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TECHNOLOGICAL METHODS OF ENSURING THE RELIABILITY OF LOCK CONNECTIONS IN MARINE GAS TURBINES

Technologiczne sposoby zapewnienia niezawodności połączeń zamkowych okrętowych turbin gazowych

Abstract: *The article presents the test results of the surface quality parameters after broaching of heat-resistant steels of grades: 1.7335 (13CrMo4-5) and 1.4841 (X15CrNiSi25-20). The aim of the work is to determine the technological methods of obtaining the lowest treated surface roughness, surface layer hardening and the elimination of surface defects after broaching. To investigate the influence of cutting conditions (cutting speed, tool geometry and feed) on surface roughness and hardness, the physical modeling method of the broaching was used. As a result of the research, recommendations for improvement of the main parameters of the surface layer quality when broaching samples from selected grades of heat-resistant steels.*
Keywords: gas turbine, reliability, lock connection, discs surface quality, broaching, heat-resistant steels**.**

Streszczenie: *W artykule przedstawiono wyniki badań parametrów jakości powierzchni po przeciąganiu stali żaroodpornych gatunków: 1.7335 (13CrMo4-5) i 1.4841 (X15CrNiSi25-20). Celem pracy jest określenie technologicznych sposobów uzyskania najmniejszej chropowatości obrobionej powierzchni, korzystnego poziomu umocnienia warstwy wierzchniej i eliminacji defektów powierzchniowych po obróbce skrawaniem. Aby zbadać wpływ warunków skrawania (prędkości skrawania, geometrii narzędzia i prędkości posuwu) na chropowatość i umocnienia powierzchni, zastosowana została metoda modelowania fizycznego procesu przeciągania. W wyniku badań opracowane zostały rekomendacje dotyczące podniesienia głównych parametrów jakości warstwy wierzchniej podczas przeciągania próbek z wybranych gatunków materiałów żaroodpornych.*
Słowa kluczowe: turbina gazowa, niezawodność, połączenie zamkowe, jakość powierzchni tarcz, przeciąganie, stale żaroodporne.

1. Introduction

The production of gas turbine engines requires the introduction of new heat-resistant materials, which have improved heat-resistant, corrosion-resistant and physical-mechanical properties. However, the implementation of such materials is complicated by the lack of research in the broaching of lock grooves in the turbine and compressor disks. The topology of the machined surfaces does not meet the design quality requirements, numerous defects are formed, which is unacceptable in difficult working conditions of gas turbine engine. It can lead to a decrease in the reliability of the lock joint, breakage of the blade root, the disc rim and the engine as a whole.

For the purposes of the research ***thesis*** was formulated:

The appropriately developed technology of finishing the grooves of the gas turbine discs' locks allows to ensure the reliability of the connections between the blades and the turbine disc by obtaining the surface layer of the grooves of increased quality.

The beginning of gas turbine production dates back to 1791, when the English creator John Barber patented the first solution of this type. Due to the low level of technology and knowledge of the theory of thermal machines, experimental constructions were launched in 1936 by the Brown Boveri company in Neuchatel, Switzerland. The power of this installation was 4 [MW], with the efficiency of 17.4% [1]. One of the main applications of gas turbines is in the fields of aviation, industry and shipbuilding. They can also be used in other fields of technology, for example being a power source for a power plant.

The first turbine used to power a ship in the maritime industry as a propulsion was the Beryl engine on the MGB2009 seagoing ship. The engine was designated as Metrovick F2. This event marked the beginning of the use of gas turbines on ships for the next two decades. The first unit that used a gas turbine as a standalone drive was called HMS Gray Goose and it was a Rolls Royce PM60 engine with a capacity of 4 [MW] [1, 11].

In 1955, during the war period of John Sergeant in the United States, the GE FS3 engine with a capacity of 4.5 [MW] was used for the first time. The Royal Navy's decision in 1967 to use only gas turbines for propulsion at their company resulted in the installation of an Olympus engine on HMS Exmouth in 1968. In the 1980s, the so-called Olympus propulsion was also delivered to such ships as HMS Invisible, HMS Illustrious and HMS Ark Royal.

In the USA, an engine derived from the GE LM2500 aviation concept was used for the naval services of the Navy in 1969. The use of gas turbine engines to propel merchant ships was much slower compared to naval ships.

