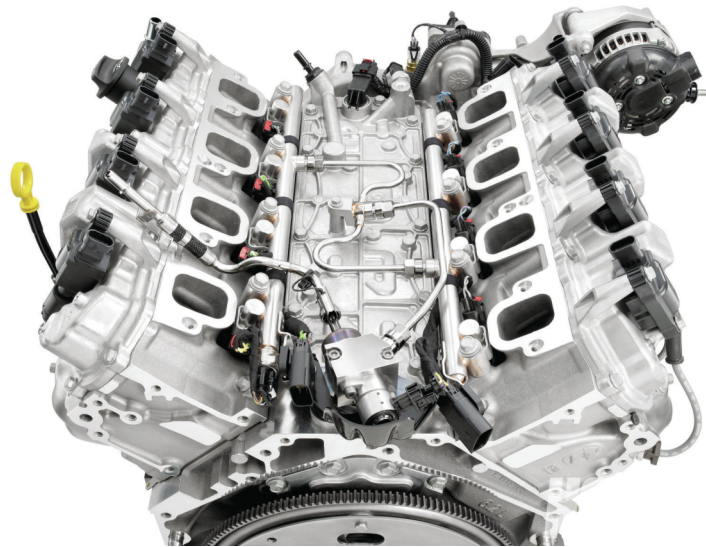


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CONTENTS

INFLUENCE OF NITROGEN ADDITION ON PHYSICAL-CHEMICAL PROPERTIES AND CORROSION RESISTANCE OF STAINLESS STEELS

Kaputkina L.M., I. V. Smarygina, D.E. Kaputkin, A. G. Svyazhin, T.V. Bobkov 3

POLYMERIC COMPOSITES OF CONSTRUCTIONAL APPLICATION BASED ON THERMOSETTING MATRIX AND CHEMICAL FIBERS

Burya A.I., N.G. Chercasova, O.I. Pilipenko, O.A. Naberezhnaya 7

DEVELOPMENT OF ECONOMICALLY ALLOYED SACRIFICIAL ALLOYS FOR PROTECTION OF METAL CONSTRUCTIONS AGAINST ELECTROCHEMICAL CORROSION

Kechin V. 10

LASER MATERIALS PROCESSING SYSTEM.

Kuzminykh Ya., V. Postnikov 13

ADJUSTING THE SALES PROCESS TO THE PERSONALITY OF THE BUYER (RESEARCH THE AUSTRIAN INVESTMENT GOODS INDUSTRY)

Füreder R. 16

SUPERFINISHING FLAT AND CYLINDRICAL SURFACES OF GEAR PUMP PINIONS

Lepadatescu B. 22

EXPERT SYSTEMS USED THROUGHOUT THE TRAINING OF MASTER ENGINEERS IN THE FIELD OF INDUSTRIAL ENGINEERING

Dinev G. 25

CORROSION PROPERTIES OF Ti-6Al-4V ALLOY WITH NITRIDE AND OXYNITRIDE COATINGS IN PHYSIOLOGICAL SOLUTIONS

Tkachuk O. 29

PLASMA TECHNOLOGIES FOR OBTAINMENT OF COMPOSITE MATERIALS DISPERSION HARDENED BY NANOSTRUCTURED PARTICLES

Sizonenko O., V. Tregub, N. Pristash, A. Zaichenko, A. Torpakov 32

ANALYSIS OF STRESS-STRAIN STATE OF ECCENTRIC ONE-WAY CLUTCHES BY THE FINITE ELEMENT METHOD

Zolotov I., O. Sharkov 36

STRUCTURE AND CHARACTERISTICS COATINGS OBTAINED AFTER COMPLEX SATURATION BORON AND SILICON ON CARBON STEEL

Chernega S., I. Poliakov, M. Krasovsky, I. Medova 39

EFFECT OF STEP THERMOMECHANICAL TREATMENT ON ELECTRICAL PROPERTIES OF AL 6101

Raab G.I., E. I. Fakhretdinova, G.Yu. Sagitova 42

EXPERIMENTAL RESEARCH STUDY ON THE USE OF A RESISTIVE TENSOMETRIC SENSOR

Ghimbaseanu I. 44

DUAL FLOW HYDROMECHANICAL PLANETARY GEAR WITH CONTINUOUSLY VARIABLE GEAR RATIO OPTION

Milev S. 48

INFLUENCE OF NITROGEN ADDITION ON PHYSICAL-CHEMICAL PROPERTIES AND CORROSION RESISTANCE OF STAINLESS STEELS

ВЛИЯНИЕ ДОБАВКИ АЗОТА НА ФИЗИКО-ХИМИЧЕСКИЕ СВОЙСТВА И СОПРОТИВЛЕНИЕ КОРРОЗИИ НЕРЖАВЕЮЩИХ СТАЛЕЙ

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Abstract: Researched were the physico-chemical properties, hardening and corrosion resistance of Cr18Ni10N type austenitic chromium-nickel stainless steels of different purity by the impurities and with different nitrogen content: from impurity level to 0.220%. It is demonstrated that nitrogen alloying is beneficial both for hardening and improvement of corrosion resistance of steel under conditions when nitrogen has the form of solid solution. Addition of 0.186-0.220% of nitrogen doesn't reduce intercrystalline corrosion in standard environment of 0.5M H₂SO₄ + 0.01M KSCN and improves resistance to general and pitting corrosion in chloride-containing environments. Pure nitric steel shows higher resistance to intercrystalline, general and pitting corrosion in chloride solutions than normal purity steel.
KEYWORDS: AUSTENITIC STEEL, NITROGEN ALLOYING, CORROSION RESISTANCE

1. Introduction

Austenitic steels of type Cr18Ni10N have been widely used as corrosion resistant, heat resistant, cryogenic steels [1–6].

Due to complexity and multifactor impact of nitrogen there are no clear criteria for selection of proper nitrogen content and resulting structure for different purpose steels yet.

Similar to the carbon the nitrogen ensures solid solution steel hardening and dispersion strengthening due to generation of nitrides and carbonitrides. Within such process the nitrogen has higher impact on solid solution hardening and improves mechanical hardening due to smaller atom diameter compared to carbon.

Nitrides in Cr-Ni steels are more dispersed and evenly distributed compared to carbides allowing to get high values of resistance, ductility and toughness at the same time.

Grain-boundary strengthening of nitric steels is also effective due to release of dispersed nitrides and carbonitrides along the boundaries and subboundaries, and grain refining upon heat treatment.

Stable Cr-Ni and Cr-Mn austenitic steels alloyed with nitrogen are often reinforced with cold plastic yield and aging.

The increase of the concentration of N and N+C can result to increase of the effects of aging both during and after deformation due to a larger supersaturation of the solid solution. It can decrease the temperature of the austenite decomposition and thus can results to decrease of the solid solution doping as well as the stability of the austenite. Thus processes of the structure formation (including recrystallization) change and corrosion resistance and other special properties deteriorate. In particular, of long-term strength can decrease due to formation of such nitrides and carbonitrides as Cr₂₃(CN)₆, Cr₂(CN). In this case, to save the properties is necessary to change the alloying of steel: to reduce the nitrogen content or to add other alloying elements.

Thermomechanical treatment is effective for nitrogen steels under proper treatment schedule. Under high-temperature thermomechanical treatment the heating temperatures can be higher than for nitrogen-free steels [7, 8].

Alloying with nitrogen improves resistance to local and intercrystalline corrosion [4–6]. However, since corrosion resistance

depends heavily on steel structure the specific temperatures of nitride discharge and solution should be taken into account.

The present work is devoted to experimental study of nitrogen alloying impact on hardening and corrosion resistance of austenitic Cr-Ni steel of different purity provided that nitrogen exists in solid solution form.

2. Material and Experiment

For this study the material was steel type Cr18Ni10N with nitrogen content of 0.186 % and 0.220 % and steel type Cr18Ni10Ti was used for comparison; chemical content of both steels see in Table 1.

The steels were produced and preliminary treated as follows. Hot-rolled industrially melted steel Cr18Ni10Ti.

Nitrogen-alloyed steels were melted in laboratory using burden material with different content of residual elements. Steel 2 (Cr18Ni10N, N=0.186 %) was produced in induction furnace by remelting nitrogen-free steel with similar chemical composition with addition of pure burden materials up to required composition.

Steel 3 (Cr18Ni10N, N=0.220 %) was melted in induction vacuum furnace, following pure materials were used as burden: ingot iron grade, electrolytic nickel, electrolytic manganese, pure chrome, nitrogenized ferrochrome, granulous aluminum.

The ingots were hot-forged and hot-rolled. Final treatment of all steels – hardening (solution heat treatment) from austenite region from 1050 °C in water.

Mechanical properties of all steels were defined with pulling test on coupons according to GOST 1497-84.

Thermal conductivity is defined by a special apparatus in the temperature range of 20–100 °C using a differential non-contact thermocouple by constructing a temperature-time dependency as follows. One end of the coupon is dipped into boiling water with temperature T₂ (i.e. T₂=const=100 °C), while the rod itself is inserted in plastic foam to prevent heat exchange between side surface and environment. On the other end the temperature is measured with thermocouple within equal time periods t until it becomes constant. At the initial time the rod has temperature T₀, then the temperature grows and reaches T₂ asymptotically (under t=∞).

Table 1. Chemical composition of investigated steels

No.	Steel	Chemical composition, wt. %*								
		C	Cr	Ni	Mn	Mo	S	P	Al	N
1	Cr18Ni10Ti	0.10	17.7	9.5	1.19	0.10	0.007	0.027	0.11	<0.01
2	Cr18Ni10N (N=0.186 %)	0.05	18.1	9.6	0.82	<0.10	0.018	0.025	0.12	0.186
3	Cr18Ni10N (i.f., N=0.220 %) **	0.007	19.1	9.3	1.42	0.012	0.004	0.002	0.035	0.220

* – base is Fe; ** – i.f. – impurity free

Temperature conductivity coefficient is defined by the following formula:

$$(1) \quad \alpha = \frac{2 \cdot L^2}{5 \cdot t_3} \ln \left(\frac{T_2 - T_0}{T_2 - T_3} \right),$$

where T_3 – temperature measured on the other end of the rod at the time t_3 ;

L – length of the rod.

Thermal-expansion coefficients and crystalline transformation effects are defined with dilatometer DIL805 under following test schedule: heating from room temperature to the temperature of 1200 °C under 5 °C/sec, holding for 1 min. and further cooling under 50 °C/sec to 50 °C.

Resistance to general, intercrystalline and pitting corrosion in different environments is evaluated. Tests are done using electrochemical station Zive MP2.

Tendency to general corrosion is defined in sea water (3% NaCl) and in acid environment (0.5M H₂SO₄), including purging with H₂S, by determination of potentials and critical current density of passivation. The test consisted of evaluation of open circuit potential (E_{ocp}) during 3 hours; establishment of polarization curve from negative potential values (cathode region) to repassivation region (in acid environment) or to the potential of stable pitting formation (in sea water).

Potential equal to maximum current density in active dissolution region is taken as critical potential of passivation (E_{cp}); potential of full passivity (E_{fp}) – is the potential behind which development current density is reduced by no more than 1 µA/cm² (for 0.5M H₂SO₄) or the potential upon which the current density is equal to 3 % from critical current density (for 0.5M H₂SO₄ + H₂S); at that the critical current density of passivation (i_{cp}) is determined as current density at critical potential of passivation, and current density in a passive state (i_p) – as minimum density of current in passive region. The potential which didn't result in current density decrease under increase of potential is taken as the potential of repassivation; for tested steels the threshold value of current density is 5 µA/cm² (for 5M H₂SO₄) or 1 mA/cm² (for 0.5M H₂SO₄ + H₂S).

Resistance to intercrystalline corrosion is defined using method of potentiodynamic development in solution of 0.5M H₂SO₄ + 0.01M KSCN according to GOST 9.914-91. The tests were dedicated to plot the potentiodynamic curve of forward (from cathode region into anode region) and backward sweep of potential (from anode region to cathode region) for all coupons. Relation of calculated total charge of potentiodynamic curve of backward sweep of potential (Q_c) to forward one (Q_a) characterizes the resistance of the coupon to intercrystalline corrosion: if it is lower than 0.11, the coupon is recognized as resistant to intercrystalline corrosion.

The resistance to pitting corrosion is evaluated according to GOST 9.912-89 by the average conditional speed of pitting corrosion. The tests included 24-hours holding of pre-weighted coupons in solution of ferric chloride (III) and following weighting. The speed of pitting corrosion V_m is determined by the weight loss using a formula:

$$(2) \quad V_m = \frac{\Delta m}{S \cdot t},$$

where Δm – total weight loss for parallel (tested at the same time) coupons, grams,

S – total area of parallel coupons, m²,

t – duration of the test, hours.

3. Results and Discussion

Steel hardness index grows with increase of nitrogen content in steels 2 – 3 Cr18Ni10N (Table 2). During the elongation all steels show high ductility (see Table 2) while pure steel 3 has the highest ductility index: El = 63% and RA = 84%.

Thermal conductivity of steel Cr18Ni10N within 25–100 °C is appropriate for austenitic high-resistance steels: for steel 3 temperature conductivity coefficient $\alpha = 3.8$ mm²/sec.

Table 2. Mechanical properties of the investigated steels

No.	Steel	UTS, MPa	YS, MPa	El, %	RA, %
1	Cr18Ni10Ti	515	230	47	51
2	Cr18Ni10N (N=0.186 %)	715	355	25	67
3	Cr18Ni10N (i.f., N=0.220 %)	750	400	63	84

Analyzed dilatograms of nitric steel heating showed that under the heating at ~5 °/sec within 50–1200 °C excessive nitrides may be discharged and dissolved. The discharge can happen under 400–700 °C, dissolution – above 1000 °C. This process should be controlled as together with improvement of hardness it can reduce the toughness and corrosion resistance.

Coefficient of thermal expansion for different temperature ranges corresponds to regular values by the order and, for example, for steel Cr18Ni10N within 50–300 °C (without excessive phase discharge) equals to 20.46·10⁻⁶ K⁻¹. Average linear coefficients for ranges of 50–800 °C and 50–1200 °C equal to 25.28·10⁻⁶ K⁻¹ and 31.72·10⁻⁶ K⁻¹ respectively. This difference results from phase content change and can be used for express-control of transformation processes. Also this difference should be considered during the size change evaluation. The products made from nitric steel should not be heated above 300 °C after the hardening to preserve the nitrogen in solid solution, as mentioned before [9].

Polarization curves of tested steels in acid environment are characterized with soft transition from cathode region into anode region, peak of active dissolution is clear and located in the range of -150–113 mV for steel 2 (see polarization curve of steel 2 Cr18Ni10N in the Fig.1) and in the range of -147–271 mV for steel 3. The width of passive region is 1145 mV for steel 2, and 996 mV for steel 3. It is estimated that repassivation starts immediately from or soon after the initiation of oxygen discharge. After the test the surface of coupons is highly etched and rough, borders of working area are clear (see Fig. 2).

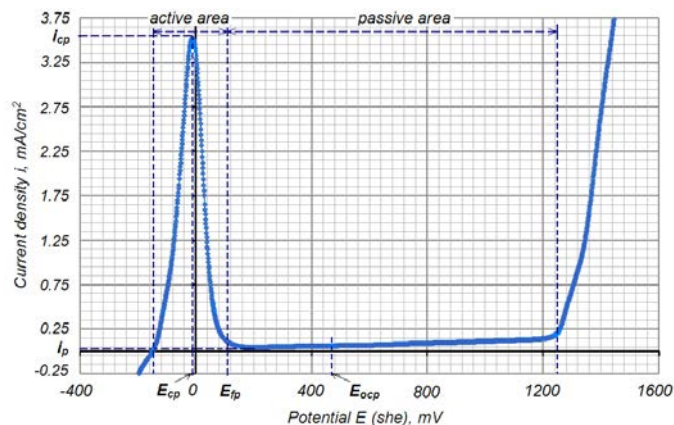


Fig. 1. Polarization curve for steel 2 Cr18Ni10N (N=0.186 %), environment 0.5M H₂SO₄, development speed – 1 mV/sec:

E_{cp} – critical potential of passivation; E_{fp} – potential of full passivity; E_{ocp} – open circuit potential; i_p – current density in a passive state; i_{cp} – critical current density of passivation; she – standard hydrogen electrode

During the test in 0.5M H₂SO₄ and purging with H₂S polarization curves of tested steels also have smooth transition from cathode to anode region; the peak of active dissolution is located in the range of -147–510 mV for steel 2 and -182–623 mV for steel 3. The passivation is sharp and abrupt, the width of passive region is 701 mV and 688 mV for steels 2 and 3 respectively. Probably the repassivation starts immediately or soon after the oxygen discharge.

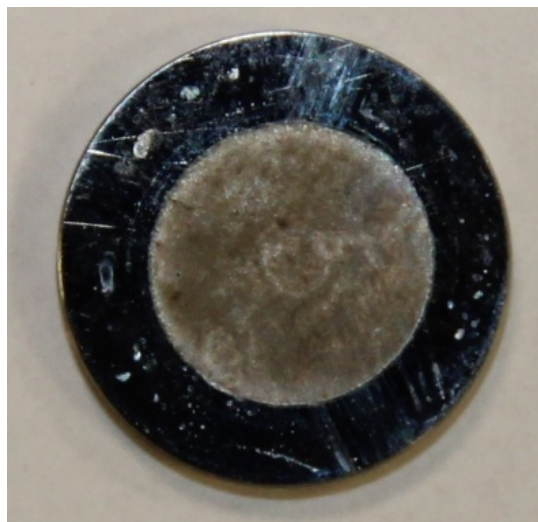


Fig. 2. Appearance of coupon made from steel 2 Cr18Ni10N (N=0.186 %) after testing in environment 0.5M H₂SO₄ (coupon outer diameter is 19 mm, working area diameter is 11 mm, coupon thickness is 2.4 mm)

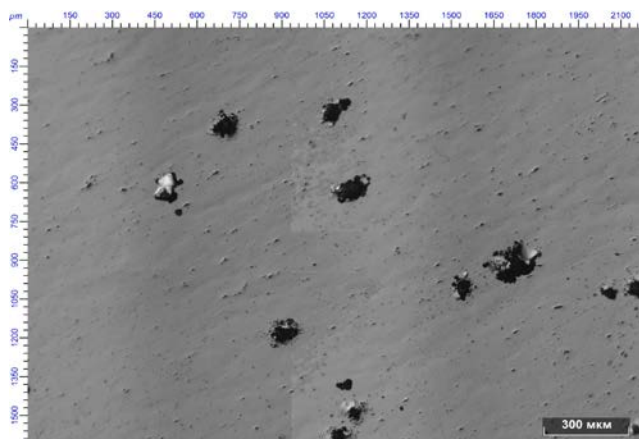


Fig. 3. Appearance of pittings formed on the coupon surface under testing in 3% NaCl



Fig. 4. Appearance of coupon made from steel 2 Cr18Ni10N (N=0.186 %) after testing in environment 3% NaCl

Within the active dissolution region black film appears on all surfaces (probably due to the porosity). This film has no protecting properties and peels after critical potential of passivation E_{cp} is reached. Based on the work [9] it is estimated the approximate composition of such film is nickel sulphide Ni₂S. The surface is evenly etched, the depth of etching is small but the surface is evenly rough: there are clear black points on the surface of coupons made from steel 2. It is presumed that such points are resulted from selective dissolution of alloy components.

Appropriate electrochemical data on testing steel resistance to general corrosion in acid environment (including purging with hydrogen sulfide) see in Table 3.

Table 3. Electrochemical data gathered upon corrosion resistance testing of steel in the acid environment

No.	Steel	E_{ocp} , mV	E_{cp} , mV	E_{fp} , mV	i_{cp} , mA/cm ²	i_p , μA/cm ²
acid environment (0,5M H ₂ SO ₄)						
2	Cr18Ni10N (N=0.186 %)	473	-11	113	3,55	52,4
3	Cr18Ni10N (i.f., N=0.220 %)	-135	0	271	11,0	8,35
acidic (0,5M H ₂ SO ₄) compressed hydrogen sulphide H ₂ S						
2	Cr18Ni10N (N=0.186 %)	-132	463	510	135	871
3	Cr18Ni10N (i.f., N=0.220 %)	-189	607	623	176	81,9

Purging of solution with hydrogen sulfide equally activates both steels: current density grows in regions of active dissolution and passivation, potential of passivation shifts to positive end and passivation region is narrowed. Probably, all steels show some change of passive state due to generation of sulfide components together with their oxides: during the testing the black film was formed in the active region. Such film had no protective properties and disappeared before the passivation begins. This behavior is typical for nickel in sulfuric environments.

According to the results, if external potential is absent steel 2 Cr18Ni10N stays passive in acid environment; steel 2 has higher corrosion resistance parameters in acid environment. During test in 0.5M H₂SO₄ and purging with H₂S both steels remain in active state, i.e. they have low corrosion resistance in this environment.

During the general corrosion resistance test in 3% NaCl (sea water) the polarization curves of all coupons do not have the regions of active dissolution, i.e. they remain passive during the whole test period. At that the open circuit potential has higher negative value than potential of pitting formation. Due to this, open circuit potential and potential of pitting formation (E_{pf}) (the potential corresponding to current density of 1 mA/cm² is taken as the potential of pitting formation) are calculated. In this environment all coupons demonstrated formation of clear pitting and insignificant general corrosion: the work area of all coupons remains glassy and pittings are equal by kind on all coupons, see Fig. 3. Pittings on tested coupons are clear and evenly distributed on the coupon surface, however steel 2 demonstrates larger pittings (see Fig. 4). All steels are exposed to gap corrosion in sea water: there are tracks of gap corrosion (appeared as big etches in the form of circles or circular sectors) along the boundaries of working area (at points of contact between waterproof gasket and metal surface).

The electrochemical data collected during testing in 3% NaCl see in Table 4.

Table 4. Electrochemical data gathered upon corrosion resistance testing of steel in the sea water

No.	Steel	E_{ocp} , mV	E_{pf} , mV
2	Cr18Ni10N (N=0.186 %)	-9	664
3	Cr18Ni10N (i.f., N=0.220 %)	32	785

According to the results, steel 3 Cr18Ni10N is more resistant to corrosion in chlorine-containing environments – potential of pitting formation for this steel is 120 mV upward than for steel 2 in average.

Results of intercrystalline resistance evaluation (see Table 5) demonstrated that tested steels are resistant to corrosion of this type as the ratio between backward sweep curve charge and forward sweep curve charge Q_c/Q_a for all steel is less than 0.11. During the test the coupons showed minimal etching and retained glassy surface.

Table 5. Results of intercrystalline corrosion resistance test

No.	Steel	Q_c/Q_a	Resistance to intercrystalline
2	Cr18Ni10N (N=0.186 %)	0,0002	resistant
3	Cr18Ni10N (i.f., N=0.220 %)	$6 \cdot 10^{-7}$	resistant

The tested steels showed similar resistance to pitting corrosion evaluated by the average conditional speed of pitting corrosion (see Table 6).

Table 6. Results of pitting corrosion resistance test

No.	Steel	$S, 10^{-4} \text{ m}^2$	$\Delta m, \text{ grams}$	$V_m, \text{ grams} \cdot \text{m}^{-2} \cdot \text{hours}^{-1}$
1	Cr18Ni10Ti	2,99	0,1586	11,06
2	Cr18Ni10N (N=0.186 %)	4,27	0,1661	16,22
3	Cr18Ni10N (i.f., N=0.220 %)	3,14	0,0997	6,61

At that, resistance of pure steel 3 Cr18Ni10N to intercrystalline and pitting corrosion is higher than of commercial steel 2. Nitrogen steel (2 Cr18Ni10N) and nitrogen-free steel (1 Cr18Ni10Ti) of regular commercial melting had similar pitting corrosion resistance value, but lower than pure steel (3).

So, the tested nitric steels showed rather close values of resistance to different types of corrosion, however by the value of critical current and passivation potential, ratio between back curve charge and forward curve charge during evaluation of resistance to intercrystalline corrosion and by the average conditional speed of pitting corrosion they can be categorized as follows (see Table 7). Pure nitric steel showed high resistance to intercrystalline, general and pitting corrosion in chloride solutions than normal purity steel.

Table 7. Resistance of tested steels to different types of corrosion

No.	Steel	General corrosion			Intercrystalline corrosion	Pitting corrosion
		acid environment (0,5M H ₂ SO ₄)	acidic (0,5M H ₂ SO ₄) compressed hydrogen sulphide H ₂ S	sea water (3% NaCl)	0,5M H ₂ SO ₄ + 0,01M KSCN	100 g/l FeCl ₃ ·6H ₂ O
		categorizing by				
		combination of parameters	combination of parameters	$E_{pf}-E_{ocp}$	Q_c/Q_a	V_m
2	Cr18Ni10N (N=0.186 %)	1	nonresistant	2	2	2
3	Cr18Ni10N (i.f., N=0.220 %)	2	nonresistant	1	1	1

4. Conclusion

Alloying of austenitic Cr-Ni steel type Cr18Ni10N with nitrogen up to 0.220% is prospecting for improvement of hardness and corrosion resistance in mildly aggressive chloride environments (like sea water) provided that there is no additional discharge of nitrides. Corrosion resistance can be additionally improved by improving the purity of steels.

5. References

1. Bannykh, O., Progress in the Research and Application of Nitrogen-Alloyed Steels. – In: Proceed. 10th Int. Conf. on High Nitrogen Steels, Moscow, MISiS, 2009, pp. 24–27.
2. Berns, H., S. Riedner, V. Gavriljuk, High Interstitial Stainless Austenitic Steels, Part I: Constitution, Heat Treatment, Properties, Applications. – In: Proceed. 10th Int. Conf. on High Nitrogen Steels, Moscow, MISiS, 2009, pp. 129–139.
3. Svyazhin, A.G., J. Siwka, L.M. Kaputkina, High-nitrogen steels – The current state and development trends. – In: Proceed. Int. Conf. Advanced Steels, China, Beijing, Metallurgical Industry Press, 2010, pp. 352–356.
4. Mushnikova, S.Yu., Yu.L. Legostaev, A.A. Harkov, and other. An investigation on the influence of nitrogen on austenitic steel pitting resistance. – Issues of material science, 2 (38), 2004, pp. 126–135. (in Russian)
5. Baba, H., T. Kodama, Y. Katada. Role of nitrogen the corrosion behavior of austenitic stainless steels. – Corrosion Science, 44, 2002, pp. 2393–2407.
6. Mudali, UK, S. Ningshen, B. Raj, Passive Films and Localised Corrosion – Role of Nitrogen. – In: Proceed. 10th Int. Conf. on High Nitrogen Steels, Moscow, MISiS, 2009, pp. 271–280.
7. Rakhshadt, A.G., L.M. Kaputkina, S.D. Prokoshkin, and other (Edtrs). Metal science and heat treatment of steel and cast iron, v. 3. Moscow, Internet Engineering, 2007, 920 p. (in Russian)
8. Schastlivtsev, V.M., V.I. Zeldovich, D.A. Mirzayev, and other. Development ideas of academician V.D. Sadovsky. Ekaterinburg, Inst. Metal Physics Ural Division RAS, 2008, 409 p. (in Russian)
9. Andreev, Y.Y., T.V. Bobkov, A.V. Dub, and other. Thermodynamics of chemisorption of sulfur from thiocyanate on nickel during electrochemical passivation. – Protection of Metals and Physical Chemistry of Surfaces, 4 (49), 2013, pp. 444–450.

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POLYMERIC COMPOSITES OF CONSTRUCTIONAL APPLICATION BASED ON THERMOSETTING MATRIX AND CHEMICAL FIBERS

ПОЛИМЕРНЫЕ КОМПОЗИЦИОННЫЕ МАТЕРИАЛЫ КОНСТРУКЦИОННОГО НАЗНАЧЕНИЯ НА ОСНОВЕ ТЕРМОРЕАКТИВНОЙ МАТРИЦЫ И ХИМИЧЕСКИХ ВОЛОКОН

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Abstract. The polymeric composites on the basis of a thermosetting matrix, chaotically reinforced chemical fibers with a broad band and high level of operating performances have been developed. The optimum geometrical parameters of a fibrous filler, degree of filling of a matrix at a different dispersibility of a filler ensuring high technological effectiveness and degree of strengthening have been defined. The thermodynamic conditions of obtaining strong adhesive connection of a matrix with a filler have been explored during receiving polymeric composites.

KEY WORDS: POLYMERS, AROMATIC POLYAMIDES, ORGANIC PLASTICS, THERMOSETTING , PRESSCOMPOSITION, ANALYSIS.

1. INTRODUCTION

One of the most perspective types of polymeric composites (PC), firmly considered as constructional materials, are PC, reinforced by chemical fibers [1-3]. A central problem originating at making such materials and articles from them, is the maximal embodying properties of initial components in multicomponent system. Strength properties PC, reinforced by fibers, the technological effectiveness of their processing depends on components relationship, strength and elasticity of a fiber (i.e. on its chemical nature and structure), strength, processing behavior of polymeric bond, interphase interaction including different processes, occurring on an interface, the structure and properties of boundary layers depends on. Also technological parameters exerting influence on properties of each of components, on processes occurring on a interface of phases, on magnitude of stresses originating in a polymeric matrix, on presence of defects of a boundary layer and all film bond [4, 5] are not less important.

The purpose of work was making PC of constructional assignment with a complex of high operating performances, study of regularities of forming of plastics properties on the basis of a thermosetting matrix (epoxy, phenolformaldehyde and their modifications).

2. THE DISCUSSION OF INVESTIGATION RESULTS

Thickness of a bond film in PC, therefore and its properties depend on the content of a filler, and its sizes [6, 7]. The share (mass, volumetric) of filler must be maximal for receiving a high-strength composite, but at the same time share of bond must be sufficient to moisten and imbue fibers, ensure continuity of a polymeric matrix, technological solidity of a material as a whole. With the purpose of definition of an optimum composition of a composite the content of a fibrous filler varied from 0 up to 80 mass % at different lengths of a fiber (from 3 up to 30 mm). The investigations have shown, that the dependence of physico-mechanical properties of organoplastics on the content of a fiber has extreme

When investigating geometrical parameters influence of a filler on properties of plastics length of a fiber varied ranging from 1 up to 100 mm, diameter - from 10 up to 28 micrometers, fibrillation of a complex filament - from 1 up to 400, twist of a complex filament - from 0 up to 200 twisting / m. The analysis of strength characteristics of plastics has shown, that their stability to shock, bending loads at lengths of fibers less than 2-4 mm does not exceed values, typical for unfilled polymers. With elongation of a fiber up to 20-25 mm the sharp growth of the indicated performances and thermostabilities of plastics is observed. The highest indexes of strength at compression were registered for plastics with length of fibers less than 10 mm ($\sigma_{cr} = 190-200$ MPa). These plastics differ by the greater

homogeneity, heightened resistance to shear stress. With growth of length of fibers up to 20-25 mm σ_{cr} is noticeably reduced.

The table

Influence of filling degree on anisotropy of chaotically reinforced organoplastics properties

Length of a fiber, mm	Coefficient of anisotropy at degree of filling, mass % $K_a = \sigma_{c } / \sigma_{c\perp}$					
	0	5	20	40	60	80
3	1	1/1	1,01/1	1,13/1,08	1,2/1,37	1,22/1,44
10	1	1/1,01	1,04/1,05	1,12/1,11	1,17/1,27	1,18/1,32
30	1	1,03/1,08	1,07/1,13	1,1/1,2	1,11/1,24	1,12/1,25

The notice: In numerator data for organoplastics on the basis of aramide fibers phenylon, in denominator - terlon.

