Donbass State Engineering Academy: Collected Work, Kramatorsk, DSMA, No.3 (9), p. p. 13–18.

8. Aliieva L. I. Selection of the kinematic modules for determining power parameters of radial extrusion(2006) *Annals of Donbass State Engineering Academy: Collected Work*, Kramatorsk, DSMA, No. 3 (5), p.p. 108–114.
9. Patent 32229 Ukraine, B21K21/00. Method of hollow parts manufacturing/ Aliiev I. S., Aliieva L. I., Zhbankov Ya. G.; Patent owner - Donbass State Engineering Academy. -No 200714594; pending 24.12.2007; publ. 12.05.2008, Bull. No. 6.
10. Patent 411889 Ukraine, B21K21/00. Method of hollow parts manufacturing / Aliiev I. S., Zhbankov Ya. G.; Patent owner - Donbass State Engineering Academy. -No 200814104; pending 08.12.2008; publ. 12.05.2009, Bull. No 6.

UDC 621.431.75

Echnological support of the gas-turbine engine parts bearing capacity by plastic deformation

Alexey Kachan

Ph.D, Professor,
Head of the aircraft engine technology department,
Zaporozhye National Technical University,
Zaporozhye, Ukraine
e-mail: vd@zntu.edu.ua

Sergey Ulanov

Laboratory assistant of the aircraft engines technology department,
Zaporozhye National Technical University,
Zaporozhye, Ukraine
e-mail: vd@zntu.edu.ua

Evgeniy Berezovsky

Ph.D. student of aircraft engines technology department

Zaporozhye National Technical University,
Zaporozhye, Ukraine
e-mail: vd@zntu.edu.ua

Abstract
The paper presents the results of experimental research of hardening the bearing surfaces of gas-turbine engine parts by surface plastic deformation (SPD).
Outer and inner surfaces of gas-turbine engine hollow shafts were hardened by diamond burnishing technique. Operating parameters and technological process conditions of diamond burnishing are specified, and their impact on surface layer quality characteristics and bearing capacity of shaft wall is studied as well. It is shown that diamond burnishing increases the endurance limit of shaft wall up to 1.57 times compared to unhardened bearing surface.
Compressor rotor blades made of titanium alloys have been hardened by surface plastic deformation technique with the use of steel balls in high-power ultrasonic field. It is shown, that this technique ensures compressor rotor blades endurance limit up to 500…650 MPa.
Key words: SHAFTS, COMPRESSOR ROTOR BLADES, DIAMOND BURNISHING, ULTRASONIC WORK-HARDENING, SURFACE LAYER QUALITY CHARACTERISTICS, ENDURANCE LIMIT.

An effective way to ensure the bearing capacity of the gas-turbine engine parts is a hardening of their of bearing surfaces by surface plastic deformation (SPD) [1].

An important task when carrying out SPD of the gas-turbine engine parts is to ensure the accuracy of the geometric dimensions and parameters of the surface layer of their bearing surfaces, as they determine under the conditions of operation of the engine its durability and reliability [2].

When the SPD the shafts, the rotor blades of the compressor drives, the buffs, are widespread. They are the major components of aircraft engines and received the following treatments: diamond burnishing and ultrasonic hardening by steel balls [3,4].

The work objective is on the base of the experimental results on the SPD hardening to determine the effect of technological support of the diamond burnishing and the ultrasonic hardening on the shaft bearing capacity and rotor blades of the compressor.

For the SPD of the thin-walled hollow gas-turbine engine shafts the diamond burnishing is applied. It allows processing of their both outer and inner surfaces.

In the process of the diamond burnishing cold plastic deformation of the surface layer parts takes place under the force P_f applied to the deforming tool (Fig. 1).

