grading, management of iron inventory. The following key problems of scheduling are defined: underdeveloped optimization algorithms and insufficient computer performance. Based on this the key provisions of a new method of melt shop and caster scheduling are proposed. The method significantly improves quality of planning. It includes the following three stages: production capacity allocation; heat building; sequencing. An experience of successful practical development and implementation of specialized software solution based on the new method at Czech special steel maker is provided.

KEYWORDS: MELT SHOP AND CASTER SCHEDULING

1. Introduction

The efficiency and effectiveness of melting, steelmaking and continuous casting management has a profound effect on competitive advantages of a steel company and in most aspects defines its financial performance. Permanently strengthening intensity of competitive struggle of steel companies and rise of volatility on the ferrous metals market define importance of development and implementation of new approaches to solving a task of qualitative melt shop and caster scheduling. This task is a NP kind problem. In fact, it is a combination of complex problems that has historically been somewhat impervious to practical, optimized solutions. Often steel companies with their partners tried to develop new methods in this area. Partners were scientific institutes and leading software vendors. Many initiatives in the area of development of specialized solution independently or in cooperation with partners have not brought desired results or fail despite significant financial and labor investments. Main reasons for that were underdeveloped optimization algorithms for the problem and insufficient computer processing speeds. Recent advances in this area allowed LOGIS specialists to develop a method and solution which let planners to create qualitative melt shop and caster schedules to directly drive efficient shop floor operations at large steel producers. The development of the new scheduling method and solution was based on data of Czech special steel maker – Trinecke Zelezarny.

2. Preconditions and means for resolving the problem

2.1. Czech steel maker description

Trinecke Zelezarny is one of the leading producers in Europe. Its production assortment includes: wire rods, rebars, rails, flat products, seamless pipes, and sections. The company produces hundreds of steel grades. Its annual production is about 2.4 million tons. The staff is about 5 500 employees. The production supply chain of the company includes integrated facilities of iron and steel making. (see Figure 1).

Steel is produced in basic oxygen furnaces (BOF) and in electric arc furnaces (EAF). Steel casting is done through continuous casters and by ingot teeming. Depending on method of casting, profiles, and sizes, semi-products (ingots, blooms, billets) are transported downstream through production supply chain. As could be seen from the scheme the melting and casting are the key stages of production. That is why melt shop and casting scheduling is so important for the company.

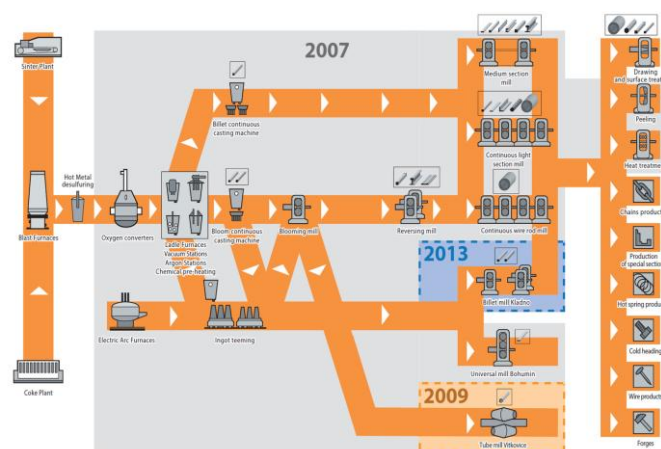


Fig 1 Supply chain scheme

The old scheduling process was arranged in the following way. Input data was prepared in manual mode by 5 specialists, who prepared requirements for casting based on planned orders of rolling mills. Based on the requirements, specialists created melt shop and caster schedules. These schedules had sufficient accuracy on the horizon of 4 – 7 days. Beyond this horizon the accuracy significantly deteriorated. Scheduling took much time and efforts.

Rolling mills requirements changes or deviations from the schedule in many cases lead to rescheduling. Often because of high laboriousness rescheduling was done after the end of working days or on weekends. Absence of rolling mills requirements beyond 1-2 week horizon significantly reduces efficiency of decision making of planners. Also data quality needed to be improved. Manufacturing execution systems monitored only general volumes of production without accounting for heats, heats sequencing, and without information about allocated orders.

As a result the company had high level of work in process and low due date performance. It was logical that the issue of rearranging of scheduling process and improving its efficiency was open.

2.2. General task formulation of melt shop and caster scheduling

Melt shop and caster schedules are normally generated at least once a day—sometimes more often. Thousands of orders must be combined and sequenced for production through iron making, steelmaking, and continuous casting. Each time this occurs, the planner tries to balance multiple business objectives, which exist in a tradeoff relationship.

The first goal of melt shop and caster scheduling is to produce orders on time, that is, to minimize order earliness and order lateness. The desired production time for each order at casting is usually given by some higher level production planning function, which balances order loads across the entire plant. Planners try to respect this requirement by scheduling each order for production on the day that it was requested. If orders are produced too early, unnecessary inventory may result. If orders are produced late, customer delivery performance suffers and unnecessary expediting costs may be incurred.

The second goal of melt shop and caster scheduling is to maximize tundish utilization. For each steelmaking grade, there is some maximum number of heats that can be cast using a single tundish. When the maximum is reached, the tundish must be switched out and relined with new refractory. Maximizing tundish utilization reduces operating cost per ton, minimizes the number of “top” and “bottom” slabs (or blooms, or billets) as a percent of total production, and helps keep liquid steel flowing for as much calendar time as possible. The Czech plant has several casters, and some portion of the order book is often considered to be “swing orders,” able to be produced at alternative casters. Tundish utilization can normally be improved by intelligent allocation of swing orders to casters during the caster scheduling process.

The third goal is to minimize grade and width transitions within the tundish. Minimizing grade transitions improves prime yield, as material from the chemical transition zone may have limited usefulness for customer orders. Reducing the number and severity of slab width transitions is important for flat products producers, as it reduces wear on both casting and hot rolling equipment, reduces breakout risk, and can improve prime yield.

The fourth goal is to minimize the amount of stock within the melt shop and caster schedule, and focus production on current demand. As manufacturing orders are combined into heats, and heats into tundish sequences, stock (or “open order”) material must sometimes be inserted, to fill out a heat or extend tundish length. Production of stock is usually a waste of precious manufacturing time, since it cannot be converted immediately into revenue, but lingers in inventory.

The fifth goal of melt shop and caster scheduling is to minimize over-grading. Each customer order has alloy requirements that must be satisfied. In order to fill out heats, extend tundish length or avoid grade transitions, orders are sometimes “over-graded,” that is, a more expensive chemistry is used to satisfy an order than is actually required by the customer. Thus minimization of over-grading reduces alloy costs.

For integrated steelmaking plants—those with blast furnace operations—there is a sixth goal: control of liquid iron inventory. In every such plant, the fleet of torpedo cars that transport liquid iron from the blast furnace to steelmaking (see Figure 7) is finite: there are only a certain number of cars available at any given time. Ironmaking is the input to this liquid iron inventory, and steelmaking consumes it. Steelmaking production volumes are driven by caster schedules—wide schedules consume more iron, narrow schedules consume less. Since blast furnace production is difficult to modulate rapidly, caster schedules must be continuously adjusted to control the amount of liquid iron “on wheels.” This helps avoid costly or environmentally irresponsible methods of disposing of excess iron.

For those steel plants that are capable of significant amounts of hot charge rolling, two additional goals help define the quality of integrated casting and rolling schedules: material charge temperature into the reheat furnace, and hot mill asset utilization. Retaining as much heat as possible in the semi-finished product reduces fuel costs per ton, and increases throughput for furnace limited mills. Hot mill utilization improves when rolling campaigns are planned at the maximum length for each campaign type, minimizing the number of required roll changes.

All of these goals exist in a complex tradeoff relationship (see Figure 2).

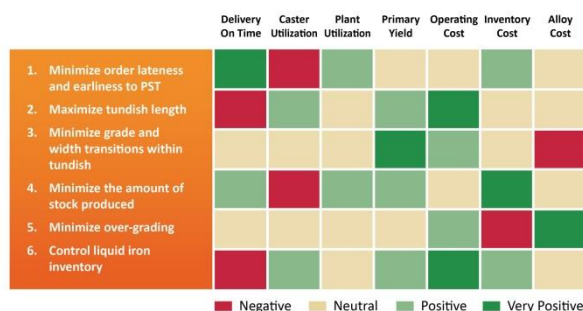


Fig 2 Six key goals of melt shop and caster scheduling

Minimizing order earliness and lateness supports good customer delivery performance, but may hurt tundish utilization and increase operating costs. Maximizing tundish length reduces operating costs, but may result in stock production and over-grading. Maximizing hot charge rolling may reduce tundish utilization, etc. The complexity of balancing above-mentioned goals taking into account specific technological constraints and rules prevented for a long time companies from achievement of efficient results in the area of melt shop and caster scheduling. Existing methods usually targeted only one of the goals. There was no method available for complex and efficient balancing of all the goals. The necessity for development of such a method was obvious for specialists at the Czech steel maker.

2.3. The key provisions of a new method

The complexity of melt shop and caster scheduling problem defines necessity to apply a decomposition method to it. Using problem structure this scientific method allows decomposing original problem into set of small interrelated and more simple tasks. The main idea of the new method is as follows: a) proper decomposition of the problem into layers; b) application of the most useful optimization techniques for each layer; and c) rapid iteration between layers until the model converges on a solution that respects the planner’s business goal priorities. The proposed method solves the problem using three layers of optimization (see Figure 3).



Fig 3 Decomposition of melt shop and caster scheduling problem

The first layer handles capacity allocation. This layer distributes orders over time by due date at casting, levels casting demand loads respecting major capacity constraints, allocates “swing orders” to multiple casters, and generally satisfies global constraints.

The second layer is the heat building model, which combines orders into heats, loads heats into available capacity, and concatenates similar heats, while respecting the next level of capacity constraints.

The third and final layer creates the detailed production sequence at steelmaking, ladle treatment and continuous casting, manages the

liquid iron inventory balance, and respects the most detailed constraints.