The first commercial vessel Auris to use a gas turbine belonged to the Saxon Petroleum Company and was installed in 1951. In 1968. Admiral WM Callaghan was equipped with two Pratt aviation derivatives and Whitney FT4 gas turbines, originally constructed as an industrial vessel, then used for logistics work. This type of propulsion was also applied to the Euroliner in 1971 and then in 1977. Mounted on the Finnjet, which at that time became the fastest and longest ferry in the world.

At the beginning of the 21st century, the Millennium Class and Queen Mary 2 cruise ships were designed in a combined system with a diesel-electric generator.

In the early 1980s, the construction of gas pipelines reduced the number of new gas turbine drive models. Leading companies involved in the construction of turbines over the next years made significant progress towards the creation of stationary energy gas turbines of medium and high power [1, 11].

Below, in table 1 is presented the main parameters of modern gas turbines manufactured in the world.

Table 1

The main parameters of modern gas turbines

Manufacturer	Turbine parameters				
	Power, [MW]	The highest cycle temperature, [°C]	Pressure ratio	Rotor rotation frequency, [r/min]	Efficiency, [%]
MS-5002 (USA)	25.00	927	8.6:1	5100	28.3
ABB-3 (Switzerland)	5.15	950	8.3:1	10000	33.0
GT-35 (Sweden)	16.00	850	12:1	6000	33.0
GT-10 (Russia)	25.00	1140	13.6:1	7700	35.0
DN71 / DI71 (Ukraine)	10.00	1470	-	4800/6500	36.0
PGT-10 (Italy)	10.43	1070	14:1	7900	32.6
ГТД 110 (Ukraine)	114.50	1483	-	3600	36.0
Rolls-Royce MT30 (GB)	36.00	-	-	3600	40.0
GE-LM2500 (USA)	30.20	-	18:1	3600	38.0
GTE-150 (Russia)	150.00	1373	-	3000	30.5

In high temperatures, pressure, rotational speed in the presence of vibration, cyclic alternating loads and an aggressive environment (fig. 1) from fuel combustion, the most loaded element of the turbine is the lock connections [2-7].

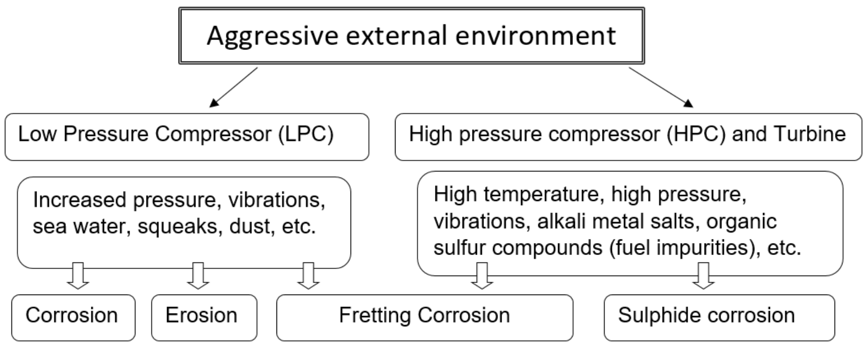
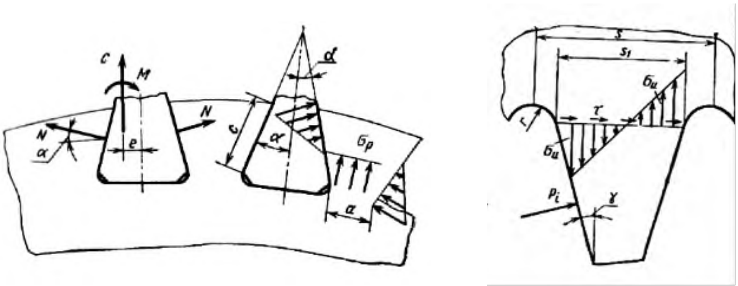


Fig. 1. Aggressive external environment in Low and High Pressure Compressor and in Turbine

In such joints, contact stresses increase significantly, the processes of fretting corrosion, cracking, sulfide erosion are activated, and numerous unfavorable processes develop.

They often cause failure not only of the interlock, but also of the gas turbine engine as a whole. Under such conditions, the unsatisfactory quality of the mating surfaces of the lock grooves, the presence of any defects, cracks, tensile residual stresses, etc. is unacceptable.