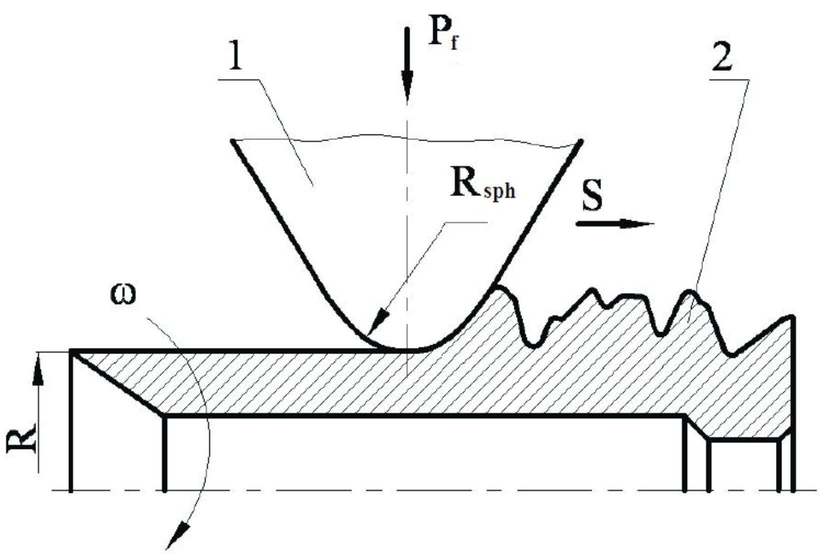


Figure 1. The scheme of diamond burnishing 1 - diamond point; 2 - a shaft ω– part rotation frequency; S – longitudinal feed; P_f – hold down pressure; R_{sph} – radius of diamond point sphere; R – radius of processed part surface .

One of the most common methods is diamond burnishing treatment with fixing the tool on the elastic mandrels, wherein the force P_f is set by elastic deformation of the mandrel or by a spring thoriated in the range of 50 to 400 N. Counting of the force P_f is carried out according to indicator [2].

The main modes and processing conditions when diamond burnishing are:

– tool advance, S, mm / rev;

– burnishing velocity, $V = \omega \cdot R$, m/s;

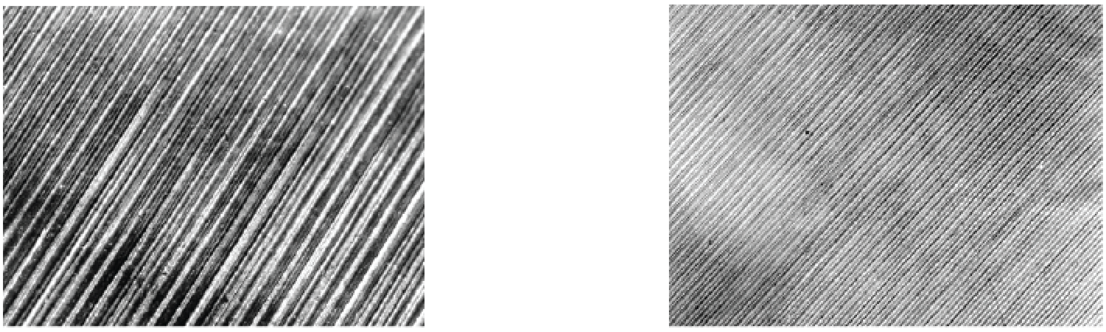
– hold down pressure, P_f, H;

– the use of cutting compound(CC).

The main controllable quality parameters of the processed part surface are:

- surface roughness;
- form of microrelief;
- mechanical condition of the surface layer (depth of hardening and residual stresses);
- endurance limit.

The surface texture of the shaft fragment after grinding followed by burnishing of the inner and outer surfaces is shown in Fig. 2 [3].



a b

Figure 2. The surface texture of the shaft fragment after diamond burnishing
a - outer (x10); b - inner (x10).

The surface roughness varies from the original R_a = 3,2…1,6 microns to R_a = 0,8…0,4 microns when burnishing mode that prevent vibration of the tool.

The microstructure of samples material after the diamond burnishing is shown in Fig. 3.