The increasing of fibers length more than 40 mm practically does not influence strength properties of plastics. It is necessary to mark, that at the length of reinforcing fibers more than 70 mm separating of a composite at destruction at the expense of shearing stresses is observed.

The technological properties of prepreps with growth of fibers length is aggravated. The rheological investigations have shown, that the viscosity of fiber reinforced plastics with heightening of a degree anisodiametricity (1/d) of a filler grows, thus the fluidity of a press-material drops, that is connected with increasing the overlapping fibers area (fig. 3). character with a maximum in the field of 55-70 mass % of a fiber (fig. 1). The magnitude of an optimum amount of a filler is determined also by its length: with increasing length of a fiber the maximum of strength characteristics is shifted in the field of higher concentrations.

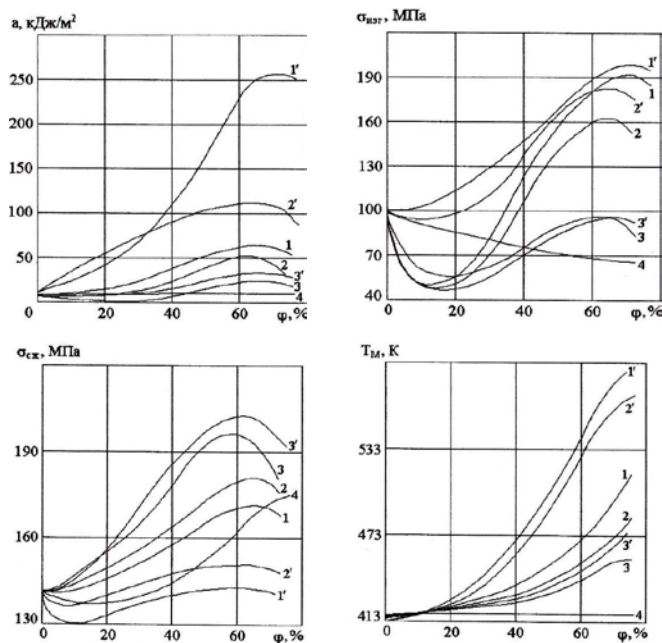
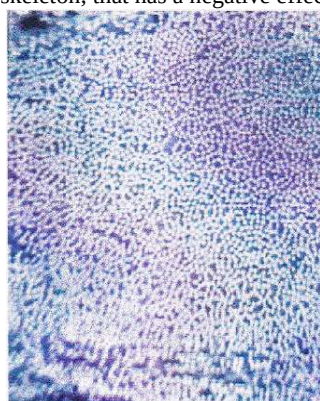


Fig. 1. Dependence of impact strength (a); breaking stress under bending (σ_0); compression (σ_c) and thermostability on the Martens (T_M) of epoxyorganoplastics on the basis of phenylon (1-4) and terlon (1-3) on degree of filling (ϕ) at length of a fiber: 1, 1'—30 mm; 2, 2'—10 mm; 3, 3'—3 mm; 4 — finely dispersed powder

The presence of porous carbon fibers leads to some growth of water absorption. However, the surface of fibers is screened by a film of polymeric bond and the velocity of magnification increasing water absorption with increasing of density of carbon filaments in an composite is rather small. Further increasing fibers in an composite more than 70 % leads to deficiency of bond for formation of a continuous flawless film of a polymer on a fiber, aggravation of fluidity of a press-material, violation of specimen solidity, to what the sharp growth of water absorption of carbon plastics, lowering of strength characteristics, both carbon, and organoplastics testifies, in particular.

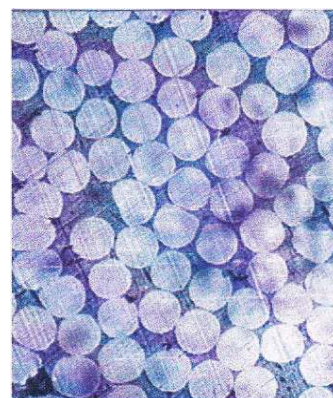
At increasing the content polymeric bond in a composite more than 50 mass % lowering strength of a material is observed at the expense of diminution of an amount of reinforcing fibers, basically carrying the load. An interlayer of a polymeric matrix between fibers is becoming thick, that leads to growth of shrinkage stresses and amount of microfissure, the homogeneity of a material is broken, the presence of defects is boosted, the strength of a plastic is reduced. At the content of fibers lower than 20-40% there is no reinforcing skeleton, that has a negative effect on strengthening (fig. 2).



a



b



c

Fig. 2. Microphotographs of plastic microsections at degree of filling 20 (a) and 70 mass % (b,c). Magnification: $\times 40$ (a,b); $\times 400$ (c)

The analysis of strength characteristics, diagram of compression, thermomechanical of curves has shown, that the higher module of elasticity and length of a fiber, the lower concentrations provide reinforcing effect.

The introduction of a finely dispersed filler (powder phenylon) practically does not influence strength characteristics of a composite. The exception makes resistance of a plastic to compression loads: at the content of filler more than 30 % the ultimate compressive strength of a material increases with growth of finely dispersed phenylon concentration noticeably.

The anisotropy of strength properties of plastics with increasing filling degree grows the more appreciably, the less the length and higher the module of a fiber (table). In the field of the low content of a filler, owing to high fluidity of a material, fractional orientation of fibers in a matrix at a compression molding of specimens, the plastics with reinforcing filler of greater length are more anisotropic.

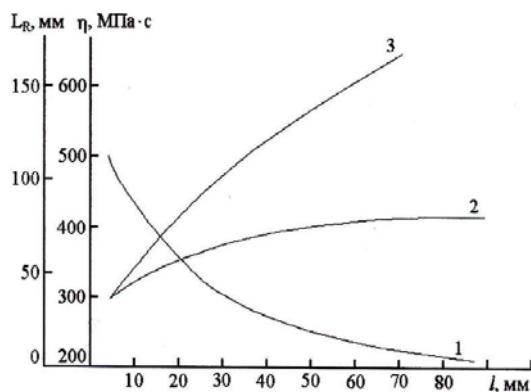
Coefficient of plastics anisotropy filled with powder phenylon, within investigated concentrations of a filler remained equal to zero.

Therefore, with the purpose of receiving high-fined (60-70 mass %) composites on the basis of thermosetting plastics with the chaotic scheme of a reinforcing, with a high level of strength characteristics, isotropy at remaining technological effectiveness of prepregs processing length of a fibrous filler of 10-25 mm, should be considered optimum.

Fig. 3. Dependence of technology characteristics of organoplastics: 1 - fluidity on Raschig (LR); 2, 3 - viscosities, from length of a reinforcing component: 2 - fiber; 3 - complex filament

At diminution of a fiber diameter its strength increases a little (for example, aramide fiber phenylon with $d = 10$ micrometers 43,3 sm/tex), its surface properties are improved [8], the degree of anisodiametricity of a reinforcing component is augmented, owing to that the thickness of a bond film between fibers is diminished, that boosts effect of reinforcing and leads to increasing of an impact strength, strength at compression. The breaking stress under bending is augmented with increasing diameter of a fiber owing to increasing of resistance to bending loads of fibers themselves.

It is stated, that at transition from a reinforcing by the elementary fiber to a reinforcing by a complex filament sharp heightening of an impact strength, strength under bending (on 50-55 %), thermostability of a plastic is observed. The increasing of the amount of elementary filaments (fibration) in a complex filament up to 300 at rather high magnitude of twist (98-115 twisting / m) leads to growth of values of these performances. At further increasing of fibration, as well as at increasing of twist more than 120125 twisting / m (at a stationary value of fibration), causing also some lowering of strength of the filament, the penetration of bond inside a filament is made difficult, the number of contacts of elementary fibers is augmented, the quality of impregnation is aggravated, the continuity of a bond film is broken and, eventually, the strength of a plastic is reduced. Compressing strength of plastics, reinforced by elementary fibers at the expense of greater homogeneity of a material, its solidity is highest (210-220 MPa). At increasing fibration of a complex filament $\sigma_{сc}$ is reduced.



Plastometric tests have shown, that at increasing the geometrical sizes of a filler the viscosity of a press-material is increased. So, press-material on the basis of finely dispersed powder phenylon (the grade C-I) has viscosity 176 MPa·s, on the basis of a staple fiber ($l = 10$ mm) - from 266 up to 352 MPa (changing of diameter of a fiber from 10 up to 28 micrometers), on the basis of a discrete complexfilament of the same length - from 448 up to 506 MPa (at increasing fibratioin of a filament from 50 up to 300). At the same time, the transition from a reinforcing by a powder, elementary fiber to a reinforcing by a complex filament causes increasing of plastic-viscous (yielding) state of a presscomposition from 7-8,5 minutes up to 12-12,5 minutes, that creates sufficient conditions for bond spreading on the surface of a fibrous filler, ensures technological solidity, homogeneity of specimens, both at reinforcing by a fiber, and complex filament.

The possibility of using waste of aramide fibers obtained at different stages of technological process as a fibrous filler has been investigated. It is stated, that use of thermopulled waste of a complex filament and staple fiber phenylon as a reinforcing component has allowed to receive composites, which, due to a complex of properties (the ultimate compressive strengths are equal to 170-230 MPa, bending - 130200 MPa, an impact strength - 40-60 kJ/m², thermostability on the Martens 423-473 K, friction coefficient at the presence of water - 0,13-0,18), wear-, water-, chemical-stability have found application as constructional bearing materials.

3. REFERENCES

- [1] Ениколопян Н.С.: Полимерные композиционные материалы. Состояние и перспективы, Ж. хим. о-ва им. Д.И. Менделеева, № 5, Т. 34, 1989, С. 435-437
- [2] Levis Clifford F.: Bigger and Better Industrial Composites, Mater. Eng., N 3, Vol. 107, 1990, P. 2731
- [3] Большепянова Е.К., Быстрова В.А.: Производство и потребление композиционных волокнистых материалов в промышленности пластических масс за рубежом, Пласт, массы, № 1, 1988, С. 57-58
- [4] Липатов Ю.С.: Межфазные явления в полимерах, Наукова думка, Киев, 1980
- [5] Плюдеман З.Э.: Поверхности раздела в полимерных композитах, Мир, Москва, 1978
- [6] Розенберг Б.А.: Масштабный эффект механических свойств полимерной пленки, Высокомолек. соедин., Б, № 12, Т. 27, 1985, С. 914-919
- [7] Павлов В.И.: Влияние толщины прослойки полимерной матрицы на релаксационное поведение наполненных эпоксидных композиций, Композиц. полимер, материалы, № 37, 1988, С. 14-17
- [8] Краснов Е.П., Лавров Б.З. Исследование ориентации и структурного образования волокна из поли-м-фениленизофталамида, Хим. волокно, № 1, 1971, С. 23-26

DEVELOPMENT OF ECONOMICALLY ALLOYED SACRIFICIAL ALLOYS FOR PROTECTION OF METAL CONSTRUCTIONS AGAINST ELECTROCHEMICAL CORROSION

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Characteristic of standard sacrificial alloys on the base of aluminum, magnesium and zinc is extremely low contents in them the cathode impurity elements. The raised content of impurities results in the chemical and structural non-uniformity of alloys causing of electrochemical heterogeneity in system metal-electrolyte that destabilizes and reduces operational properties of cast protectors.

To stabilize the electrochemical properties of sacrificial alloys with high content of cathode impurities and possibility of use in the preparation of alloys from metals of technical grades and waste products was designed principles of alloying that help to reduce and neutralize impurity elements.

In this message results of researches on influence of the selected alloying elements on the main electrochemical properties of sacrificial alloys with the raised content of iron, copper and lead are provided.

Most undesired impurity of these cathode impurity elements is iron. During the preparation of alloys and casting of protectors risk of contamination is high enough, as the source of their falling

into the melt in addition to the charge materials is melting-casting tool, and in the case of use of return materials – steel fixings details of protectors. Contamination of molten zinc with lead and copper at smelting process do not occur, and contents of these elements in the alloy are determined by their content in the original charge materials. Therefore, when evaluating the possibility of applying for the manufacture of zinc protectors technical grade materials should focus on studying of the behavior of iron in zinc and zinc sacrificial alloys.

Investigation of the effect of iron content on the electrochemical properties of of zinc and alloy TsP1 (system Zn-Al) in seawater performed using known methods [1,2] (fig. 1). These results allows to suggest that increasing the iron content in the zinc from 0.001 to 0.05% leads to decrease in the coefficient of use efficiency (CUE) from 93 to 38.2% and to shift of the working capacity in the positive direction from -730 to -305 mV. On the base of results of processing of the experimental data was obtained by the regression equation describing the dependence of the basic electrochemical properties of zinc from iron content:

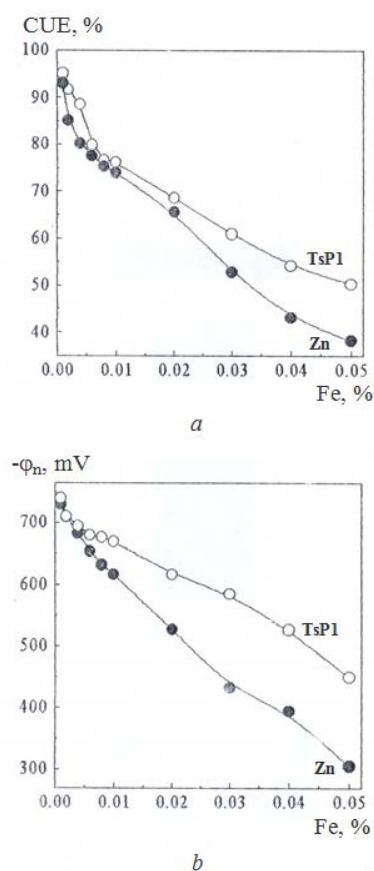


Fig. 1. CUE (a) and work potential (b) of zinc and zinc alloy TsP1 with different content of iron

$$CUE = 93,41 - 3649,87Fe + 208880,55Fe^2 - 6103174,6Fe^3 + 58919914Fe^4;$$

$$\varphi_n = -740,1 + 15511,54Fe - 276757,69Fe^2 + 2791165,8Fe^3;$$

Studies of the effect of iron on the electrochemical properties of the standard zinc sacrificial alloy TsPl (system Zn-Al) show that increasing the iron content from 0.001 to 0.05% with a fixed content of copper and lead (not more than 0.001% and 0.005, respectively) leads to a large reduction and spread of values of CUE from 95 to 50% and work potential from -740 to -450 mV. The dependence of these properties from the iron content of the alloy within specified limits described by the following regression equations:

$$CUE = 98,67 - 3743,06Fe + 176714,85Fe^2 - 4240142,2Fe^3 + 36352656Fe^4;$$

$$\varphi_n = -740,3 + 11391,91Fe - 421137,85Fe^2 + 9558385,5Fe^3 - 67350184Fe^4.$$

At solving of problem of improving and stabilizing of electrochemical properties of zinc containing iron above the limits permissible by standards are possible two ways. The first is pre-refining of zinc from iron by introducing of elements non-dissolving in zinc prone to extraction [3], while the second provides an introduction to the zinc elements-additives which are alloying components, i.e. creation of new compositions of zinc sacrificial alloys. These elements must meet the following requirements:

- forming a solid solutions with zinc, and (or) intermetallic compounds whose potential is close to that of zinc, or don't interact with it;
- to form solid solutions with iron and (or) intermetallic compounds, reducing or completely neutralizing its harmful effects;
- to stabilize and improve the electrochemical properties of zinc;

- exclude passivation of zinc.

For zinc with high iron content using the principles of synthesis of alloys and taking into account the physico-, metal-, electrochemical and technological properties of the elements, the nature of their interaction with zinc and iron, and technical-economic indicators [4] was identified a number of alloying elements - aluminum, manganese, silicon and cadmium. Aluminum is the major alloying element in the sacrificial zinc alloys, which increases and stabilizes the electrochemical properties of zinc; manganese and silicon forming with iron area of limited solid solutions and intermetallic compounds, binding and neutralizing its and simultaneously increasing of electrochemical properties of zinc; cadmium promotes destruction of the passivating film formed on the zinc surface in seawater.

To assess the influence of selected alloying elements on the properties of zinc have been studied basic electrochemical (CUE and φ_n) properties of the alloys of the Zn-Al, Zn-Mn, Zn-Si and Zn-Cd with different contents of the alloying elements and impurity of iron. The concentration of adding in zinc alloying elements (aluminum, manganese, and cadmium) corresponds to the area of solid solutions in the system "zinc - alloying element", concentration of silicon corresponds to its content in known sacrificial zinc alloys of high purity and concentration of iron impurities corresponds to its content in zinc of grades from TsV00 to Ts2 and in return materials. According to the results of researches was found that additions of selected alloying elements can increase and stabilize CUE of zinc with a high content of iron impurity, and the greatest positive influence have cadmium, manganese and silicon (fig. 2).

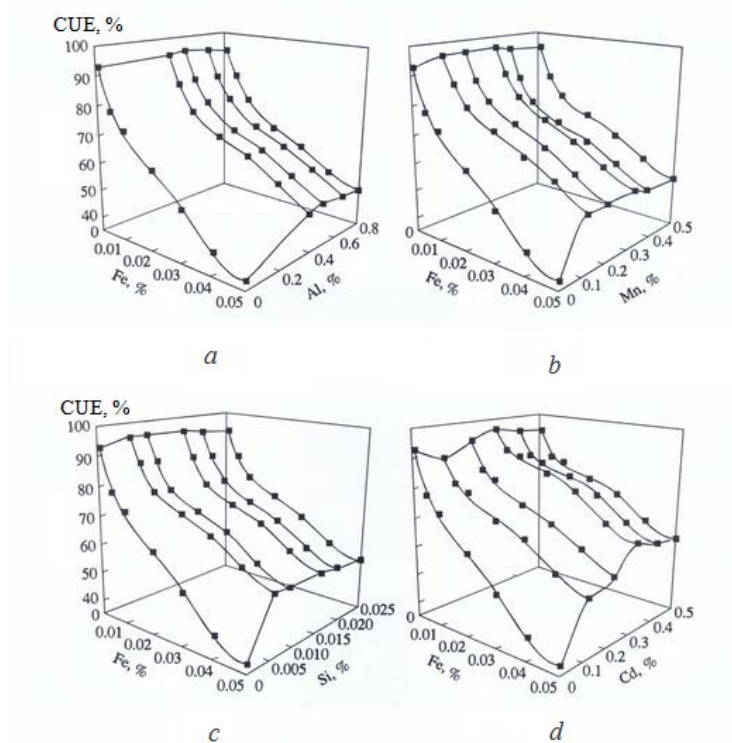


Fig. 2. CUE of alloys of systems Zn-Al (a), Zn-Mn (b), Zn-Si (c), Zn-Cd (d) with different content of iron

Introduction of aluminum, manganese and silicon to zinc with a high content of iron impurities can significantly increase and

stabilize its electronegative potential at polarization (Fig. 3).

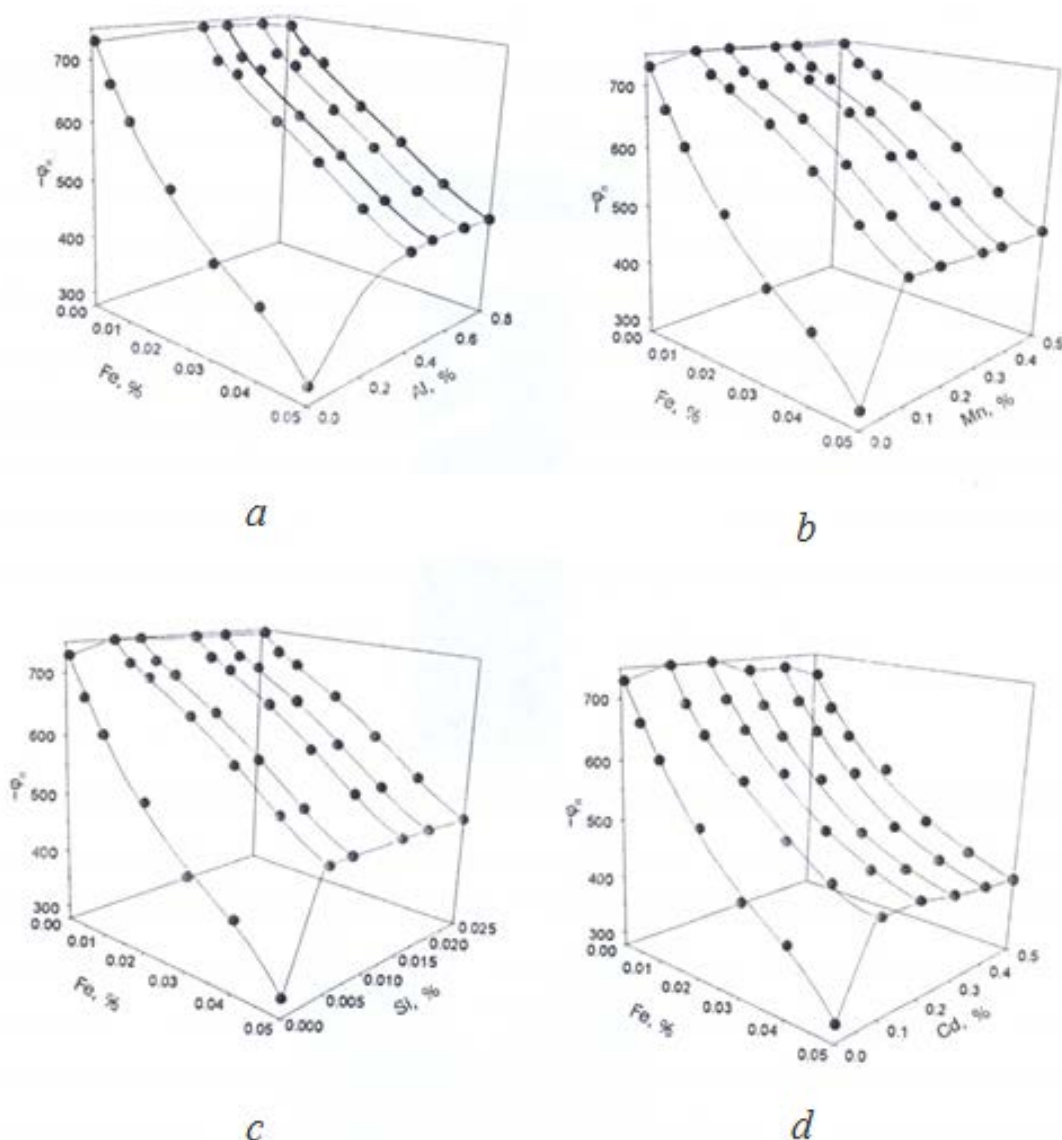


Fig. 3. Work potential (mV) of alloys of systems Zn-Al (a), Zn-Mn (b), Zn-Si (c), Zn-Cd (d) with different content of iron

Highest values of CUE and φ_n of alloys of studied binary systems comply with the following concentrations of alloying elements:

system Zn-Al: (0,4÷0,6% Al):

CUE = (94÷95) .. (48÷50) %; φ_n = -(738÷740) .. -(445÷450) mB ;

system Zn-Mn: (0,1÷0,3% Mn):

CUE = (95÷96) .. (54÷55) %; φ_n = -(747÷750) .. -(473÷480) mB;

system Zn-Si: (0,005÷0,025% Si):

CUE = (93÷95) .. (53÷56) %; φ_n = -(745÷750) .. -(470÷480) mB;

system Zn-Cd: (0,1÷0,3 % Cd):

CUE = (89÷96) .. (55÷65) % ; φ_n = -(730÷750) .. -(425÷440) mB.

At such content of alloying elements alloys of studied systems have maximal level of structural and electrochemical homogeneity. Further increase in the content of alloying elements increases the structural and electrochemical heterogeneity alloys, resulting in decreasing and destabilization of electrochemical properties, especially CUE.

Conclusion

1. Increase in the content of the cathode impurity of iron in zinc and zinc alloys leads to decreasing and destabilize their basic electrochemical properties, especially the CPI.
2. For zinc with a high content of iron impurity aluminum, manganese, silicon and cadmium are recommended as alloying elements.
3. Using of selected alloying elements can improve and stabilize the CUE and the negative potential at polarization of zinc with a high content of iron impurities, and the greatest positive influence have cadmium, manganese and silicon.

Literature

1. L.I. Freiman, V.A. Makarov, I.E. Bryksin. Potentiostatic methods in studies of corrosion and electrochemical protection. L., Chemistry (1972).
2. Fokin M.N., K.A. Zhigalova. Methods of corrosion testing of metals. M., Metallurgy (1986).
3. Kechin V.A., Solozhenko V.L. Melting and casting of sacrificial alloy. J. Foundry, 1996, № 10, p.24.
4. Kechin V.A. Methodological bases of synthesis of sacrificial alloys / Proceedings of the 10th Anniversary International Conference "Foundry today and tomorrow", St. Petersburg. Publ Cult-Inform-Press., 2014, p. 215-221.

LASER MATERIALS PROCESSING SYSTEM.

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Absract

In this paper are given results of investigations of characteristics of radiation of the compact fiber laser. It is established that at work in pulse and in pulse periodic modes the fiber laser generates enough stably radiation with length of a wave 1,083 microns with peak power to $1,5 \div 2$ kW. The area of stable generation of radiation is limited to a pumping current 8 A. There are shown possibilities of treatment of materials by radiation of the investigated laser.

KEYWORDS: LASER RADIATION, OPTICAL FIBER, FIBER LASER, SPECTRAL ANALYSIS, TREATMENT OF MATERIALS

1. Introduction

Laser systems find the increasing application in laser marking and laser treatment of materials. For industrial appendices excellent quality of a laser beam at the big radiated power, decrease in current working costs, increase in quantity of qualitative products and reliability growth is especially important. At present in the market of industrial laser systems for treatment of materials four basic systems prevail. It sealed-off lasers and flowing CO₂- lasers, solid-state lasers on the basis of glass or crystal materials, fiber lasers and disk-shaped diode lasers (HPDDLs).

The most widespread industrial laser systems on the basis of gas lasers even more often are replaced recently on a systems with solid-state lasers and semi-conductor lasers.

Fiber lasers are one of the brightest achievements of modern quantum electronics [1, 2]. In comparison with traditional industrial CO₂ and Nd:YAG lasers powerful fiber lasers have important advantages:

- high coefficient of efficiency (up to 30%);
- several times smaller dimensions and weight;
- high stability of output parametres (nearly 1 % on output power);
- high quality of radiation;
- transportation of laser radiation to unlimited distances almost loss-free;
- high reliability and the big resource of basic elements and systems.

At present are developed and are manufactured industrial laser systems on the basis of fibres, which are doped by ions Yb³⁺, Er³⁺, Tm³⁺.

2. Preconditions and means for resolving the problem

The fiber laser consists of three basic elements: the module of the pumping, the generating module and a fiber light guide [3]. The pumping module assure transfer of necessary quantity of electric energy to an active part of the generating module. The generating module will transform brought energy to energy of laser radiation. Radiation generation occurs in active fibres that excludes difficult schemes of an leading of a beam in a treatment zone. The fiber light guide assure transportation of laser radiation to a place of treatment with preservation of power of radiation without considerable losses.

In the majority of fiber lasers the generating module is constructed under the classical scheme - an optical fibre with a double cover in which the central single-mode core is covered by a multimode cover with a smaller index of refraction, than at single-mode cores. The multimode cover provides input of pumping radiation in a single-mode core which is doped by ions of rare-earth elements.

2.1. Theoretical Model

In the usual solid-state laser the crystal or the glass doped by ions of an element which luminesces at optical excitation is used as the active medium. The greatest distribution was received rare-earth elements - Nd, Yb, Er, etc. Powerful lamps or semi-conductor radiators are applied to optical excitation. For generation beginnings the active element is located in the resonator which contained two mirrors - blind and translucent, - through which a radiation comes into light guide. Such lasers demand mirrors alignment and their rigid fixing. Besides, there are the problems connected with heating of the active medium.

The construction of the fiber laser is essentially easier. In it an active element is the fiber light guide with core which is doped by active ions (Yb, Er, Ho, Tm, Sm, etc.) [4]. As the mirrors forming the resonator, are used intrafiber Bragg grating with various factors of reflexion which are simply welded on an active light guide. Such laser is pumped up by a small-sized semi-conductor radiator with a fiber exit which also is welded to an active light guide. Thus composes the compact and easy device, easy-to-work, possessing an effective heat extraction because of the big area of a lateral surface and having high quality of the output radiation, caused by waveguide character of its distribution. All these factors do the fiber laser by a reliable and stable source of radiation.

2.2. Experimental stand

The fiber pulsed laser offered for treatment of materials, operates in a pulsed and pulse-periodic mode at achievement of the maximum of output power. The pulsed operating mode of the laser is characterised by single pulses of laser radiation, the following one after another through short time frame. In an pulse-periodic operating mode is created series of impulses with a time interval between series which is much more of an interval between pulses.



Fig. 1. External view of the fiber laser.

The scheme of pumping up and generating modules is presented on fig. 2.

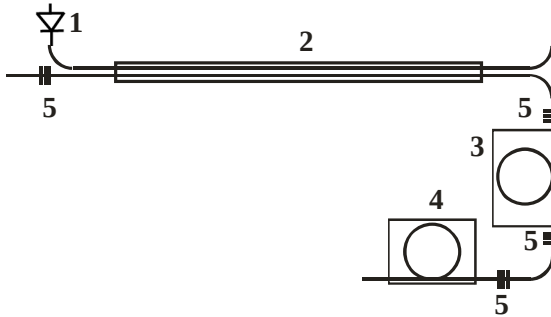


Fig. 1. The scheme of fiber laser [5].

1 – pumping diode; 2 – cascades of amplification; 3 – fiber generator; 4 – absorber; 5 – fiber Bragg gratings.

Pulses are generated by the fiber generator 3 on a basis of Ho^{3+} -fibre with the specified frequency of repetition. Laser radiation of the fiber generator intensify cascades of amplification 2. Strengthening cascades are made from two-element's optical Yb^{3+} -fibres and are pumped up by semi-conductor laser diodes.

Realisation of the presented above scheme has allowed to create the fiber laser with following parameters of radiation:

- Length of a wave of radiation – 1083 nm.
- Average power of radiation – $3,5 \div 4$ W (when a pumping current till 8A).
- Duration of pulses – 50 ns.
- Frequency of repetition – $40 \div 50$ kHz.
- The maximum energy in an pulse on an exit of a fiber light guide – 75 mJ.
- The maximum peak power of the fiber laser - 1,5 kW.

3. Results and discussion

Technological characteristics of the fiber laser are defined by parametres of generation of laser radiation.

The oscillogram of work of the fiber laser in a pulse mode on fig. 3 is presented.

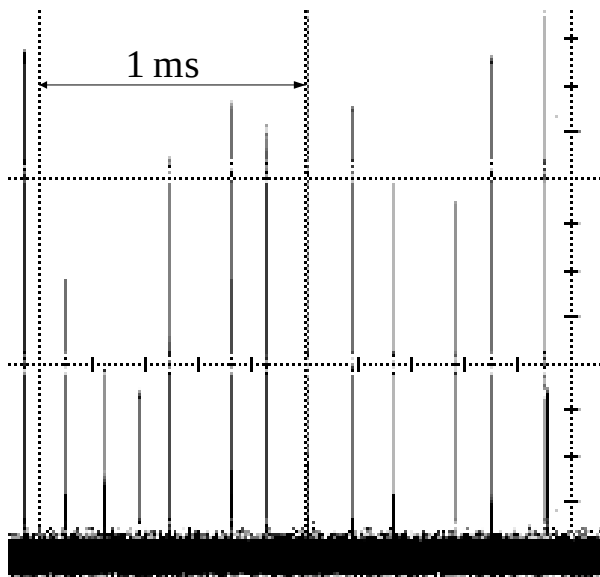


Fig. 3. The oscillogram of pulses sequence.