A significant disadvantage of rotor and turbine lock jones is their low damping capacity. As a result of blade vibrations, local alternating contact stresses arise, which can be the cause of the formation of centers of fatigue failure and the subsequent failure of the blade root and disk protrusion. This shortcoming applies to a much lesser extent to the fir-tree type compounds. Since the essence of this connection is the uniform distribution of the load with reduced pressure over the fir-tree profile elements blade root and disk grooves. They work reliably if satisfactory contact between the surfaces of the blades root and the disk grooves is ensured. Compressor and turbine blades are under the action of centrifugal forces C, which create variable stresses in them along the airfoil height, the maximum of which is usually located at its base and tends to pull the blades out of the lock groove [22]. The centrifugal force C is balanced by the normal force N acting on the side faces of the groove. Collapse stresses and tensile stresses of the bridge depend on the size of the area of contact between the blade lock part and the disk. Therefore, at the stage of designing the shape of disk groove, it is necessary to take into account the centrifugal forces maximum of in various modes of the turbine operation. Under the action of gas forces in the turbine blades, bending stresses σ_u arise, its maximum is based on the airfoil (fig. 2).

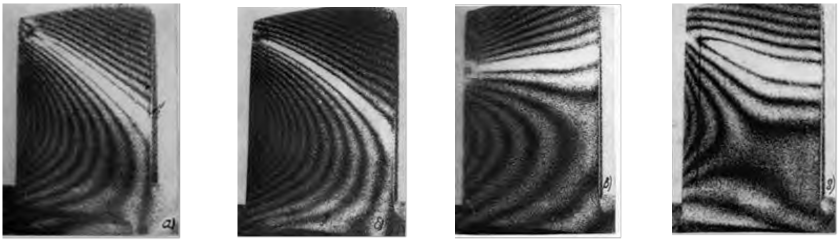


a) b)

Fig. 2. Stressed state of the lock connection: a) scheme of the crushing stress distribution on the lock side surfaces; b) scheme of the bending stress distribution at the tooth base

Since the stiffness of the blade and the average value of the gas flow forces are related to the level of σ_u from gas forces, it means that there is a correlation between vibration and bending stresses.

Therefore, when designing blades, try to reduce the σ_u to a minimum, thereby ensuring a decrease in vibration stresses. GTE operation experience shows that the main part of engine breakdown and failure (about 70%) occur as a result of fatigue phenomena during rotor blade vibrations [18]. Studies of the blade dynamic characteristics by various vibrometry methods show that, in all forms of vibration for all types of blades, they do not attenuate at the root section, but propagate deep into the fixed lock joint (fig. 3) [12,16,20].



a) b) c) d)

Fig. 3. Results of dynamic characteristics studies of the blades by the method of strobogalagraphic vibrometry: a) oscillations frequency f = 8915 Hz; b) oscillations frequency f = 9150 Hz; c) oscillations frequency f = 9870 Hz; d) oscillations frequency f = 10536 Hz

Experimental data are shown that, despite the large clamping force, it is not possible to dampen vibrations in the lock. Therefore, the prevailing type of wear in lock joints is fretting corrosion [21]. This is a process that occurs during cyclic loading of contact parts that form a press or inactive joint between themselves. The minimum amplitude A_p at which the process is observed may not exceed 100 Å, and at $A_p \approx 200–300$ µm, the fretting wear process becomes dominant. When a lock joint is exposed to normal N and tangential F_p forces, the joint surfaces are displaced with an amplitude of $\pm A_p$. In this case, particles of the damaged surfaces, sub- and microcracks are formed near the contact boundaries [17]. Initial fatigue cracks, being potential sources of stress concentration and being in the local contact zone for a long time, can be removed by abrasive particles, develop to macrocracks, and periodically leave the local contact zone. At the same time, the stress-strain state in these zones is keeps changing.

A number of authors have established that the value of the fretting-endurance limit of the lock joint depends on:

1) the mechanical properties and chemical composition of the materials used,
2) the design of the lock groove disk and the blade root,
3) the contact surface stress, which is largely determined by the angle of inclination of the contact edge and the quality of its surface.