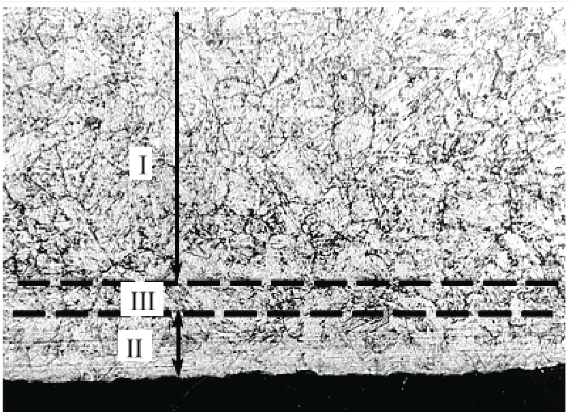


Figure 3. The microstructure of the samples processed by diamond burnishing:
I - area of the initial structure;
II - crushing area of the grain when plastic deformation;
III - transition zone of deformation.
Processing modes: P = 100 H; S = 0,08 mm/rev;
V = 63 m/min; the number of passes– 1; R_{sph} = 2,5 mm

The maximum micro hardness occurs in layers close to the surface of the part and with the distance from the surface it decreases to a value higher than the initial micro hardness by 5 ... 8% (Fig. 4).

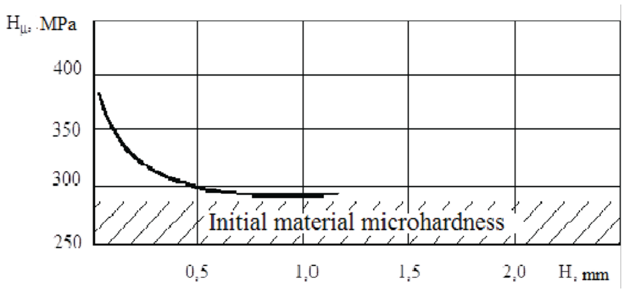


Figure 4. The distribution of the micro hardness in samples H12NMBF-SH alloy after the diamond burnishing with the force P_f =150 N and longitudinal feed S = 0,08 mm/rev.

After the diamond burnishing in the part surface layer residual compressive stresses are formed which magnitude exceeds the residual stresses after the grinding 1.5 ... 2.0 times (Fig. 5).

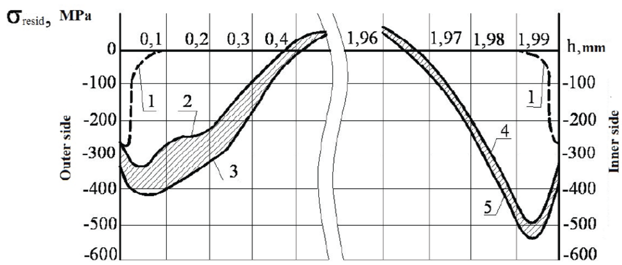


Figure 5. The distribution of the residual stresses on the wall thickness of the part (δ = 2 mm):1 - for the grinded inner and outer surfaces;2.3 - limits of variation of residual stress on the outer side; 4.5 - limits of variation of residual stresses on the inner side.

The effect of the diamond burnishing from the alloy samples H12NMBF-SH cut out from full-scale shaft, the value of the endurance limit for the various parameters of technological modes were evaluated on the basis of tests N = 10^7 via hardening coefficient $\gamma = \sigma_{-1hard} / \sigma_{-1}$, where σ_{-1hard} and σ_{-1} are the limits of endurance of the hardened and initial material parts respectively (Table1) [3].

Table 1. The dependence of the endurance limit from the technological modes of the sample processing from steel H12NMBF-SH

Type of material processing	Processing technological modes				σ_{-1}, MPa	γ
	S, mm/rev	P, H	V, m/min	Number of passes, K		
Grinding	-	-	-	-	300	1.0
Diamond burnishing	0.15	100	150.8	3	430	1.43
	0.15	100	150.8	2	430	1.43
	0.15	150	150.8	1	470	1.57
	0.08	100	226.1	2	470	1.57
	0.15	50	150.8	1	420	1.40
	0.13	100	59.4	1	400-420	1.33-1.40
	0.21	100	150.8	1	350-360	1.17-1.20

The greatest effect is achieved by hardening when processing by modes (see Table1), for which the endurance limit is 470 MPa that corresponds to γ = 1.57.