The optimization layers iterate until the total KPI balance is achieved. The first layer executes, and control is passed to the next level down. If infeasibility is detected at the second or third layer, control is returned to the next level up for resolution. The model cycles up and down between layers until the total KPI balance requested by the planner is achieved.

Thanks to the decomposition of the scheduling problem into layers and the usage of the best fitting combinations of solvers for each layer the computations are executed as efficiently as possible.

Scheduling information system

The new method of scheduling was used as a base for development of a solution for the Czech production company. Also the Czech company specialists and LOGIS project team members defined a set of key requirements for a new solution.

Whether assessing the relative merits of multiple scheduling scenarios, or reacting to shop floor problems that require immediate schedule changes, model execution speed is simply fundamental, and must be accomplished without compromising schedule quality.

No model, however sophisticated, can fully represent the richness and variation of physical reality. Therefore the planner must be able to easily make manual adjustments, with complete visibility to any potential constraint violations.

The quality of any melt shop and caster schedule can be measured along vectors that correspond to the goals for scheduling. The planner must have real-time visibility to the full set of Key Performance Indicators that reflect the value of the schedule, after every model run and after every manual adjustment.

The goals for melt shop and caster scheduling can have different relative importance for different steel plants, and can vary for the same plant as business conditions change. For example, when alloy prices are high relative to steel prices, it's more important to control over-grading. The planner must be able to adjust the priority of caster scheduling goals, and have the model produce schedules that comply.

The planning environment evolves constantly: new facilities added, new products introduced, changed commercial priorities, etc. The melt shop and caster scheduling model must represent constraints in a way that allows planners to make model changes without long IT wait times. Constraints should be represented in the model as data and the planner should be able to add, change or delete constraints as needed.

To implement these and other requirements LOGIS specialists developed a new solution. During the implementation project the model of melt shop and caster scheduling was set up in the solution. To solve a complex problem, one must be able to represent the problem. The UI representation of scheduling data structures, constraints, and the schedule itself is another critical component of usability. The developed solution has a number of standard reports that characterize the schedule, including views of tundish utilization, over-grading, production to stock, and order earliness and lateness.

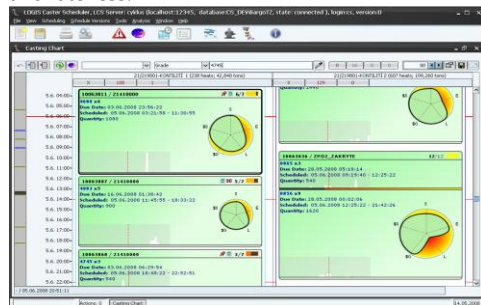


Fig 4 Material flow through casters

The system was developed in C++ and it uses memory resident architecture which means that the solution doesn't use hard drive during calculations and thus it has high performance. The system uses for modeling constraint satisfaction programming algorithms

including linear and mixed integer programming, constraint-based search, heuristics and other OR algorithms (Taha H., 2005).

The key results of the implementation of the developed system are: significant rise in speed of calculation (it takes minutes not hours now); improvement of schedule quality thanks to detail modeling of steel making rules, application of contemporary optimization algorithm and friendly user interface for manual changes of a schedule.

3. Results and discussion

The process of melt shop and caster scheduling was completely renewed at Trinecke Zelezarny thanks to implementation of the new solution. Today casting requirements are generated automatically based on a valid calendar production plan. This allows a planner to work on the complete calendar production plan horizon – up to 4 months. Currently melt shop and caster schedules are created for 40 days. The first 14 days of the horizon are planned in detail. The schedule is updated regularly based on real situation in production. The visibility of schedules and wide planning horizon significantly improved economic and technological reasonableness of planners' decisions.

The result of new process implementation was efficiency improvement not only in melting and casting but also at the company in general. One of the key performance indicators of steelmaking is the level of wasted tundish life at continuous casting. An improvement of this indicator enables a decrease in the costs of production, with simultaneous increase of the total performance of the steel plant. The achievement of a good level for this indicator is especially difficult due to the following factors: necessity to produce a large variety of steel grades, taking into account special requirements of individual customer orders; high share of small orders in proportion to one heat, let alone to the minimal size of a tundish lot. The level of wasted tundish life at continuous casting is evaluated as the difference between the theoretical maximum and the planned sequence length for individual steel grades, where the theoretical sequence length derives from the maximum length of sequence given by the technology of production and the planned sequence length derives from the casting schedule at the continuous casters. Statistics of average tundish continuous casting is provided on Figure 5.

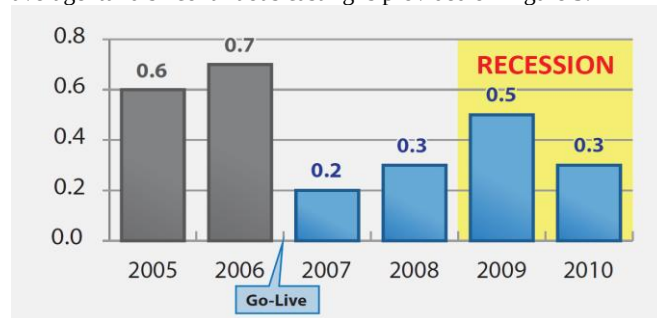


Fig 5 Statistics of wasted tundish life at continuous casting

In 2007 when go-live of the solution started the company was able to lower tundish life wasting at continuous casting to 60% comparing with 2006. Although crisis happened in 2008 the indicator was improved by more than 70% comparing with 2006. It is worth mentioning that using specialized solution in crisis period allowed the company using achieved additional competitive advantages to get leading positions on the market in its segment. Thus the implementation effect was obvious even during the uneasy period when supply on the steel market was much higher than demand.

In general the integration of the new process of melt shop and caster scheduling into the process of order fulfilment planning significantly improved quality of customer service. In 2007 the company was able to achieve due date performance (daily accuracy) of 91% keeping high operational excellence. Then the indicator only improved though significant increase in number of

products and in number of steel grades (see Figure 6).

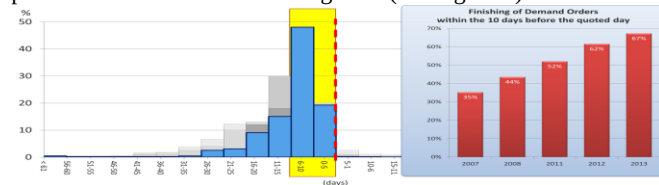


Fig 6 Finishing of Demand Orders in relation to the Quoted Day (2013)

4. Conclusion

The quality of melt shop and caster schedules has a profound effect on competitive advantages of a steel company and in most aspects defines its financial performance. Steelmaking constraints are specifically important in order fulfilment planning for companies which have hundreds and thousands grades of steel.

The developed method and the solution help planners to effectively solve problem of melt shop and caster scheduling in short time. These method and solution were implemented at a set of international industrial companies. They proved their efficiency and they are recommended for use at similar companies.

Grant information

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GRAPHICAL USER INTERFACE FOR OPTIMIZATION OF ELECTRON BEAM WELDING BY NEURAL AND REGRESSION MODELS FOR OBTAINING DEFECT-FREE WELDS

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Abstract: This paper considers the process electron beam welding of stainless steel type 1H18NT in vacuum. Based on experimental data, the influence of the variations of the following process parameters: electron beam power, welding velocity, the distances from the magnetic lens of the electron gun to the beam focus and to the surface of the treated sample is investigated.

Neural and regression models for the geometry characteristics of the welded joints: surface of the weld cross-sections, weld depths and mean weld widths of the samples are estimated, as well as models for defining the areas of the process parameters, where the appearance of defects is or is not expected. The obtained models are used for developing the graphical user interface aiming investigation and prediction of the electron beam welding characteristics and process parameter optimization. This software can be implemented for supporting the operator's choice of appropriate work regimes, obtaining the required welds quality standards, for education and investigations.

Keywords: STAINLESS STEEL; ELECTRON BEAM WELDING; GRAPHICAL USER INTERFACE; NEURAL NETWORK MODELS; DEFECTS; OPTIMIZATION

1. Introduction

The complexity of the processes occurring at intensive electron beam interaction with the material in the welding pool and the vaporized treated material hinders the development of physical or heat model for enough accurate prediction of the geometry of the weld cross-section and adequate electron beam welding process parameter selection. Concrete reason for the lack of adequate prognostication is the casual choice of the heat source intensity distribution, not taking into account the focus position toward the sample surface and the space and angle distribution of the electron beam power density, the distance to the sample surface at constant beam formation conditions, etc.

In this paper various empirical modelling approaches for the estimation of adequate models for the dependencies of the electron beam weld characteristics on the process parameters as well as process optimization on that base are considered. An expert system for supporting the operator's choice of appropriate work regimes, obtaining the required welds quality standards, for education and investigation is developed and its functional elements are presented.

2. Methodologies

2.1. Response surface methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. Regression models (polynomial models of some order), giving an adequate functional relationship between a response of interest y (performance characteristic) and a number of associated control (or input) variables (process parameters) $x_1, x_2, \dots, x_m$, are estimated:

$$\hat{y}(\vec{x}) = \sum_{i=1}^k \hat{\theta}_i f_i(\vec{x}) + \varepsilon$$

ε is a random experimental error, assumed to have a zero mean, $\hat{\theta}_i$ are the estimates of the model coefficients.

2.2. Robust engineering design

During the industrial processes despite of the control there always occur variations in the process parameters and uncontrolled noises that cause variations in the product quality parameters. These errors cause additional variations in the performance characteristics of the obtained welds, which are not due to the intentional changes of the process parameters. The idea of the robust engineering approach to model the variation (variance) of the performance

characteristics depending on these measurement and control errors and by the minimization of this variance optimal solutions that are robust (less sensible) towards the errors in the process parameters to be found [1, 2].