Radiation of the fiber laser represents stable enough sequence of pulses of different intensity. At pumping currents more than 2 A occur delays of generation of the next pulse. Frequency of delays of generation increases in process of increase in a current of a pumping. It is experimentally established that the increase of a pumping current till 8 A have not an appreciable impact on stability of technical characteristics of the laser, but allows to achieve of

considerable power in an pulse. The increase in a pumping current more than 8 A can lead to failure of generation.

The structure of a separate pulse of of the fiber laser radiation is presented on the detailed oscillogram (fig. 4.).

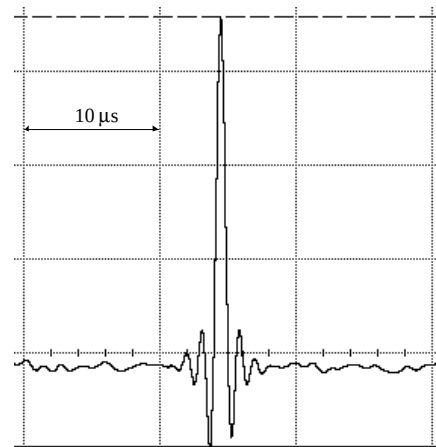


Fig. 4. The oscillogram of a separate impulse.

According to this oscillogram each pulse represents sequence of short-time generations. Intensity of each separate generation and on forward front of an pulse, and on back front of an pulse changes on exponential law. Duration of each generation does not exceed $1 \div 2$ μs.

The spectrogram of the fiber laser radiation, which was received by use of spectrum analyzer YOKOGAWA, is presented on fig. 5.

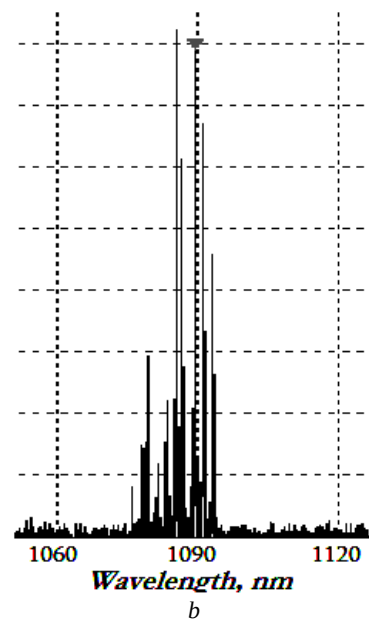


Fig. 5. The spectrogram of radiation of the fiber laser.

From this spectrogram is visible that the fiber laser radiates in narrow enough spectral wave band (<25 nm). The average wave length of radiation is 1082 nm.

One of possible applications of the developed fiber laser is surface treatment of materials. As an example of such treatment it is possible to propose a manufacturing techniques and fine tunings of film resistors which is carried out by evaporation of a resistive layer at focusing on it of laser radiation. The compact sizes of the fiber laser and rather simple way of delivery of radiation allows to place in a processing zone this highly effective device directly on a workplace of the radio technician.

On fig. 6 are presented results of laser pickling of a resistive layer on the basis of chrome silicide [6]. The width of a zone of pickling is about 18 mcm.



Fig. 6. A strip of laser pickling of a resistive layer on the basis of chrome silicide.

By means of the fiber laser it is possible to make punching of sheet products from plastic. On fig. 7 are presented results of punching of sheet of textolite and polyethylene film which is filled with soot.



a



b

Fig. 7. Example of perforation of sheet of textolite (a) and polyethylene film (b) which is filled with soot.

4. Conclusion

Investigations of characteristics of radiation of the fiber laser have shown possibility of microsecond pulses obtaining with peak power to 1,5 2 kW. Enough stable pulse and pulse periodic operating modes of this laser allow to receive sustained performance of radiation. The high coefficient of efficiency, simplicity of a construction, compactness and possibility without difficult optical schemes to convey laser radiation to a treatment place do this laser as promising both for handwork, and for using into technological lines.

Performance parameters of this fiber laser executed under the offered scheme, allows effectively to use of it in many problems of materials treatment. In particular, such laser can be used for superficial microprofiling of metallic and of nonmetallic surfaces. Rather effective there can be use of this laser in processes of microwelding and laser pickling.

5. References

1. Jackson S. D., Sabella A., Hemming A., Bennetts S., and Lancaster D. J. «High-power 83 W holmium-doped silica fiber laser operating with high beam quality», *Optics Letters* 32, 2007. – p. 241.
2. А.С.Курков, Е.М.Дианов. «Непрерывные волоконные лазеры средней мощности». *Квантовая Электроника*, **34**, 2004. – с. 88.
3. Hayes J. *Fiber Optics Technician's Manual*. – 2th Edition. – Delmar Cengage Learning, 2000. – 242 p.
4. D. Y. Shen, J. K. Sahu, and W. A. Clarkson. «High-power widely tunable Tm: fibre lasers pumped by an Er,Yb co-doped fibre laser at 1.6 μm ». *Optics Express*, **14**, 2006. – p. 6084.
5. A.S. Kurkov, E.M. Sholokhov, O.I. Medvedkov, V.V. Dvoyrin, Yu.N. Pyrkov, V.B. Tsvetkov, A.V. Marakulin, and L.A. Minashina. «Holmium fiber laser based on the heavily doped active fiber», *Laser Phys. Letters*, 6, 2009. – p. 661.
6. Е.Л.Сурменко, Т.Н.Соколова, И.А.Попов, А.С. Курков, «Волоконные лазеры в обработке пленок и поверхностных покрытий», *Материалы Всероссийской конференции по волоконной оптике*, Пермь, 12-14 октября 2011, А-5-8. *Фотон-Экспресс*, 6(94), 2011. – с. 64.

ADJUSTING THE SALES PROCESS TO THE PERSONALITY OF THE BUYER (RESEARCH THE AUSTRIAN INVESTMENT GOODS INDUSTRY)

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ABSTRACT: *The sales process in the investment goods industry is sophisticated and long-lasting when compared to commodity products. Sometimes it takes years to close the business. Therefore it is of enormous importance for both parties – the buyer and the seller – that this process is as efficient as possible. Commitment, trust and cooperation are key elements in developing enduring and successful relationships between sellers and buyers in a b2b setting. Commitment and trust can only be developed when individuals understand each other and the expectations of each other (pervin, cervone and john 2000, p. 526). Understanding does not just mean that it is based on business information, e.g. Technical specifications; it is extremely important to understand the buyer as a whole person – the personality of the person. People are different and people behave differently; therefore based on an individual's personality, he or she will have different expectations and also expect different things depending on how he or she is treated.*

The motivation to explore this topic is derived from the tremendous influence that the buyer's personality can have on the sales process and outcome. Adapting to personal needs, preferences, thinking and decision-making styles shows the buyer that the seller understands him or her, which consequently establishes a strong relationship.

KEYWORDS: SALES PROCESS, PERSONALITY TYPES, BEHAVIOR, COMMITMENT, TRUST, RELATIONSHIP, DECISION MAKING

1 INTRODUCTION

When evaluating a product or service, B2B buyers consider rational selection criteria such as price, quality, technical service, delivery reliability and delivery lead time (Munson & Tullous, 1992). Despite all rational aspects, a lack of positive personal chemistry is often mentioned as the reason why business relationships fail to develop, and/or fail to be maintained over time (Anderson & Narus, 1990). This article explores the idea of not just fulfilling customer requirements regarding rational selection criteria such as price or quality but also addresses the personal needs and requirements that are connected to the particular personality of a buyer.

The article is structured so that first the industrial goods industry will be analyzed in regards to requirements. In order to gain a deeper understanding, the sales process in that industry will be analyzed and every phase of the process will be explained and discussed in detail. In addition, it analyzes which phases of the sales process are influenced most by different personality characteristics. In order to find out the different personality characteristics, MacLean's theory of the "Triune Concept of Brain" will be used. Using the information gathered, the sales process is adjusted to the three personality types that have been selected. Phases such as prospecting, needs analysis and negotiations are heavily influenced by the personality of the buyer. Furthermore, the effectiveness of sales arguments and promotional activities depends on the personality type and must consequently be tailored to personal preferences. The methodology which was applied for this research is a qualitative approach. Ten qualitative interviews with sales managers in the investment goods industry in Austria were applied. This article should help salespeople better understand their customers and develop long-term relationships that are based on trust and respect.

In order to explore these topics the following research questions will be answered:

1. What does a typical B2B sales process in the investment goods industry look like?

2. What are the main stages of the sales process in the investment goods industry?
3. Which stages of the sales process are affected most by the personality of the buyer?
4. How can the sales process be adjusted to suit the individual personality type of the buyer?

2 THEORY BACKGROUND

2.1 Investment Goods Industry

Backhaus and Voeth (2009) define basic business-to-business models by measuring the dependency between transactions and the number of potential customers. They came up with four different types: supplier to industry, system business, investment business and product business.

According to the model of Backhaus & Voeth (2009), the investment goods business is defined by a low number of potential customers and low level of dependency between business transactions. Products are complex and highly customized, which results in a long, intense buying/selling process. Investment goods are used by the buyer to produce further products or services (Backhaus & Voeth, 2009). The business can also be described as project business because selling is rather long-lasting and complex (Cova, Ghauri & Salle, 2002).

The market is defined by a low number of potential customers resulting in a competitive selling situation. Examples for such a product could be: manufacturing machinery, steel plants or buildings (Backhaus & Voeth, 2009).

Due to highly customized products and the high investment involved there is a correspondingly high risk for both parties (Cova, Ghauri & Salle, 2002), which was the main reason why the authors have chosen this industry sector for their analyses.

2.2 The sales process in the investment goods industry

A well-structured and thoroughly developed sales process is essential for successful selling in the investment goods industry. Masover (2009) defines seven steps as the winning sales process:



Figure 2 – Sales process (Masover, 2009)

Empirical research has shown that most of the interviewed companies in the investment business followed the sales process of Maslow (2009).

2.2.1 Leads and Pre-Qualification

The first step in every sales process is to find the proper customers. The goal of the first phase of the sales process is to find potential customers and make potential customers find the company. Lead generation is also a marketing area whose premise is to find (e.g. via market research) and attract those prospects (Masover, 2009).

2.2.2 Prospecting

The target of prospecting is to create an opportunity for communication which enables the seller to qualify the customer. Every task at the beginning of the sales process should be directed at the final goal: selling and closing (Masover, 2009).

From a psychological view, prospecting can be seen as a difficult activity as people do not like rejection or the possibility that they might fail. Salespeople often do not know how to do it and have unreasonable expectations about the success rate. (Masover, 2009)

2.2.3 Qualification

The process of qualifying focuses on saving resources, in terms of time and money, by qualifying candidates. (Brennan J., 2008) The process of qualification should be completed before starting to analyze the needs of a potential customer (Masover, 2009).

Miller (2012) suggests the three M's model for the qualification process. Good qualification should focus on the three M areas which are:

- Money
The selling company needs to find out if the buyer has the needed capital to pay for the product or service. Furthermore, there is an analysis of how the decision is made within the company and who the members of the decisions committee are. (Miller, 2012)
- Method
The seller will make attempts to systematically describe the buying process in order to understand the steps and the time frame. The salesperson will also tackle the analysis of decision criteria, which can be product/service features and benefits, quality, professional support, investment or image. The seller has to determine the targeted implementation date. (Miller, 2012)
- Motivation
The final M of the model suggested by Miller (2012) is to define the motivation of a prospect and the reason why he or she is interested in the product or service. Questions regarding the existence of a need and the possibility to satisfy this need are outlined. After knowing the needs and motivation, the seller has to analyze if he or she can meet the buyer's needs with the offered solutions. (Miller, 2012)

2.2.4 Needs analysis

Needs analysis is the phase when the seller learns in detail about the buyer's needs that have to be satisfied. This part of the sales process is critical and tremendously influences success. If the seller does not know the needs and source of the problem of the buyer he/she cannot come up with a persuasive offer (Masover, 2009).

The process of analyzing needs is a great opportunity for the seller to establish credibility, rapport and trust. Additionally, a seller can differentiate him- or herself from the competition and build a strong, long-lasting relationship. (Masover, 2009)

2.2.5 Presenting the solutions

The seller has to focus on institutional as well as individual values within the presentation. Although individual reasons may be decisive, the seller should always justify the solution for business as the buyer has to argue for the decision in front of his or her superiors (Miller, 2012). Professional sellers also consider the buyer's personal needs. Personal advantages of the solution are mentioned by the seller as they heavily influence the decision process.

2.2.6 Objective / Negotiations

The phase of handling objections is closely connected with the negotiation phase (Masover, 2009).

The seller's goal of handling objections is finding out whether consequence issues exist, clarifying them, and helping the customer to resolve these issues.

Theory argues that the negotiation phase for the investment goods industry generally lasts through several meetings, which can be held via telephone, e-mail and/or face-to-face meetings. The main negotiation process takes place in face-to-face meetings, whereas intermediate negotiations may take place via telephone or other digital means of communication (Backhaus & Voeth, 2009).

2.2.7 Closing

The goal of the seller is to make the buyer want to close the deal, though it does not mean that the seller should simply wait for the order. Closing a deal without obstacles in the last phase is also unlikely to happen no matter how well the sales process was performed (Eades, 2003).

Based on the short description of each step in the sales process, research question 3 should be answered: "Which stages of the sales process are affected most by the personality of the buyer?"

Based on empirical findings the following phases are mainly influenced by the personality of the buyer:

- Prospecting
- Qualification
- Needs analysis
- Sales arguments (Presenting the solutions)
- Objections / Negotiation
- Closing

2.3 Personality Types

"By personality, we refer to the complexity of psychological systems that contribute to unity and continuity in the individual's conduct and experience both as it is expressed and as it is perceived by that individual and others. [...] From the perspective of the individual, one's own personality is the collection of one's attributes and inclinations." (Caprara & Cervone, 2000, p. 10)

A common approach to explain personality is by defining characteristics or qualities of a person. Such definitions include

mental, emotional, social, and physical characteristics. Long-lasting and critical characteristics that strongly influence a person's behavior are therefore defined as the aspects of one's personality (Ewen, 2003).

There is a long history of personality typing. Psychologists developed personality types for categorization, which allows remembering and understanding personalities. There are different models available such as the Enneagram, personality types based on cognitive styles, the MacLean theory of the triune brain, the DISG Model or the Myer-Briggs Type Indicator.

It is impossible to discuss these theories in detail in this article. Therefore the authors have employed the suggestion of Berens & Nardi (1999), i.e. in order to use such theories or models for a practical purpose, understandable and simple models are essential. This was the reason why the authors decided to use the MacLean theory of the triune brain, which will be described in detail in the next chapter.

MacLean Theory of the Triune Brain

In 1969, the American neuroscientist and physician Paul MacLean developed the concept of the "triune brain" in the field of neuroscience and biological psychiatry which addresses brain and behavior research from an evolutionary perspective. MacLean chose the name "triune" as it means "three-in-one". He argues that humans have three different brains which control the thinking and behavior. All humans are controlled by the reptilian brain (hindbrain), the paleomammalian brain (limbic system) and the neomammalian brain (neocortex) (Lambert, 2003).

The Three Brains

All three brains vary in their structure and function. Each of the three brains can be considered as a biological computer that has its own intelligence, perception of time, memory and other distinct functions. (MacLean, 1990)

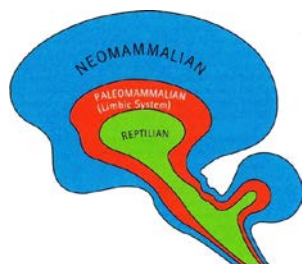


Figure 4 – Triune Brain - Three different brains (Schoemen, 2011, p. 36)

Reptilian Brain

The core task of this brain is to ensure self-preservation and survival. It controls the basic body functions including breathing, metabolism and basic behavioral patterns that ensure survival. Feelings such as hunger and thirst activate this brain (Schoemen, 2011).

Limbic System

The limbic system is oriented towards the present to fulfill the requirements of changing situations within the hunting process. Fast and impulsive reactions are essential for the predator as well as for the prey (Schoemen, 2011).

Neocortex

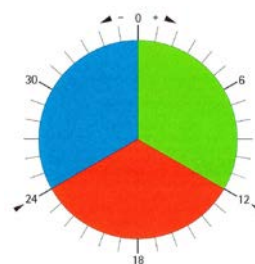
The neocortex has also developed the feeling for individual needs and self-actualization. Social relationships and communication skills have been developed within the neocortex (Schoemen, 2011).

Personality Typology and Biostructural Analysis

Thus, human behavior is defined by the complex interaction of these three brains. Nevertheless, this interaction does not go without conflict. This explains why individuals have contradictory feelings, emotions and rationalities. Irrational and illogical behavior is caused by this conflict. MacLean clearly states that there is no judgment of a better or worse brain. Moreover, there is also no more or less important brain. All three brains together are the prerequisite for human life (Schoemen, 2011).

The degree of involvement of the three brains is genetically assessed and defines the personality of an individual. MacLean argues that one of the three brains dominates and consequently characterizes the personality (Schoemen, 2011).

The so-called "Structogram" shows the strength of the three brains. The reptilian brain is defined as the green brain, the limbic system as red, and the neocortex as blue. Green has been selected as it is the color of nature, red is impulsive and dynamic, and blue is considered as cold and rational. The Structogram composition is individual for every personality and shows the strongest, second strongest and weakest brain (Schoemen, 2011).



The theory contends that for 90% of all individuals one dimension clearly dominates and forms characteristics and behaviors (Menthe & Sieg, 2013).

Green Type

Green types prefer close relationships with other people and like to be embedded in a community (Schoemen, 2011). Green types are attracted by human relations and a warm-hearted and cozy environment (Schirm, 1982). They often have a distinct altruistic type of thinking and serve the needs of the others rather than focusing on fulfilling their own needs. Moreover, Green types need the feeling of being part of society and accepted by the group (Kastor, 2003). Greens are successful because they are sympathetic and likeable (Schoemen, 2011).

Within the purchasing process, the personal opinions of family and friends heavily influence decisions. Green types trust the information they receive from their peer group more than written factual information. A hard-sell approach will result in avoidance by the buyer, who will try to pass on the decision. Confirmation of a correct decision is highly appreciated and needed by this type to reduce the anxiety of having made a wrong decision. (Pepels, 2004)

Red Type

Red types tend to be domineering. Within relationships they attempt to be superior and prefer to dominate situations (Schoemen, 2011). A red type has high self-esteem and a hands-on mentality (Menthe & Sieg, 2013).

They constantly strive for a powerful image and do not hesitate to participate in rivalries. In order to stay on top, such personalities will participate in anything that represents progress and an improvement of their power position (Schirm, 1982).

Sellers could positively influence red types by product demonstrations and benchmarks with competitive products. Red types can be quickly inspired by a solution that can be promptly replaced by an even bigger and better offer (Pepels, 2004).

Blue Type

In order to focus on rational aspects of life, the blue type tends to keep a distance from others. Individuals with a strong blue component always need a safety zone between themselves and society. They are conservative, cautious and rather reserved towards other people (Schoemen, 2011). Through rational arguments and attention, Blue types try to communicate their love and affection (Kastor, 2003).

Detailed planning before taking action enables them to develop continuously. As Blue types think and plan about the future, they strive to make progress and achieve goals (Schoemen, 2011).

Within a business environment Blue types are attracted to rational expertise and know-how. To reduce their perceived risk they prefer and trust in factual objectiveness rather than in people. Moreover, a structural approach and detailed organization are preferred for processes and situations (Schirm, 1982).

3 RESEACH DESIGN

In order to answer the research questions an empirical research study was conducted. This paper has been written as an exploratory study to reveal where salespeople see dissimilarities in the personality characteristics and preferences of potential and existing customers. The stages of the sales process that are affected most by the personality of the buyer were ascertained. Finally, empirical research addresses how the sales process is adjusted by salespeople in the field to suit the individual personality of the buyer.

In order to discover individual perspectives from the respondents, in-depth interviews were performed for this research. Statistics indicate that in 2010, 469 Austrian companies were registered as part of this industry (Statistik Austria, 2013). For this article 10 interviews with sales personnel from one sector (investment industry) were conducted. Each interview lasted between 40-60 minutes. The interviews were recorded and a verbatim transcript of each was created. All transcripts were analyzed with the help of the software MAXQDA. The development of the coding system was done inductively and deductively in order to achieve valuable results. The primary findings were interpreted and evaluated based on the theory.

4 EMPIRICAL FINDINGS

Based on the empirical findings the following phases of the sales process are influenced by the personality type of the buyer; Prospecting, Qualification, Need Analysis, Sales Arguments (presenting the solutions), Objections / Negotiation and Closing. In this chapter the different sales phases and the behavior of the different personality types are combined in order to answer the key research questions of this article:

“How can the sales process be adjusted to suit the individual personality type of the buyer?”

In order to obtain a good overview of the different findings (empirical and theoretical) the authors will provide a distinct description of the three personality types in accordance with the different steps of the sales process and how each of them influences it.

	Green Type
Prospecting	Based on the empirical study, the sellers can meet the Green buyers mainly at fairs (face-to-face communication is important). Promising prospecting methods are trade shows, seminars, referrals and networking. Creating harmony by talking about general topics is the preferred way for prospecting Green types. Harmony can be created when the seller talks about himself. In this way an opportunity for Green types to become acquainted with the person calling is presented.
Qualifying	Qualifying of customers usually takes place in person or by telephone. At the very first meeting it is important to show interest in the buyer as an individual, in his environment, and in the things he/she likes. The empathy received and credit given always pay off. Small talk is always helpful in order to break the ice. During this first step Greens decide whether or not to confide in the person before him (building trust is of utmost importance). Greens should always feel that the seller has all the time in the world at his disposal and he/she is not in a hurry. Small talk about the journey, the new design of the office, or a family photograph on the buyer's desk will slowly and safely “warm” the atmosphere. As similar behavior creates a feeling of confidence, Greens very often rely on intuition and decide within a few minutes whether they are in good hands or not, so creating confidence from the very beginning is of great importance. The seller should do so by focusing on building trust and commitment before asking questions qualifying the customer.
Need Analysis	Greens care about people - special in their community. (Schoemen, 2011) They are more willing than others to provide information about their needs and the buying center itself. Prerequisites for trust are social interactions and knowing each other in detail (Stanko, Bonner & Calantone, 2007). The empirical research has shown that social activities outside work greatly help in this respect, for example joint dinners, skiing, etc. These personal interactions help to create common values, emotional ties and a pleasant atmosphere where business problems can be solved more efficiently. Being in constant contact with each other will create a feeling of importance in the potential customer. The seller should inform him of every issue that could affect them in the future – positive and negative – or share information that he is not obliged to provide, thus building a bridge of confidence between the two sides. In order to develop trust the seller should conform to the official subordination in the buyer's company and never go over his head to speak with his superior. The needs of others in the buying center are important to them, requiring the analysis of such needs as well.
Sales Arguments (Presenting Solutions)	Green types like to have win/win solutions. They also like to serve other people and therefore sellers must state how solutions would influence their colleagues as well. Trust (friendship) seems to be the key success factor when dealing with this type. Generally, Green buyers trust experience, e.g. traditional solutions or proven technologies. Buyers with this personality usually trust the whole company, so they need to meet more people from the organization and be a part of a group, thus providing them a feeling of security.(Pepels, 2004) Greens want to be sure that they will have the seller's support in case of malfunction of the purchased item after the transaction has been finalized. Availability of after-

	sales support is an essential argument for Green types and considerably influences their final decision. Certainly the seller has to prove his or her good will concerning this issue during the sales process. As Greens prefer personal relationships, inviting them to visit the company is highly appreciated. Green types rely on their peer group more than on written factual information; hence the buying center must be convinced first. Frequent updates regarding status and scheduled meetings would be a good argument for Green personalities to decide in favor of a supplier. Greens trust experience rather than new technologies; therefore they will prefer traditional solutions that have been proven to work. Overall, arguments should center much more on the selling team as individuals rather than the technical aspects of the solution.		for permission to continue. The seller should bear in mind that Red buyers are always right and they have a low tolerance level when their opinions are called into question. Furthermore, the seller should never try to convince and “teach” a Red type how things work because it will have a negative effect on them. By being aware that Red types are impatient, spontaneous and prone to making quick decisions, sellers should be flexible enough to adapt solutions and discuss them with the buyer before working out a detailed concept. (Kastor , 2003)
Objections /Negotiation	Sellers have to focus on fair and transparent negotiations based on empirical findings. It is more difficult for salespeople to negotiate with Green buyers than with the other two types. Empirical findings have shown that Green buyers normally get the lowest price.	Sales Arguments (Presenting Solutions)	Red types focus on the near future. Consequently, sales arguments have to be about improving the situation of the company in the short term as they prefer tangible benefits in the here and now. In this respect providing profit calculations and samples for the offering are warmly welcomed. They normally prefer suppliers with the lowest price. Red buyers prefer to have "strong" partners (excellent company image, premium brand, etc.). Conventional solutions should be avoided. The Red type highly appreciates advanced technologies. Red buyers tend to doubt all sales arguments in the beginning in order to achieve a strong position. (Red types want to be perceived as strong and powerful. (Schirm, 1982)) Normally, frequent communications, small gifts or invitations are not appreciated. One of the most important features of Red types is that they prefer to do business on their own territory.
Closing	Green buyers have to be pushed a bit to sign the contract as they tend to avoid decisions. One reason is that they try to fulfill the wishes and the requirements of everyone involved, which may not always be possible.		

	Red Type
Prospecting	Red types like to converse and like to be listened to; hence it is better for sellers to let Red customers do the talking. They have a powerful image - winning and being successful are the most essential goals in their lives. Red buyers focus on the company's needs, but they are also extremely interested in their own personal needs. They welcome rivalry and competition; therefore sales managers must show self-confidence. The first meeting should be short, concise and about the major benefits for the company as well as for the buyer personally.
Qualifying	Red buyers provide as little information as possible to suppliers. There is a tendency to pressure the seller to make quick offers without the needed qualified analysis. (Eades, 2003) The empirical study has shown that Red types like to present themselves as powerful personalities and decision-makers. On the other hand, by keeping in mind that such individuals like to talk and show off, sellers can use this characteristic to obtain more information by asking open questions and motivating the seller to talk about his or her business.
Need Analysis	Red types like to consider the big picture rather than details. (Schoemen, 2011) They will not normally involve themselves in the phase of detailed analysis. It is very important to them that personal benefits are provided. Moreover Red types prefer solutions that provide an immediate personal benefit rather than one that benefits the company in the long run. They like being involved in only major decisions. Red types are spontaneous and make quick decisions; therefore, sellers should be able to adapt their solutions to this idiosyncrasy of the buyers. In order to make Reds feel important, which they like most of all, sellers should develop and present semi-finished solutions to them and ask

Objections / Negotiation	Red types like to dominate the discussion. Based on the empirical findings, their behavior in a negotiation could be described as follows: aggressive, emotional, focused mainly on price, and always using counterarguments. A fact-based approach is the best way to handle their aggressive style. Red types focus mainly on win/lose solutions and like to play games and change tactics, which is typical for them. It is therefore recommended that the seller use the same method. (Empirical results show that Red types achieve worse results in price negotiations than Green types.)
Closing	A Red buyer will proactively start the closing process only after his/her ego is gratified. Only in this case can a negotiation be expected to be successful. Sellers should read contracts carefully as buyers may add, delete or change conditions that have already been agreed upon. This element was also one of the outcomes of the empirical study.

	Blue Type
Prospecting	Blue types become interested in a company through reading articles, finding technical solutions in the internet, or hearing something interesting at conferences. They like discussing their field of specialization. Blue buyers need a certain safety zone between them and others. Consequently, sellers should not get too close or even touch them in a friendly way to avoid scaring them off. Their main focus is the future and how they can reach their goals. Sellers need to have detailed knowledge about their product in order to be accepted by a Blue type. These types of customers are very punctual. (Kastor, 2003) They are usually perfectionists and expect no less from their suppliers. (Schoemen, 2011)

Qualifying	They need to receive information in detail. Blue types normally know beforehand if there is a fit between their problem and the solution offered by the supplier. When using a rational and structured approach, Blue types are more likely to provide the necessary information.
Need Analysis	Sellers have to provide detailed information in order to obtain information in return. A Blue buyer would appreciate it if the seller is a technical expert. Sellers should present all needed information in a structured, clean and neat manner. Blue buyers carefully prepare for a meeting; they are punctual and expect the same from their suppliers.
Sales Arguments (Presenting Solutions)	Blue buyers prefer rational arguments. The latter must be backed up with facts and figures. Trust can be developed by logical arguments and calculations. Sales arguments have to be carefully prepared and customized to the specific situation. Blue types have a long planning horizon; therefore sellers should focus on long-term benefits and solutions. Furthermore, concepts such as TCO/total cost of ownership, which considers a long-term benefit of a solution, convince Blue types. (Ellram & Siferd, 1993) High quality and certifications are excellent sales arguments. Sales arguments such as image, design or recommendations are normally not successful. Business relationships with Blue types should be based on professional behavior rather than on personal ties. Hence, after-meeting activities like joint dinners or skiing are not appropriate measures to convince a Blue type. An agreement made by a Blue type can be perceived as a binding promise.
Objections / Negotiation	Blue types negotiate rationally, i.e. they do not demand things that are illogical. Negotiations with Blue buyers are detached from emotions. Sellers should argue with facts and invalidate counterarguments with technical specifications. Moreover, during negotiations Blue types need a certain distance between themselves and their partners. The sales price has to be argued with a detailed calculation that explains what the offered sales price consists of. They are willing to compromise if rational arguments are presented and prefer to have fact-based communication about common interests.
Closing	Blue types need time to make a decision; they evaluate and consider various scenarios of solutions and consequences. (Kastor, 2003) Blue types never make final decisions before contemplating all the pros and cons. Therefore, pushing them into a decision is counterproductive.

Literature and empirical results illustrate that sales professionals in the investment goods industry sell to customers with varying personalities.

Customers have different personal preferences, ways of thinking and perceptions. Moreover, primary findings clearly established that personal issues, such as a good relationship, empathy and trust, heavily influence the sales process. Hence, considering personality characteristics of buyers within the sales process is indispensable.

5 LIMITATIONS

The main limitation is that the empirical study was conducted with a limited number of interview partners. In addition, only the perspective of the seller was investigated. It would be interesting to examine how the buying process is perceived from the perspective of customers.