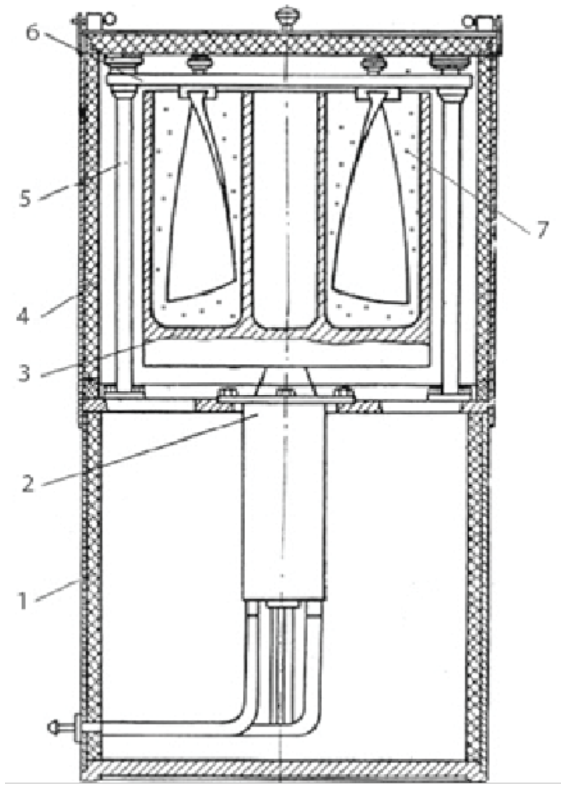


Figure 6. Installation for ultrasonic deformation hardening of the blades. 1 - base; 2 - PMS15A-18; 3 - waveguide; 4 -sound-insulated casing with a cap; 5 – rods; 6 - process flange; 7 - steel balls.

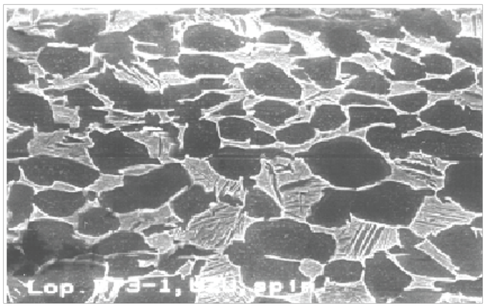
Installation of ultrasonic hardening SPD of the compressor rotor blades consists of an ultrasonic generator, a magnetostrictive transducer, changeable waveguides, the device for fixing a magnetostrictive transducer, a work table for the installation of technological equipment, the processed parts and the sound-insulating casing (Fig. 6) [4].

After the ultrasonic hardening of blades airfoil made of titanium alloy VT8M the roughness R_a = 0.36…0.42 micron is observed and micro hardness on the surface of the airfoil is in the range from the 4150 to 4320 MPa at the initial microhardness of the core 3750 ... 3800 MPa. It indicates the heterogeneity of the initial characteristics of the surface layer of the blades airfoil formed in the previous technological operations of their manufacture.

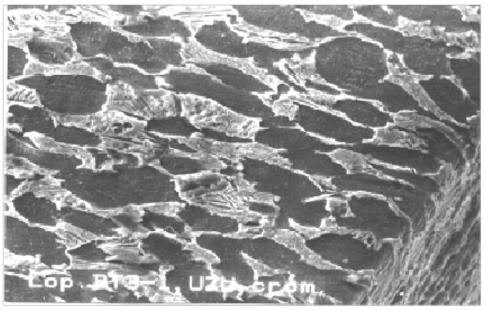
Ultrasound deformation hardening of the blades airfoil LPC (low pressure compressor) of the stage III by the steel balls leads to the formation of structural heterogeneity associated with a greater degree of deformation of the edge surface when hardening (Fig. 7).