The robust engineering design involves the estimation of two models describing the mean value and the variance of the performance characteristics at production conditions [3]. The mean value model of the response is:

$$\tilde{y}(\mathbf{x}) = E[y(\mathbf{z})] = \eta(\mathbf{x}) + \boldsymbol{\theta}^T E(\mathbf{g}),$$

where $\mathbf{z} = \mathbf{x} + \mathbf{e}$ is a vector of the real parameters values in production conditions (with errors $\mathbf{e}$). The first term $\eta(\mathbf{x}) = \mathbf{f}^T \hat{\boldsymbol{\theta}}$ is a response model, obtained in laboratory conditions without errors in process parameter levels. The second term takes into account the variations of the process quality characteristics caused by these errors. $\hat{\boldsymbol{\theta}}$ is a vector of estimates of the model coefficients; $E(\mathbf{g})$ is the mathematical expectation of vector $\mathbf{g}$ ($\mathbf{g} = \mathbf{h} - \mathbf{f}$, where $\mathbf{f}$ is a vector of the regressors $\mathbf{x}$ – known functions of process parameters x_i , and $\mathbf{h}$ is a vector of the regressors $\mathbf{z}$).

The variance model of the response is:

$$\sigma^2 = \sigma^2[y(\mathbf{z})] = E(\hat{\boldsymbol{\theta}}^T \boldsymbol{\Psi} \hat{\boldsymbol{\theta}}) + s_\varepsilon^2 = \hat{\boldsymbol{\theta}}^T \boldsymbol{\Psi} \hat{\boldsymbol{\theta}} + s_\varepsilon^2,$$

where:

$\boldsymbol{\Psi} = \mathbf{g} - E(\mathbf{g})$; the matrix $\boldsymbol{\Psi} = E(\boldsymbol{\Psi} \boldsymbol{\Psi}^T)$ depends on the structure of the resulting model; s_ε^2 is an estimate of the random error of the response.

2.3. Neural networks

Neural networks are universal approximators with low sensitivity to errors, which determines the benefits of their use in different application areas [4, 5].

For developing the expert system two type of neural networks are used: feedforward neural and pattern recording problems the neural network.

The neural network consists of a series of layers. The first layer has a connection from the network input. Each subsequent layer has a connection from the previous layer. The final layer produces the network's output.

Feedforward neural network

Feedforward networks can be used for any kind of inputs to output mapping. The two-layer feed-forward network with sigmoid hidden neurons and linear output neurons is shown on Fig. 1. It can

fit multi-dimensional mapping problems arbitrarily well, given consistent data and enough neurons in its hidden layer. The network is trained with Levenberg-Marquardt backpropagation algorithm [5, 6].

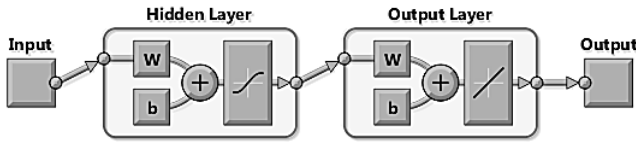


Fig. 1. Feedforward neural network structure

The linear activation function, produces output results equal to the activation potential $\{u\}$, having its mathematical expression given by:

$$g(u) = u$$

The sigmoid function is defined by:

$$g(u) = \frac{1}{1 + e^{-\beta u}}$$

where β is a real constant associated with the function slope in its inflection point.

Pattern recording neural network

In pattern recording problems the neural network classify inputs into a set of target categories. A two-layer feed-forward network, with sigmoid hidden and output neurons (Fig. 2). The network is trained with Scaled Conjugate Gradient backpropagation algorithm. It belongs to the class of Conjugate Gradient Methods, which shows superlinear convergence on most problems and it is considerably faster than the standard backpropagation method [6, 7].

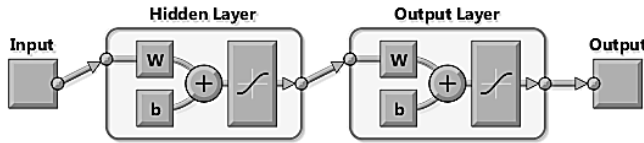


Fig. 2. Pattern recording neural network structure

2.4. Multi-criteria graphical optimization

The implemented here approach for multi-criteria optimization is the graphical optimization approach. It applies the estimated models (regression, robust or neural models) for building contour plots of the investigated performance characteristics, depending on the process parameters. By superimposing of these diagrams compromise zones for the process parameters can be found. For each response, the acceptable tolerance limits must be defined and the low and upper limits are represented by contours on the contour diagrams. After superimposing of the low and upper limit contours, the regions for the process parameters can be determined, where all required tolerance limits are fulfilled

3. Experimental investigation and modelling

An experiment was performed with samples of stainless steel, type 1H18NT [8]. The accelerating voltage is 70 kV. 81 experimental weld cross-sections are investigated. The following operating process parameters are varied: power (P) - 4.2, 6.3 and 8.4 kW; welding velocity (v) - 80 cm/min, 40 cm/min and 20 cm/min; distance between the main surface of the magnetic lens of the electron gun and the beam focusing plane (z_o) - 176 mm, 226 mm and 276 mm and different distances between the main surface of the magnetic lens of the electron gun and the sample surface (z_p) in the region 126 mm and 326 mm.

The following quality characteristics are considered: transverse toward the movement of the electron beam weld cross-section area - S , weld depth H , mean weld width B , and the number of defects is counted. For prediction and classification the experimental

observations are separated into three groups (classes): 0 - without defects, 1 - with one defect and 2 - with two defects. The type of the defects is not taken into account.

The collected data are used to obtain and estimate the regression models for the geometry characteristics of the welded joints: cross-section area - S , weld depth - H and mean weld width - B , as well as the appearance of defects is or is not expected [4, 9].

For each of the considered performance characteristics two models, describing their mean value and variance at production conditions, are estimated. They take into consideration the errors of the process parameters (Table 1) and their transmission as variation of the output characteristics [4].

Table 1. Tolerance limits for EBW parameters

Process parameter	Coded	Tolerance limits	Coded variances σ_i^2
P [kW]	x_1	$x_1 \pm 3\% x_1$	$\sigma_1^2 = 0.0009 + 0.0002 x_1 + 0.0001 x_1^2$
v [cm/min]	x_2	$x_2 \pm 3$	$\sigma_2^2 = 0.011$
z_o [mm]	x_3	$x_3 \pm 5$	$\sigma_3^2 = 0.011$
z_p [mm]	x_4	$x_4 \pm 5$	$\sigma_4^2 = 0.000278$

Another implemented approach is to predict appearance of defects and the weld characteristics by neural models. For development purposes, two types of neural networks are trained: Feedforward and Pattern recording neural network that contains different count of hidden neurons in there hidden layer. [4, 10, 11]

For training, validation and testing of the each neural network, the experimental data are randomly separated into 3 parts: 70% (57 datasets) for training, 15% (12 datasets) for validation and 15% (12 datasets) for testing.

The estimated set of empirical models is used for developing the graphical user interface.

4. Expert system

The graphical user interface, representing an expert system, consists from three functional parts (Fig. 3)

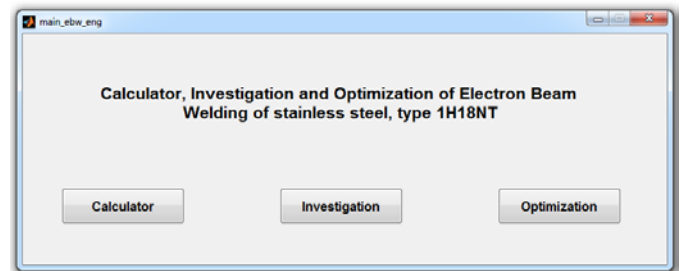


Fig. 3. Starting window of the graphical user interface for Electron beam welding of stainless steel type 1H18NT

- *Calculator* - for calculation of the geometric characteristics of the welds as well as for prediction of the appearance of defects.
- *Investigation* - gives the user the opportunity to investigate the welds at different working regimes.
- *Optimization* - multi-criteria graphical optimization is performed to find the regions of the process parameters where the requirements (given by acceptable tolerance limits) are met and the welds are defect-free.

From the starting window shown on Fig. 3 the operator has to choose between these three options. The first is the Calculator (Fig. 4). This window is used to calculate the geometric characteristics of the welds: weld cross-section area - S , depth - H and mean weld width - B , as well as the defects.

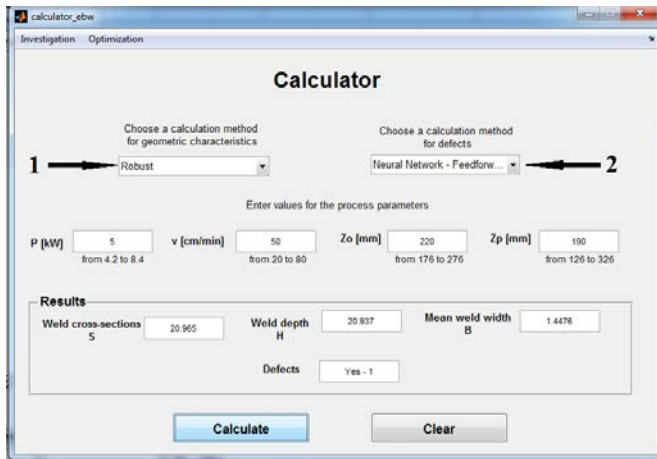


Fig. 4. Calculator window of the graphical user interface for Electron beam welding of stainless steel type 1H18NT.