The most important operational properties of machine parts are depended on their contact interaction [16,18,19]. One of the most important parameters of the contact interaction of joints is the amount of convergence of mating surfaces. The contact approach of the surfaces occurs due to elastic-plastic deformations of the roughness and underlying layers. The primary influence on the transition of elastic to plastic deformations, with the same material, is exerted by the quality of the surface, which depends on the technological methods of processing the contacting surfaces. An important influence is exerted by a change in the relative position of the processing marks on the contacting surfaces. Changes in the physical and mechanical properties of the surface layer (microhardness and residual stresses) and surface geometry, as shown by the results of numerous studies, cause a change in the critical approach and the actual contact area of the mating surfaces.

A large number of works [12,18-20] are devoted to the study of the relationship between the quality of the surface and the surface layer and fatigue resistance, the analysis of which indicates that the fatigue The strength of the vast majority of heat-resistant materials at elevated temperatures is mainly a function of the magnitude and nature of the roughness. An increase in the degree of roughness both across the specimens and along them causes an increase in stress concentration, leads to a decrease in fatigue strength under conditions of bending vibrations, which are subject to interlocks.

In this case, the endurance limit is affected not only by the height of the microroughness, but also by the location of the tool marks. The most dangerous is such an arrangement of machining marks when they cut the lines of the force field on the surface of the part at a right angle. Relatively deep machining marks (risks) can be stress concentrators.

The main operational properties of the lock joint depend on the surface quality characteristics. The surface geometry affects the endurance limit and corrosion resistance. In this case, microgeometry and local surface defects are very important. The lower the surface roughness, the greater the endurance limit of the lock grooves. The endurance limit is affected not only by the height of the microroughness, but also by the location of the tool marks. Therefore, when inspecting surfaces, it is necessary to check not only the conformity of the obtained level of roughness, but also the absence of defects and traces of processing. Surfaces with high roughness values are less resistant to fretting corrosion in an aggressive working environment. Contact stiffness, wear resistance and vibration resistance also depend on the surface quality of the lock joint elements.

Summarizing the analysis of research works on the relationship between the fatigue strength of the interlock joints and the surface quality, we can state that the strength of the lock for the vast majority of heat-resistant materials at elevated temperatures is mainly a function of the main parameters of its surface quality.

2. Research materials and methodology

Two grades of heat-resistant steel were chosen for experimental research. The material used for the production of components exposed to high temperatures is low-alloy steel 1.7335 (13CrMo4-5, 15HM). It is a chrome-molybdenum boiler steel grade with a relatively low carbon content compared to other related grades used for operation at high temperatures, characterized by good cold and hot forming properties, very good machinability, weldability and corrosion resistance while maintaining high properties strength at room temperature and elevated temperature [9]. This material works perfectly in an acidic environment, often found in construction equipment and installations for the refining, petrochemical and gas industries [15].

The next tested material is 1.4841 (X15CrNiSi25-21, H25N20S2) [10]. It is a high-alloy chrome-nickel-silicon steel with an austenitic structure, heat-resistant up to 1150°C (in practice up to 1100°C), used for heavily loaded parts of devices requiring resistance to oxidation and numerous loads at high temperatures. This steel is the right choice for components working in an environment with gases containing Nitrogen and Oxygen. Unfortunately, this grade does not have the same properties when working in contact with sulfur compounds. At high concentrations, its heat resistance drops to approximately 900°C.

The chemical composition and mechanical properties of the tested materials are presented in tables 2, 3 and 4.

Table 2

The chemical composition of the steel 1.7335 (13CrMo4-5, 15HM)

Steel 1.7335 (13CrMo4-5, 15HM), PN-98/H-74252, PN-70/H-94009, PN-75/H-84024											
Chemical composition, [%]											
C	Mn	Si	P	S	Cr	Mo	Ni	V	Cu	W	Al
0,11–0,18	0,4–0,7	0,15–0,35	<0,04	<0,04	0,7–1,0	0,40–0,55	<0,35	-	<0,25	-	<0,02

Table 3

The chemical composition of the steel 1.4841 (X15CrNiSi25-21, H25N20S2)

Steel 1.4841 (X15CrNiSi25-21, H25N20S2), PN-71/H-86022											
Chemical composition, [%]											
C	Mn	Si	P	S	Cr	Mo	Ni	V	Cu	W	Al
<0,2	<1,5	2,0–3,0	<0,045	<0,030	24,0–27,0	<0,5	18,0–21,0	<0,2	<0,3	<0,5	-