REFERENCES (IN ALPHABETICAL ORDER)

- Anderson, James C. & Narus, James A. (1990). A Model of the Distributor's Perceptive of Distributor-Manufacturer Working Relationships. *Journal of Marketing* Vol. 48, p. 2.
- Backhaus, Klaus, & Voeth, Markus (2009). *Industriegütermarketing* - 9th Edition. Munich: Vahlen Verlag.
- Berens, Linda V. & Nardi, Dario. (1999). *The Sixteen Personality Types - Descriptions for Self-Discovery*. Huntington Beach: Telos Publications.
- Brennan, Ross (1997). Buyer/Supplier Partnering in British Industry: The Automotive and Telecommunications Sectors. *Journal of Marketing Management*, Vol. 13, Issue 8, November, p. 759-775.
- Caprara, Gian Vittorio & Cervone, Daniel (2000). *Personality - Determinants, Dynamics, and Potentials*. Cambridge: Press Syndicate of the University of Cambridge.
- Cova, Bernard, Ghauri, Pervez N. & Salle, Robert (2002). *Project marketing: beyond competitive bidding*. New York: John Wiley & Sons Ltd.
- Dwyer, Sean, Hill, John & Warren, Martin (2000). An Empirical Investigation of Critical Success Factors in the Personal Selling Process. *Journal of Personal Selling & Sales Management*, Volume XX, Issue. 3, Summer, p. 151-159.
- Eades, Keith M. (2003). *The New Solution Selling*. New York: McGraw-Hill.
- Ewen, Robert B. (2003). *An Introduction to Theories of Personality* - Fourth Edition. Hove: Psychology Press - Taylor & Francis Group.
- Kastor, Michael (2003). *Psychologie der Individualität*. Würzburg: Königshausen & Neumann.
- Lambert, Kelly G. (2003). The life and career of Paul MacLean: A journey toward neurobiological and social harmony. *Physiology & Behaviour*, p. 343-349.
- Masover, David (2009). *Mastering your sales process*. Leipzig: Amazon.
- Mattson, Lars-Gunnar (1973). System selling as a strategy on industrial markets. *Industrial Marketing Management*, Vol. 3, Issue 3, p. 107-120.
- Menthe, Thomas & Sieg, Manfred (2013). *Kundennutzen: die Basis für den Verkauf*. Wiesbaden: Springer Gabler.
- Miller, William (2012). *Proactive Selling - Control the Process, Win the Sale*, Second Edition. New York: American Management Association.
- Pepels, Werner (2004). *Marketing* - 4th Edition. Munich: Oldenbourg Wissenschaftsverlag GmbH.
- Quinton, Brian (2012). Prospecting on all platforms. *Chief Marketer*, Vol. 3, Issue 7, February/March, p. 16-21.
- Rackham, Neil (1989). *Major Account Sales Strategy*. New York: McGraw-Hill.
- Reid, David A., Plank, Richard E. & Minton, Ann P. (1997). Industrial Buyers' Assessment of Sales Behaviors. *The Journal of Marketing Management*, Vol. 7, Issue 1, Spring/Summer, p. 1-13.
- Schoemen, Jürgen (2011). *Evolution der Persönlichkeit - Die Grundlage der Biostruktur-Analyse* - 14. Auflage. Luzern: Structogram International.
- Schirm, Rolf W. (1982). Signale für eine verlässliche Welt. In W. K. Disch, *Wundersame Welt der Marktartikel* Hamburg: *Marketing Journal*, p. 67-80.

SUPERFINISHING FLAT AND CYLINDRICAL SURFACES OF GEAR PUMP PINIONS

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Abstract: The quality of the flat and cylindrical surfaces of the gear pump pinions is a restrictive condition for a suitable work. The required quality of these surfaces is very high, $R_a = 0,04 - 0,08 \mu\text{m}$. As well, there are restrictive conditions input for the form and positioning deviations. So far, the manufacturing of these surfaces used to be achieved by grinding and no one could guarantee that the surface roughness was in accordance with the technical documentation. The presented constructive solution allows obtaining a good quality of the flat and cylindrical surfaces. It uses a superfinishing attachment that can be mounted on the engine lathe.

KEYWORDS: SURFACE FINISH, PRODUCTIVITY, ATTACHMENT, ACCURACY

1. Introduction

The process of superfinishing is called sometimes micromachining and is a short-stroke honing working at low temperature and with low stock removal material. This method makes it possible to reach high and reproducible surface finish quality on rotationally symmetrical workpieces with practically every kind of material. The surface structure is improved in the micron range - up to $0,004 \mu\text{m Ra}$. The main advantage of this method is consistent finish over the entire surface. Superfinish improves the bearing ratio (T_p) resulting in greatly improved wear resistance. Stock removal is typically in the order of a few microns. The achievable surface finish quality is comparable to levels reached only by honing or lapping.

Superfinishing removes the amorphous structure of the material, or „soft skin“. This layer is usually, $0,002$ to $0,008 \text{ mm}$ thick and is created by high temperatures generated by the grinding wheel. Superfinishing enables the user to achieve virtually any-surface texture parameter, because only the roughness peaks are removed. The geometry of the workpiece remains unchanged.

The superfinishing process results in a number of significant benefits including [4];

- Increased part life;
- Decreased wear rates;
- Higher load bearing surfaces;
- Improved sealing capabilities;
- Elimination of the “break in” period;
- Reduction in energy consumption.

During grinding, extreme heat and aggressive stock removal often alters micro structure and base metal hardness. This creates slight dimensional and surface imperfections such as smeared peaks, waviness and chatter. Superfinishing, a low temperature, low stock removal process, improves part geometry and surface finish by removing the amorphous layer formed during the grinding process. This dramatically improves these imperfections, which can compromise part quality and performance.

The superfinishing process results in a controlled surface finish in which relatively small amounts of material are removed to achieve surface finishes as fine as $0,012 \mu\text{m}$. While polishing processes attempt to achieve a mirror-like surface, superfinishing leaves a tightly controlled cross-hatch pattern. This pattern is attained by the interaction of three interrelated motions. These are 1) Oscillation of the stone, or wheel rotation; 2) Rotary movement of the component; 3) Pressure of the abrasive tool on the workpiece [3]. Stones are used to finish cylindrical shapes. Fine grit cups and cylinder wheels are used to finish flat and spherical surfaces.

During the superfinishing process, parts pass through several distinct phases. When the abrasive tool makes initial contact with the part, dull grains fracture or pull away from the matrix to produce a new cutting surface. As the tool “self dresses,” relatively

large amounts of stock will be removed from the workpiece. Proceeding through the stock removal phase, abrasive grains begin to dull, while surface irregularities and geometry continue to improve. This results in a cross-hatched surface free of irregularities and amorphous material.

2. Method of superfinishing cylindrical surfaces of gear pump pinions

The pinions in the gear pump structure have a great constructive variety from the point of view of dimensions and shapes. In fig.1 you can see the surfaces that must be processed. These are $\varnothing A$ and $\varnothing B$ with the width K . The variation of these dimensions is between $0,05-0,016 \text{ mm}$, and the diameters A and B have values between $\varnothing 7$ and $\varnothing 28$, while K dimension is between $12,3$ and $30,5 \text{ mm}$.

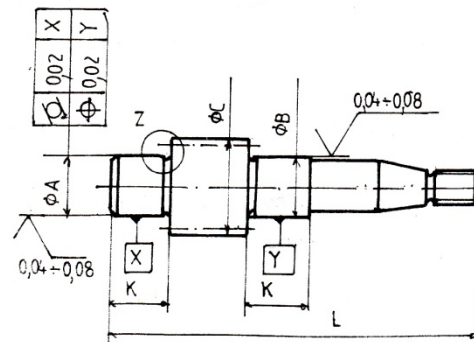


Fig.1 Schematic illustration of a gear pump pinion.

2. 1 The constructive solution and the way of processing

In order to process the cylindrical surfaces of the gear pump pinions, a superfinishing attachment, adaptable on the universal lathe, was designed (Fig.2). This superfinishing device is placed on the supporting plate (pos.6) fixed on the transversal slide (pos.8) of the universal lathe. The method was thought with two working stations to simultaneously process two work pieces. The rotating motion of the work pieces is achieved through the agency of the rolls (pos.9) fitted up on the shaft (pos.7) that, in turn, receives the rotating motion from the lathe. This constructive solution of obtaining the rotating motion allows a good positioning on the shaft (pos.7) for all the rolls (pos.9) in the range. The cutting speed must have a value between $20-25 \text{ mm/min}$, obtainable if the lathe has a rotary speed of $300-350 \text{ rot/min}$.

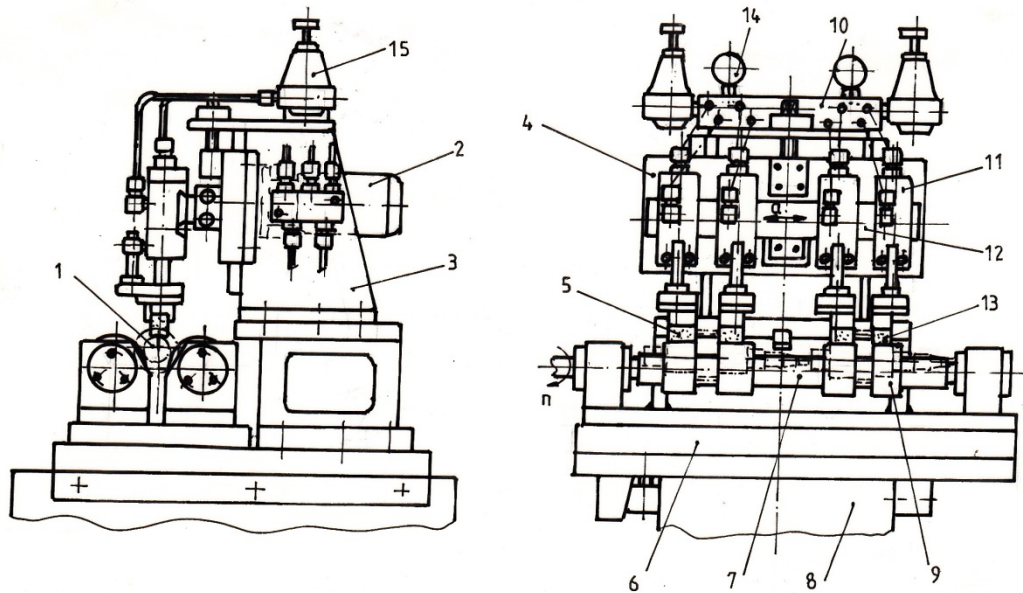


Fig. 2 The superfinishing attachment to machining cylindrical surfaces of gear pump pinions.

A very accurate positioning of the workpiece on the shaft (pos.7) is required, since between the external and the frontal surfaces there is only 1 mm (see the detail Z in fig.1). At the first working station, an abrasive stone (pos.5) is used with the granulosity of 600-800, while, at the second working station, the abrasive stone (pos.13) must have a grains size of 1200.

The abrasive stones are fixed on the supports (pos.11) that have a vibrating motion with an amplitude $a = 1-2$ mm and a frequency $f = 1500$ double stroke / min. All this assembly is set up on the plate (pos.4), where a mechanical generator, supplied from the electric motor (pos.2), could be found as well. The cutting force is achieved pneumatically through the agency of a regulator (pos.15) and a manometer (pos.14) mounted on the pneumatic distributor (pos.10). The processing lasts between 25-35 seconds and a new piece for processing will be manually placed. In order to process other type of work piece, a few adjusting movements are necessary. First, the rolls (pos.9) must be adjusted and fixed in a new position. Then, the abrasive stones for each working station will have a new dimension according to size K (fig.1). The last adjustment is made to regulate the compressed air pressure, by means of a regulator (pos.15) and to check-up with the manometer (pos.14). All this preparations are made at the beginning of the processing operation and take only 20-22 minutes, but results in a good flexibility for this superfinishing method.

3. Method of superfinishing flat surfaces of gear pump pinions

The flat surfaces of the gear pump pinions must have a high quality, as it is shown in Fig.3 and table 1 [1]. These parts could have a wide range of dimensions and are very restrictive in what concerns the shape and positioning errors, as it is indicated in Fig.3. The width "b" has a value between 2, 215 – 66, 35 mm and the variation of this dimension before and after the processing goes from 0,010 to 0,015 mm.

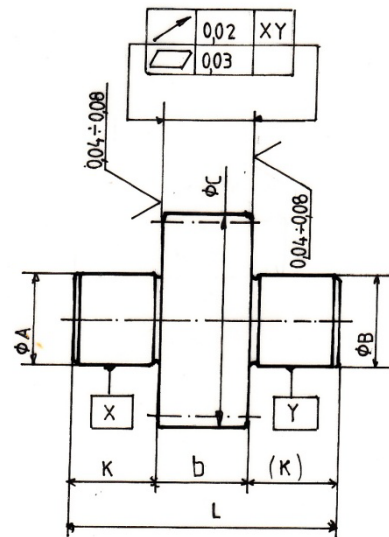


Fig.3 Schematic illustration of a gear pump pinion whose flat surfaces are machining by superfinishing.

3.1 Technological equipment to superfinishing flat surfaces of gear pump pinions

A superfinishing attachment, adaptable on the engine lathe, was designed in order to achieve a good quality of the mentioned plane surfaces (Fig.4). The presented method involves two working stations having the same construction. The only difference between the two working stations refers to the grain size of the abrasive stones to be used. So, for the first working station, the grain size is 600 while for the second, this is equal to 1200 [1].

The workpieces are fixed between the two centers of the lathe from which, one is movable. The rotary motion for the workpiece is achieved by the means of the following chain: lathe motor, gear, (pos.11), shaft (pos.1), gear (pos.3). The cutting speed must have a value between 20-25 m/min. The different cutting speeds for different sizes of work piece are obtained by only changing the gear (pos.15).

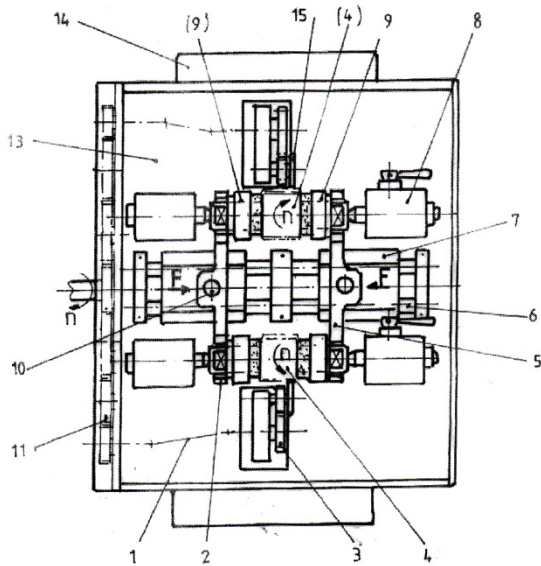
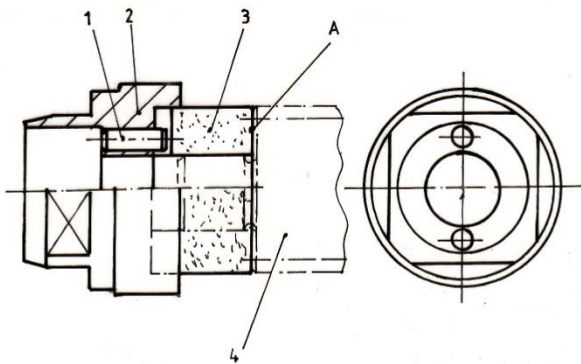


Fig.4 Superfinishing attachment to machining flat surfaces of the gear pump pinions.

The cutting force is achieved by the means of the pneumatic engine (pos.7) that has a longitudinal movement along the rods (pos.6). The body of the abrasive stones (pos.3) is fixed in the support (pos.2) and the bolt (pos.1). For each type of work piece, there is a type of abrasive stone that is fixed on the lever (pos.5) of the pneumatic engine, in a square space that ensures a good position during the processing.



The attachment system of the abrasive stone has two degrees of freedom, one of them given by the turning of the lever (pos.5) around the pin (pos.10) and the other, given by the turning of the tool support in the lever (pos.2). These two degrees of freedom provide a good positioning of the tool on the plane surfaces of the work pieces, which doesn't depend on the accuracy of the work pieces placing between the lathe centers. In that case it is possible that the longitudinal positioning errors of the work piece. The machining process is performed by the means of an abrasive tool, presented in Fig.5.

In order to process another type of work piece, it is only necessary to change the abrasive tool (fig.3) and to make an axial adjustment, according to the length of the work piece. The processing lasts 33 – 35 seconds and the resulted roughness of the surfaces is $R_a = 0.04 - 0.08 \mu m$.

4. Conclusions

The equipment for superfinishing the external surfaces, including two working stations, has the advantage of a large flexibility in processing all range of work pieces and of the possibility to be mounted on all types of universal lathe. The accurate position of the work pieces and the mechanical generation of vibrations can provide a good control of the stones movement.

This constructive solution represents an original system to machining flat surfaces and can be used for any other type of work piece [2]. The device was designed as easy-to-make equipment and it also has a great productivity.

Fig. 5 Abrasive tool to machining flat surfaces.

References

- [1] Buzatu, C., Piukovici, I., Nedelcu, A., Lepadatescu, B: Processing work piece finishing in manufacturing technology, Lux Libris, Brasov, 1998.
- [2] Lepadatescu, B.: Study of processing by superfinishing with abrasive tools – Master degree thesis, Brasov, 1998.
- [3] Gebhardt, E., - Methods of finishing for manufacturing cylinders of rolling mills – In Werkstatt und Betriebs no.1, 1979.
- [4] Harris, C.M., - Shocks and vibrations. Editura Tehnica, Bucuresti, 1985.
- [5] Borkowski, J., A. Szymanski., - Uses of Abrasives and Abrasive Tools. Chichester, Eng.: Ellis Horwood, 1992.

EXPERT SYSTEMS USED THROUGHOUT THE TRAINING OF MASTER ENGINEERS IN THE FIELD OF INDUSTRIAL ENGINEERING

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Abstract: The article offers an approach for training of students from qualification degree 'Master' in the specialty of 'Industrial engineering'. It represents analyses of suitable expert systems which are used throughout the process of computer-based designing and diagnostics of mechanical products. We have created a scheme of an expert system for gear transmission designing as well as algorithms based on rules of production for the purpose of investigation of stress concentrators and change of the geometry of segments from a gear or a shaft. We have also rationalized the usage of appropriate methods for engineering analysis and the usage of software products for simulation modeling and investigation of designed objects' behavior through the use of a Frequency Analysis. The latter also includes searching for collisions that take place during the generation of the designed objects' assembled unit. The results are useful for the purpose of acquisition of skills and knowledge in the field of expert systems application; they would help in the process of searching for creative solutions within the stages of computer-based designing of technical objects, and in the process of diagnostics of their exploitation.

Keywords: EXPERT SYSTEMS, PRODUCTION SYSTEM, TEACHING, MASTER DEGREE, INDUSTRIAL ENGINEERING

1. Introduction

The expert systems for monitoring and diagnostics have had widest application in industry but lately they have been also used in engineering, computer-based designing of technical objects [1,12]. The basic conditions about the expert systems are shown in [5]. The expert systems are based on artificial intellect and that's the reason why they have been widely studied through the training of engineers [8,9].

The Artificial Intellect, according to Bar and Feigenbaum, is a part of Informatics related to design of intellectual computer systems, as intelligence in human behavior and etc. The Artificial Intellect is a new field of human activity from traditional computer sciences. They represent a module from integrated systems for computer-based designing of technical objects as well as details, assembled mechanical units, etc.

In order to establish a base of knowledge and symbolic presentation, one has to use a specialized programming language which is based on rules of production of the 'condition-action' type or of the 'situation-action' type. According to Newel's and Simon's hypothesis [5], each of the physical, symbolic systems has ample, required means for universal, intelligent actions like Heuristic search for solutions. The Heuristic searching is related to specific knowledge and is used as a basis of a graph model.

The presentation which has been made gives us a ground point to consider that the reviewed issue is relevant within the process of training of the forthcoming master engineers who are to use computer-based designing, methods for diagnostics of constructive solutions, and methodology of the bone tissue diagnostic images processing [11].

The main tasks which are to be assigned are the following ones:

- a brief analysis of the training program and a rationale of specific application tasks for the purpose of training in a particular subject and acquisition of knowledge and practical skills within the field of engineering activity;
- application of expert systems for diagnostics of machines and facilities as well as an engineering analysis for searching of creative, constructional solutions.

2. Analysis of the program and rationalization of application tasks throughout the training in the field of expert systems

Expert systems is an optional subject for students from educational degree 'Master' from specialty 'Industrial Engineering'.

The students must acquire knowledge and skills in the usage of expert systems within the process of engineering designing in a CAD environment as well as knowledge and skills in the process of searching for optimal versions of technical solutions throughout the development of constructional documentation. The training course of the subject reviews issues in relation to engineering informatics, structure of expert systems which are based on Artificial Intellect and algorithms created for the purpose of knowledge acquisition in the field of process management. The exercises in a laboratory environment are related to development of algorithms for the purpose of creation of expert systems structures, adaptive control models and management of objects and processes. They also develop knowledge and skills in work with applicable software products whose purpose is to search for creative, technical solutions throughout the designing of mechanical products and methods for diagnostics and improvement. In relation to everything mentioned above, we have reviewed the following issues:

- diagnostics and control of machines and facilities through the use of a vibration analysis;
- development of an expert system and rules of production;
- a frequency analysis of geometrical models through the use of resonance frequencies and their geometrical shape.

2.1 Reducer diagnostics according to a criterion of vibration

Mechanical drives are most frequently encountered in practice as they are represented of gearboxes, reducers, variable-ratio transformers, etc. as they contain bearing knots, couplings, gear transmissions and other units [4]. Fig.1 shows the main machines of a mechanically driven system and the spots in which the vibration in the bearing knots is measured since they are representative extract in the present research [1,7]. According to normative documents VDI 2056 and ISO 10816, the maximum of admissible vibration frequencies in the bearing knots must vary from 10 Hz to 1000 Hz.

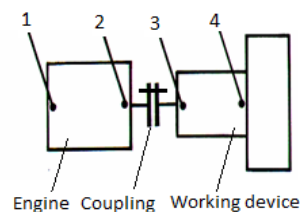


Fig. 1 Measurement of the vibrations in the bearing knot

Fig.2 shows the distribution of vibration frequency of a mechanically driving system which includes an electric motor and a reducer according to the type of breakdowns given by R. Jigulic's 'Theory of oscillation' inherent in this type of a mechanically driving system. It is possible that the following types of stresses could occur throughout the process of exploitation: pulsing stress and altering stress with asymmetrical and symmetrical cycles.

In order to perform diagnostics of elements of a reducer in accordance with a criterion of vibration presence, it is necessary to use a software product for treatment of experimental data as well as a reference record of the normal state of the reducer which corresponds to the condition of performance. An assessment is to be done regarding the vibrations, i.e. strong ones and weak ones [3].

On Fig.3 are shown some reference records which concern the spectrum of vibrations of a reducer.

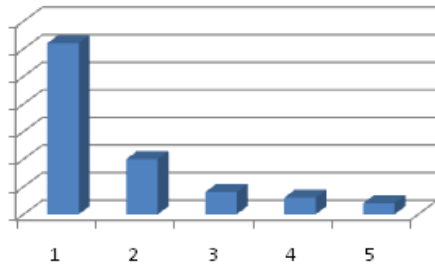


Fig.2 Distribution of the frequency of vibrations

1- Breakdowns in bearings, 2- Imbalance, 3- Axial incompatibility; 4- High temperature, 5- Breakdowns in gears

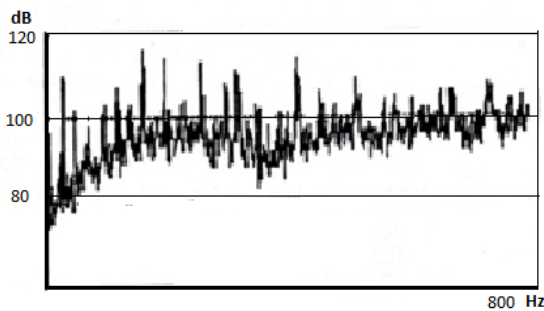


Fig.3 Spectrum of vibrations of a reducer

This methodology can be used for the purpose of establishment of decisions throughout the process of replacement of some machine elements. This is to be performed by preparation of a conclusion made by experts as the most rational way of achieving that is to obtain the conclusion from the system for data treatment. As a result, one can form a recommendation based on the obtained motives as one can have a basis for the decision. The application of this approach can be illustrated by an example of a bearing replacement which is shown on Table 1.

Table 1: Results from diagnostics of bearing vibration test

Conclusion
RECOMMENDATION: To change the bearing. Reason: Accumulation of amplitudes in specter of vibration. The diagnostic symptoms in specter of vibration. 73,06 Hz [59%]; 147.12 Hz [11%]; 218.48 Hz [36%]; 292.3 Hz [11%]; 367.2 Hz [18%].
Remark: >High level in harmonic component of specter; >Strongly harmonic component in region of filter.

Another example of decision establishment during replacement of a bearing can be performed according to a criterion of performance.

2.2 Establishment of a decision for bearing replacement according to the 'performance' criterion

After the completion of all necessary observations and analyses, we have established the following most frequent defects which cause bearing performance loss. These malfunctions can be assessed according to the following indexes: heating, noise, vibrations and durability, and the possible defects are shown on the Table 2.

Table 2: Criteria for diagnostics and defects in bearing elements

Index	Possible defects	Degree
Heating	Break surface, Lubrication	Badly, Strongly
Noise	Break separator, Break ring	Faint noise, Strong noise
Vibration	Deflection in bearings	Badly deflection, Strong deflection
Durability	Catalogue limit live in hours (L_h)	< or >

The complex assessment is to be prepared by the use of two phases of influence: weak and strong or low and high, i.e. in accordance with the durability of the bearing measured in hours time.

The same example can be observed throughout the process of bearing assembly designing in accordance with complex indexes: Durability - by choosing a proper bearing; Heating- by choosing a proper assembly and suitable lubricant; Noise and vibrations- by choosing a camping scheme and determination of the admissible deformations.

3. Application of Production systems.

Production rules are a formalism used in design of program languages before it was used in psychological modeling and in Expert systems. Some of most popular model from "production rules" include: Rules from kind "IF" and "THEN"; Different kinds of network; Logistic equations for coding of facts and principles [2].

In literature concerning expert systems sometimes they are called "condition-action" type of rules or "situation-action" type of rules. This is due to the fact that they are used in order to code empiric relations between models of data presented to the system and actions as the system must execute them as a consequence.

3.1 Solving of conflicts

The strategy of conflict solving is of particular importance for the work of production system and for this purpose must be chosen precisely. The mechanisms for conflicts solving varied but three of them are very popular and often are used in combination thus forming a global direction regime.

Unity. One rule cannot be used more than once for one and the same data.

Actuality. The elements in operational memory in OPS5 contain a field for time, thus it is known on the period of which cycle they are added to operational memory.

Specificity. The concrete elements, drawn from more specific rules, for example rules with greater number of condition, are more difficult to be satisfied and therefore are prefer before more general rules with smaller number of conditions.

Fig.4 shows a sketch of a composed expert system for computer-based designing of a gear transmission with the participation of a constructor and an expert in a dialogue mode. The

constructor has an opportunity to look for technical solutions for improvement of the construction. In most cases, these solutions concern concentrators of stresses. In such a case, the constructor has to make a decision about what to change by composing an algorithm for another geometrical shape or brand of the used material.

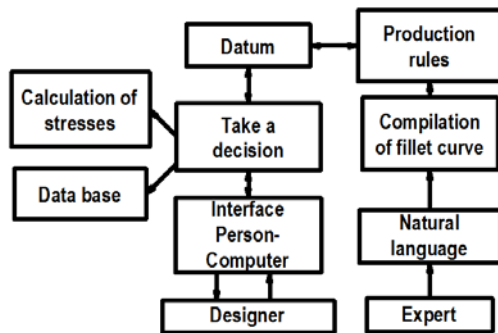


Fig.4 Scheme of expert system for design

This is illustrated by the following algorithm:

If: 1. The fillet radius of curve is 0,5 mm;
 2. The stress $\sigma > 0,260E9$.MPa
 Then: To change the fillet radius of 1,5 mm.
 If: The stress $\sigma > 0,200E9$.MPa
 Then: To chose Steel grade 41Cr4
 If: The stress $< 0,200E9$.MPa.
 Checking of stress is to be performed regularly by the use of the Method of the finite elements ANSYS. Fig.5 shows its corresponding example.

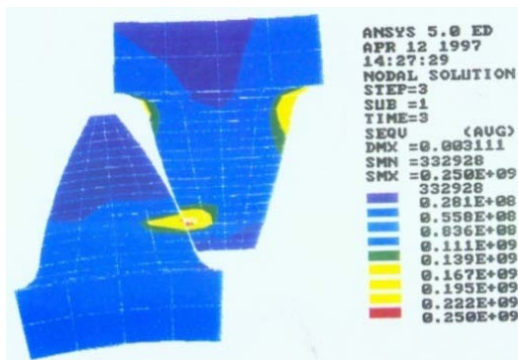


Fig.5 Distribution of stresses in pinion and gear

For investigation of stresses in fillet curves of shaft with Finite Element Methods by ANSYS the designer used 3D geometrical model of shaft and determined theoretical distribution of stresses in character points and surfaces concentrators. Next pictures shown graphical presentation of finally results (Fig.6 and Fig.7).

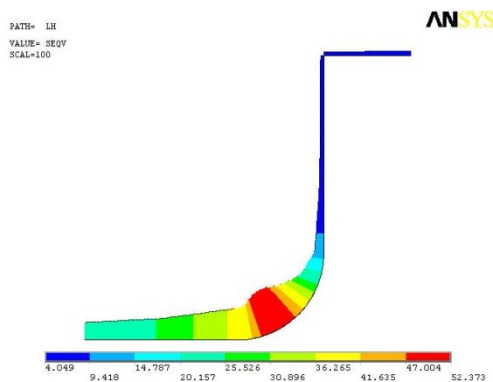


Fig.6 Distribution of stresses in left fillet curve of shaft

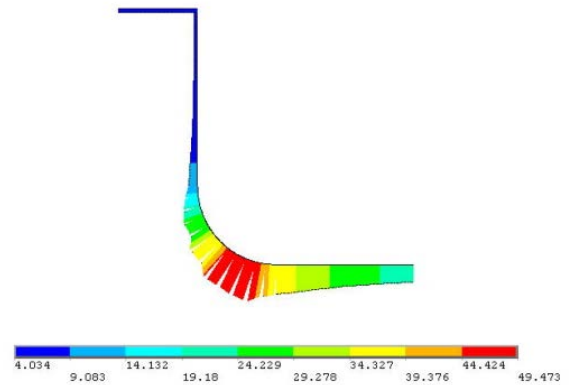


Fig.7 Distribution of stresses on right fillet curve of shaft

The results shown that maximum value for stresses are in left and right zone of fillet curve. This value are from 49 MPa to 53 MPa in the both sides of shaft. The designer can to used the same algorithm.

3.2 Application of simulated modeling for the purpose of engineering analysis

Virtual analysis becomes more and more widely used throughout the process of computer-based designing of mechanical products and their manufacturing. The virtual initiative and development of products include their respective production, manufacture and marketing after their designing is completed. Hence it is advisable to utilize the capabilities of engineering analysis and simulated modeling of technical objects throughout the training in the field of Expert systems. This yields an opportunity for acquisition of better skills and knowledge in the search of creative solutions throughout the engineers' designing thesis works [10].

To this end, one has to use the following methods:

- an engineering analysis through the use of the finite elements method (FEM) which allows researching of the created 3D geometrical models for concentration of stresses [4]. Frequency analysis for the purpose of resonance frequencies verification as well as checking of their respective shape [6] ;
- an engineering analysis in order to verify the turbulent streams through the designing of objects that work with fluids and consistent materials through the usage of the COSMOFLOW software product;
- usage of the Failure Mode and Effects Analysis (FMEA) in order to provide quality of products as means for decreasing of the number of errors during a system analysis. These methods also can reveal the causes for these errors;
- creation of geometric models for kinematic and simulation analysis for the purpose of assembling of the compound parts of assembled units which are planned for the purpose of searching of collisions performed by SolidWorks.