The Calculator has two pop-up menus:

- Pop-up menu 1 – gives the user the opportunity to choose between three options for the way to calculate the geometric characteristics:
 1. Regression models,
 2. Robust regression models,
 3. Neural Networks.
- Pop-up menu 2 has 8 different options to calculate and predict the defects:
 1. Regression (Yes/No defects)
 2. Neural Network – Feedforward - with 4 hidden neurons (Yes/No defects)
 3. Neural Network - Feedforward - with 14 hidden neurons (Yes/No defects)
 4. Neural Network - Pattern recording - with 4 hidden neurons (Yes/No defects)
 5. Neural Network - Pattern recording - with 14 hidden neurons (Yes/No defects)
 6. Neural Network – Feedforward - with 4 hidden neurons (2, 1 or 0 defects)
 7. Neural Network – Feedforward - with 8 hidden neurons (2, 1 or 0 defects)
 8. Neural Network – Feedforward - with 14 hidden neurons (2, 1 or 0 defects)

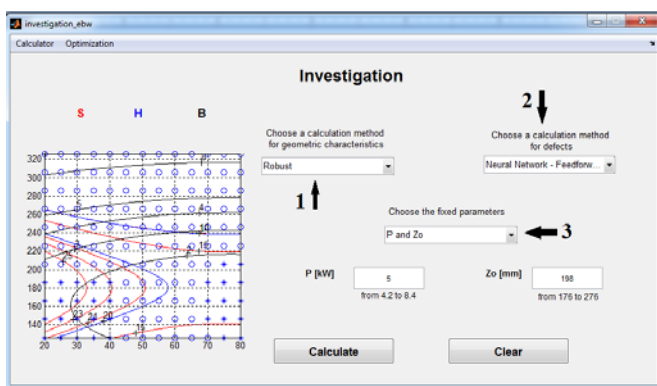


Fig. 5. Investigation window of the graphical user interface for Electron beam welding of stainless steel type 1H18NT, where S – red, H – blue, B – black, “o” – defects free zone, “*” – have defects/have 1 defect and “+” – zone with 2 defects.

The Investigation (Fig. 5) feature has the same two pop-up menus that give the user chance to choose between different ways to predict the geometric characteristics and defects. Since the investigated process parameters are four, for the graphical investigation two of them should be chosen to vary and two of them should be fixed at constant values. That is why there is a third pop-up menu from where it is possible to choose which two of the process parameters will be varied and which two will be fixed. The

calculation results are shown as contour plot where the contours of the weld cross section area are given with red color, the weld depth – blue color, the mean weld width B – black color and the defects - sign “o” indicates that it is a defect free zone, star “*” is a symbol for predicted presence of defects in this area, (in the cases of prediction of 0, 1 or 2 defects “*” means 1 defect and plus “+” indicates two critical defects).

Fig. 6 represents the Graphical optimization interface. This view again gives the opportunity to choose through the pop-up menus the estimated empirical models for the prediction of the geometric characteristics and the defects, as well as the two parameters that will be fixed on specified constant values.

Here the operator has to set the requirements for the minimum and maximum acceptable limits for the weld geometric shapes. After that the program will return a diagram that will help to choose the working regime where all criteria are fulfilled.

The optimization window has two clear buttons too.

- Clear figure – clears only the graphical representation of the calculation and saves all other choices and criteria's. In such way the user can change only some of them and don't lose the others.
- Clear all – returns the window in a “start” position for new optimization.

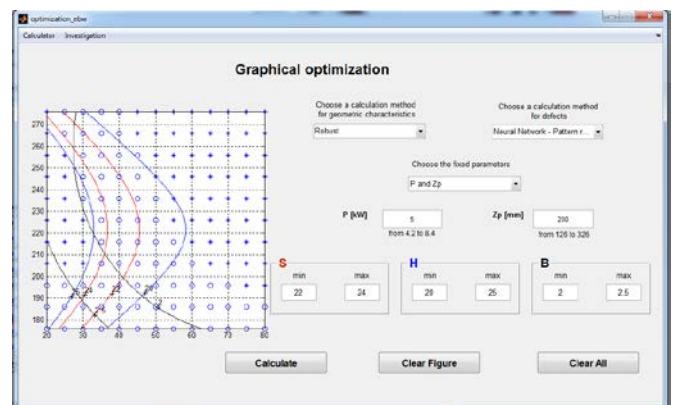


Fig. 6. Optimization window of the graphical user interface for Electron beam welding of stainless steel type 1H18NT, where S – red, H – blue, B – black, “o” – defects free zone, “*” – have defects/have 1 defect and “+” – zone with 2 defects.

On Fig. 6 is shown an example, where the electron beam power is $P = 5$ kW and the distance between the main surface of the magnetic lens of the electron gun and the beam focusing plane is $Z_p = 200$ mm. The acceptable tolerance limits for the performance characteristics are set as follows: weld cross-section area between 22 and 24 mm², weld depth from 20 to 25 mm and width: 2-2.5 mm. The graphic optimization shows that if the welding velocity is between 30 and 40 cm/min and the distance Z_0 is from 185 to 210 mm the obtained welds will meet all set requirements and will be defect-free.

5. Conclusions

The developed graphical user interface system aims investigation of the electron beam welding process of stainless steel type 1H18NT and process parameter optimization. It can be used for obtaining the weld joints with specific characteristics and lack of defects. The program can be used to support the operator's choice of appropriate work regimes, obtaining the required quality standards, education and investigation.

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APPLICATION OF NONLINEAR CONTROLLED COOLING REGIMES FOR STRUCTURE FORMATION MANAGEMENT IN EUTECTOID STEEL

ПРИМЕНЕНИЕ РЕЖИМОВ НЕЛИНЕЙНОГО КОНТРОЛИРУЕМОГО ОХЛАЖДЕНИЯ ДЛЯ УПРАВЛЕНИЯ СТРУКТУРООБРАЗОВАНИЕМ В ЭВТЕКТОИДНОЙ СТАЛИ

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Abstract: Using computer modelling with originally developed semi empirical physical grounded models study of structure formation when austenite transformation during cooling by certain regime in eutectoid steel was carried out. The model allowed us to predict final structure. Cooling curves leading to fine pearlite (almost without bainite) and lower bainite (with a small part of fine pearlite) structures were found out. The results obtained could be useful for high carbon ordinary instrumental and constructional steels with higher manganese production and processing (rails, cord and rope wire, springs, low stressed instruments). Realization of the fine pearlite obtaining regime needs equipment that could provide cooling rates from 0.04 deg./sec. to 6.6 deg./sec. with average value of 1.1 deg./sec.. For bainitic structure obtaining the range of cooling rates provided should be from 0.14 deg./sec. to 14.0 deg./sec. with average value of 2.2 deg./sec. The cooling intensity must have an ability to arbitrary and controlled changing during process.

KEYWORDS: STEEL, STRUCTURE FORMATION, AUSTENITE TRANSFORMATION, HEAT PROCESSING

1. Introduction

The objective of the research is to define cooling two regimes one of which leads to formation of a fine pearlite structure without or almost without bainite and martensite, and another that provides a lower bainite structure with less content of pearlite (only fine one) and higher bainite, martensite also is not wished.

Ordinary high carbon eutectoid steels have quite wide area of usage. They have their application in cases where high hardness or resiliency or wear resistant is needed. They do not have so much hardness and ability to rapid cutting (which needs from material ability to save hardness at higher temperatures) as some high alloyed instrumental steels. But they are rather useful for hand tools, or wood and plastic machining cutting tools. As a constructional material they are known as steel for springs, steel for cord and metal rope wire, and very important area of their application is material for rails [1, 2].

Normal equilibrium structure of this type of steels is pearlite – eutectoid which consists of ferrite and carbide (cementite) plates. The smaller thickness of this plates the finer pearlite is the higher its mechanical properties. Finer pearlite is forming at lower temperatures. Along with pearlite in some conditions at lower temperatures bainitic structures also could be obtained in these steels. Bainite could be present in this steels mixed with pearlite or the structure could be almost fully bainitic. High carbon steels have also good ability to quenching during which martensite is forming [1].

There is no one certain opinion whether lower bainite or fine pearlite is better. The most wide spread and useful now are steels with pearlitic structure. Bainitic structure for construction materials was studied [3, 4], but the properties obtained in steel with bainite were not much better, sometimes even worse than in the same steel but with fine pearlitic structure [4]. But in work [3] it was shown that changing chemical composition of the steel it is possible to obtain much better complex of properties (especially wear resistance) in bainitic steels. These steels have much less content of carbon, more Mn and some amount of Mo and Cr [3]. But bainitic structure sometimes is helpful in instrumental steels instead of martensite. It is because lower bainite is less brittle and more elastic than martensite.

Detailed description of the mathematic model of austenite transformation is given in our works [5, 6] and detailed model examples with experimental verifications are presented in [5, 7]. It allows calculation of nucleation and growth of different phases that could occur in steels. Thermodynamics of phase transformation is also calculated by the model. But the main objective of it is calculation of kinetics. One of the most important essences of the model is that it allows to predict the material structure which could

form in the certain conditions of temperature regime during transformation process.

2.1. Studied material

Chemical composition of the studied steel in this work is given in table 1.

Table 1

Chemical composition of the studied steel							
Fe	C	Mn	Si	Cr	Ni	Mo	Cu
base	0.75	0.95	0.35	0.03	0.05	0.02	0.06

It's seen that the steel is near to eutectoid and has higher amount of Mn and normal concentration of Si. Content of other elements is small, but they were also taken into account in simulation. It is a typical rail or spring steel.

According to thermodynamic calculations equilibrium critical points of this steel are $A_1 = 729^\circ\text{C}$ and $A_3 = 733^\circ\text{C}$.

2.2. Calculation and its results

Different shapes of cooling curves were used in the simulations. It was predicted that the structure which almost totally consists of fine pearlite could be formed when the cooling regime is responding to one that is shown on figure 1.

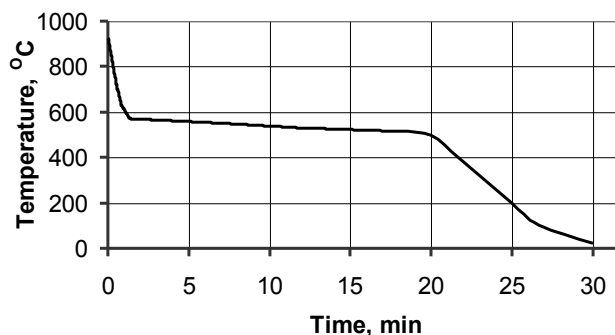


Figure 1 – Cooling regime for fine pearlite bainiteless structure obtaining in the eutectoid steel

Results of austenite transformation simulation (kinetic curve) in the investigated steel when temperature changes according to the cooling curve from figure 1 is shown on figure 2. From this illustration we can see that the transformations are almost completely end at about 514°C . This moment comes after 1094 s

from the beginning of the process and after 1063 s after the pearlite transformation starts (about 18 min) according to computer simulation. The pearlite transformation starts below 727 °C, but goes very slowly at the beginning. Because we don't need rough pearlite the cooling rate in this period should be competently fast: from 5.0 to 6.6 deg./sec.