Table 4

The mechanical properties of the tested materials

Parameter	1.7335 (13CrMo4-5, 15HM)	1.4841 (X15CrNiSi25-21, H25N20S2)
Tensile strength Rm, [MPa]	450 - 600	550 - 750
Yield point Re, [MPa]	≥ 300	> 230
Elongation extension A, [%]	≥ 20	> 28
Hardness HB	130 - 175	< 223
Specific heat at 20°C, [cal/g °C]	0,14	0,12
Heat capacity cp20-100°C, [J · kg^{-1} · K^{-1}]	470	500
Heat conductivity, λ [W · m^{-1} ·K^{-1}]	44	14,7
Linear expansion coefficient α ·10^{-6}, [K^{-1}]	13	15

Among the known machining methods used in the production of energy machines, one of the most stable and efficient and the least studied is the broaching method. Broaching is a machining process in which all machining allowance is removed in one pass of the tool called a broach. This process is carried out according to two schemes for removing the generating and profile allowance on horizontal and vertical machine tools of various types and designs (fig. 4).

Fig. 4. Broaches used to machining turbine disk lock groove

The cutting parameters for broaching are selected depending on the properties of the material being processed and the operation being performed. The broaching is commonly used in the production of power machine parts with high accuracy and surface layer quality [4,8,22].

The purpose of the tests described in this chapter was to determine the broaching conditions for heat-resistant steels 1.7335 and 1.4841. ensuring the lowest level of surface roughness and appropriate hardness of the surface layer.

A tool which is a physical model of the broaching process was used for the research. Physical modeling is distinguished primarily by the fact that the research is carried out on installations that show physical similarity, i.e. the preservation of all (or at least part) of the nature of the phenomena. The similarity of phenomena means that the data on the occurrence of processes obtained in the study of a single phenomenon can be extended to all similar phenomena. With a physical similarity, the fields of the respective physical parameters of both systems are similar in space and time. Therefore, in order to carry out research, a cutting tool of a special design was manufactured (Ukrainian Patent No. 65776) with two changing cutting elements made of high-speed steel SW7M (HS6-5-2) and geometry (clearance angel $\alpha = 3$ °; rake angle $\gamma = 20$ ° and $\gamma = 27$ °) is identical to the broach teeth (fig. 5) [5,8].

Fig. 5. Planer tool as a physical model of broaching process

The simples made of steel 1.7335 (13CrMo4-5, 15HM) and steel 1.4841 (X15CrNiSi25-21, H25N20S2) were tested under different cutting condition are shown on figure 6.

a) b)

Fig. 6. Photos of samples after machining from grade steel: a) 1.7335 (13CrMo4-5, 15HM); b) 1.4841 (X15CrNiSi25-21, H25N20S2)

According to the research methodology, at the first stage, the main technological factors were established to the greatest extent that affect the roughness and hardening of the treated surface during steel broaching. These include cutting speed, feed, cutting tool geometry, quality of the material being processed, and the type of lubricating-cooling fluid used. To ensure the reproducibility of the experimental data, the studies were carried out in two parallel experiments in accordance with the experimental plan presented in table 5.

Table 5

Experimental cutting conditions

Study number	Slider stroke length L, [mm]	Cutting speed V, [m/min]	Rake angle γ, [°]	Clearance angel α, [°]
1	75	2.5	20	3
2	75	2.5	20	3
3	75	5	20	3

4	75	5	20	3
5	75	10	20	3
6	75	10	20	3
7	75	2.5	27	3
8	75	2.5	27	3
9	75	5	27	3
10	75	5	27	3
11	75	10	27	3
12	75	10	27	3

In order to determine the influence of the cutting conditions during broaching on the surface roughness and its hardness, the following were carried out:

- machining the surface of the material using the physical model on the SZ-400 Planer (fig. 7 a), type of cutting fluid used is MEGOL-46S, with different cutting parameters;

- roughness measurement was performed on the Profilometer "HOMMEL-ETAMIC W20" [13] (fig. 7 b);

- hardness measurement was performed Vickers method [14] on the Qness Q250M universal hardness tester (fig. 7 c), which is equipped with a 6-position automatic measuring head, enabling the mounting of indenters and lenses and the Qpix T12 software enables the preparation of a measurement report, full archiving of measurement data, including saving photos of the imprint.

a)

b)

c)

Fig. 7. Study position and measuring equipment: a) planer model SZ-400; b) profilometer "HOMMEL-ETAMIC W20"; c) universal hardness tester Qness Q250M

3. Test results

The measuring results of surface roughness and hardness are presented in tables 6 and tables 7 respectively, which were created in accordance with the research plan implemented.