Residual stresses have been determined after the ultrasonic hardening of the blades of I stage HPC (high-pressure compressor) from the VT8 alloy. The diameter of the balls is 1.6 and 2.4 mm. The composition of the mixture is 50-50%; the processing time is 10 min. The balls weight is 400 g.

In the surface layer of the airfoil a residual compression stress from 400 to 440 MPa is observed with a depth distribution of 92 ... 130 micron (Fig. 8) [1].



a – x2000



b – x2000

Figure 7. The microstructure of the surface layer of the compressor blades airfoil after the ultrasonic hardening a - on the surface of the suction side; b - on the edge surface of the airfoil

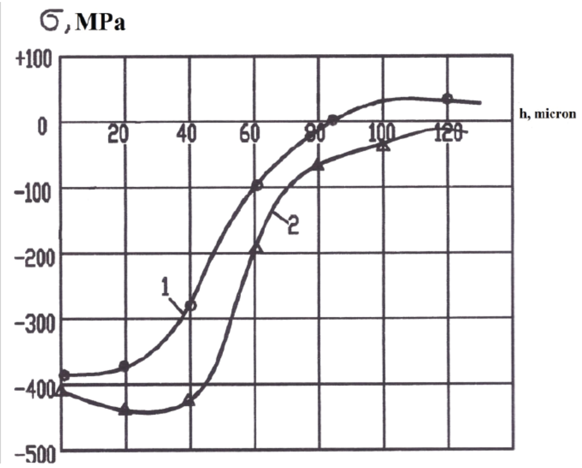


Figure 8. The distribution of residual stresses on the surface of the blades airfoil of I st. HPC VT8 alloy after:
1 – ultrasonic hardening / I = 35 ... 40 mA /;
2 - ultrasonic hardening / I = 55 ... 60 mA /.

The research of the effect of the ultrasonic hardening processing on the basis of

10^8 cycles on the fatigue resistance of the blades III stage LPC of the D-36 motor have indicated that this method provides their endurance limit in the range of 500 to 650 MPa.

Conclusion

The represented experimental study of the methods of surface plastic deformation of the shaft bearing surfaces and rotor blades of the gas-turbine engine compressor has shown that when the shaft processing the most effective method is static - diamond burnishing, and for rotor blades of the compressor - the dynamic method - with the use of ultrasonic hardening by applying steel balls.

The ranges of operating parameters and technological conditions for processing of the specified parts for each of the methods of surface plastic deformation are determined, within which their high bearing capacity is provided.

References

1. Boguslayev V. A. *Otdelochno-uprochnyayuschaya obrabotka detaley GTD* [Finishing-hardening processing of the gas-turbine engine parts], Zaporozhye, JSC "Motor Sich", 2005, 559 p.
2. Boguslayev V. A. *Formirovanie poverhnostnogo sloya detaley vyiglazhivaniem s ultrazvukovyim nagruzheniem* [Formation of the surface layer of parts by burnishing with ultrasonic loading], Zaporozhye, JSC "Motor Sich", 2012, 236 p.
3. Boguslayev V. A. *Tehnologicheskoe obespechenie ekspluatatsionnyih harakteristik detaley GTD. Valyi GTD. Chast IV* [Technological maintenance of operational GTE parts performance. GTE shafts. Part IV], Zaporozhye, JSC "Motor Sich", 2014, 291 p.
4. Boguslayev V. A. *Tehnologicheskoe obespechenie ekspluatatsionnyih harakteristik detaley GTD. Lopatki kompressora i ventilyatora. Chast I.* [Technological maintenance of operational GTE parts performance. Fan and compressor blades. Part I], Zaporozhye, JSC "Motor Sich", 2003 , 396 p.