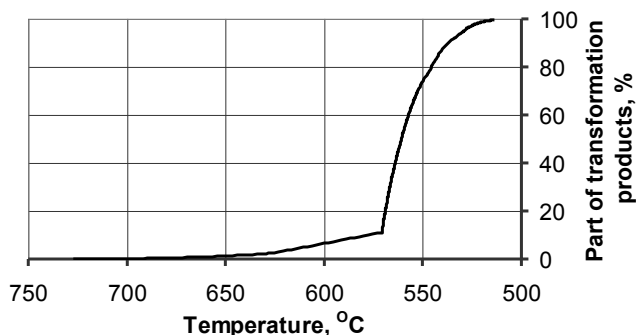


Figure 2 – Kinetic curve of austenite transformation in the regime of fine pearlite structure obtaining

Especially fast cooling rate is necessary lower 650 °C when the transformation process becomes quite swift. In this research it was considered that the fine pearlite structure should be obtained without quenching or cooling in liquid metal melts but by fast air cooling. This process has its limits, so that we obtain about 10 % of pearlite formed higher 575 °C. But fortunately amount of the pearlite formed higher 630 °C is very small. The bent of the kinetic curve near 570 °C is caused by slowing of the cooling rate (see figure 1). This deliberately decrease of the cooling rate to 0.4...0.7 deg./sec is needed to make pearlite transformation completely performed in a limited temperature range. This range is from 570 to 515 °C and its duration is about 19 minutes. This is enough to make pearlite transformation completely finished. Lower 515 °C according to calculations there is a possibility of higher bainite formation which is not wished in this case.

Another regime is aimed to a bainite structure obtaining. Its cooling curve is shown on Figure 3.

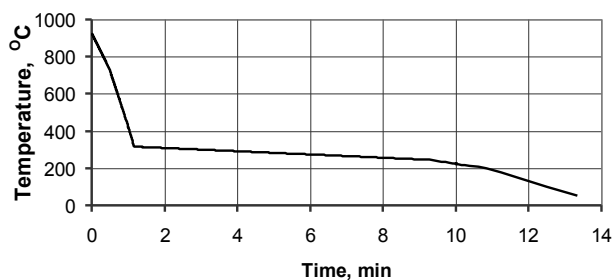


Figure 3 – Cooling regime for lower bainite structure obtaining in the eutectoid steel

This technique needs faster cooling rate at the beginning of the process. During first 80 seconds it should be 7...14 deg./sec. After this time metal should have temperature 325 °C. According to simulation it is the temperature when lower bainite becomes forming, but significantly higher than temperature of martensite transformation start which is 228 °C. Thus for lower bainite structure obtaining it is necessary to decrease the cooling rate to value 0.14...0.15 deg./sec. After about 7 minutes the bainite transformation is complete. The temperature at the end of the transformation is about 250 °C which is higher than temperature of martensite transformation start. Thus there is no martensite in the structure. A kinetic curve of the process is given on figure 4.

From the curve a certain separation of pearlite and bainite transformation is seen. Some pearlite which seems to be a fine one appear between 630 and 455 °C. Its amount in the structure is estimated to be 25.3 % from which 22.8 is a fine disperse pearlite

and 2.3 is ordinary pearlite. The fastest cooling rate should be set in the temperature range from 450 °C to 325 °C. Austenite is less stable in this period and is able to transform to brittle higher bainite, which is not a wished structure. Thus the cooling rate should be raised up to 14 deg./sec. Lower 325 °C austenite transforms to lower bainite. In the final structure by our computer model presence of 74.1 % of lower bainite was estimated.

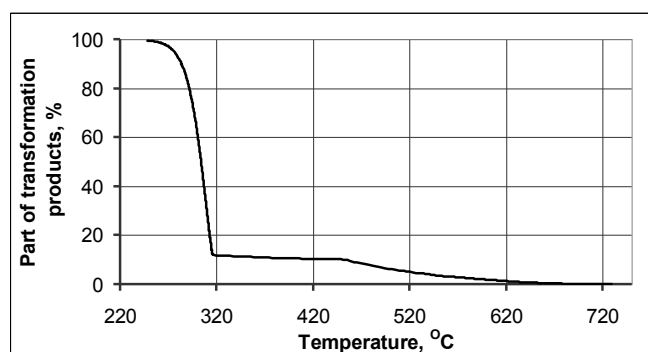


Figure 4 – Kinetic curve of austenite transformation in the regime of bainite structure obtaining

3. Conclusions

Using self developed computer model regimes for fine pearlite and bainite structure in eutectoid steel with higher manganese obtaining were developed. The regimes provide turning of higher cooling rate to slower ones at certain temperatures. Pearlite forming needs cooling rate 5.0...6.6 deg./sec. before 575 °C and then slowing it to 0.04...0.7 deg./sec. for 19 minutes. Regime for bainite structure obtaining is some faster. It needs cooling with rate 7...14 deg./sec. higher 325 °C (especially intensive at 450... 325 °C) and then slowing it to 0.14...0.15 deg./sec. for 7...8 minutes.

The obtained results present in the paper are useful for high carbon ordinary instrumental and constructional steels with higher manganese thermal processing regimes developing.

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STUDY OF STRUCTURE FORMATION AND HARDENING IN CARBON STEELS DURING HPT AT TEMPERATURES BELOW RECRYSTALLIZATION

ИССЛЕДОВАНИЕ ОСОБЕННОСТЕЙ СТРУКТУРООБРАЗОВАНИЯ И УПРОЧНЕНИЯ В УГЛЕРОДИСТЫХ СТАЛЯХ ПРИ ИПДК В ОБЛАСТИ ДОРЕКРИСТАЛЛИЗАЦИОННЫХ ТЕМПЕРАТУР

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Abstract: The impact of the parameters of thermomechanical treatment on the structural changes and micro-hardness of low- and medium carbon steels under a high hydrostatic pressure at high pressure torsion (HPT) is investigated. It is established that for HPT the deformation temperature has a decisive impact on the efficiency of refinement and hardening. This is caused by the effect of dynamic strain ageing (DSA) at 250 and 400°C during HPT. At the same time the level of accumulated strain in the sample intensifies the refinement under the effect of dynamic strain ageing (DSA). It should be noted that an increase of the carbon content to 0.2 % and 0.45% in steel leads to an increase in the temperature of dynamic strain ageing (DSA) to 400°C. It is stated that HPT under the effect of dynamic strain ageing (DSA) results in the formation of a gradient structure in the samples after five rotations of the anvil ($\epsilon_{\max}=6.26$) at a hydrostatic pressure of 6 GPa.

Keywords: MICROSTRUCTURE, DSA, CARBON STEEL, HPT, SPD, MICROHARDNESS

1. Introduction

High pressure torsion is widely used to increase the properties of metal materials [1-4]. Generally, this is cold treatment with the high level of accumulated strain. However, the strength of materials increases 2-3 times due to the formation of a grain structure of the ultrafine and/or nanostructured range [4-8]. During the cold treatment by HPT the hardening of the samples subjected to 5 rotations of the anvil $\epsilon_{\max} = 3.45$ as a rule levels, this is especially typical of pure metals [2, 4]. HPT processing of the alloys with the solution supersaturated with alloying elements (thermal-hardened) generally leads to the formation of new stable phases as nanoparticles located both in the bodies and boundaries of ultrafine and nano grains. Consequently, this contributes to more effective hardening of the samples after deformation [7, 8].

Recently the attention of researches has been focused on the effect of dynamic strain ageing (DSA), its full occurrence depends on the temperature of deformation. The temperature range of occurrence of this effect is usually 200-400°C, and it is located in the range below the recrystallization temperatures. The effect of DSA also impacts the intensity of dispersion of the structure and the degree of its defects (hardening) [8, 9]. Of particular interest in that connection is the study of the features of structure formation and hardening of commercial steels depending on the temperature and the carbon content under the critical conditions relevant to HPT, i.e. a high hydrostatic pressure of 6 GPa and ultrahigh accumulated strain of $\epsilon_{\max}=6.26$. Besides, the DSA effect is observed in steels during traditional plastic deformation [9–12].

2. Material and procedures of experiments

This paper investigates the impact of the carbon content in steels on the formation of a gradient structure under severe plastic deformation of steels 10, 20 and 45 with standard chemical composition [13].

The initial samples for the investigation are discs with a diameter of 10 and 20 mm, thickness of 0.5 mm. The steel samples are subjected to HPT under 6 GPa at temperatures of 20, 250 and 400°C. Figure 1 shows the scheme of the HPT process [8, 9].

The strain degree is determined by the equation [2, 3]

$$\epsilon = \ln(\vartheta \cdot r/h), \quad (1)$$

where ϑ – the angle of torsion (radian), r and h – the radius and thickness of disc, correspondingly.