Table 6

The measuring results of surface roughness

Test number	1.7335 (13CrMo4-5, 15HM)			
	Ra1	Ra2	Ra3	Ra average
1	3.94	0.98	0.45	**1.79**
2	1.22	1.19	0.86	1.09
3	0.94	0.82	0.86	0.87
4	0.64	0.42	0.57	0.54
5	0.95	0.56	0.58	0.70
6	1.11	0.38	0.055	**0.52**
7	1.03	1.12	1.33	1.16
8	0.66	1.59	0.84	1.03
9	0.75	0.78	1.05	0.86
10	0.99	0.61	1.58	1.06
11	1.03	0.96	0.86	0.95
12	1.07	1.24	1.39	1.23

Test number	1.4841 (X15CrNiSi25-21, H25N20S2)			
	Ra1	Ra2	Ra3	Ra average
1	3.94	5.45	5.8	5.06
2	14.56	7.61	10.7	10.96
3	11.51	5.08	9.18	8.59
4	4.63	8.37	12.94	8.65
5	2.7	2.76	2.08	2.51
6	0.88	1.3	0.89	**1.02**
7	12.48	13.53	3.28	9.76
8	4.37	10.09	2.87	5.78
9	3.14	2.55	2.13	2.61
10	17.01	14.44	7.09	**12.85**
11	7.94	6.69	5.97	6.87
12	8.72	4.83	7.65	7.07

Table 7

The measuring results of surface hardness

Test number	1.7335 (13CrMo4-5, 15HM)			
	HV_1	HV_2	HV_3	HV average
1	148	169	157	158
2	160	166	201	176
3	156	153	151	153
4	149	136	268	**184**
5	163	162	158	161
6	146	146	149	**147**
7	144	178	187	170
8	164	164	170	166
9	152	147	146	148
10	153	142	175	157
11	159	164	174	166
12	146	162	162	157

Test number	1.4841 (X15CrNiSi25-21, H25N20S2)			
	HV_1	HV_2	HV_3	HV average
1	277	263	291	277
2	287	276	267	277
3	358	271	372	334
4	328	313	323	321
5	259	295	358	304
6	358	384	374	**372**
7	268	259	254	**260**
8	352	285	273	303
9	284	274	293	284
10	280	280	277	279
11	313	292	309	305
12	284	276	298	286

For each tests, the grooves with the highest and the lowest level of roughness and hardness were marked. During the tests, the best roughness Ra $_{avg}$ = 0.52 μm was obtained when machining steel 1.7335 (13CrMo4-5, 15HM) at a cutting speed of V = 10 m/min and rake angle γ = 20° (test number 6), while the worst Ra $_{avg}$ = 12.85 μm was obtained when processing 1.4841 (X15CrNiSi25-21, H25N20S2) at a speed of V = 5 m/min and rake angle γ = 27° (test number 10).

When testing samples made of steel 1.7335 (13CrMo4-5, 15HM), the highest hardness HV 184 was obtained when machining groove number 4 for cutting condition V = 5 m/min, γ = 20°, while the lowest hardness HV 147 was obtained for test number 6 for cutting condition V = 10 m/min, γ = 20°. When testing 1.4841 (X15CrNiSi25-21, H25N20S2), the highest hardness HV 372 was obtained when machining groove number 6, the lowest hardness HV 260 was obtained for test number 7 (V = 2.5 m/min, γ = 27°).

For fixing and visual analysis of the samples surface after mechanical treatment, the Smart Zoom 5 digital industrial microscope by Zeiss was used (fig. 8).