Fig.8 depicts the results from the simulated modeling and from the Frequency Analysis of computer-based investigation of the critical frequency of rotation of a shaft with a symmetrically placed disc, and investigation of the resilience deviation of the shaft. These results could be analyzed and compared to the results which are obtained from exercises performed through the use of a test machine which are frequently conducted through the training in the 'Basics of construction' subject.

The constructor has an opportunity to acquire skills working with Simulation Manager by Solid Works in order to perform frequency analyses of assembled units. The following results are obtained throughout the process of working:

- visual representation of given limitations, division of finite elements of geometrical models (fig.7), and a list of resonance frequencies;

- visual representation of the results obtained from the process of deformation at various resonance frequencies which is done via the use of a fundamental geometric shape (Fig.8).

Fig.9 represents a developed 3D geometrical model of a safety overflow valve which is composed during seminar exercises of the subject 'Basics of construction'. Two basic tasks can be resolved through the use of a simulation model: a mechanical task and a hydraulic task. The mechanical task is related to the axial shifting of the piston whereas the hydraulic task concerns the alteration of pressure and viscosity of the fluid. The distribution of pressures in the inner geometrical shape within the body of the safety overflow valve can be investigated by the use of computer-made simulations.

The useful applicability of the presented models appropriates important motivation to the students when they utilize relevant methods in order to find creative solutions throughout the process of computer-based designing of technical products. The students would be able to use informative materials that are necessary for practical task execution, forming of decisions which concern diagnostics and control of the exploitation reliability of industrial machines and facilities.

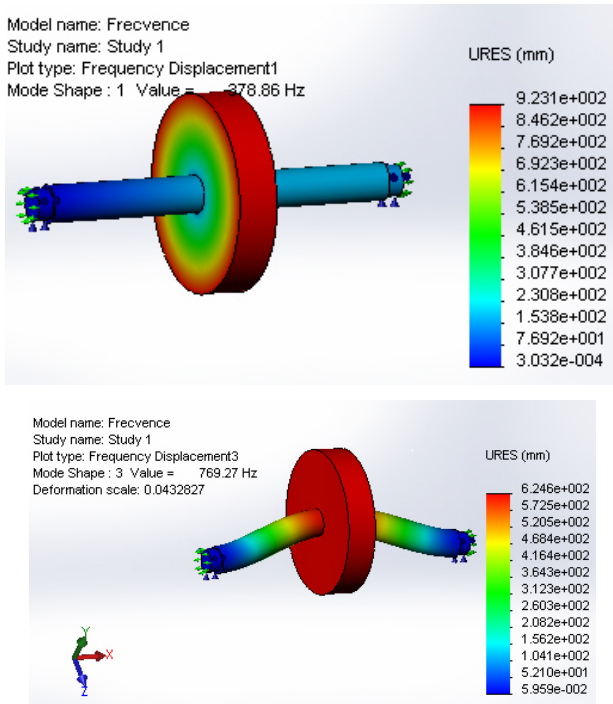


Fig.8 3D simulation model of a rotating shaft

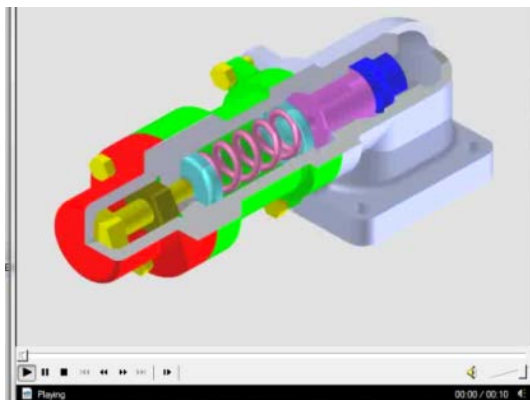


Fig.9 3D simulation model of safety overflow valve

4.Conclusion

Contextual issues related to the training of students studying in the field of qualification degree of 'Master engineer' have been structured in accordance with the already developed curriculum. Specific practice tasks have been assigned as they concern vibration analysis in bearing knots which refer directly to malfunctions and diagnostics of reducers according to criteria of vibration. The excessive clearance in a rolling bearing can cause generation of discrete harmonics frequencies. The typical failures are the following ones: defects on the inner and outer rings, defects of the balls, and, finally, defects in the separator.

A sketch of an expert system has been made as it could be used for the purpose of designing of a gear transmission and algorithms that are based on rules of production which concern investigation of concentrators of stresses and changes of the geometry of elements in a gear or in a shaft.

We have also rationalized the usage of methods for engineering analysis; software products for simulated modeling; investigation of the behavior of designed objects via the Frequency Analysis as well as the process of searching for collisions during the generation of an assembled unit.

The results are useful for the purpose of acquisition of skills and knowledge throughout the application of expert systems as well as for the purpose of development of creative solutions through the stages of computer-based designing of technical objects and the diagnostics of their exploitation.

5.References

1. Barkov A., Monitoring and diagnostic of rotor machine vibration, Sankt Peterburg, 2000 (Barkov I., N. Barkova, A. Asovzev), (In Russian).
2. Dimitrov K. Fault Diagnostics in Industrial systems, PROPELIERS, 2012.
3. Dimitrov K. Reability of mechanical equipment machines and systems, ABC TECHNICA, Sofia, 2011.
4. Dinev G. Principles of Mechanical Design, AVANGARD PRIMA, 2011.
5. Jackson P. Introduction to expert systems. Allison Wasley Longman, 1998.
6. Tashev M. Engineering analysis with Finite Elements Metod, EKS-PRES, Gabrovo, 2012 (Tashev M.,P. Jordanov),(In Bulgarian).
7. Dinev G. Some investigation of failure mechanisms in gears from tractive reducers, Journal of Material Sciences and Technology, Bulgarian Academy of Sciences, Sofia, vol.4., 2002, pp. 30-41.
8. Dinev G., Application of expert systems by computer design of transport gear boxes, Journal mechanic of machines,Varna, Vol.2, 2006, pp. 16-17 (Dinev G., D. Katzov).
9. Dinev G., Computer design and precision control for assembling of mechanical assembly unit, Academic Journal Manufacturing Engineering, Brasov, Vol.10, ISSUE 3, 2012, pp. 32-37 (Dinev G., L. Popa, B. Lepadatescu).
10. Dinev G., Virtual analysis of manufacturability of vane pumps, Journal Applied Mechanics and Materials, Zurih, Vol.555, 2014, pp 479-484 (Dinev G., P. Angelov, E. Chalakov).
11. Milojevic Z., Methodology of the bone tissue diagnostic images processing, Academic Journal Manufacturing Engineering, Brasov, Vol.10, ISSUE 3, 2012, pp. 63-70 (Milojevic Z., M. Vicevic, M. Zelejkovic, S. Navalusic).
12. Mechdi K., in: An integrated CAD system for design of a gear transmission box, Procciding of International Conference,September, 1955, New Castle Upon Tyne, pp. 213-219 (Mechdi K., D. Benchouine , D. Play).

CORROSION PROPERTIES OF Ti-6Al-4V ALLOY WITH NITRIDE AND OXYNITRIDE COATINGS IN PHYSIOLOGICAL SOLUTIONS

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Abstract: In this work, the corrosion resistance of Ti-6Al-4V alloy with nitride and oxynitride coatings was investigated in isotonic 0.9 % NaCl solution and Ringer's solution at temperatures of 36 °C and 40 °C, which simulates the transition from normal to inflammatory condition of the human body. It was determined that the change of temperature of both physiological solutions does not decrease the protective function of nitride coating on Ti-6Al-4V alloy. It was shown that the corrosion properties of oxynitride coating are deteriorated by increasing the temperature up to 40 °C, especially in 0.9 % NaCl solution.

Keywords: TI-6AL-4V ALLOY, NITRIDE AND OXYNITRIDE COATINGS, CORROSION, 0.9 % NaCl, RINGER'S SOLUTION

1. Introduction

Titanium alloys are widely used for orthopaedic and dental implants under load-bearing conditions because of their excellent characteristics such as chemical inertia, low density, mechanical resistance, absence of toxicity, resistance to corrosion and biocompatibility [1–4]. Among all titanium alloys, Ti-6Al-4V alloy is the most frequently used as hard tissue replacement in artificial bones, joints and dental implants [5–7].

The relatively poor tribological properties and possible corrosion problems using titanium implants require the surface engineering to increase near-surface strength, improving the hardness and abrasive wear resistance thereby reducing the coefficient of friction as well as avoiding or reducing the transference of ions from the surface or bulk material to the surrounding tissue [4, 7–10]. Titanium nitrides can effectively improve the corrosion and wear resistance of titanium alloys, so they are widely used in implants as coating material [8, 9, 11]. The addition of oxygen to titanium nitride (TiN) to form titanium oxynitride (TiN_xO_y) has recently attracted attention [8, 9, 12, 13]. This is due to the fact that titanium oxynitrides benefit from many remarkable properties of both insulating titanium oxides (chemical stability, optical properties) and metallic titanium nitrides (hardness, wear resistance). In comparison with TiN, titanium oxynitride has shown new interesting properties that can be used as biomaterials.

All the surgically implantable metallic materials, including the most corrosion-resistant materials, undergo chemical or electrochemical dissolution due to the influence of corrosive environment of human body [14, 15]. Therefore, the investigations of the corrosion behaviour of Ti-6Al-4V alloy with protective coatings in physiological solutions simulating the human body fluid are sufficiently urgent.

The purpose of this work is to study the corrosion resistance of Ti-6Al-4V alloy with nitride and oxynitride coatings at the change of temperature of the physiological solutions (0.9 % NaCl solution and Ringer's solution) from 36 °C to 40 °C.

2. Experimental procedure

The samples of ($\alpha+\beta$) Ti-6Al-4V alloy (Al – 6.0, V – 4.0, Fe – 0.25, C – 0.1, O – 0.15, N – 0.04, H – 0.015 wt. %, Ti – balance) of dimensions 15×10×1 mm were investigated. The samples were mechanically ground using different grades of SiC papers, followed by diamond polishing to a surface roughness of $R_a=0.06\text{ }\mu\text{m}$. Then they were ultrasonically cleaned with alcohol and dried.

Nitriding of Ti-6Al-4V alloy was conducted by the thermodiffusion treatment in nitrogen at 850 °C for 12 h. The partial pressure of nitrogen was 1 Pa.

Titanium oxynitrides were formed by the subsequent oxidation of preformed titanium nitrides in oxygen-containing gas medium on the cooling stage from 650 °C to 500 °C.

The phase of surface layers of Ti-6Al-4V alloy after thermodiffusion treatment was determined using X-ray diffractometer (XRD) with $\text{CuK}\alpha$ radiation operated at 30 kV and 20 mA. The diffraction pattern profiles were refined by the Rietveld method with two different pseudo-Voigt functions using Powder Cell 2.4 [16] and Sietronix programs. Titanium oxynitride was identified using the standard diffraction pattern obtained in accordance with the model by Levi et al. [17]. This model assumed that the non-metal sub-lattice was disordered (the N and O atoms randomly occupied the $(\frac{1}{2}\ \frac{1}{2}\ \frac{1}{2})$ positions), whereas the Ti atoms occupied the (0 0 0) positions.

Elemental analysis of the alloy surface after potentiodynamic polarization was evaluated using energy dispersive X-ray spectrometer INCA Energy 350.

The electrochemical tests of Ti-6Al-4V alloy with nitride and oxynitride coatings were carried out in isotonic 0.9 % NaCl solution and Ringer's solution ((in g/l): NaCl – 9.0; KCl – 0.43; CaCl_2 – 0.24; NaHCO_3 – 0.20) at temperatures of 36 °C and 40 °C. The transition from normal to inflammatory condition of the human body was simulated by the change of temperature of the solution. The potentiodynamic polarization curves were recorded using IPC-pro potentiostat in the potential range of -1.0...2.5 V at a scan rate of 2 mV/s. All potentials were measured against the Ag/AgCl reference electrode. Three-electrode glass cell with a platinum counter electrode and a saturated Ag/AgCl reference electrode was used. Surface of the working electrode of Ti-6Al-4V alloy was coated with epoxy resin, leaving area for exposure to the electrolyte of 1 cm^2 .

3. Results and discussion

The nitride film delimited from the alloy matrix by diffusion zone was formed in the process of nitriding of Ti-6Al-4V alloy. According to the results of X-ray analysis (Fig 1 a), the film contains mainly Ti_2N phase (~ 65 %), represented by the (101), (111), (002), (320) and (321) reflections. At the same time the (111), (200) and (220) reflections of the weak relative intensity indicate on the presence of TiN phase (~ 4 %).

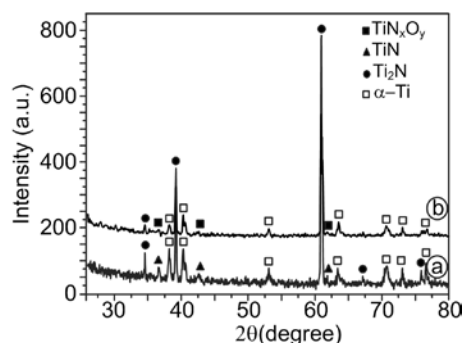


Fig. 1 Diffraction spectra of Ti-6Al-4V alloy after nitriding (a) and subsequent oxidation of nitride coating (b).

During oxidation of Ti-6Al-4V alloy with nitride coating the oxynitride film was formed on its surface. It is represented by the (111), (200) and (220) reflections (Fig 1 b). In addition, the reflections of Ti_2N phase and α -Ti phase are presented in the diffraction spectrum of the alloy.

The potentiodynamic polarization curves obtained for Ti-6Al-4V alloy with nitride and oxynitride coatings in isotonic 0.9 % NaCl solution and Ringer's solution at 36 °C and 40 °C are shown in Fig. 2–Fig. 5. Table 1 and Table 2 represent the corresponding corrosion parameters.

On the anodic branch of the potentiodynamic curve of Ti-6Al-4V alloy with nitride coating in 0.9 % NaCl solution at 36 °C (Fig. 2, curve 1) there are two peaks of the anodic dissolution at potentials of 0.07 and 0.3 V after the region of the active dissolution of the film. They are associated with the dissolution of the nitride film with the formation of corrosion products on the surface.

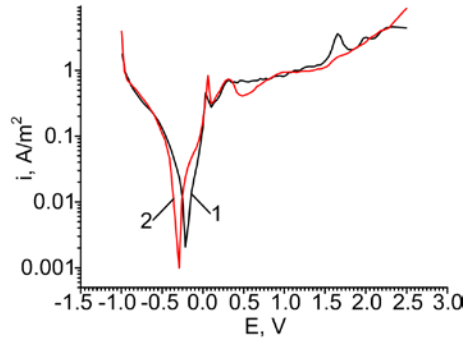


Fig. 2 Potentiodynamic curves of Ti-6Al-4V alloy with nitride coatings in 0.9 % NaCl solution at 36 °C (curve 1) and 40 °C (curve 2).

By increasing the temperature of the solution to 40 °C two peaks of the anodic dissolution are observed on the anodic branch of potentiodynamic curve also (Fig. 2, curve 2). The passive region is observed in the range of potentials 0.75...1.5 V. The passive current density is 0.9 A/m². This is due to the formation of more protective passive films on the surface which slow the anodic dissolution of surface. The decrease of chlorine content on the surface from 0.23 to 0.11 wt.% also indicates on the less dissolution of nitride film at 40 °C. The corrosion current density decreases in 1.5 times (Table 1).

Table 1: Corrosion parameters of Ti-6Al-4V alloy with nitride coatings in physiological solutions.

Physiological solution	36 °C		40 °C	
	i_k [A/m ²]	E_k [V]	i_k [A/m ²]	E_k [V]
0.9 % NaCl solution	0.006	-0.20	0.004	-0.30
Ringer's solution	0.020	-0.23	0.023	-0.41

On the anodic branch of the potentiodynamic curve of Ti-6Al-4V alloy with nitride coating in Ringer's solution at 36 °C (Fig. 3, curve 1) the anodic dissolution of surface film is occurred to potential of 0.45 V. Further decrease of the anodic current density is obviously caused by the formation of unstable films on the surface, which then dissolve.

By increasing the temperature of the solution to 40 °C the corrosion current density of Ti-6Al-4V alloy with nitride coating isn't changed practically (Table 1). The first passive region is occurred in the range of potentials -0.1...0.4 V (Fig. 3, curve 2). The passive current density is 0.08 A/m². The second passive region is observed at the potentials of 1.10...1.34 V. It is due to the formation of more protective passive films on the surface. The passive current density is 0.3 A/m².

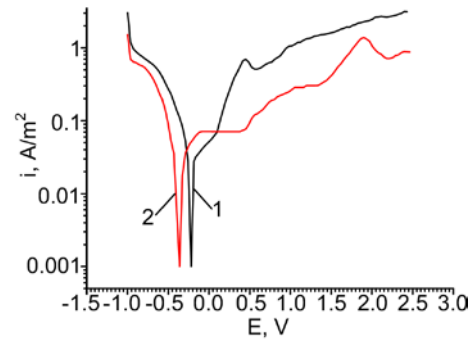


Fig. 3 Potentiodynamic curves of Ti-6Al-4V alloy with nitride coatings in Ringer's solution at 36 °C (curve 1) and 40 °C (curve 2).

Thus, increasing the temperature of both 0.9 % NaCl solution and Ringer's solution from 36 °C to 40 °C does not deteriorate the corrosion properties of Ti-6Al-4V alloy with nitride coating.

On the anodic branch of the potentiodynamic curve of Ti-6Al-4V alloy with oxynitride coating in 0.9 % NaCl solution at 36 °C (Fig 4, curve 1) the wide passive region at the potentials of 0.1...1 V is observed. The passive current density is 0.013 A/m². The existence of this passive region is caused by the resistance of oxynitride film formed in the process of oxidation of preformed titanium nitride. In addition, according to the results of the energy dispersive X-ray spectroscopy, the corrosion products on the base of titanium, oxygen and chlorine are formed on the surface in the process of polarization. It obviously provides the additional protection of the surface.

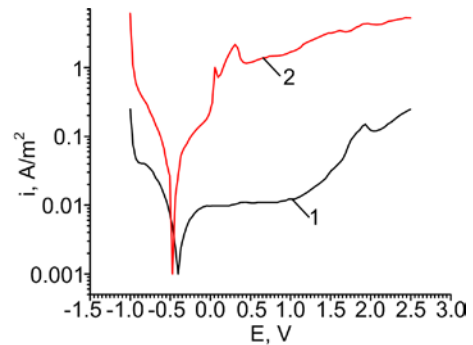


Fig. 4 Potentiodynamic curves of Ti-6Al-4V alloy with oxynitride coatings in 0.9 % NaCl solution at 36 °C (curve 1) and 40 °C (curve 2).

By increasing the temperature of the solution to 40 °C the corrosion current density increases in 6.5 times (Table 2) and corrosion potential shifts to more negative potential range (Fig. 4, curve 2). It indicates on the decrease of the corrosion resistance of oxynitride film.

Table 2: Corrosion parameters of Ti-6Al-4V alloy with oxynitride coatings in physiological solutions.

Physiological solution	36 °C		40 °C	
	i_k [A/m ²]	E_k [V]	i_k [A/m ²]	E_k [V]
0.9 % NaCl solution	0.002	-0.41	0.013	-0.43
Ringer's solution	0.017	-0.33	0.022	-0.40

On the anodic branch of the potentiodynamic curve of Ti-6Al-4V alloy with oxynitride coating in Ringer's solution at 36 °C (Fig. 5, curve 1) there is a wide passive region at the potentials of -0.1...0.7 V. It is due to the resistance of oxynitride film formed in the process of the oxidation of preformed titanium nitride. The passive current density is 0.06 A/m².

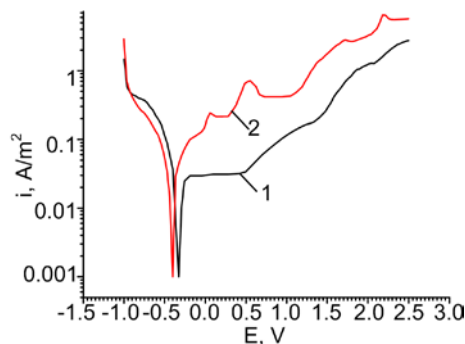


Fig. 5 Potentiodynamic curves of Ti-6Al-4V alloy with oxynitride coatings in Ringer's solution at 36 °C (curve 1) and 40 °C (curve 2).

By increasing the temperature of the solution to 40 °C the interaction of chloride ions with the surface intensifies: the content of chlorine increases to 1.14 wt.%. The corrosion potential shifts to more negative potential range and corrosion current density increases (Table 2). The short passive region is observed in the potential range of 0.10...0.25 V (Fig. 5, curve 2). The passive current density is 0.2 A/m². Further increase of the current density is caused by the dissolution of surface film. The passivation of surface is observed at the potentials of 0.65...1.0 V. The passive current density is 0.4 A/m².

Thus, increasing the temperature of both physiological solutions from 36 °C to 40 °C leads to decrease of the corrosion protection of Ti-6Al-4V with oxynitride coating, especially in 0.9 % NaCl solution.

4. Conclusions

Increasing the temperature of both 0.9 % NaCl solution and Ringer's solution from 36 °C to 40 °C, which simulates the environment of human body in normal and inflammatory conditions, does not deteriorate the protective function of nitride coating on Ti-6Al-4V alloy.

By increasing the temperature of the physiological solutions from 36 °C to 40 °C the corrosion protection of Ti-6Al-4V alloy by oxynitride coating is deteriorated due to an activation of the interaction of the surface with chlorine ions.

5. References

1. Souza J.C.M., Barbosa S.L., Ariza E., Celis J.-P., Rocha L.A., Simultaneous degradation by corrosion and wear of titanium in artificial saliva containing fluorides, *Wear*, 292-293, 2012, 82-88.
2. Xie F.X., He X.B., Cao S.L., Lu X., Qu X.H., Structural characterization and electrochemical behavior of a laser-sintered porous Ti-10Mo alloy, *Corrosion Science*, 67, 2013, 217-224.
3. Fojt J., Joska L., Málek J., Corrosion behaviour of porous Ti-39Nb alloy for biomedical applications, *Corrosion Science*, 71, 2013, 78-83.
4. Yildiz F., Yetim A.F., Alsaran A., Efeoglu I., Wear and corrosion behaviour of various surface treated medical grade titanium alloy in bio-simulated environment, *Wear*, 267, 2009, 695-701.
5. de Assis S.L., Wolynec S., Costa I., Corrosion characterization of titanium alloys by electrochemical techniques, *Electrochimica Acta*, 51, 2006, 1815-1819.
6. El-Taib Heakal F., Ghoneim A.A., Mogoda A.S., Awad Kh., Electrochemical behaviour of Ti-6Al-4V alloy and Ti in azide and halide solutions, *Corrosion Science*, 53, 2011, 2728-2737.
7. Gu Y.W., Khor K.A., Cheang P., In vitro studies of plasma-sprayed hydroxyapatite/Ti-6Al-4V composite coatings in simulated body fluid (SBF), *Biomaterials*, 24, 2003, 1603-1611.
8. Probst J., Gbureck U., Thull R., Binary nitride and oxynitride PVD coatings on titanium for biomedical applications, *Surface & Coatings Technology*, 148, 2001, 226-233.
9. Subramanian B., Muraleedharan C.V., Ananthakumar R., Jayachandran M., A comparative study of titanium nitride (TiN), titanium oxynitride (TiON) and titanium aluminum nitride (TiAlN), as surface coatings for bio implants, *Surface & Coatings Technology*, 205, 2011, 5014-5020.
10. Vadiraj A., Kamaraj M., Effect of surface treatments on fretting fatigue damage of biomedical titanium alloys, *Tribology International*, 40, 2007, 82-88.
11. Piscanec S., Colombi Ciacchi L., Vesselli E., Comelli G., Sbaizero O., Meriani S., De Vita A., Bioactivity of TiN-coated titanium implants, *Acta Materialia*, 52, 2004, 1237-1245.
12. Martin N., Lintymer J., Gavaille J., Chappé J.M., Sthal F., Takadom J., Vaz F., Rebouta L., Reactive sputtering of TiO_xN_y coatings by the reactive gas pulsing process. Part II: The role of the duty cycle, *Surface & Coatings Technology*, 201, 2007, 7727-7732.
13. Do H., Wu Y.-H., Dai V.-T., Peng C.-Y., Yen T.-C., Chang L., Structure and property of epitaxial titanium oxynitride grown on MgO(001) substrate by pulsed laser deposition, *Surface & Coatings Technology*, 214, 2013, 91-96.
14. Güleriyüz H., Cimenoglu H., Effect of thermal oxidation on corrosion and corrosion-wear behaviour of a Ti-6Al-4V alloy, *Biomaterials*, 25, 2004, 3325-3333.
15. Kwok C.T., Wong P.K., Cheng F.T., Man H.C., Characterization and corrosion behavior of hydroxyapatite coatings on Ti6Al4V fabricated by electrophoretic deposition, *Applied Surface Science*, 255, 2009, 6736-6744.
16. Kraus W., Nolze G., Powder Cell – a program for the representation and manipulation of crystal structures and calculation of the resulting X-ray powder patterns, *Journal of Applied Crystallography*, 29, 1996, 301-303.
17. Levi G., Kaplan W.D., Bamberger M., Structure refinement of titanium carbonitride (TiCN), *Materials Letters*, 35, 1998, 344-350.

PLASMA TECHNOLOGIES FOR OBTAINMENT OF COMPOSITE MATERIALS DISPERSION HARDENED BY NANOSTRUCTURED PARTICLES

ПЛАЗМЕННЫЕ ТЕХНОЛОГИИ ПОЛУЧЕНИЯ МНОГОФУНКЦИОНАЛЬНЫХ ДИСПЕРСНОУПРОЧНЕННЫХ НАНОСТРУКТУРИРОВАННЫМИ ЧАСТИЦАМИ КОМПОЗИЦИОННЫХ МАТЕРИАЛОВ

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Abstract: Prospects for creation of plasma electric discharge technology for production of dispersion-hardened by nanoparticles composite materials are considered. Physical modelling of plasma formations distribution in discharge camera is performed. The regularities of the electric discharge processing parameters influence on dispersity, phase composition and electrical resistivity of obtained powders are studied. The regime for spark plasma sintering of processes powders is theoretically and experimentally justified.

Keywords: PLASMA TECHNOLOGY, ELECTRIC DISCHARGE, SPARK PLASMA SINTERING, POWDERS, CARBIDE-STEEL

1. Introduction

The expectations of the industry to the hardness and wear resistance of structural and tool materials increases, so obtainment of multifunctional materials by powder metallurgy is promising [1]. Properties of consolidated powder material depends both on the properties of the initial blend and on the mode of its sintering. In turn, the properties of the blend depends largely on the method of its preparation. Conventional mechanical milling is quite energy consuming and leads to the appearance of inclusions, which could affect the properties of the consolidated material [2]. It is known that conventional consolidation methods lead to grain growth due to prolonged heating.

A new approach in developed plasma technologies consists in the fact that dispersion-hardening additives (in particular, TiC and TiB₂) are not introduced mechanically to the powder mixture as an additional component in the blending of powders, as in the conventional methods, but instead are formed during electric discharge (ED) processing as a result of the reaction of synthesis under the influence of microplasma discharges. A distinct feature of new approach for creating dispersion-hardening additives is the implementation of a cyclic pulse (a few microseconds), substantially non-oxidizing ED in the disperse system "hydrocarbon liquid - powder". Due to the pyrolysis of hydrocarbon liquids by discharge plasma channel, nanocarbon of various allotropic forms (depending on the composition of the fluid) is synthesized. Intense thermal (plasma) and mechanical (shock wave) impact on the initial powders and mixtures thereof is accompanied by an increase in the number of defects in the crystal structure that promotes activation and dispersion of particles material. Also, due to exposure to low temperature plasma melting or evaporating of particles may occur, which leads to changes in their properties during rapid cooling in liquid. The prospect of using ES technology is associated with the possibility of obtaining a uniformly distributed micro- and nano-sized particles with a high level of free energy in the composition of the powder blend and, consequently, with an increased ability to intensively react with nanocarbon particles to create a strengthening phases.

Preservation of high dispersion of the products material grains is carried out through the use of spark plasma sintering (SPS). During SPS, which consists in passing the pulsed current (superposition of AC and DC) through the powder while the mechanical seal, plasma formation in the gas phase that fills the gaps between the particles arouses. This contributes to the rapid heating and (under external pressure) intensive compaction to almost nonporous state that would greatly ensure the safety of the ultrafine structure and makes possible obtaining high-density powder composites with improved physical and mechanical properties [3].

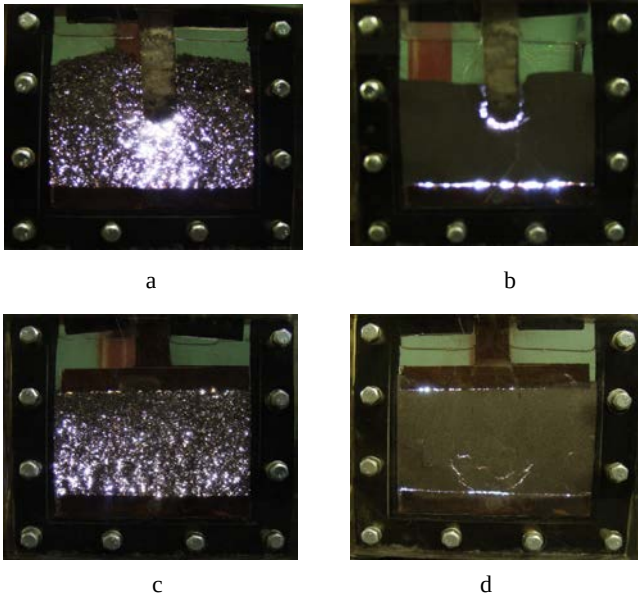
The aim of present work is consideration of a holistic approach to the technology of obtaining multifunctional, dispersion-

hardened by nanostructured particles composite materials using a set of plasma processing technologies containing steps from the production of powder blend to production a finished product with improved functional properties.

2. Modelling of electric discharge processes in a layer of Ti powder in kerosene

Effective management of the processes of plasma ED preparation of powders requires knowledge about the influence of the configuration of the electric field (studies have been performed with the systems of the point-plane or plane-plane) and the dispersion of the treated powder patterns on distribution of plasma formations and nature of the process of high-voltage electrical discharge. Therefore, physical modeling of electric discharge processes occurring in a layer of Ti powder in kerosene was performed. The use of flat, transparent discharge chamber, allowed to photograph discharges in powder thicker. During the investigations it was found that the use of the electrode system (ES) point-plane, as compared with the case of applying ES plane-plane, increases the density of the plasma formations in the central area of the chamber and as a consequence, increases current density and the proportion of the energy released in that area. Application of plane-plane system allows to achieve greater uniformity of treatment of the powder, but the use of the point-plane in conjunction with the mode of processing, which provides mixing particles of the powder, improves the processing efficiency due to the concentration of energy to the electrode region. It is also found that the influence of the electric field configuration on the distribution of plasma formation is minimized by reducing the average diameter (d_{av}) of the processed powder (see Fig. 1).