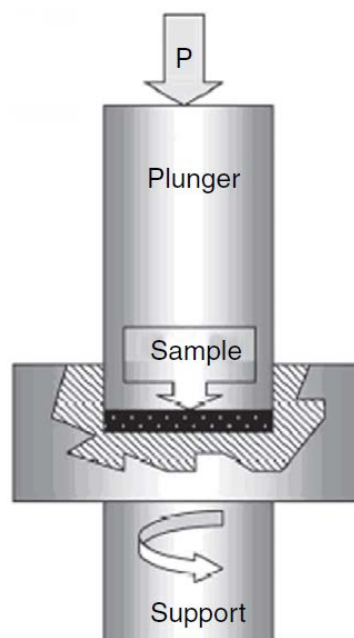
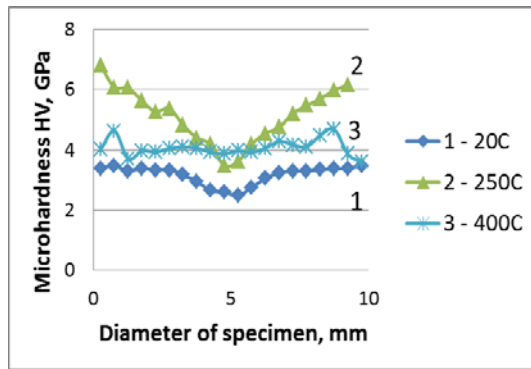


Fig. 1 Scheme of the deformation node for high pressure torsion

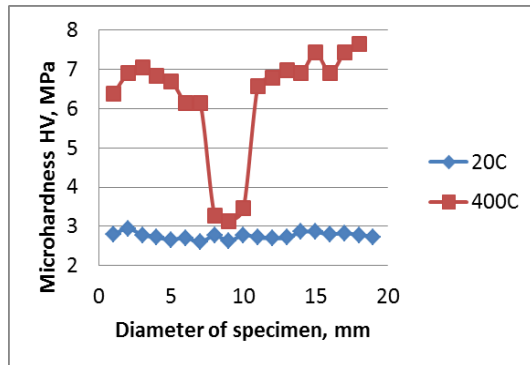
After the deformation the microhardness of these samples is determined by their diameter, and the structure of the central and peripheral parts is investigated by light and scanning electron microscopes.

3. Results of experiments and their discussion

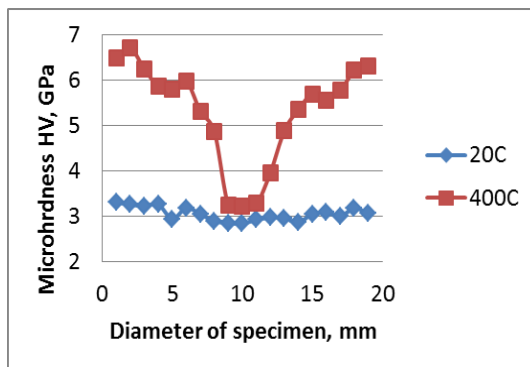
Figure 2 shows the results of the investigations of microhardness of the steels after HPT at the chosen temperatures for the three chosen steel grades. Figure 3 demonstrates the microstructure of steel 10 after HPT at a temperature of 20°C.



a)



b)

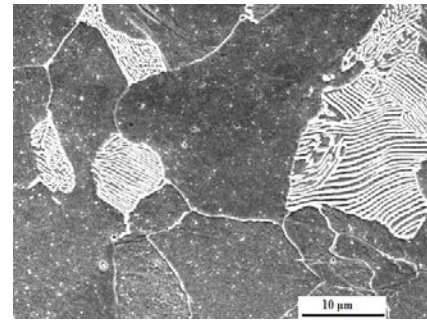


c)

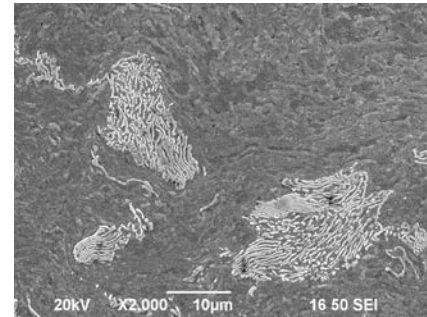
Fig.2 Plots of microhardness distribution in the samples where a) Steel 10 after deformation at 20°C(1), 250°C(2), 400°C(3); b) Steel 20 after deformation at 20°C(1) and 400°C(2); c) Steel 45 after deformation at 20°C(1) and 400°C(2).

The analysis of the microhardness distribution along the diameter section of the samples shows that the minimum values of the hardness are obtained after cold treatment of the steels (20°C). However, the lower values HV in comparison with the periphery are observed in the center of the steel 10 samples, but the microhardness values are roughly the same along the whole diameter of the samples of steel 20 and steel 45.

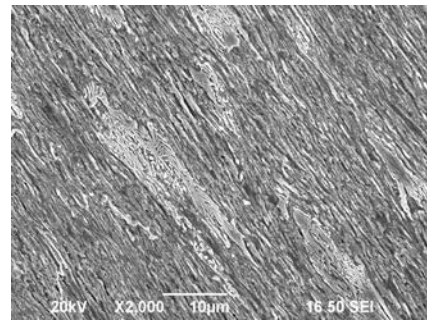
The microstructural studies are conducted to determine the causes of the observed features of the microhardness change of the sample after HPT. Figure 3 shows the images of the microstructure of steel 10 in the initial state and after HPT. The plates of cementite in the grains of perlite in the initial state are located mainly parallel with each other. After HPT the plates of cementite are divided into pieces which are randomly located towards each other in the most grains of perlite. This demonstrates the development of dislocation sliding and occurrence of rotary modes of deformation in the grains of perlite. Such action of rotary modes of deformation were also observed in [8], which described equal channel angular pressing of steel 10.



a)



b)



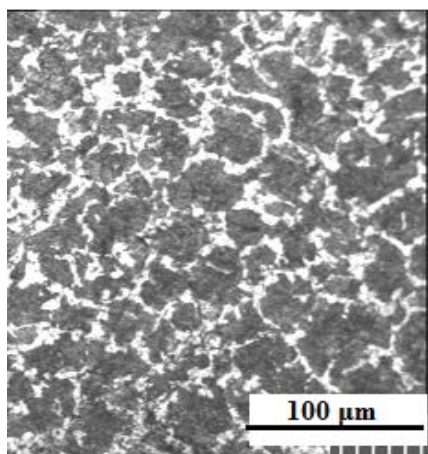
c)

Fig. 3 Microstructure of steel 10: a – initial state, b, c – 5 HPT rotations at 20°C, b – centre of samples, c – periphery. Scanning electron microscope

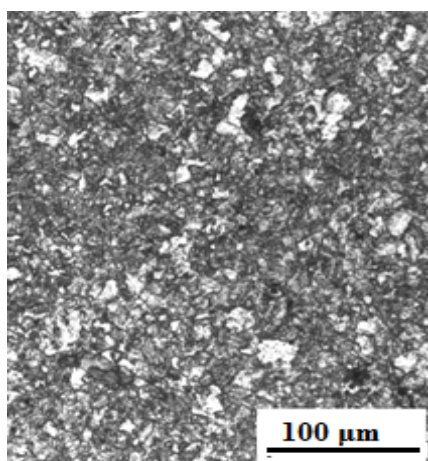
In the periphery of the samples, where the strongest structure refinement occurs, perlite and ferrite grains are highly elongated along slip bands (Figure 3c). A substructure with relatively equiaxed cells forms in these ferrite and perlite grains during HPT, which corresponds to the previously obtained data on other materials [3].

A decrease in the microhardness values in the steel 10 samples deformed at 400°C in comparison with the HV values obtained after HPT at 250°C indicates that the effect of DSA becomes weaker at a temperature of 400°C for low carbon steel 10 due to activation of diffusion processes. An increase of the carbon content in the steel to 0.2% and 0.45% leads to an increase in the temperature the DSA effect to 400°C (Figure 2).

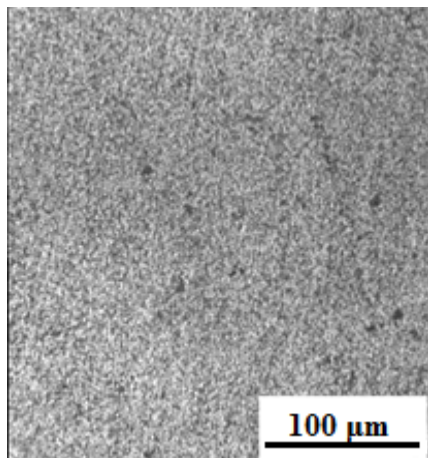
Figure 4 shows the microstructure of steel 45 after 5 rotations ($\epsilon \approx 3.45$) of HPT. The structure refinement is $\sim 300\text{--}400$ nm in the center, and in the periphery of samples it is $\sim 100\text{--}200$ nm especially at increased temperatures (Figure 4). Consequently, the microhardness values in the periphery of the samples after HPT at 400°C exceed more than two times (to 6.5 GPa) the values of HV in the centre of the samples (~ 3 GPa). The similar change in the microstructure and microhardness is observed in steel 20 under HPT.



a)



b)



c)

Fig. 4 Microstructure of the samples of steel 45: a – initial state; b, c – after 5 HPT rotations ($\epsilon \approx 3.45$) at 400°C; b – center of the sample, c – periphery of the sample. Light electron microscope

Consequently, the cell size reduction from the center to the periphery of the samples and a considerable increase in the microhardness demonstrate the formation of the gradient structure and properties of the steel samples subjected to HPT under DSA. Similar behavior under HPT are observed in [14, 15].

Nowadays the study of regularities of formation of gradient structures is an urgent trend in modern material science [16-20], and this investigation contributes to it.

4. Conclusions

1. The features of formation of the gradient structure at high pressure torsion of steel 10, steel 20 and steel 45 have been investigated, when the effect of dynamic strain aging occurs. The deformation mechanisms in different parts of the samples of the steels during HPT have been analyzed.

2. The temperature range of 250 – 400°C of the DSA effect exhibition during high pressure torsion of the studied steels has been determined. The relation between activation of the DSA effect and the structure state has been demonstrated.

3. The structural changes of the steels under HPT and, consequently, the formation of the gradient structure in the steels have been investigated in the temperature range of the DSA effect. It is shown that under HPT the most effective refinement of the structure (cell sizes d_{cell} , decrease to 0.1-0.2 μm) is in the periphery of the samples in comparison with the center ($d_{\text{cell}} > 0.3 \mu\text{m}$) that is characterized as a gradient structure.