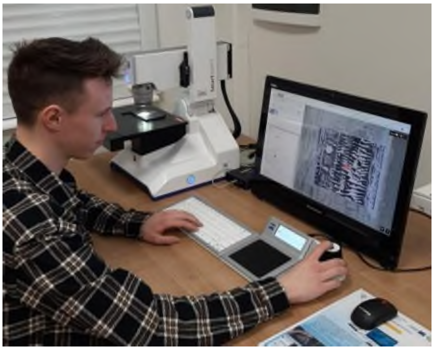
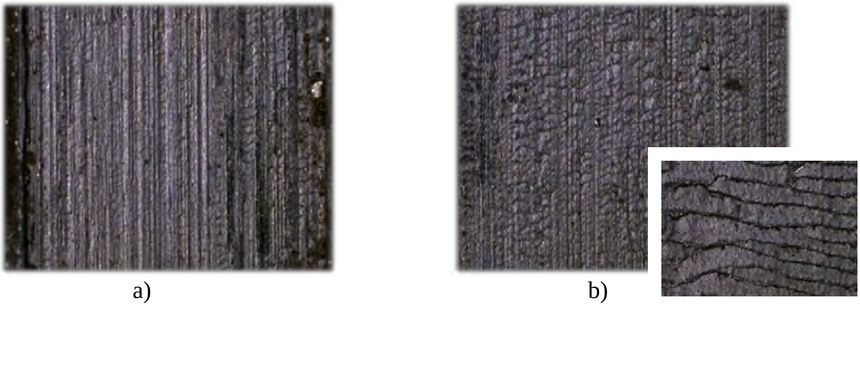


Fig. 8. Visual control and fixing workplace

The microscope Smart Zoom 5 is equipped with an optical system that allows to obtain magnifications up to 1000 times. The automated table has a range of movement in the x-axis up to 130 mm, and in the y-axis up to 100 mm. During the measurement, various ways of illuminating the measured object can be used.

Results of visual analysis are shown in fig. 9.



a) b)

c)

d)

Fig. 9. Photo of the machining grooves surface magnification x 36: a) Ra $_{avg}$ = 1.02 μm (steel 1.4841, test number 6); b) Ra $_{avg}$ = 12.85 μm (steel 1.4841, test number 10); c) Ra $_{avg}$ = 0.52 μm (steel 1.7335, test number 6); d) Ra $_{avg}$ = 1.79 μm (steel 1.7335, test number 1)

4. Conclusions

1. The physical modeling method of the broaching process has received further development, which allows studying the parameters of the machined surface quality of heat-resistant materials while reducing the time for testing, the cutting tool and processed materials cost when studying of cutting conditions.

2. It has been experimentally proven that the surface roughness of the lock connection grooves of turbine discs and high and low pressure compressors discs made of both tested steel at the level of design requirements (Ra = 0.52 – 1.02 μm) in the absence of unwanted traces of processing and any surface defects is achieved by broaching at a speed of V = 10 m/min, with cutting tool made of high-speed steel SW7M (HS6-5-2) and geometry with rake angle $\gamma = 20\,°$ and clearance angel $\alpha = 3\,°$.

3. The level of surface roughness during of heat-resistant materials broaching is most affected by the cutting speed of the lock groove broaching and a lesser extent influenced by the geometry of the tool's cutting edge.

4. To ensure a low level of surface roughness when broaching lock connection grooves in discs made of steel 1.4841 (X15CrNiSi25-21, H25N20S2), low cutting speeds of V = 2.5 – 5 m/min should be avoided.

5. It was determined that when broaching steel 1.4841 (X15CrNiSi25-21, H25N20S2) at speed V = 5 - 10 m/min and the tool rake angle $\gamma = 20^o$, the surface layer hardness is increased. This is useful for the connection of compressor discs operating at relatively low operating temperatures. At the same time, the surface of the lock connection grooves of turbine disks operating at high temperatures (750...1530°C) should not be hardened. Because hardening lowers the limit of long-term strength and durability the more the higher the operating temperature. Therefore it is recommended to form a small hardness layer on the surface of the connection by broaching at a lower speed V = 2.5 m/min with rake angle $\gamma = 27^o$.

6. The dependence of the surface roughness and hardness of the lock connection grooves on the technological parameters of the steels 1.7335 (13CrMo4-5, 15HM) and 1.4841 (X15CrNiSi25-21, H25N20S2) broaching in the cutting speeds of V = 2.5 – 10 m/min can be used in research of the surface quality different grades of heat-resistant and stainless steel.

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