Obtained results were used for the design of electric discharge reactors in the development of plasma technologies. The dependence of the distribution of plasma formations in the discharge chamber on the dispersion of the processed product and the configuration of the electric field showed the possibility for development of new technological methods for powders ED processing oriented on changing the morphometric characteristics of the solid phase and its phase composition.



a – $d_{av}=1\text{mm}$, ES point-plane; b – $d_{av}=0,1\text{mm}$, ES point-plane; c – $d_{av}=1\text{mm}$, ES plane-plane; d – $d_{av}=0,1\text{mm}$, ES plane-plane

Figure 1 – Integral images of discharges in the disperse system "titanium powder in kerosene."

3. Impact of ED processing on dispersity and phase composition of obtained powder blend

Results of physical and theoretical modeling of ED processes in the disperse system "metal powder - kerosene", presented in Section 2 and papers [4, 5], helped to create an experimental stand and to set processing modes, providing high dispersion of the powder and the appearance of a dispersion-hardening phases [5].

Regularities of impact of current rise rate, pressure in discharge channel, integral energy and processing time onto regularities of morphometric characteristics change and dispersion kinetics of powder mixtures 75 % Fe + 20 % Ti + 5 % B_4C (mass portions) and 80 % Fe+20 % Ti (mass portions) as well as of Fe and Ti powders in kerosene were experimentally found out. It is established that ED treatment with current rise rate $di/dt \sim 28 \text{ GA/s}$ and integral energy $W_2=4 \text{ MJ}$ allows to obtain highly disperse (35 % of particles has sizes from 0,05 to 1 μm) homogenous blend for carbide steels – system of iron-carbon alloy – carbide (diboride) of titanium.

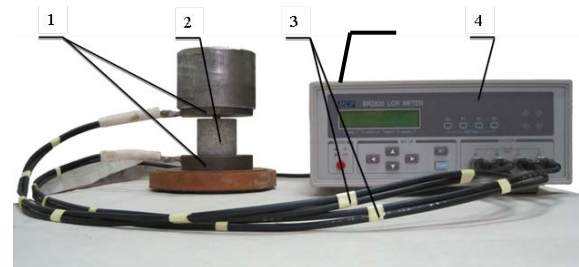
Phase composition of powder mixture 75 % Fe + 20 % Ti + 5 % B_4C (mass portions) after ED treatment changes in every one of chosen and theoretically justified treatment regimes. Achievement of current rise rate no less, then $\sim 17 \text{ GA/s}$ is a condition for formation of phases like TiC, FeB, Fe_2Ti and $Fe_3(B_{0,7}C_{0,3})$. The regularities of communication of titanium powder carbidization (up to 98 %) with an increase of current density j_k in the discharge channel from 0,08 to 0,56 kA/mm^2 are found out. ED treatment opens a way for controlling homogeneity of synthesized titanium carbide by variation of energetic parameters and allows obtaining powder blend, saturated with nanostructured dispersion-hardening carbides and borides particles.

4. Changes of powder blend electrical resistivity as a result of ED processing

When using electric current consolidation methods electrical resistance of the powder composition plays an important role: high resistance impedes the flow of current, resulting in uneven heating of the sample and disruption of its integrity. Electrical resistance of metal powders is associated with the composition, size and shape of the powder particles. Thus, a large amount of coarse particles of spherical or fragmental shape reduces contact area and increases the

value of electric resistance. It is possible to reduce electrical resistance by varying the fineness and shape of the powder particles, and removing a surface oxide film. As shown in Section 3, ED treatment leads to a refinement of the particles, changing the shape and phase composition of the powder, which should affect the change in electrical resistance of the blend.

Studies of electrical resistance change of powder compositions 75% Fe+25% Ti and 75%Fe+20%Ti+5% B_4C , treated by ED in kerosene with constant total processing energy 1 MJ and variation of single discharge stored energy in the range from 0.25 to 1 kJ (amount of energy stored in the capacitive storage and released to the work environment at one discharge of a series) were performed. Experimental stand (see Fig. 2) was assembled to determine the electrical resistance. Powder was filled in a dielectric cell (Fig. 2, position 2), which was then put in the press (not showed on Figure), and then cyclic loading of samples was performed. The number of cycles was at least 3, the pressure load of each series of cycles ranged from 0.6 to 60 MPa.



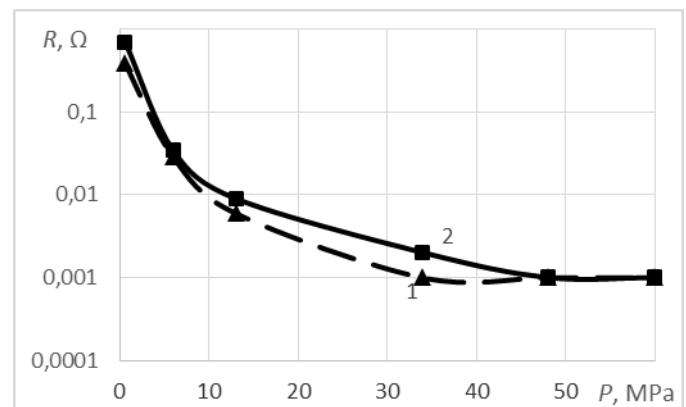
1 - punch - contacts; 2 – dielectrical cell; 3 – commutation cables; 4 - MCP "BR 2820" LCR METER; 5 – load, providing pressure of 0,6 MPa

Figure 2 – Stand for the resistance of the powders determination

It is found out that composition of studied mixture has significant impact on electrical resistance: presence of semiconductive B_4C (5 %) in the composition of 75 % Fe + 20 % Ti mixture leads to the increase of electrical resistivity from ~ 120 up to $\sim 200 \text{ k}\Omega$.

ED treatment of powder mixtures of 75 % Fe + 25 % Ti and 75 % Fe + 20 % Ti + 5 % B_4C compositions leads to decrease of electrical resistance from ~ 120 and $\sim 200 \text{ k}\Omega$ to $\sim 1,5$ and $\sim 400 \Omega$ with $W_1=0,25 \text{ kJ}$ and to $\sim 0,4$ and $\sim 0,7 \text{ m}\Omega$ with $W_1=1 \text{ kJ}$ respectively to composition.

Increase of mechanical pressure from 0,6 up to 60 MPa leads to decrease of electrical resistance R of studied powders, but it is still affected by presence of boron carbide. However ED treatment of the mixtures with $W_1 = 1 \text{ kJ}$ leads to the fact that when a pressure is greater than 40 MPa, the composition of the initial mixture does not affect the electrical resistivity (see Fig. 3).



1 – 75% Fe+25% Ti; 2 – 75%Fe+20%Ti+5% B_4C ;

Figure 3 – Dependence of the electrical resistivity of powder mixtures of different initial composition after ED treatment with $W_1 = 1 \text{ kJ}$ on the prepressing pressure

Analysis of data obtained by measuring the electric resistance of the powder mixtures allows to select the optimum characteristics of consolidation by electric current depending on the initial pressure. Furthermore, the obtained dependencies of powder electrical resistance on its particle size and phase compositions have allowed to establish the methodology of express analysis of resulting powder blend quality by monitoring its electrical resistance without direct study of dispersion and phase composition.

5. Technological methods of spark plasma sintering of powder blend, obtained by plasma ED technology of powders preparation

To preserve fine-grained structure of the material during the sintering methods of consolidating the concentrated streams of energy are used. These methods are characterized by high heating rates and less time of holding at the maximum temperature than when using conventional methods of sintering. Spark plasma sintering (SPS) is one of such methods [3].

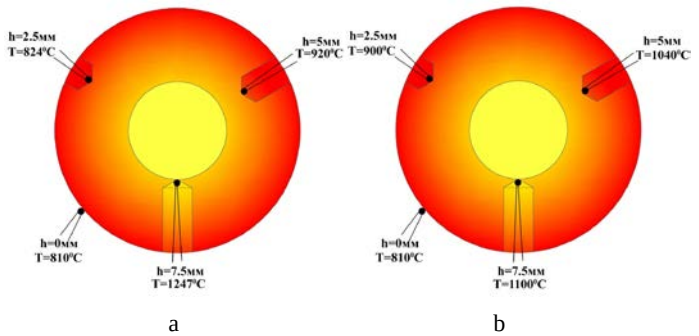
Experimental SPS complex "Gefest-10" [6] has been developed in IPPT NASU. This complex is based on the direct passage of output current with an amplitude value of 1 kA (superposition of DC and high frequency, up to 10 kHz AC) through powder composition. Direct current heats evenly all section of the briquette, but due to the heat sink peripheral areas are cooled. The alternating current due to skin effect is partly displaced to the surface section of the sample and preferably carries out heating of the peripheral portion. This compensates for the effect of the heat sink and aligns temperature conditions over the section of specimen.

"Gefest-10" experimental complex consists of current source, manual hydraulic press PRG -1, vacuum chamber, vacuum pump 2NVR-5DM and control systems. Current source - spark-plasma sintering generator, consists of high-frequency power rectifier - transformer module, a high-frequency inverter with an air cooling system, the transistor driver and the control system. "Gefest-10" contains RS-485 digital Interface for displaying controlled parameters of temperature in the sintering zone, the current through the sintered sample and voltage across sintering chamber current buses on the PC.

Studies were performed using blend, prepared by plasma ED method (see Sections 3, 4). Power of heat flow was calculated using experimentally measured values of electrical resistivity of blank during sintering[7]. It allowed theoretical evaluation of thermal field distribution in matrix basing on Fourier law (see Fig. 4, a).

Experimental verification of the theoretical evaluation of distribution of the thermal field in the matrix was performed by examining the distribution of the temperature field with thermocouples by drilling during walls of graphite matrix to a depth of 2.5, 5 and 7.5 mm from the surface (see Fig. 4, b). Matrix made of MPG-6 graphite with wall thickness of 7.5 mm was used, the weight of obtained samples was 3 grams, height 7 – mm, diameter - 10 mm.

Theoretical evaluation of the thermal field distribution and experimental studies of sintering system Fe-Ti-BC blend showed the existence of low-melting eutectics, that facilitates high-density material, when the temperature on the surface of the matrix $T = 810^{\circ}\text{C}$ (the temperature of sample $T = 1100^{\circ}\text{C}$). Blend compaction kinetics was studied to determine optimal heating ratio when entering the sintering regime. Ashby power creep model was chosen as a model of deformation [8].



a – theoretical distribution of thermal field;
b – experimental distribution of thermal field

Figure 4 – The stationary distribution of the temperature field through the thickness of a single layer of the cylindrical wall of the graphite matrix with the theoretical calculation of control points

It is found that at a heating rate of $100^{\circ}\text{C}/\text{min}$. ($1,65^{\circ}\text{C}/\text{s}$) sample, which was released on the exposure mode, has a total porosity of about 10%, which is reduced to 1-2% during exposure (exposure time – 120 s). Further increase of heating rate leads to increase of porosity, and decrease of heating rate increases the possibility of structure grain growth.

Accuracy of presented methodology was tested on the example of the SPS of blend, batch obtained by ED treatment of powders mixture 75% Fe-20% Ti-5% B_4C . Taking into account performed experimental and theoretical studies such SPS parameters were selected: sintering pressure $P=60\text{ MPa}$, heating rate when entering sintering mode – $100^{\circ}\text{C}/\text{min}$. ($1,65^{\circ}\text{C}/\text{s}$), holding temperature $T=810^{\circ}\text{C}$, holding time $\tau=120\text{ s}$.

Flexural strength of obtained metal matrix composites amounted up to 1350 MPa, hardness - 68 HRC, frictional wear resistance paired with diamond wheel - 28 mg / km. For comparison - wear resistance of high-speed steel P6M5 under these conditions is 40 mg / km.

Conclusions

1. The holistic approach to the technology of obtaining multifunctional, dispersion-hardened by nanostructured particles composite materials using a set of plasma processing technologies containing steps from the production of powder blend by ED preparation of powders to production a finished product with improved functional properties by SPS was developed.

2. Established dependence of nature of plasma formations distribution in the discharge chamber on the dispersion of the processed product and the configuration of the electric field led to the development of new technological methods of ED powders treatment targeting both the change in morphometric characteristics of the solid phase and its phase composition

3. The parameters of ED processing for obtaining fine (35% has a size of $0,05$ to $1\text{ }\mu\text{m}$), uniform blend for carbide steels and for carbidization of titanium powder (up to 98%), are established which allows to obtain a powder blend, saturated with dispersion-hardening nanostructured particles of carbides and borides.

4. The methodology of express analysis of resulting powder blend quality by monitoring its electrical resistance without direct study of dispersion and phase composition is developed.

5. Technological methods for spark plasma sintering of powder blend, obtained by plasma ED technology of powders preparation, are developed.

4. Possibility for obtaining material with almost theoretical density, hardness up to 68 HRC, flexural strength of 1350 MPa and wear resistance higher, than of high-speed steel P6M5, is shown.

Literature

1. Williams, B. Powder Metallurgy: A Global Market Review, IPMD 15th Edition 2012-2013. Электронный ресурс. Режим доступа к документу: http://www.ipmd.net/pdf/Global_Market_Review
2. Ходаков Г.С. Физика измельчения. / Г.С. Ходаков – М.: Наука, 1972. – 308 с.
3. Райченко, А.И. Основы процесса спекания порошков пропусканием электрического тока / А.И. Райченко. – М.: Металлургия, 1987. – 128 с.
4. Сизоненко, О.Н. Влияние электроразрядного воздействия на дисперсность и фазовый состав порошков Fe-Ti-B₄C / О.Н. Сизоненко, Г.А. Баглюк, А.А. Мамонова, Э.И. Тафтай, Е.В. Липян, А.Д. Зайченко, Н.С. Присташ // Материалы XV Междунар. научной конференции: Физика импульсных разрядов в конденсированных средах. – Николаев, 2011 – С. 125 – 128.
5. Сизоненко, О.Н. Изменение дисперсности порошка Fe-Ti-B₄C под воздействием высоковольтного электрического разряда / О.Н. Сизоненко, Г.А. Баглюк, А.И. Райченко, Э.И. Тафтай, Е.В. Липян, А.Д. Зайченко, А.С. Торпаков, Е.В. Гусева // Порошковая металлургия № 3/4, 2012 – С. 3 – 11.
6. Пат. 63477 України на корисну модель, МПК В 22 F 3/12 (2006/01). Пристрій електроживлення установки для спікання порошкових матеріалів електричним струмом / Литвинов В.В., Сизоненко О.М., Райченко О.І., Конотоп С.В., Хвоцян О.В.; заявник і патентовласник ІПТТ НАН України. – № u2011 03047; заявл. 15.03.11; опубл. 10.10.11, Бюл. № 19. – 3 с.
7. Лабай В.Й. Тепломасообмін: підручник для ВНЗ / В.Й. Лабай. – Львів: Тріада Плюс, 2004. – 260 с.
8. Theory of sintering: from discrete to continuum / E.A. Olevsky // Material science and engineering. – 1998. – R. 23. – P. 41 – 100.

ANALYSIS OF STRESS-STRAIN STATE OF ECCENTRIC ONE-WAY CLUTCHES BY THE FINITE ELEMENT METHOD

АНАЛИЗ НАПРЯЖЕННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ ЭКСЦЕНТРИКОВЫХ МЕХАНИЗМОВ СВОБОДНОГО ХОДА МЕТОДОМ КОНЕЧНЫХ ЭЛЕМЕНТОВ

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Abstract: Outer shell is important structural element of one-way clutch and its stress-strain state was not researched enough before. Stresses and strains distribution in the eccentric one-way clutch outer shell is researched using computer simulation and finite-elements method calculation. Effect areas and change character of stresses and strains in the non-friction eccentric one-way clutch outer shell are determined.

Keywords: STRESS-STRAIN STATE, FINITE-ELEMENTS METHOD, OUTER SHELL, ONE-WAY CLUTCH

1. Introduction

One-way clutch is one of the important units used in machine and technological equipment transmissions. Issue of particular assemblies' stressed condition analysis remains actual due to big variety of its design schemes, notwithstanding numerous researches of one-way clutch strength and load characteristics [1-7].

Structural model of outer shell (Fig. 1) can be represented as a short thin-walled cylindrical cover (ring), which is free at one edge and conjugated with thin ring plate, transforming into a thick-walled cylindrical cover (hub) at the other edge. A key slot is performed on a hub to transmit load from the hub to mechanical drive elements. Also there are other design solutions as girth gear, spline or profiled connection.

Stress-strain state of eccentric one-way clutch outer shell is determined by complex of geometrical parameters [8] (Fig. 1 and Fig. 3): D – inner diameter of the outer shell; β_0 – engagement angle area; h_1/D – ratio of cover thickness h_1 to the inner diameter of the shell D ; h_2/D – ratio of plate thickness h_2 to the diameter D ; l/D – ratio of cover length l to the diameter D ; l_1/l – ratio of engagement area length l_1 to cover length l ; D_h/D – ratio of hub outer diameter D_h to the shell diameter D ; d_h/D – ratio of hub inner diameter d_h to the shell diameter D .

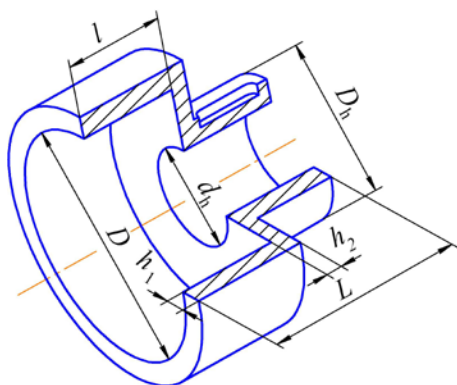


Fig.1 Structural model of the outer shell.

According to design experience [9] aforementioned parameters should be appointed within the following limits: $D=40-240$ mm; $\beta_0=50-90^\circ$; $h_1/D=0,06-0,14$; $h_2/D=0,04-0,12$; $l/D=0,20-0,50$; $l_1/l=0,50-1,0$; $h_2/h_1=0,65-0,85$; $D_h/D=0,35-0,55$; $d_h/D=0,55-0,75$.

Outer shell incurs action of normal and tangential forces acting on its inner working surface while the mechanism operates. Outer shell is in volume-stressed state under the influence of these forces.

Significant number of cylindrical shells stress state calculation methods has been reviewed in modern scientific and technical literature. However, the proposed methods are pretty cumbersome and not suitable enough for practical use and generally can be applied in the simplest cases of loading shells.

The most precise stress-strain state research of such details as outer shell can be accomplished using by the finite-elements method (MFE).

2. Computer experiment

Implementation of the finite-elements method was performed using software packages T-FLEX CAD 11 designed to solve problems of engineering design and constructing within CAD/CAE methodology [10].

At the first stage of the research three-dimensional outer shell solid model was created within CAD design methodology using by software package T-FLEX CAD 11 (Fig. 1).

At the second stage engineering analysis within CAE methodology was conducted using by T-FLEX CAD 11 Analysis software package. Created an outer shell solid model was integrated into the T-FLEX CAD 11 Analysis software environment, wherein finite element mesh (Fig. 2) was created based on the geometric model.

The geometric model is a pattern of constant volumes, which allows to create a regular finite element mesh and to apply three-dimensional element of eight units' volume stress-strain state as a finite element, which allows to approximate calculation model more precisely and provides the best economic figures in terms of time saving.

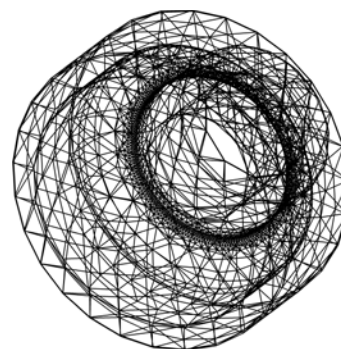


Fig.2 Finite-elements model of the outer shell.

Since the forces are easily determinable at initial stage of research, interfacial conditions of outer shell and eccentric rings working surfaces' interaction were set in loads. Uniformly distributed normal and tangential loads act on the inner working surface of outer shell from the eccentric rings while the mechanism operates. Outer shell is in volume stress-strain state under the influence of these loads.

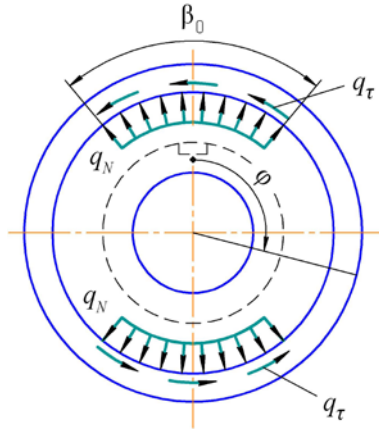


Fig. 3 Design model of the outer shell.

Simulation of force interaction of outer shell and eccentric rings working surfaces was achieved by using a combination of force factors – normal q_n and tangential q_τ loads.

Normal and tangential loads (Fig. 3) were determined by the following formulas:

$$q_n = \frac{F_n}{S_\beta} \text{ and } q_\tau = \frac{F_\tau}{S_\beta},$$

wherein F_n – normal force; F_τ – tangential force; S_β – square of outer shell engagement area, which is determined by the angle β_0 .

Normal and tangential forces were determined by the following formulas:

$$F_n = \frac{2T \cos \lambda}{zd \sin(\lambda + \alpha)} \text{ and } F_\tau = \frac{2T}{zd_w},$$

wherein T – torque transmitted by eccentric one-way clutch; z – number of eccentric rings, $z=2$; d – diameter of eccentric, $d = 0,62D$; α – jamming angle, $\alpha = 11^\circ 30'$; λ – pressure angle, $\lambda = 14^\circ$; d_w – pitch circle diameter, $d_w \approx D$.

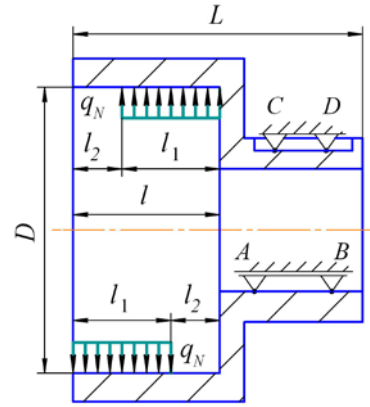
Value of the transmitted load is set according to durability of ratchet's teeth limited by assumed bearing failure stress within $[\sigma] = 10\text{-}20$ MPa.

Interfacial conditions of outer shell working surfaces' interaction with drive elements are set in displacements. Distributed movable support AB was set on inner cylindrical surface of the hub and distributed fixed support CD was set on the surfaces of a key slot (Fig. 3).

According to the distortion hypothesis (The von Mises yield criterion [11]) equivalent stress σ_e and radial strain δ_R of outer shell were accepted as researched factors during the computational experiment. Geometric parameters of the outer shell and a value of the transmitted load were accepted as independent factors.

Researches were conducted for an outer shell with following geometrical parameters: the inner diameter of the shell $D = 140$ mm; the relative thickness of the cover $h_1/D = 0,10$; the relative thickness of the plate $h_2/D = 0,08$; the relative length of the cover $l/D = 0,35$; the relative length of the engagement area $l_1/l = 0,70$; total shell length $L = 114$ mm; engagement area angles $\beta_0 = 50, 70$ и 90° ; outer and inner hub diameters $D_h = 90$ mm and $d_h = 60$ mm correspondingly.

Material of calculated model is ball bearing steel 100Cr6 (elasticity modulus of the material $E = 2,11 \cdot 10^5$ MPa, Poisson's ratio $\nu = 0,3$). Value of torque transmitted by eccentric non-friction one-way clutch is $T = 700$ N·m.



The results of research are presented as graphs which obtained by using a cubic spline interpolation of data (operator «cspline» of MathCAD14 package).

3. Stress distribution in the outer shell

Analysis of the equivalent stress distribution along the length of the outer shell L for different angles β_0 (Fig. 4) shows that the greatest stresses arise at the free edge of the cylindrical cover ($\sigma_e = 60\text{-}82$ MPa) and in areas of plate conjugation with the cover and with the hub ($\sigma_e = 105\text{-}124$ MPa). Character of stress changes is similar for all values of the angle β_0 .

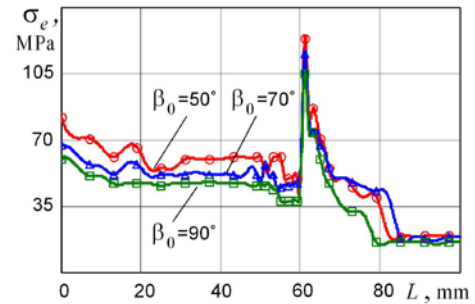


Fig. 4 Stress distribution in the axial section of the outer shell.

In the first case, the greatest stresses arise in the areas of load application on the inner cylindrical surface of the outer shell from the eccentric rings.

In the first case, the maximum stress occurs due to an increase of the applied load action arm and as a result due to increase the bending moment. This corresponds to the calculated scheme - one end of the cylindrical cover is free, the other is fixed (conjugated with a cylindrical plate).

In the second case coverage area of maximum stress is determined by loading conditions of plate which is exposed action of bending moment unequally distributed over its outer edge, because of radial strains of cylindrical cover caused by normal loads.

Because of the cover torsion caused by tangential loads, the plate is additionally exposed action of torque unequally distributed on its plane.

Due to action of these force factors plate is in complex stress state, characterized by the combined action of both normal and tangential stresses.

There is a decrease of stresses which have a value of about 15-19 MPa along the length of the hub.

Analysis of the equivalent stress distribution in the radial section of an outer shell depending on the polar angle φ (Fig. 5)

shows that the maximum stresses ($\sigma_e = 105\text{--}124$ MPa) arise at an angle $\varphi = 180^\circ$.

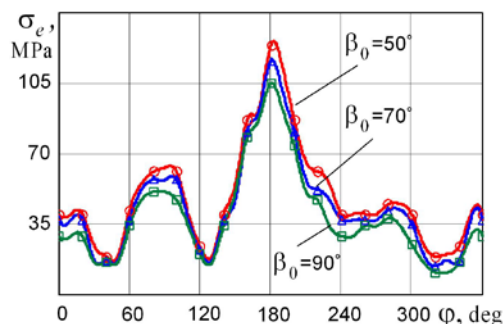


Fig. 5 Stress distribution in the radial section of the outer shell.

In the rest areas stresses are considerably smaller and vary within the limits ($\sigma_e = 12\text{--}58$ MPa). This is explained by the scheme of cylindrical cover loading from the eccentric rings of variable length. When $\varphi = 180^\circ$ their engagement occurs closer to the free edge of the cover, when $\varphi = 0^\circ$ – closer to its fastened edge.

Selected section corresponds to the area of maximum stresses at the place of plate conjugation to the hub. It should be noted that when the angle β_0 is changing within the range of $50\text{--}90^\circ$ equivalent stresses are reducing in 1,18–1,36 times due to increase of the load application area.

4. Strain distribution in the outer shell

Analysis of the radial strain distribution along the length of the outer shell for different angles β_0 (Fig. 6) shows that the greatest strains ($\delta_R = 72\text{--}101$ microns) arise on the free edge of cylindrical cover.

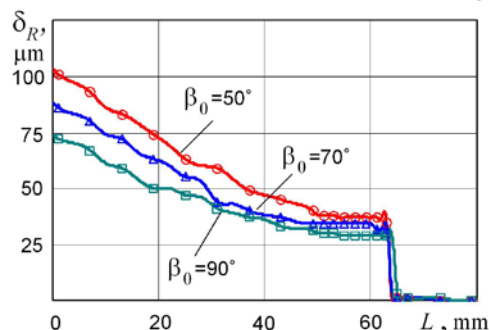


Fig. 6 Strain distribution in the axial section of the outer shell.

Then they are gradually decreasing along the length of cylindrical cover to the value ($\delta_R = 27\text{--}39$ microns) and almost to zero in the area of the hub. Character of strain change is similar for all angle β_0 values.

Such strain change character is explained by decreasing of load application arm along the length of the cylindrical cover from free edge to confirmative plate and as result by decreasing of bending moment value. Strain value is decreasing along the length of the cylindrical cover in 2,58–2,90 times in dependence close to linear.

When the angle β_0 is changing within limits of $50\text{--}90^\circ$, radial strain is decreasing in 1,33–1,44 times due to increase of load application area.

Analysis of the strain distribution in the radial section of outer shell depending on polar angle (Fig. 7) shows that outer shell has a radial strain ($\delta_R = 72\text{--}101$ microns) for the angle $\varphi = 180^\circ$ in 4,8–6,0 times bigger than for angle $\varphi = 0^\circ$ ($\delta_R = 12\text{--}21$ microns).

Negative values correspond to the strain of the cylindrical cover towards the center thereof.

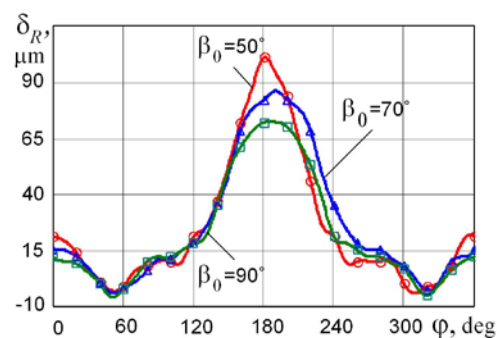


Fig. 7 Strain distribution in the radial section of the outer shell.

5. Conclusion

Extreme stress and strain coverage areas in non-friction eccentric one-way clutch outer shell and its influence on engagement area angle values were determined by numerical calculations in the program T-FLEX CAD 11.

It was found that the stresses arising in the outer shell have quite small value about $\sigma_e = 105\text{--}124$ MPa.

However, in some cases, such as eccentric one-way clutch working in high-speed machine drives, failure of outer shell occurs as result of its fatigue failure under stresses significantly less than that is assumed.

It was found that the outer shell is not strained symmetrically relative to a vertical axis, as it assumed before, but it has radial strain in 4,8–6,0 times bigger in engagement area located closer to the edge of the cylindrical cover.

6. References

1. Orthwein W.C. Clutches and brakes: design and selection. New York, Basel: Marcel Dekker, 2004, 330 p.
2. Childs Peter R. N. Mechanical design. Oxford: Butterworth-Heinemann, 2004, 358 p.
3. Shigley Joseph E., Mischke Charles R. Standard handbook of machine design. New York: McGraw-Hill, 1996, 1761 p.
4. Sclater N., Chironis Nicholas P. Mechanisms and mechanical devices sourcebook. New York: McGraw Hill Professional, 2006, 512 p.
5. Sharkov O., Vasiliev A., Kalinin A. Impulse variable-speed drives of machines. Proceeding of the International scientific conference Power transmissions-03 in 4 parts. 23–25 September, 2003, Varna, Bulgaria, 2003, Part1, pp. 247–250.
6. Park J., Tak T., Kuk M., Kim D., Shin S. Analysis of one-way clutch mechanism of motorized retractors and evaluation of motor scenarios. SAE technical paper series, № 2007-01-3745, Warrendale, Pa.: SAE, 2007, p.7.
7. Архангельский Г.В., Архангельский А.Г. Роликовые механизмы свободного хода. Одесса: Наука и техника, 2009, 92 с.
8. Sharkov O.V., Zolotov I.A. Influence of the geometric properties of an external housing on its stress-strain state. Russian engineering research, 2011, V.31, № 4, pp. 335–337.
9. Горин М.П. Эксцентриковые механизмы свободного хода. Санкт-Петербург: Политехника, 1992, 272 с.
10. Бунаков П.Ю. Сквозное проектирование в T-FLEX CAD, Москва: ДМК, 2009, 399 с.
11. Boresi Arthur P., Schmidt Richard J., Sidebottom Omar M. Advanced mechanics of materials. New York, Singapore: John Wiley & Sons, 1993, 811 p.