4. As a result of the DSA effect, in the process of severe plastic deformation, additional refinement of the structure of the alloys and, consequently, a more significant increase in the yield stress and microhardness takes place in comparison with the samples deformed at room temperature. The increase in the lattice friction stress due to the interaction of atoms atmospheres of impurities with mobile dislocations leads to the additional increase in the density of dislocations in ferrite and perlite grains.

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THE IMPACT OF ELECTRIC FIELD DISTRIBUTION DURING Ti – Al – C SYSTEM BLEND PREPARATION ON PHYSICAL-MECHANICAL PROPERTIES OF CONSOLIDATED MATERIALS

ВЛИЯНИЕ РАСПРЕДЕЛЕНИЯ ЭЛЕКТРИЧЕСКОГО ПОЛЯ ПРИ ПОДГОТОВКЕ ШИХТЫ СИСТЕМЫ Ti – Al – C НА ФИЗИКО-МЕХАНИЧЕСКИЕ СВОЙСТВА КОНСОЛИДИРОВАННЫХ МАТЕРИАЛОВ

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Abstract: The possibility of control of efficiency of different factors of high voltage electric discharge (HVED) impact on Ti – Al – C powders system for aimed synthesis of dispersion-hardening components is shown. Nanolaminate-composite Ti_3AlC_2 – TiC with hardness of $HV_5 = 7$ GPa, obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED with the use of multi-point electrode system has needle structure of Ti_3AlC_2 ($a = 0.3068$ nm, $c = 1.844$ nm) with size up to 10 μm , and TiC dispersion-hardening phase ($a = c = 4.4331$ nm) with particle size no more than 1 μm is situated between grains of Ti_3AlC_2 . Dynamic strength of specimens depending on electrode system used during HVED treatment of blend varied in range from 160 to 620 MPa, Young modulus – from 13 to 22 GPa at deformation rate from 600 to 900 s^{-1} . Material has high levels of heat resistance, relative change of mass is no more, than 0.001.

KEYWORDS: ELECTROMAGNETIC FIELD, METAL-MATRIX COMPOSITE, POWDER MATERIAL, DISPERSE FILLER, HIGH VOLTAGE ELECTRIC DISCHARGE, POWDER METALLURGY, BLEND PREPARATION, ALUMINUM MATRIX COMPOSITES, PHASE COMPOSITION, SYNTHESIS, DISPERSION, MAX-PHASE

1. Introduction

Efficiency of the usage of high voltage electric discharge (HVED) for preparation of homogeneous highly disperse blend for production of metal-matrix composites (MMC) of different compositions was shown earlier in papers [1, 2]. The possibility of control of efficiency of different HVED impact factors for aimed synthesis of dispersion-hardening fillers was shown in work [2]. HVED treatment combines even distribution of interparticle discharges plasma and hydrodynamic impact, which intensifies processes of structure and phase formation.

It is shown in paper [3], that control of volumetric distribution of interparticle discharges plasma in powder is possible by control of electromagnetic field (EMF) by variation of electrode system construction, which can impact processes of structure and phase formation in treated blend.

The goal of present work is to study the impact of electrode system configuration on the distribution of plasma formations in “kerosene – powder” disperse system and on the properties of obtained blend and consolidated materials.

2. Preconditions and means for resolving the problem

Mixture of metal powders of PA-4 GOST 6058-73 (IIA-4 ГОСТ 6058-73) Aluminum powder (mean diameter 23 μm) and TU U14-10-026-98 (ТУ У 14-10-026-98) Titanium powder (mean diameter 63 μm) of 15 % Al : 85 % Ti mass relation was used as initial material.

HVED treatment was performed at experimental stand, which is described in detail in work [2]. Powder mixture was loaded into discharge chamber, then TS-1, GOST 11128-65 (TC-1, ГОСТ 11128-65) kerosene was added (relation of disperse and continuous phases was 1:10 [4]). Specific treatment energy was 25 MJ/kg, which allowed synthesis of necessary for dispersion-hardening components synthesis quantity of nanocarbon as a result of hydrocarbon destruction under the impact of discharge channel plasma [4].

Consolidation of powder materials was performed at spark-plasma sintering (SPS) device [5] in vacuum by passage of superposition of direct and pulsating currents with 10 kHz

frequency at working voltage of 2 V. Powder was poured into MPG-6 (МПП 6) graphite matrixes with inner diameter of 10 mm, pressure of blend pre-pressing was ~ 30 MPa and sintering pressure was ~ 60 MPa in all considered experiments. Measurement of specimens temperature during sintering was performed by standard K-type thermal couple. Al – Ti – C system specimens isothermal holding temperature was 1100 $^{\circ}\text{C}$ according to MAX-phases formation zones [6]. Specimens heating rate during consolidation was selected according to works [7, 8] and was 10 $^{\circ}\text{C/s}$. According to work [9], it was determined that isothermal holding time has to be no more, than 3 min, in order to preserve ultrafine nanostructured phases during consolidation.

BIOLAM-I (БИОЛАМ-И) optical microscope with maximal magnification of $\times 1350$ and REMMA-102 (РЕММА-102) raster electron microscope with magnifications range from $\times 10$ to $\times 250000$ were used for analysis of powder particles morphology.

Studies of phase composition and crystal structure were performed by X-ray diffraction analysis using Rigaku Ultima IV X-ray diffraction meter ($\text{CuK}\alpha$ radiation). Vickers hardness was determined using IT 5010 (ИТ 5010) hardness meter.

Dynamic compression strength of specimens was studied using their compression diagrams, obtained by using experimental device for dynamic tests by Hopkinson-Kolsky method [10].

3. Results and discussion

Three types of electrode system (ES) construction were used during powders HVED treatment: “point – plane” (P – P), No. 1 (See Fig. 1, a) and two variants of “multipoint anode – plane” ES (MP – P), No. 2 and No. 3 ((See Fig. 1, b and c correspondingly).

It is worth noting, that cyclic formation gas-vapor cavity only in near-electrode zone while using ES No. 1 (see Fig. 1, a) leads to ejection of powder from chamber central part and leads to amplification of hydrodynamic impact. Yet, amplification of hydrodynamic impact leads to weakening of erosion (ablation) of particles due to decrease of solid phase concentration in chamber central part.

The picture of plasma formations distribution caused by No. 2 ES construction (see Fig. 1, b) is not qualitatively different from distribution, caused by No. 3 ES construction (see Fig. 1, c) – in both cases interparticle discharges plasma is almost evenly distributed in powder volume.

Due to cone shape of No. 3 ES, which follows the shape of chamber bottom, volumetric distribution of plasma formations is more even if compared to No. 2 ES.

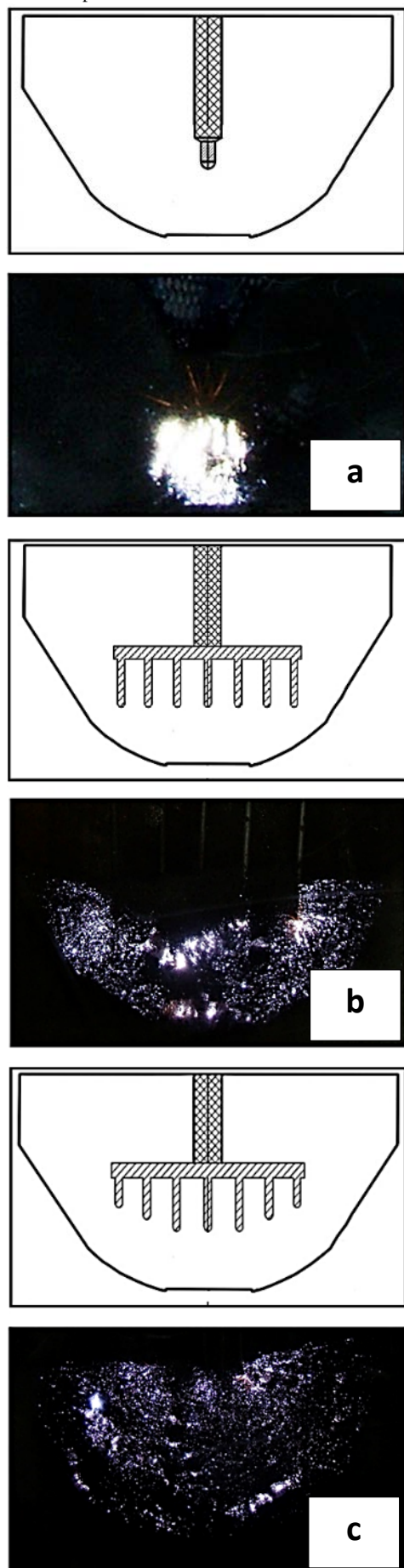


Fig. 1. Construction of electrode systems and plasma formations distribution

a – ES No. 1; *b* – ES No. 2; *c* – ES No. 3

The possibility of control of efficiency of different HVED factors impact on Ti–Al system for aimed synthesis of dispersion-hardening components (TiC titanium carbide, AlTi₃, AlTi, Al₂Ti, Al₃Ti, Ti₃AlC intermetallic compounds, Ti₃AlC₂ and Ti₂AlC MAX-phases and Lonsdaleite) by changing electric field configuration by using different types of ES was shown earlier in works [11, 12]. It was experimentally found out, that HVED treatment of Ti–Al powder systems (75 % Ti + 25 % Al, 50 % Ti + 50 % Al and 25 % Ti + 75 % Al) in kerosene leads to their dispersion, main peak of their size distribution moves to point of ~ 3 μm, and no less than 20 % of particles have size less than 1 μm.

As a result of HVED treatment of powder mixture of 85 % Ti + 15 % Al composition, considered in present work, particles mean diameter decreased ~ 4.5 times in case of ES No. 1 usage, and while using ES No. 2 and No. 3 dispersion efficiency decreases ~ 3 times. Change of phase composition also occurs TiC dispersion-hardening component is synthesized ($a = c = 4.329 \pm 0.003$ nm), intensity of its synthesis increases when using ES No. 2 and No. 3.