STRUCTURE AND CHARACTERISTICS COATINGS OBTAINED AFTER COMPLEX SATURATION BORON AND SILICON ON CARBON STEEL

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The results of research coatings coatings obtained after complex saturation boron and silicon in the powder environment on steel 45. Determine the thickness and microhardness of the resulting coatings, their phase and chemical composition. It has been established that the coatings obtained after complex saturation boron and silicon more plastic and have a 1.8 times higher fracture toughness (K_{IC}) and 1.5 times higher than the wear resistance as compared with coatings obtained by borating.

Keywords: BORON CARBIDE, BORIDING, BORIDE LAYER, SILICON, MICROSTRUCTURE, MICROHARDNESS, WEAR RESISTANCE, CRACK RESISTANCE.

1. Introduction

Operational properties and durability of each mechanism is largely determined by the surface state of the material layers in which high stresses are concentrated and which are responsible for such properties as corrosion resistance, heat resistance and wear resistance of the article or a mechanism in general.

One of the main methods of increasing the life of machine parts and tools is chemical - heat treatment (CHT), which allows to give the surface of metals and alloys, high hardness and wear resistance, corrosion and erosion, increased heat resistance and resistance to radiation exposure. In many cases, CHT is the only possible means to solve a specific technical problem.

Improving the reliability and durability of machines and mechanisms depends largely on the durability of the surface components operating friction. The most common types of such CHT as carburizing, cyanidation, nitriding, which often can not meet the growing demands for durability work surfaces. In this regard, recently paid much attention to the development of new types of wear-resistant coatings.

Among the CHT relatively new process takes place special diffusion borating metals and alloys with the addition of other elements that can change the structure and phase composition of the boride layers and, consequently, to obtain a higher surface hardness and wear resistance as compared with other types of treatment [1 – 6].

In order to improve the wear resistance, heat resistance and corrosion resistance of metals and alloys used boriding with additions of silicon. As a result of diffusion saturation changes the structure of the surface of boride layers on steel and formed sublayer enriched saturating elements having a high performance properties.

Saturation boron and silicon allows to improve the surface characteristics, reduce the brittleness of the coating and ensures high durability and low production cost. This process can be used in metallurgical, chemical, aerospace, engineering and shipbuilding industries.

2. Materials and methods research

Saturation boron and silicon was performed powder method in a special container under reduced pressure at a temperature of 970 °C for 4 hours. The study was conducted on samples of steel 20, 45, U8A.

Selection of the optimal temperature saturation process is an important factor at saturation boron and silicon. For example, at a temperature below 900 °C, the saturation process, and slows considerably decreases the content of elements in the diffusion layer, and at temperatures above 1000 °C, a layer with increased fragility, porosity and deep radial cracks which lead to a deterioration in performance properties. Therefore, the selected temperature is optimal for this type of treatment.

The samples, previously ground, polished and degreased in ethanol, and then charged into a stainless steel container and covered with a mixture of saturating. The distance between the

sample and the walls of the container is not less than 5 mm. Saturation of boron and silicon steel conducted in mixtures containing boron carbide technical B_4C and Fe-Si powder and Si. As the dopant used fluoroplast.

To separate the reaction space of the container from the furnace atmosphere and prevent the penetration of air, closed container and covered with a sheet of asbestos and filled with sodium silicate glass thickness of 10 mm. When heated to a temperature of boriding, at melted sodium silicate glass (750 – 800 °C) and seal the container. Heating crucibles and following isothermal exposure was carried out in a laboratory furnace type SNOL – 1,6,2,5.1/11M.

At the end of the isothermal holding items fetched from the container from the oven and cooled to room temperature in air. After cooling container, silicate smashed and container unpacking and recovered items with a clean surface, which do not require further purification.

This method has the following advantages: simplicity of the process, allows the processing of products of various configurations, it is possible to obtain the diffusion layers of different thicknesses.

Visual inspection and microstructural studies were performed on boride coatings metallographic microscope Carl Zeiss increase in the range of 100 ... 1000.

Polished thin sections were performed on a polishing wheel grit diamond paste from 28 to 1 mm, which allows a number of high surface quality research.

As the reagent used for the chemical etching of 3 ... 5% solution of nitric acid in ethanol; Exposure – 30 sec.

Measuring the thickness of the diffusion layers and microhardness were carried out on a PMT-3 is not less than 10 – 15 fields of view at a load of 0.49 – 0.98 N. Microhardness measurement accuracy is ± 500 MPa.

The phase composition of the coatings was analyzed by X-ray diffractometer DRON 2.0 in copper $K\alpha_1$, $K\alpha_2$ monochromatic radiation, and chemical composition were determined on the analyzer «Camebax Sx50».

3. Results and discussion of research

The resulting diffusion layer at saturation technical boron carbide (B_4C) with addition of silicon powder unlike boride coatings obtained at saturation in B_4C consisted of boride phases FeB, Fe_2B and additionally detected graphite phase, which was confirmed by X-ray diffraction analysis (Fig. 1). Graphite phase first discovered when added to a mixture of saturating boriding silicon. When introducing the medium to saturate Te, Cr, V, Nb, Mo, W, or other elements of the graphite phase is not allocated [7].

Phase analysis was carried out with a sample surface boride coating, in resulting saturation boron and silicon, X-rays penetrate to a depth of 15 microns, set quantitative distribution of phases in the near-surface zone. It is found that the phase of FeB is 68.13 wt%, 28.36 wt% Fe_2B , 3.51 wt% graphite. In conducting research on the same samples that obtained after boronization in the surface layer was found only FeB phase. X-ray diffraction studies

confirm the volume redistribution phases FeB and Fe₂B in boride coating. At saturation in powder medium supplemented with silicon fixed volume reduction phase FeB.

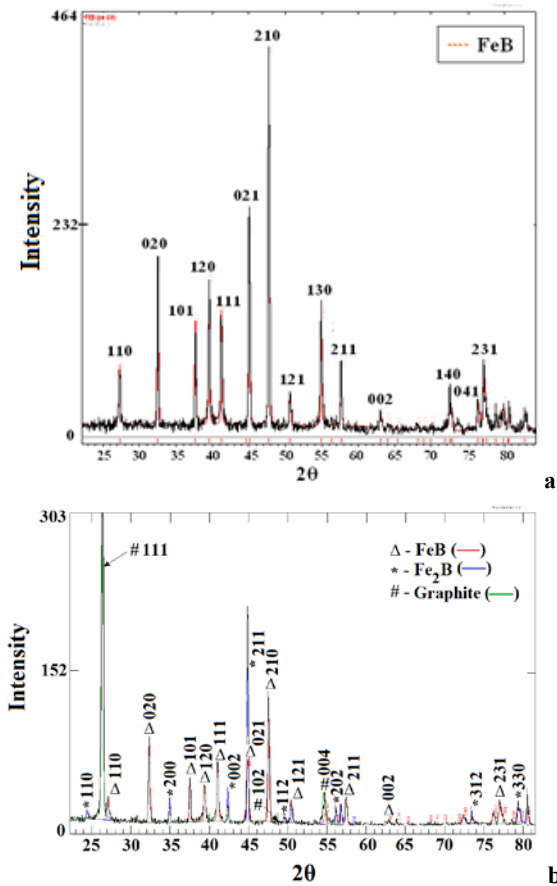


Fig. 1: Diffractograms taken from the surface of the steel 45 with boride coatings in Cu K α_1 , K α_2 monochromatic radiation: a – coatings after boriding; b – coatings obtained after complex saturation boron and silicon, diffraction peaks of C (graphite) line (111) (102) (004)

In table 1 shows the parameters of a crystallographic lattice boride FeB phase searches and studies the lattice constant changes FeB phase after introduction in to saturate the environment of silicon powder.

Table 1: The parameters of the crystal lattice phase after boriding and after complex saturation boron and silicon

Name of phase	The crystal lattice parameter, Å		
	a	b	c
FeB (after complex saturation boron and silicon)	4,0549	5,4899	2,9457
Fe ₂ B (after complex saturation boron and silicon)	5,1021	-	4,2450
Graphite (after complex saturation boron and silicon)	2,6040	-	6,6963
FeB (after boriding)	4,0603	5,5023	2,9504
Changing the crystal lattice parameters of the phase FeB after complex saturation boron and silicon	$\Delta a = -0,0054$	$\Delta b = -0,0124$	$\Delta c = -0,0047$

From the data in table shows that there is a change of the crystal lattice periods FeB phase (fig. 2) that due to the formation of substitutional solid solutions (Fe, Si)B and (Fe, Si)₂B. Si has an atomic radius of 0.111 nm, the atomic radius Fe – 0,156 nm, B – 0,087 nm.

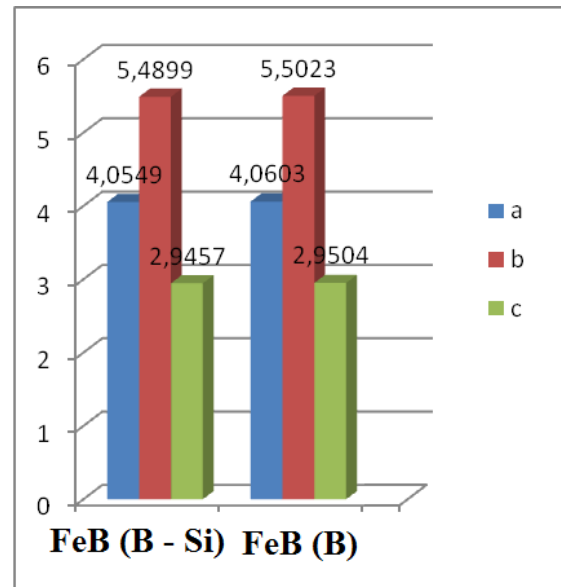


Fig. 2: Change the lattice parameters phases after boriding and after complex saturation boron and silicon

Reduction unit periods of the crystal lattice due to saturation of boride phase elements with smaller atomic radius, contributes to the strength of the crystal lattice during the formation of substitutional solid solutions.

Reducing the volume of the crystal lattice leads to a change of the interatomic bonds in the crystal lattice, which promotes the growth of microhardness of boride phases doped Si. By doping Si lattice periods rhombic phase FeB decrease, the largest change is observed for parameter b.

Microstructure of boride layer is a needle borides, which are oriented perpendicular to the sample surface and wedged into the matrix and graphite inclusions, which we revealed (Fig. 3).

Acicular structure boride layers indicates that for the formation of boride phase growth occurs in a direction perpendicular to the sample surface, while along the surface development of these phases occurs slightly.

Graphite phase is concentrated in the surface and near-surface coating zone, accumulates in the pores to form dark zones alternating with light portions FeB phase (clearly seen in the structure of the cross-sections of boride coatings on Fig. 3). The size and number of pores which can be identified as dark component structure of the surface layer increases with increasing carbon content in the steel. So, for steel U8A (Fig.3, c), up to 40% of the surface occupied by pores, which may be graphite.

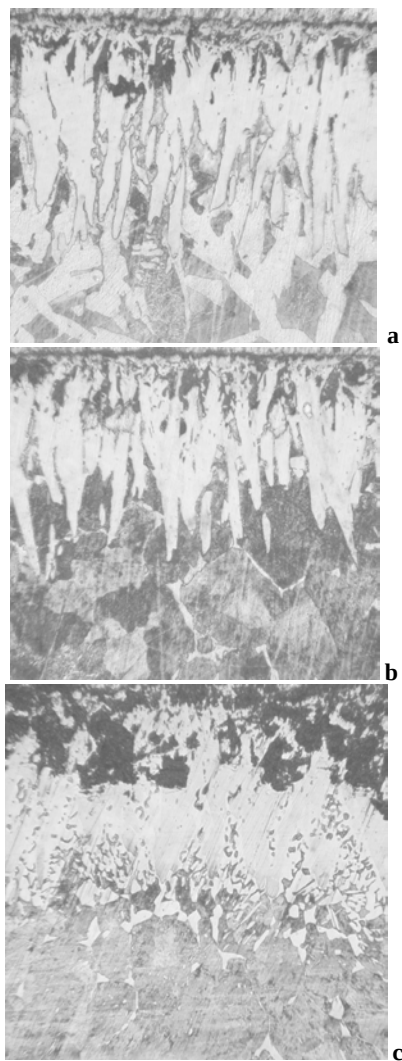


Fig. 3: The microstructure of the coatings on steels after complex saturation boron and silicon: a – 20, b – 45, c – U8A, x200

To measure the fracture toughness of single crystals of solid crystalline materials used method Charles – Evans [8 – 11]. In this K_{IC} determined by the length of radial cracks formed around the indentation of the Vickers indenter with a semi – empirical relation:

$$K_{IC} = 0,015 \cdot (E/H)^{1/2} \cdot P/C^{3/2} \quad (1)$$

or a graphic dependence between $(K_{IC} \cdot F/H) - (H/E - F)$ and c/a , where F – Marsha constant; H – Vickers hardness; a – half of the diagonal of the impression; c – length of radial cracks; E – Young's modulus.

Critical fracture stress was determined by the formula:

$$\sigma = K_{IC} / \alpha \cdot L^{0,5} \quad (2)$$

where σ – critical stress fracture, L – transverse grain size of boride, α – geometric constant (π).

Calculation data cleaving stresses which may arise boride phases depending on the parameter K_{IC} steel 45 shown in table 2.

Table 2: Calculation data stresses chipping boride coatings (phase FeB)

Environment for saturation	$K_{IC} \cdot m^{0,5}$	$\sigma_{cleaving} \text{ at } L =$	
		15 microns	20 microns
		MPa	MPa
$B_4C + Si$	1,97	299,27	237,18
$B_4C - Fe-Si$	1,94	289,07	229,93
B_4C	1,10	218,69	189,53

The chemical composition of the coatings was determined by X-ray analysis, which was performed on a scanning electron microscope – SEM at 2000 times magnification, accuracy measurement is 0.01 wt.%. Chemical analysis performed by EDS, the calculation of the quantitative chemical composition – by the method of ZAF.

It has been established that silicon is uniformly distributed in a coating thickness of up to 0.8% by volume. In addition, there are areas in which the silicon contains up to 50% by volume.

4. Conclusions

Saturation boron and silicon provides a change of the phase composition of boride phases, namely the allocation of graphite phase, and a reduction in phase FeB 30% in the coating. Also the redistribution characteristics boride phases, namely increasing microhardness FeB phase to 20 – 22 GPa, Fe_2B phase to 17 GPa and fracture toughness K_{IC} increase 1.8 times and an increase in cleaving stress values of 1.3 – 1.4 times. Growth of porosity in the surface areas of boride coatings when the pores are filled with graphite enhances durability boride layers by reducing the friction coefficient. Increasing microhardness FeB phase, Fe_2B after complex saturation boron and silicon compared microhardness after these phases boriding phase due to saturation of the silicon – $(Fe, Si)B$, $(Fe, Si)_2B$, which is confirmed by changing the periods a, b, c orthorhombic phase grating, wherein the lattice parameters decrease.

It was established that the carbon content of the steel affects the thickness of the diffusion layer. This is due to the fact that the carbon in the transition zone is displaced. Therefore, with the increase of carbon content in the base material, the coating thickness decreases.

5. Literature

1. Ляхович Л. С. Состояние и перспективы развития процесса борирования. – К.: «Наукова думка», 1972. – 194 с.
2. Алиев А. А., Булгаков В. П., Приходько Б. С. Диффузионное борирование стали и шероховатость поверхности // Вестник Астраханского государственного технического университета. – 2005. – № 2. – С. 91 – 95.
3. Кухарева Н.Г., Петрович С.Н., Галынская Н.А., Протасевич В.Ф., Смирнова Т.Н. Борирование углеродистых и легированных сталей в кипящем слое // Наука и Техника. – 2012. – № 5. – С. 11 – 17.
4. Самсонов Г. В., Серебрякова Т. И., Неронов В. А. Бориды. – М.: Автомиздат, 1975. – 376 с.
5. Похмурский В. И., Далисов В. Б., Голубец В. М. Повышение долговечности деталей машин с помощью диффузионных покрытий. – Киев.: Наукова думка, 1980. – 188 с.
6. Спиридонова І. М. Фазові перетворення в композиційних матеріалах з залізними зв'язками, що містять бор та вуглець / І. М. Спиридонова, О. В. Сухова, О. Г. Безрукава // Доповіді НАН України. – 2002. – № 10. – С. 93 – 97.
7. Баландин Ю.А. Комплексное насыщение поверхности инструментальных сталей бором, медью, хромом в псевдооживленном слое // Изв. Вуз. Черная металлургия. – 2005. – №5. – 50с.
8. Чернега С.М. Комплексное насыщение углеродистых сталей бором и хромом в активированной среде // Изв. Вуз. Черная металлургия. – 1999. – №1. – 58с.
9. Нарва В.К. Полеченко А.В. Нанесение покрытий карбидосталей на стальную основу // Изв. Вуз. Черная металлургия. – 1995. – №1. – 47с.
10. Ирвин Дж., Перле П. Основы теории роста трещины и разрушения // Разрушение. – М.: Мир, 1976. – Т.3. – С.17 – 66.
11. Evans A. G., Charles E. A.. Fracture toughness determination by indentation. – J. Amer. Ceram. Soc., 1976, v. 59, N 7 – 8, p. 371 - 372.

EFFECT OF STEP THERMOMECHANICAL TREATMENT ON ELECTRICAL PROPERTIES OF AL 6101

ВЛИЯНИЕ СТУПЕНЧАТОЙ ТЕРМОМЕХАНИЧЕСКОЙ ОБРАБОТКИ НА СВОЙСТВА ЭЛЕКТРОТЕХНИЧЕСКОГО СПЛАВА AL6101

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Abstract: This work is focused on investigation of different thermomechanical treatment (TMT) regimes influencing mechanical and electrical properties of Al-Mg-Si alloy. Three TMT regimes were chosen, which differ in the number of treatment steps. Grain size, microhardness, electrical conductivity were measured. It was revealed that dividing TMT into 2 stages favorably affects formation of mechanical and electrical properties in Al6101.

KEYWORDS: ALUMINUM ALLOYS, SEVERE PLASTIC DEFORMATION METHODS, ULTRAFINEGRAINED STRUCTURE, THERMOMECHANICAL TREATMENT, ELECTRICAL CONDUCTIVITY

1. Introduction

At the present moment ageing Al alloys are used as structural materials in construction, aircraft and car industry. Heat-hardenable alloys of the Al-Mg-Si system (alloys of 6XXX series) are the most important aluminum alloys, they contain Fe, Mn, Cu as additional alloying elements. The alloys are characterized by enhanced ductility, good weldability and high quality of semi-product surface. The alloys of these group applied in electrical engineering have been recently studied. As result of the studies, it becomes possible increasing their consumer and service properties [1-3]. Thus, when using special thermomechanical treatment, the alloy acquires high electrical properties at relatively high strength. In this connection the aim of the present work is to search for the most rational thermomechanical treatment (TMT) regimes, analyze structural states and their relation with mechanical and electrotechnical properties of Al 6101.

2. Material and experiment

The material of studies is aluminum alloy Al6101 (Al-Mg-Si system).

Table 1. Chemical composition of Al 6101

Al	Si	Mg	Fe	Impurities, not exceeding			
				Zn	Cu	B	Other impurities – each element separately does not exceed 0.03
base	0.30-0.70	0.35-0.80	Not over 0.50	0.10	0.10	0.06	Ti, V, Ni, Ga, Cr, Mn – totally not exceeding 0.10

Drawing in round dies was applied at room temperature for shape forming. The drawing was performed on a special drawing bench using technological lubricant “Rosoil 555” [4].

The initial length of samples with a diameter of 12 mm was 160 mm before drawing. After drawing the diameter was 3 mm and the length was 1500 mm.

A muffle furnace Nabertherm L15/11 was used for thermal treatment.

Electron microscopy studies were carried out on a transmission electron microscope JEM-2100 EX Jeol at an accelerating voltage of 200 kV.

The objects for fine structure studies were prepared by jet polishing of thin foils on a “Tenupol-5” set in the solution of 20 % nitric acid (HNO₃) and 80 % methanol (CH₃OH) at a temperature of – 25...35°C and a voltage 15...20 V.

The average size of structural elements (subgrain size) was taken through at least 200 measurements done with the help “Grain-Size” software for structure analysis.

Mechanical characteristics of Al 6101 wire were determined during static tensile tests of samples with a gage length (l_0) of 40 mm in accordance with GOST 10446-80 [4] on an electromechanical measuring system Instron 5982.

Electrical conductivity of experimental samples of Al 6101 wire was determined according to GOST 7229-76 [5] with the help of an aspirated hydrometer MV-4M (error ± 2 %), an aneroid barometer BAMB-1 (a division value 0.1×10^3 Pa) and a microohmmeter BSZ (precision 0.1).

The Vickers hardness (HV) was measured on a Micromet-5101 set at 50 g of test load and dwell time of 10 sec.

3. Experimental procedure

Table 2 presents 3 experimental schemes that allow evaluating the influence of TMT on the end-use properties of samples. The main focus of studies is connected with influence of a step TMT cycle on the end-use properties of items (wire). The total strain degree for each regime was $\epsilon = 0.94$.

Table 2. Treatment regimes

Regime 1	Regime 2	Regime 3
Water quenching at 540°C, 2h	Water quenching at 540°C, 2h	Water quenching at 540°C, 2h
Ageing at 140°C, 6h	Drawing to Ø9mm	Drawing to Ø3mm
Drawing to Ø9mm	Ageing at 140°C, 6h	
Ageing at 140°C, 6h	Drawing to Ø3mm	
Drawing to Ø3mm		

4. Discussion of results

As a result of studies it was stated that a grain-subgrain type structure formed in the produced wire samples after the processing. Fig. 1(a-c) displays the results of structure studies. It is established that the subgrain sizes of the sample produced via regime 1 were

441.3 ± 5.2 nm, via regime 2 — 431.9 ± 5.4 nm, via regime 3 — 414.3 ± 4.8 nm. Fig. 1(d) displays a diagram of produced subgrain sizes. It is seen that deformation of Al alloy without step TMT results in a finer structure.

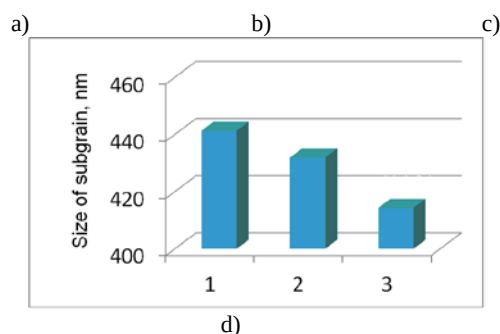
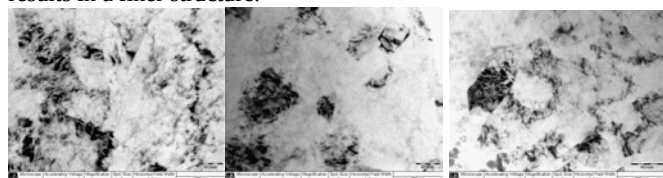


Fig. 1 – Structure of samples obtained with TEM. *a* – via regime 1, *b* – via regime 2, *c* – via regime 3, *d* – diagram of subgrain distribution for all three regimes

Study of strength and microhardness of samples showed (Fig. 2) that TMT resulted in microhardness and strength increase. After TMT the microhardness of the sample produced via regime 1 is 134.7 MPa, that of the sample produced via regime 2 — 144.8 MPa, that of the sample produced via regime 3 — 119.3 MPa. One can state the correlation between the obtained microhardness and strength values for all the three processing regimes. Microhardness increase in the samples produced via regimes 1 and 2 is connected with mechanisms of fine-dispersed phase precipitation (ageing) [7]. Thus, step TMT favorably affects the strength enhancement of Al wire.

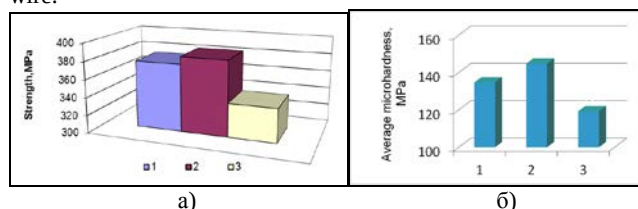


Fig. 2. Distribution of strength for 3 TMT regimes (*a*) and average microhardness value for 3 TMT regimes (*b*)

Investigation of electrical conductivity of deformed samples showed that use of step TMT resulted in enhancement of electrical conductivity to the values 49.436 % IACS (regime 1), 49.27 % IACS (regime 2), 44.74 % IACS (regime 3). The increase of the number of TMT steps does not improve the electrical conductivity (Fig.3).

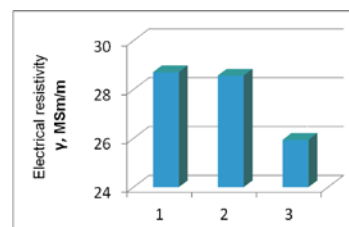


Fig. 3. Diagram of electrical conductivity distribution for 3 processing regimes

5. Conclusions

1. It is stated that a grain-subgrain type structure forms in wire of Ø 3 mm irregardless of the used TMT regimes. The smallest subgrain size was achieved through processing via regime 3, in which thermal treatment was not used after processing. This state demonstrates lower microhardness and strength values due to absence of ageing effect from post-deformation temperature impact.

2. The investigation of electrical conductivity of deformed samples showed that the step TMT resulted in electrical conductivity enhancement to 28,7 MSm/m in the samples processed via regime 1 and to 28,5 MSm/m in the samples processed via regime 2, which is 1,1 times higher as compared to regime 3. One can see that increase of TMT steps does not lead to electrical conductivity enhancement.

3. Regime 2 should be considered as the most rational regime, since strength and electrical conductivity increase in the samples with an ultrafinegrained subgrain structure.

Acknowledgements

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References:

1. Fridlyander I.N., Sister V.G., Grushko O.E., Berstenev V.V., Sheveleva L.M., Ivanova L.A. Aluminum alloys – the advanced material in automotive industry // Physical metallurgy and thermal treatment of metals. 2002. No 9. P.3-9 (in Russian).
2. Yelagin V.I. Structural nanostructured aluminum-based alloys // Technology of light alloys. 2008. No 2. P.6-20 (in Russian).
3. Alieva S.G., Altman M.B., Ambartsumyan S.M. Commercial aluminum alloys. – M.: “Metallurgy”, 1984. 528p (in Russian).
4. TS 0258-055-06377289-2004, “Self-financing Creative Center of Ufa aviation institute” LLC, Ufa
5. GOST 10446-80 Wire. Tensile testing technique.
6. GOST 7229-76 Cables, wires and cords, method for electrical conductivity determination in conductors.
7. E.V. Bobruk, M.Yu. Murashkin, V.U. Kazykhanov and R.Z. Valiev Aging behavior and properties of UFG aluminum alloys of Al-Mg-Si system // Reviews on Advanced Materials Science 31 (2012) pp.109-115.

EXPERIMENTAL RESEARCH STUDY ON THE USE OF A RESISTIVE TENSOMETRIC SENSOR

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Abstract: The paper presents a method using the electric tensometry. The electric tensometry is a method for measuring the deformations by using some transducers. These transducers turn the variation of a mechanical size into variations of an electric size. The principle of functioning of the resistance tensometric transducer is the modification of the electric resistance depending on the variation of the specific deformation.

Keywords: sensor, transducer, sensitive element.

1. Introduction

Sensors are used in all kinds of automated systems and actions, regardless of the field of science or engineering, or of the nature of processed they are supposed to analyse and control. They are used on a large scale, ranging from the chemical, food, automotive, aerospace industry, passing through medicine, biology, environment protection, agriculture to the military industry. [1]

One can state that the sensors convert the size to be measured applied at the input into another size able to form the signal of measurement which will be processed and transmitted along the measurement chain. Consequently, the sensor will be considered to be the sensitive element converting the size to be measured applied at the input, and the transducer represents the entire assembly mounted and connected to the sensor. As the technological developments are in a continuous progress, new types of sensors are created and designed and are based on semi-conductive materials, optical fibers as well as new materials (polymers, elastomers) that lead to the improvement of the sensors' importance and to the uses they have in covering new fields of interest.

The transducer can contain in its structure one or more sensors, able to convert the size to measure into another size having the quality of being easily measured. The sensors and the transducers could be considered as the source of a new technical revolution.

2.1 Sensors and tensometric resistive transducers

The tensometric resistive sensors are those resistive sensors where the electrical resistance variation is produced caused by the variation of the conductor's length, as an effect of the elongation or of the contraction. Whether the tensometric sensor is mounted on a certain part of the piece subjected to deformation caused by a stress, then, it will suffer deformations in the same time with the piece supporting it.

Measuring the variation of the sensor's resistance through electrical methods, being proportionally with its elongation, the deformation of the part of the piece subjected to study can be determined on the basis of a previous measurement standard, establishing in the end the non-electric size inducing this deformation. According to the way of manufacturing and mounting of the resistive sensor, one can distinguish the following types of tensometric transducers.

a) **Simple tensometric transducers** – the resistive sensor is mounted directly on the piece and strictly follows its deformations. As the resistive wire has the dimension of a hundred part of a millimeter, the process of mounting these sensors is a difficult operation. Therefore, the method is used only for measuring the deformation for the pieces operation at very high temperatures.

b) **Tensometric transducers with paper support** – In order to avoid the difficulties caused by the direct mounting of the resistive sensor on a piece, the transducer is previously stuck, by using a glue, on a paper support. As the electric resistance of the sensor must be higher enough as the transducer should have a corresponding sensitivity, the total length of the resistive wire is of about 10^2 mm. To reduce the surface on which the sensor is laid, the wire should be grid-shaped (fig. 1). [2].

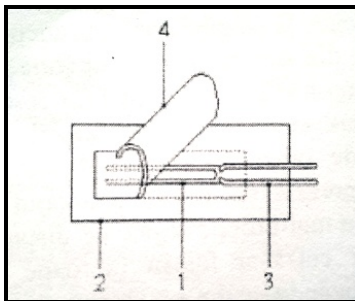


Fig. 1. Tensometric transducer with paper support

Grid 1 is mounted on the paper support 2, at both ends two copper conductors 3 are glued to the larger surface, by means of which the transducer is connected in the circuit of measurement. The resistive sensor of the transducer is protected by a thin foil of paper 4 which is glued above. This type of transducer, well-known, has a series of

advantages, among which a relative easy mounting, a possibility of manufacturing transducers of various shapes and configurations, a uniformity of transducers produced simultaneously and keeping the quality standard.

c) **Tensometric transducers with metallic foil** – they are identical to the previous ones, principally, the only difference being given by the fact that the sensor is a thin wire, its place being retaken by a foil made up of a resistiv material, its thickness having the values

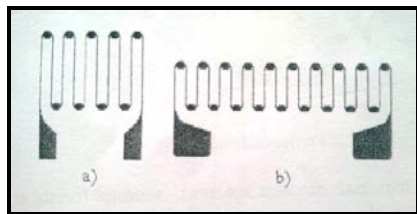


Fig. 2. Tensometric resistive transducer with metallic
a) normal width; b) increased width

These transducers has the advantage of a mechanical and thermal contact with the piece they are mounted on, and this allows its functioning using a higher measurement current. This is the reason for which a better use of the surface is achieved, these transducers having even smaller dimensions lead to simplify their high series production.

d) **Tensometric transducers of semi-conductor** – they have been created during the recent year, due to the evergrowing progress of the physics of semi-conductors, where the sensor is a semi-conductor (germanium and silica). The main advantage of these types of transducers is their high sensitivity to deformations (approximately 50-60 times higher than the wire transducers or foil ones) presenting instead the disadvantage of a certain lack of linearity more pronounced and even of the presence of a problem connected to the way they are laid on the measuring surface. The semi-conducting material that is often used (almost exclusively) is silica, the semiconductor-terminals being made of gold, silver or nickel.

between 2 and 20 μm applied previously on a support cut by using photo-chemical means. The creation of this type of transducers is due to the progress of the development of the industrial technique.[2]

e) **Tensiometric transducers obtained out of metallic deposits** – are created directly on the surface subjected to measurement, surface that had been covered by a insulating layer. The sensor is formed by using methods of evaporation or particle bombing. Their main application is on the diaphragm for force transducers and couples, their very small dimensions offering the advantage of supporting high temperatures (1200 $^{\circ}\text{C}$).