From practical point of view, it is important to study the impact of powder blend characteristics change due to the use of different ES types on consolidated materials properties.

SPS consolidation of blend, obtained while using ES No. 1, led to phase transformations in consolidated material – formation of TiC ($a = c = 0.86413 \pm 0.0015$ nm) and Al₃Ti ($a = 0.38512 \pm 0.0019$ nm, $c = 0.8607 \pm 0.0004$ nm) with the release of free Carbon (see Fig. 2). Large quantity of Carbon impacted the structure and hardness of obtained material. Carbon is uniformly distributed by specimen volume (see Fig. 2), creating dark zones with microhardness of 0.7 GPa and light zones with microhardness of 1.3 GPa. Vickers hardness of specimens was 0.9 GPa.

As a result of HVED treatment with the use of ES No. 2 and subsequent consolidation, formation of Ti₃AlC₂ ($a = c = 0.390 \pm 0.003$ nm) and Al₄C₃ ($a = 0.33357 \pm 0.00006$ nm, $c = 2.5288 \pm 0.0004$ nm) occurs, as well as absorption of Aluminum (see Fig. 3). This leads to formation of light zones with microhardness up to 11 GPa and gray zones of hardened Titanium with microhardness up to 8 GPa (see Fig. 3). Vickers hardness of obtained material was 5.28 GPa.

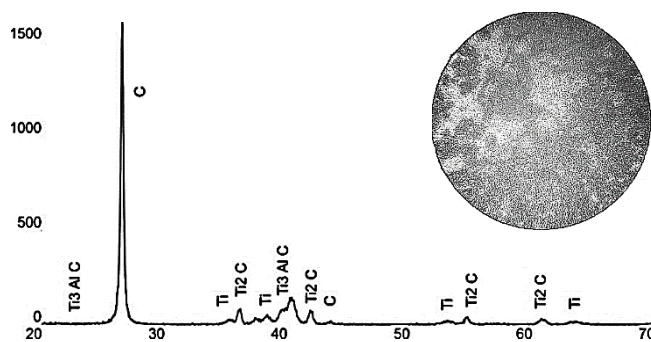


Fig. 2. Phase composition and structure (magnification ×250) of MMC, obtained from powder of 85 % Ti + 15 % Al initial composition after HVED treatment with the use of ES No. 1

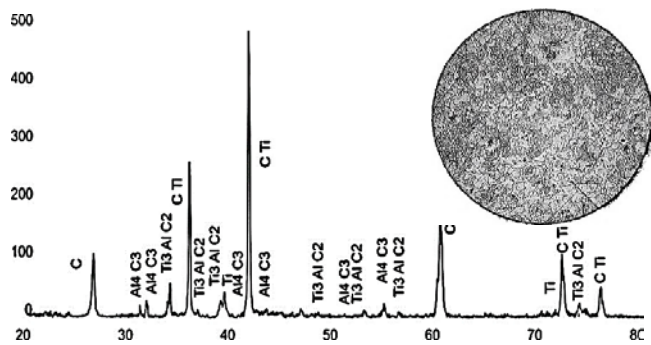


Fig. 3. Phase composition and structure (magnification $\times 250$) of MMC, obtained from powder of 85 % Ti + 15 % Al initial composition after HVED treatment with the use of ES No. 2

Metal-matrix composite, obtained from blend, prepared by HVED with the use of ES No. 3 consists of Ti_3AlC_2 ($a = c = 0.4131 \pm 0.0007$ nm) and Al_4C_3 ($a = 0.3344 \pm 0.0004$ nm, $c = 2.509 \pm 0.003$ nm) phases (see Fig. 4). Light zones with microhardness up to 13.8 GPa and gray zones of hardened Titanium with microhardness up to 7 GPa are formed in specimen structure (see Fig. 4). Vickers hardness of obtained nanolaminate-composite $\text{Ti}_3\text{AlC}_2 - \text{TiC}$ with homogeneous fine grain structure is 7 GPa.

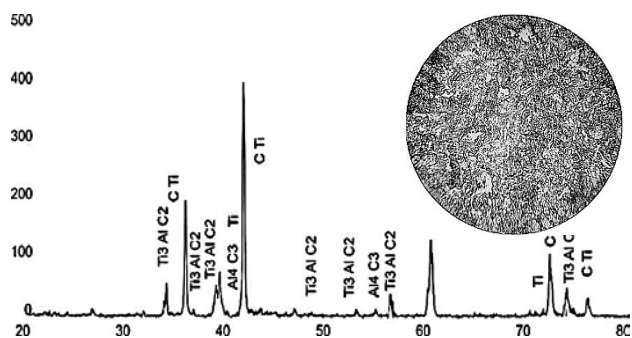


Fig. 4. Phase composition and structure (magnification $\times 250$) of MMC, obtained from powder of 85 % Ti + 15 % Al initial composition after HVED treatment with the use of ES No. 3

Materials, obtained from powder of 85 % Ti + 15 % Al initial composition after HVED treatment with the use of ES No. 3 have the highest hardness ($\text{HV}_5 = 7$ GPa) among considered specimens (see Fig. 5).

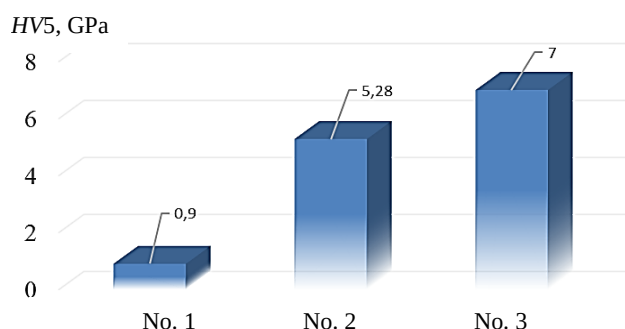


Fig. 5. Vickers hardness of MMC specimens, obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED treatment with different ES types

Dynamic strength of specimens, obtained from blend after HVED treatment, depending on used ES type, varied in range from 280 MPa to 600 MPa (see Fig. 6), and Young modulus varied in range from 13 GPa to 22 GPa at deformation rate from 600 s^{-1} to 900 s^{-1} (see Fig. 7).

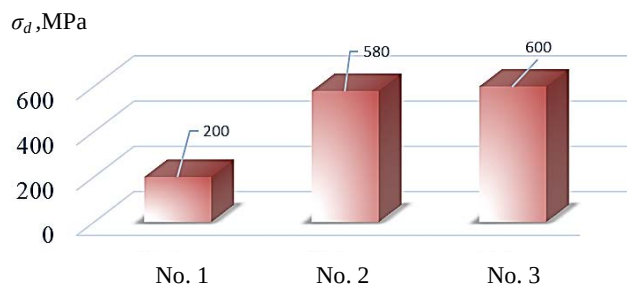


Fig. 6. Dynamic strength of MMC specimens, obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED treatment with different ES types

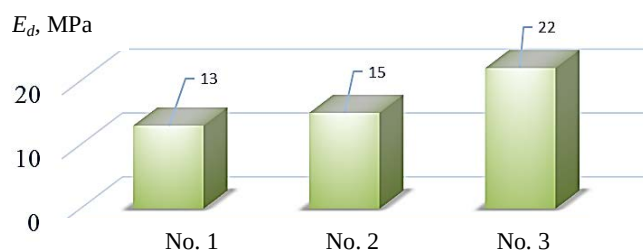


Fig. 7. Young modulus of MMC specimens, obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED treatment with different ES types

Results of heat resistance studies show, that unbound Carbon has negative impact on heat resistance of composite, consolidated from blend after HVED treatment with ES No. 1. Relative mass change for such specimens was 0.09. Nanolaminate-composite $\text{Ti}_3\text{AlC}_2 - \text{TiC}$, obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED treatment with ES No. 2 and No. 3, contrary to case of ES No. 1, have high values of heat resistance (see Fig. 8)

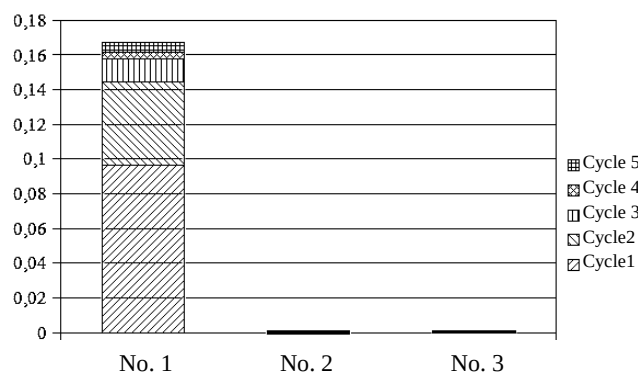


Fig. 8. Relative mass change of MMC specimens, obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED treatment with different ES types

4. Conclusions

1. It is found out, that control of efficiency of different HVED impact factors for aimed synthesis of dispersion-hardening components is possible by changing EMF configuration due to use of different ES types.

2. Nanolaminate-composite Ti_3AlC_2 – TiC with hardness of $HV_5 = 7$ GPa) obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED treatment with ES No. 3, has needle structure of Ti_3AlC_2 ($a = 0.3068$ nm, $c = 1.844$ nm) with size up to 10 μm , and TiC dispersion-hardening phase ($a = c = 4.4331$ nm) with particle size no more than 1 μm is situated between grains of Ti_3AlC_2 .

3. Dynamic strength of specimens, obtained from blend after HVED treatment, depending on used ES type, varied in range from 280 MPa to 600 MPa, and Young modulus varied in range from 13 GPa to 22 GPa at deformation rate from 600 s^{-1} to 900 s^{-1} .

4. Nanolaminate-composite Ti_3AlC_2 – TiC, obtained by consolidation of blend of 85 % Ti + 15 % Al initial composition after HVED treatment with ES No. 2 and No. 3, contrary to case of ES No. 1, have high values of heat resistance due to formation of fine grain hardened Ti_3AlC_2 – TiC structure – relative mass change is 0.001.

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