The tensiometric transducers with smaller lengths, under 20 mm, are used for measuring the deformation of homogenous materials (steel), instead, the transducers having bigger lengths are used for measuring the deformation of non-homogeneous materials (concrete or wood).

The resistive material the sensor is made of, the insulating support and the glue of the transducers are all chosen according to the maximum working temperature and to the environment's humidity. For measurements reaching 200 $^{\circ}\text{C}$ in temperature, any of the materials shown in table 1 can be used, and for temperatures ranging from 200 $^{\circ}\text{C}$ to 800 $^{\circ}\text{C}$, nickel-chrome and karma alloys are used. Generally, for temperatures exceeding 400 $^{\circ}\text{C}$, only dynamic measurement can be made by using these materials. [2]

Table 1. Characteristics of resistive materials

Material	Sensitivity	Rezistivity $\Omega \cdot \text{m}$
Constantan	2...2,1	$0,47 \cdot 10^{-6}$
Manganine	0,47	$0,42 \cdot 10^{-6}$
Nickel-Chrome	2,5	$1 \cdot 10^{-6}$
Isoelastic	3,6	$1,05 \cdot 10^{-6}$
Karma	2,1	$1,02 \cdot 10^{-6}$
Silica p [111]	100 ... 170	$(0,01 \div 10) \cdot 10^{-6}$
Silica n [100]	-90 ... -65	$(0,01 \div 10) \cdot 10^{-6}$

2. Experimental research study on sensing a tensometric sensor on paper support

2.1 Description of the probe endowed with ternsometric marks subjected to mechanical traction

The sketch of the probe is shown in Fig. 3. The material used is steel OLC45.

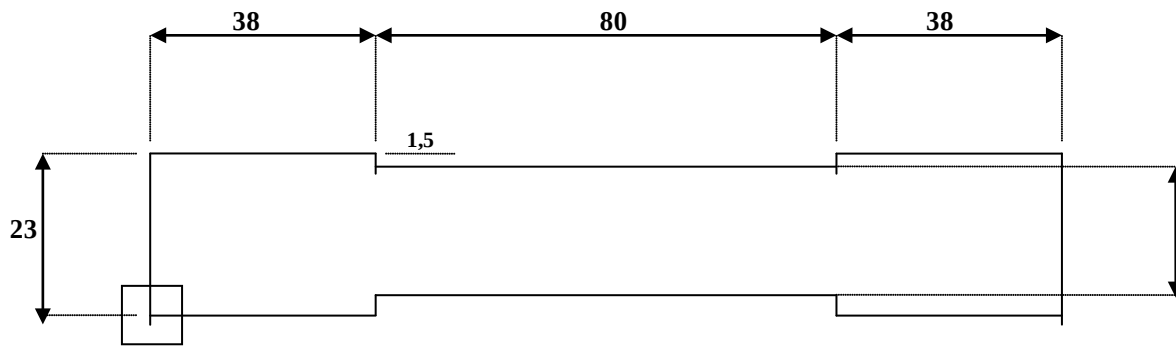


Fig.3 The sketch of the probe

2.2 The equipment used for the experimental research study

For testing the traction and determining the relative elongation, a traction device and a Wheanstone bridge are used and are shown in figure 5.

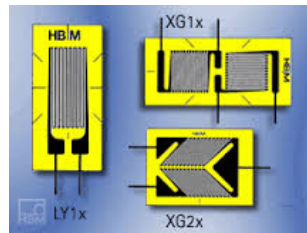


Fig. 4 Tensometric marks

Input range: $\pm 24\text{mV DC}$, accuracy: 0,02% of reading + $30\mu\text{V}$, impedance: 100Mohm , 10 VDC bridge excitation.



Fig. 5 Device for the traction test

2.3 Experimental test

On the basis of the calculation of the unbalanced tension of the bridge, the following equation results, as it can be shown below:

The obtained graph $F=f(\epsilon)$ is shown in fig 6.

The method used allows the rising of the characteristic $F=f(\epsilon)$ on the elastic and linear segment.

$$\epsilon^2(K^2 \cdot \Delta U + K^2 \gamma^2 \cdot \Delta U + 2K^2 \gamma \Delta U - K^2 \cdot U_{alim} + K^2 \gamma^2 U_{alim}) + \epsilon(4K \cdot \Delta U - 4K \gamma \Delta U - 2K U_{alim} - 2K \gamma U_{alim}) + 4\Delta U = 0$$

The data for the 13 tests one can obtain, are recorded in Table 2

Table 2 Experimental data

Δu m v	b_0 mm	h_0 mm	R_0 Ω	K	γ	E N/ mm ²	L mm	$\epsilon[10^{-3}]$	Δl	ν N/mm ²	F N
1	16	1	121,1	1,98	0,3	2,1 ·10 ⁵	143	1,4	0,02678	8,61	1226
4								2,2	0,03211	12,4	1538
5								25,3	0,04244	53,13	1840
6								36,5	0,05422	76,65	2045
7								45,8	0,06320	96,18	2157
8								54,9	0,07850	115,29	3216
9								64,2	0,09180	134,82	4126
10								121	173,03	173,03	5142
11								132	188,76	188,76	6342
12								146	208,78	248,43	7014
13								162	231,66	486,48	7783
14								188	268,56	564,56	9012
15								208	297,44	634,62	9993

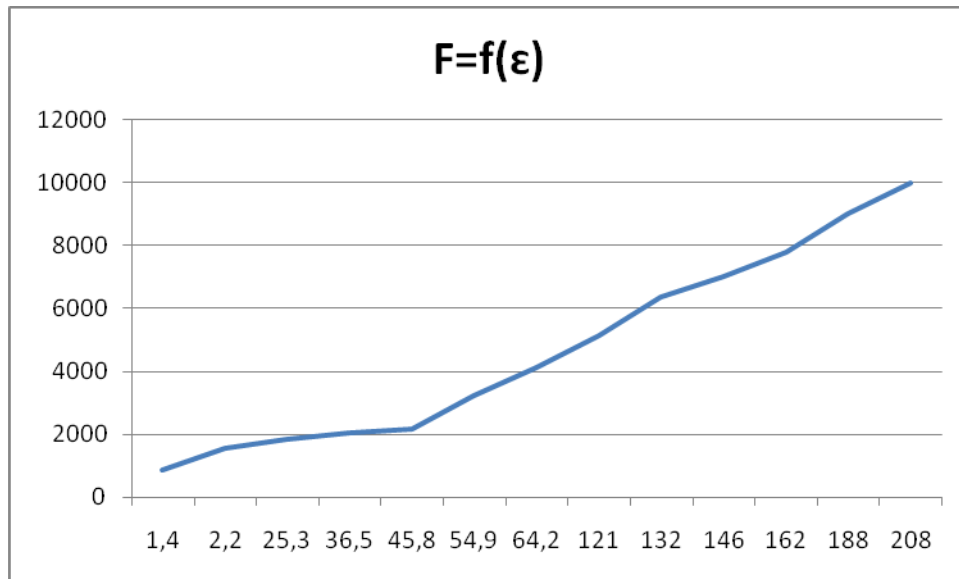


Fig 6. The characteristic $F=f(\epsilon)$

3. Conclusions

The experimental research study we made shows the importance of using tensometric marks in determining the mechanical tensions occurring in the used probe. One can determine through calculation the values of the force acting on a probe and the elongations corresponding to it. At the same time, the method permit the determination of the values of the force, of the tensions of elongations applied to different materials and then, by comparing these values, the best material can be chosen, responding to technological requests. The method used in this experiment can determine the valued mentioned above on a place of the probe where the tensometric marks are mounted.

4. References

- [1]. Ciobanu L. , Sensors and transducers, Ed.Matrix Rom, Bucharest, 2006;
- [2]. Chiță M. , Sensors and transducers, Ed.Matrix. Rom, Bucharest, 2006;
- [3]. Atanasiu C., Material's testing, Technical Publishing House, Bucharest, 1982;
- [4]. Gutt G., Testing and characterizing metallic materials, Technical Publishing House, Bucharest, 1985;
- [5]. Nicolau Th., The electronics measurements in industry, Technical Publishing House, Bucharest, 1964.

DUAL FLOW HYDROMECHANICAL PLANETARY GEAR WITH CONTINUOUSLY VARIABLE GEAR RATIO OPTION

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Резюме: The automatic variability option of changing the angular velocity is a perspective tendency for coordination of the characteristics of the engine with the working machine. That gives the ability to enhance the productivity of the machine, to simplify their controls and to increase their efficiency factor. All of that led to the creation of many methods and ways of lightly regulation of angular velocity and to a wide variety of constructions and many more. The main disadvantage of the mentioned mechanisms, and other similar mechanisms also, having the continuously variable gear ratio option is that the pump as an element of all of them appears to be only a consumer of power in all duty. The consumed power by the pump turns into heat and heats the oil which makes it necessary for it to be in greater amounts. This lowers the efficiency factor and field of application of mentioned mechanisms and more. For removing this disadvantage a solution is proposed with the realization of a hydromechanical gear with hydrovolume regulating contour.

Keywords: hydromechanical, continuously variable gear ratio option, angular velocity, hydrovolume regulating contour,

1. Introduction

Up to date the gears are the most used machine elements for modification of the angular velocity (respectively the torque) of the engine machines. The gears are many different types – cylindrical, helical, spur, worm gears, face gears, hypoid gears, planetary gears and more [1, 2, 3, 4]. All of them has a constant gear ratio i.e. it's a constant value. This is so, because the gear ratio is a function of the number of gear teeth and gear sizes, which cannot be changed (modified) after they are made. However the gear ratio of a certain gear sometimes in a certain application of the gear is not always appropriate enough, according to that outer factors and resistances are changing (they are not constant), and the duties of work are almost always different and several in number – to make it possible the human factor to have a choice to decide what's more appropriate. This forces the creation of a multiple gear reducers and gear boxes. This means designing a knot with a several gears, each with different abilities and gear ratios – different gears (different steps).

The gear ratio can be modified continuously/stepless (variability option) i.e. the gear ratio can be changed by a single gear (the gear itself) i.e. the gear changes the gear ratio itself but it's not a gear with teeth – it's other type of gear (not with gear wheels) called variator (constantly variable) [2, 3, 4] or friction gear (the motion is transmitted via the friction properties of the wheels, not via the teeth of the gear wheels) [2, 3, 4].

The gears with gear wheels cannot modify their gear ratio – it's constant as mention above, because of the mentioned above reasons. The gears with gear wheels don't have the continuously variable gear ratio option.

The progress of the science and technique is not going to inventing of gears with gear wheels capable of modifying the gear ratio (having the continuously variable gear ratio option). Engineering solutions for continuously variable gear ratio option is searched and researched in other methods and it's been working on improving the present mechanisms with continuously variable gear ratio option such as variators (constantly variable gears) mostly, and friction gears (which are rarely used because of their weaknesses).

The gear presented with this report is with gear wheels – it's a planetary gear, which can modify it's gear ratio i.e. has the continuously variable gear ratio option.

2. Dual flow hydromechanical planetary gear with continuously variable gear ratio option. Principles of work. Analysis of the kinematic and working

characteristics – separation of angular velocities, torques and powers in statics.

Kinematic scheme of the dual flow hydromechanical planetary gear with continuously variable gear ratio option is shown at figure 1.

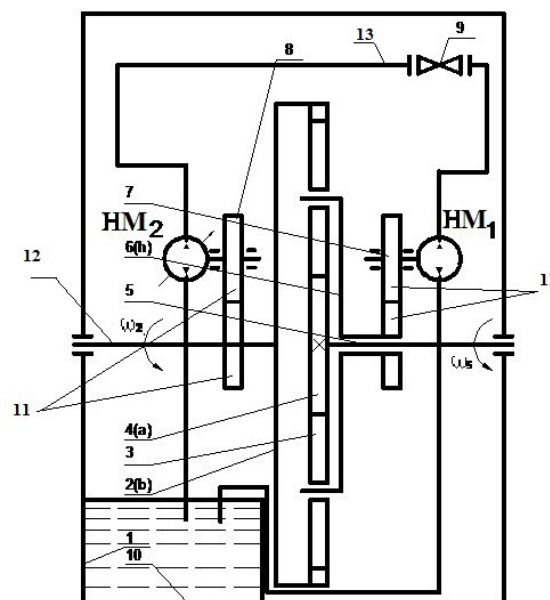


Figure 1. Dual flow hydromechanical planetary gear with a continuously variable gear ratio option.

Elements: 1. Body, 2. Ring gear, 3. Satellite/planetary gears, 4. Sun gear, 5. Input shaft, 6. Planet carrier, 7. Gear pump HM₁ (hydro pump which can work also as a hydro motor), 8. Hydro motor HM₂ (which can work also as a hydro pump), 9. Throttle, 10. Oil (fluid) reservoir, 11. Cylindrical gears (gears), 12. Output shaft, 13. Pressure pipeline

The presented with the present report gear consists of a differential mechanism based on a 2k – h type planetary gear [5] and hydro machines HM₁ и HM₂ which are being regulated by a throttle in the pressure pipeline. Viewing the figure 1, the input shaft is 5, and the output shaft is 12. It is possible the shaft 12 to be the input shaft and the shaft 5 – the output one. The connection between them is made by the central gear 4 (the sun gear, which is unmovably mounted on the input shaft, and the satellite/planetary gears 3. The planet carrier 6 (h) via the gear 11 rotates and moves the gear pump 7 (HM₁). The hydro motor 8 (HM₂) via cylindrical gear 11 transmits it's torque to the output shaft 12 (which in the presented case is mounted on the ring gear 2 of the planetary gear). The hydrostatic pressure in the pressure pipeline is being

transformed into mechanical energy (torque) in the hydro motor 8 (HM₂). The gear pump 7 (HM₁) and the hydro motor 8 (HM₂) are controlled by the throttle 9 and they form the gearless regulating (continuously) contour of the gear (the hydraulic part of the gear). The gear is characterized exactly with this hydro regulating contour. All this elements including the reservoir 10 (which is also a part of the hydro regulating contour – it's connected with both hydro machines 7 and 8) are placed in the body – 1.

Working as a gear with a continuously variable gear ratio option (a gear which can modify it's gear ratio) the input shaft 5 rotates the sun gear 4, which itself rotates the satellite/planet gears 3, and they rotate the planet carrier 6 (*h*) if the throttle 9 in the pressure pipeline 13 is open. This way the pump 7 begins to suck oil (fluid) from the reservoir 10. At a partial closed throttle 9 the pressure in the pressure pipeline is rising (increasing), which makes the rotation of the planet carrier 6 (*h*) harder and respectively it lowers its angular velocity, which makes the output shaft 12 to rotate faster (with greater angular velocity) – its angular velocity begins to raise.

At fully closed throttle 9 the braking torque is so great that the planet carrier 6 (*h*) is not rotating (becomes blocked), and the output shaft 12 reaches its maximum angular velocity determined by the gear ratio of the planetary gear 2k – h (the parameter of the differential at the presently revised case ; with a different kinematic scheme the gear ratio of the gear will be different) i.e. in this case the gear works as a simple planetary gear (with one of its elements being blocked). The hydrostatic pressure of the working liquid (fluid) is being transformed by the hydro motor 8 (HM₂) into torque, which is being transmitted to the output shaft 12 and this way part of the power consumed by the gear pump is being used for overcoming the sum of resistances on the output shaft i.e. to increase the efficiency factor of the entire gear. At the start all of the power of the output shaft is being transmitted via the hydro motor 8 (HM₂). After that redistribution of power being transmitted to the output shaft happens gradually, like the part of it that is being transmitted by the hydro motor 8 (HM₂) decreases, and the part being transmitted by the mechanical part of the planet gear increases. The coefficient of transformation (the power ratio) [7] and the diapason of regulation (of the gear ratio) of the gear decreases so, as the smaller part of the torque is being transmitted by the hydro motor 8 (HM₂).

This way the angular velocity can be modified from zero to its maximum value.

Changing the direction of rotation of the input shaft 5, the gear works just the same way described above. Transmitting rotary motion to the shaft 12 the way described above – from the input shaft 5 – the gear can work in duty of reductor, in duty of multiplicator and also in duty of clutch (with overall gear ratio 1). The duty depends on chosen kinematic scheme of the planetary gear i.e. which element is the input one (mounted on the input shaft), which element is the output one (mounted on the output shaft) and how open is the throttle 9. All the operations of work remain the same.

The gears 4, 3, and 2 form a differential mechanism with two degrees of freedom [2, 5]. The angular velocity of the output shaft 12 – ω_2 is determined only if angular velocities of the input shaft 5 and the planet carrier 6 (respectively ω_5 and ω_h) are known. This means that if the angular velocity of the input shaft 5 is constant, a continuously variable gear ratio option is possible via modifying the angular velocity of the planet carrier 6 (*h*) by the way spoken above.

The maximum angular velocity of the planet carrier 6 (*h*) and the gear pump 7 (HM₁) in a positive direction (same as the direction of the angular velocity of the input shaft 5) will be obtained at the start (with a stopped output shaft 12 $\omega_2=0$), and in a negative direction it will depend on the value of the ω_2 and i_{52}^h . Because ω_2 and i_{52}^h can grow theoretically illimitably, this means that ω_h can also grow illimitably.

Advantages of the dual flow hydromechanical planetary gear with a continuously variable gear ratio option towards the preceding stage of the science: this planetary gear allows continuously variable gear ratio option. The simple planetary gears known to present science can't do that. This can be called a technical problem.

The connection between the angular velocities of the main elements/units of the differential mechanism can be achieved for example using the method of Willis [1, 2]. The entire mechanism is rotated with angular velocity ω_h , but with opposite direction, and this way the planet carrier becomes held/blocked and respectively the mechanism is transformed to a simple gear with immovable/fixed axes. Working out the formula

$$\frac{\omega_5 - \omega_h}{\omega_2 - \omega_h} = i_{52}^h = -\frac{Z_2}{Z_4} \quad (1)$$

where: i_{52}^h is the gear ratio between the input shaft 5 and the output shaft 12 having a stationary (blocked) planet carrier (*h*):

Z_4 and Z_2 – number of gear teeth of the corresponding gears.

For the angular velocity of the planet carrier we get:

$$\omega_h = \frac{\omega_5 - \omega_2 \cdot i_{52}^h}{1 - i_{52}^h} \quad (2)$$

The maximum angular velocity of the planet carrier and the gear pump (HM₁) in a positive direction (the same direction as the direction of the input shaft 5) we will have at the start (having a stopped output shaft $\omega_2=0$), and in a opposite direction it will depend on the value of ω_2 and i_{52}^h . Because ω_2 and i_{52}^h can grow theoretically illimitably, then ω_h can also grow theoretically illimitably.

The ratio of the angular velocities of the input shaft 5 and the output shaft 12 is called the gear ratio [2] of the mechanism with the continuously variable gear ratio option, hydromechanical gear - $i_{52}^{(HMP)}$.

$$i_{52}^{(HMP)} = \frac{\omega_5}{\omega_2} \quad (3)$$

We substitute equation (3) into equation (1), but before that we transform it so we can get the ratio $\frac{\omega_5}{\omega_2}$ we work it out according to

$$i_{52}^{(HMP)} = i_{52}^h = \frac{\omega_{h(1-i_{52}^h)}}{\omega_2} \quad (4)$$

Analogically with the hydrodynamic gears we lay

$$i' = \frac{\omega_2}{\omega_h} \quad (5)$$

i' - is the gear ratio of the hydraulic part of the gear [7] – on of their most important feature. Substituting into (4) we get :

$$i_{52}^{(HMP)} = \frac{1 - i_{52}^h(1 - i')}{i'} \quad (6)$$

The angular velocity of the output shaft can be determined by the equation (6) by substituting $i_{52}^{(HMP)}$ with its quantity in equation (3) :

$$\omega_2 = \frac{\omega_5 i'}{1 - i_{52}^h(1 - i')} \quad (6)$$

From the analysis of the equations (4) and (6) we can come to the conclusion that the hydromechanical gear will work in a duty of a clutch when:

$$\frac{\omega_2}{\omega_5} = -1 \quad \text{and} \quad i' = \frac{i_{52}^h - 1}{i_{52}^h + 1}$$

If the planet carrier *h* is connected to the gear pump (HM₁) via gear with gear ratio i_{hHM_1} between the gear and the planet carrier and $i_{hHM_1} \neq 1$ the angular velocity of the pump is determined by multiplying the equation (2) with i_{hHM_1} :

$$\omega_{HM_1} = \omega_h \cdot i_{hHM_1} = \frac{\omega_5 - \omega_2 \cdot i_{52}^h}{1 - i_{52}^h} \cdot i_{hHM_1} = \frac{\omega_2}{i'} \cdot i_{hHM_1} = \frac{i_{52} \cdot \omega_2 - \omega_2 \cdot i_{52}^h}{1 - i_{52}^h} \cdot i_{hHM_1} \quad (7)$$

To form a mechanism with a continuously variable gear ratio option it is necessary $i_{52}^h \neq -1$ which is always true for the reviewed mechanism, because the conditions $i_{52}^h \in (-\infty; -1)$ at $i_{52}^h \neq \frac{1}{1-i'}$; at $i' \neq 0$ are fulfilled.

In the next considerations it is considered that the gear ratio of the reformed mechanism is $i_{52}^h < 0$, because at a blocked planet carrier, the gears 4 and 2 are rotating in opposite directions i.e. :

$$i_{52}^{(HMP)} = \frac{\omega_5}{\omega_2} < 0 \quad (8)$$

From $i_{52}^h < 0$ and the equation (4) for the area of variation of i_{52}^h it follows that:

$$-\infty < i_{52}^h < -1 ; i_{52}^h \in (-\infty; -1) \quad (9)$$

From equation (4) or (6) after substitution in equation (3) about the ratio $i' = \frac{\omega_2}{\omega_h}$ it is formed:

$$i' = \frac{1 - i_{52}^h}{i_{52}^{(HMP)} - i_{52}^h} \quad (10)$$

The connection between the torques of the input shaft T_5 , the output shaft T_2 , and the planet carrier T_h is determined by the equations:

$$T_2 = T_5 \cdot i_{52}^h \cdot \sin \angle_{52}^{h+1} \quad (11)$$

$$T_5 \neq T_2 + T_h = 0 \quad (12)$$

The sign of the exponent in the equation (11) is determined by the dependence of the sign of the expression $\frac{\omega_5 - \omega_h}{\omega_5} > 0$ then in equation (11) a plus sign is taken.

If $\frac{\omega_5 - \omega_h}{\omega_5} < 0$, then in equation (11) a minus sign is taken. In equation (11) with $\angle_{52}^h$ is marked the efficiency factor of the reformed (with blocked planet carrier) mechanism. In the reviewed case having $i_{52}^h < 0$, $\frac{\omega_5 - \omega_h}{\omega_5} > 0$, for the cases when $\frac{\omega_h}{\omega_5} < 0$, which using the equation (2) gives $\frac{\omega_2}{\omega_h} \leq 0$. From the equations (11) and (12) using a plus sign in the exponent of equation (11) gives the following expressions for the torques, acting on the input shaft 5 and the planet carrier 6 (h), expressed via the torque of the output shaft 12.

$$T_5 = \frac{T_2}{i_{52}^h \cdot \angle_{52}^h} \quad (13)$$

$$T_h = T_2 \cdot \left(\frac{1}{i_{52}^h \cdot \angle_{52}^h} + 1 \right) \quad (14)$$

Because it was accepted that the shafts 5 and 12 are rotating in a different directions and from equations (2) and (10) at $i_{52}^h < 0$ it follows that ω_5 have the same direction as ω_h and a different one from ω_2 if:

$$\frac{1}{i_{52}^h} < \frac{\omega_2}{\omega_5} < 0$$

If $\left| \frac{\omega_5}{\omega_2} \right| > |i_{52}^h| \omega_5$ there are different directions than ω_h and the engine torque T_5 has the same direction as ω_5 , and the resistance torque on the output shaft T_2 has a direction that is the same with the one on the shaft T_5 (see equation 13), i.e. the shaft 12 will be loaded (T_2 and ω_2 has opposite directions).

From equation (14) it follows that T_h will have the direction of T_2 , if the conditions $i_{52}^h \in (-\infty; -1)$ and $\frac{\omega_2}{\omega_5} \in \left[0, \frac{i'}{2-i'} \right)$ are fulfilled i.e. its direction will be opposite to the ω_h and the gear pump will be a consumer of power.

The signs of the torques T_h and T_2 will be different in the cases when $\frac{\omega_2}{\omega_5}$ and i_{52}^h belong to the intervals of variation

$$i_{52}^h \in (-1, 0) \text{ и } \frac{\omega_2}{\omega_5} \in \left[\frac{i'}{2-i'}; i' \right)$$

Because the direction of the angular velocity of the planet carrier ω_h is different from the direction of the angular velocity ω_2 , respectively it will be opposite to the direction of the torque T_h , and in this case the gear pump appears to be a consumer of power. This enhances the area of application of the reviewed mechanism. When the input shaft becomes output one and conversely, and with a change of their direction of rotation – the same equations are valid which can be proven by their analysis.

On figure 2 are shown illustratively the change of the values of the quantities ω_h , ω_2 , and i' in dependence of i_{25} at $\omega_5 = \text{const}$

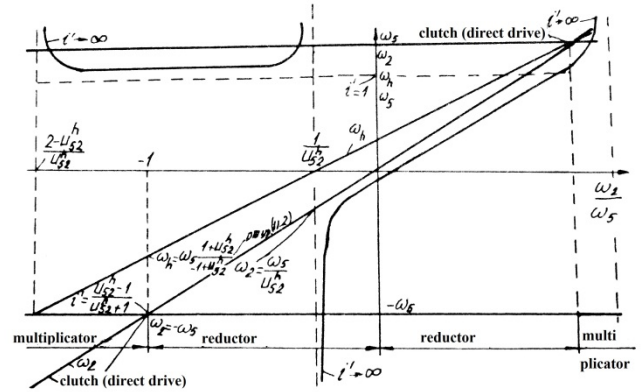


Figure 2. change of the values of the quantities ω_h , ω_2 , and i' in dependence of i_{25} at $\omega_5 = \text{const}$

From the received results from the analysis of the gear with i_{52}^h the next very important conclusion can be made:

- The mechanism works steady as a reductor, clutch and as multiplier as well in both of directions of rotation in dependence of the angular velocity of the planet carrier h , which is regulated by the throttle 9 – figure 1.

3. Examples of realization.

Every planetary gear from the $2k - h$ type [5] has three elements/units (two central gears and a planetary carrier with planetary/satellite gears mounted on it with bearings), called sun gear and ring gear (the central gears) and the planetary carrier. On two of this units of the gear are mounted the input and the output shafts. The unit on which the input shaft is mounted is called the input unit/element – or just the input. Respectively the unit on which the output shaft is mounted is called the output unit/element – or just the output. The third unit is blocked (if the gear is a simple planetary one) and is called the blocked unit. Respectively there are six different combinations of kinematic connections (kinematic schemes) each with different abilities and gear ratios [1, 4, 6], and to be precise:

Table 1

	Input unit	Output unit	Blocked unit
1.	Sun gear	Ring gear	Planet carrier
2.	Ring gear	Sun gear	Planet carrier
3.	Sun gear	Planet carrier	Ring gear

4.	Planet carrier	Sun gear	Ring gear
5.	Ring gear	Planet carrier	Sun gear
6.	Planet carrier	Ring gear	Sun gear

* On figure 1 is shown example № 1 of this table, respectively the described principle of working is related to this example too. It is absolutely possible to realize the other five examples of kinematics presented in this table, and each one of them has different kinematic abilities and gear ratios compared to one other.

On the basis of all of this six types of kinematic connections (kinematic schemes) can be designed and produced the so called dual flow hydromechanical planetary gear with a continuously variable gear ratio option (because it is from the type of $2k - h$ planetary gear – as mentioned before). Just on the blocked unit is placed a single gear wheel in mesh with the gear wheel (forming a standard cylindrical gear) of one of the hydro machines (the gear pump, which can also work as a hydro motor) and respectively this way it is connected to the to the hydroregulating contour. On the output shaft on the other hand is mounted another gear wheel that meshes with the gear wheel of the other hydromachine (hydro motor that can also work as a hydro pump as well), again connecting it to the hydro regulating contour, so the entire gear can function according to the idea of technical novelty.

As mentioned above, the dual flow hydro mechanical planetary gear with a continuously variable gear ratio option can be realized (produced/made) for example as the described graphically on the figure 1 way, with the described in details there elements/units. The planetary gear with the continuously variable gear ratio option can analogically and clearly enough, be realized using the other five types of kinematics shown in table 1. All elements of the gear remain the same, but are connected by a different way (input, output and blocked unit are different – the blocked unit is always connected to the hydroregulating contour). The principles of work remain the same.

The gear can be designed in a way, that the gears 11 (figure 1) can be all known types (cylindrical, face gear, worm gears and so on).

All gear details in the structure of the dual flow hydromechanical planetary gear with the continuously variable gear ratio option are made by the known methods and technologies and with the known machines (cutter or gouge for example) and with the appropriate bearings are installed in the body (which can be made by casting) according to the views and ideas of the engineer constructors. The hydro machines are chosen among the produced worldwide.

4. Application of the dual flow hydromechanical planetary gear with continuously variable gear ratio option.

The presented with this report gear can be used in all fields and spheres of the mechanical engineering and machine-building in which the engineer constructors and designers assesses that its abilities will be of use or will be needed. The dual flow hydromechanical planetary gear with a continuously variable gear ratio option is appropriate for machines that needs to modify the angular velocity of its shafts in a wide diapason, machines in which is not appropriate to install a simple gears or variators (or friction gears). One simple example in which is appropriate to design the machine with this gear is a lathe.

5. Literature:

1. "Gear geometry and applied theory – second edition" Faydor L. Litvin, Alfonso Fuentes. "Cambridge University press" 2004.
2. Minchev N., Jivkov V., Stoyanov P., and others "Theory of the mechanisms and machines" Softtrade Sofia 2011
3. Stoyanova K. "Machine elements" Color Print Varna 2000
4. Lefterov L., Dimitrov I., Yordanov P., Ganey E. "Machine elements" Tehnika Sofia 1994
5. Kudryavcev V. N. "Planetary gears" Mashgiz, M. L. 1960 and 1966
6. Gigov B. "Automatic transmissions" TU Sofia 2011
7. Beckmann K. "Wirkungsgrad und Stellbereich von Planeten getrieben mit Uberlagerungs-zweig in Abhangigkeit vom Verhaltnis der Uberlagerungsleistung zur Gesamtleistung", Konstruktion, №9,1988
8. Kistochkin E. S. "Выбор параметров планетарного механизма замкнутых бесступенчатых передач" В кн. „Прочность и надежность механического привода” Машиностроение, 1977
9. Bashta T.M., Zaychenko I. Z., Ermakov V.V. and others. "Объемные гидравлические приводы" Машиностроение 1989