

MATERIALS AND METHODS

The diesel turbocharger blade is the most heavily loaded component, operating under severe conditions, which determines the service life of the turbocharger, i.e., its resource. In addition to stretching and bending due to centrifugal forces, bending and torsion due to the gas flow, the blade root also experiences thermal stress, rapid heating during engine start-up, and rapid cooling during engine shutdown.

Based on studies [1–3] and previously conducted theoretical and experimental studies, the roughness index R_a was determined to depend on the process parameters for finishing abrasive machining of workpieces made of hard-to-machine cast alloys:

$$R_a = 2 \times 10^4 \left(\frac{t^{0.17} v_{wp}^{-0.6} S^{0.6}}{v_w^{0.85}} \right), \quad (1)$$

where t is the grinding depth, selected based on the allowance value, mm; v_{wp} is the longitudinal speed of the workpiece, m/min; v_w is the wheel rotation speed, m/s; S is the transverse grinding feed, mm/dv. stroke.

Of primary importance are the graphical dependencies that characterize the influence of the process parameters on the surface roughness value. When determining the dependence of roughness on grinding depth, the variable factors at given grinding wheel speeds are within a certain range ($t_1 = 0.05 \times 10^{-3}$ m; $t_2 = 0.1 \times 10^{-3}$ m; $t_3 = 0.15 \times 10^{-3}$ m).

When the grinding depth varies within the above range, the calculated roughness parameters R_a have the following values:

$$\begin{aligned} R_{a1} &= 2 \times 10^4 \\ &\times \left[\frac{(0.05 \times 10^{-3})^{0.17} (4.16 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{30^{0.85}} \right] \\ &= 0.75 \mu\text{m}; \\ R_{a2} &= 2 \times 10^4 \\ &\times \left[\frac{(0.1 \times 10^{-3})^{0.17} (4.16 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{30^{0.85}} \right] \\ &= 0.84 \mu\text{m}; \\ R_{a3} &= 2 \times 10^4 \\ &\times \left[\frac{(0.15 \times 10^{-3})^{0.17} (4.16 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{30^{0.85}} \right] \\ &= 0.91 \mu\text{m}. \end{aligned}$$

Analysis of the dependence graph (Fig. 2) showed that intensive wheel wear occurs at $t_3 = 0.15$ mm, with a wheel speed of $v_{w3} = 25$ m/s. When determining the change in surface roughness with the longitudinal velocity of the workpiece v_{wp1} ($v_{wp1} = 2.5 \times 10^{-3}$ m/s;

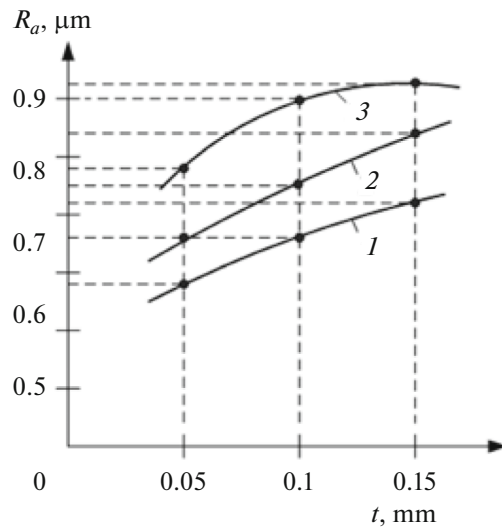


Fig. 2. Roughness versus grinding depth with changing wheel speed: (1) $v_w = 35$ m/s; (2) $v_w = 30$ m/s; (3) $v_w = 25$ m/s.

$v_{wp2} = 4.16 \times 10^{-3}$ m/s; $v_{wp3} = 5.8 \times 10^{-3}$ m/s), the following values of the R_a criterion were obtained:

$$\begin{aligned} R_{a1} &= 2 \times 10^4 \\ &\times \left[\frac{(0.05 \times 10^{-3})^{0.17} (2.5 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{30^{0.85}} \right] \\ &= 0.91 \mu\text{m}; \\ R_{a2} &= 2 \times 10^4 \\ &\times \left[\frac{(0.05 \times 10^{-3})^{0.17} (4.16 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{30^{0.85}} \right] \\ &= 0.67 \mu\text{m}; \\ R_{a3} &= 2 \times 10^4 \\ &\times \left[\frac{(0.05 \times 10^{-3})^{0.17} (5.8 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{30^{0.85}} \right] \\ &= 0.54 \mu\text{m}. \end{aligned}$$

Turbine blades (see Fig. 1), in particular, fir-tree lock joints, are machined using creep-feed grinding [4, 5].

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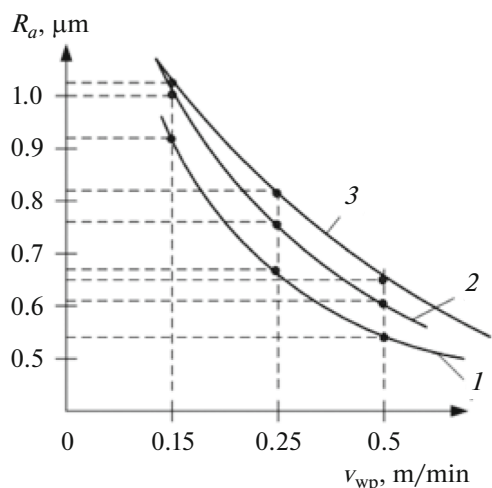


Fig. 3. Surface roughness versus longitudinal feed rate of the workpiece at different roughness depths: (1) $t = 0.05$ mm; (2) $t = 0.1$ mm; (3) $t = 0.15$ mm.

When determining the change in surface roughness as a function of the longitudinal feed speed of the workpiece v_{wp} ($v_{wp1} = 2.5 \times 10^{-3}$ m/s; $v_{wp2} = 4.16 \times 10^{-3}$ m/s; $v_{wp3} = 5.8 \times 10^{-3}$ m/s), the following values of the R_a criterion were obtained:

$$R_{a1} = 2 \times 10^4 \times \left[\frac{(0.05 \times 10^{-3})^{0.17} (2.5 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{30^{0.85}} \right] = 0.91 \mu\text{m};$$

$$R_{a2} = 2 \times 10^4 \times \left[\frac{(0.05 \times 10^{-3})^{0.17} (4.16 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{30^{0.85}} \right] = 0.67 \mu\text{m};$$

$$R_{a3} = 2 \times 10^4 \times \left[\frac{(0.05 \times 10^{-3})^{0.17} (5.8 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{30^{0.85}} \right] = 0.54 \mu\text{m}.$$

The study of the dependence of the roughness indices R_a on the longitudinal feed speed of the workpiece at different grinding depths is shown in Fig. 3.

From the graph (see Fig. 3) it follows that with a decrease in the longitudinal speed of movement of the workpiece, a sharp increase in surface roughness occurs, while a process of intensive wear and volumetric destruction of the abrasive grains of the wheel occurs [3, 6].

Determining the application of the surface roughness parameter R_a to the grinding wheel rotation speed

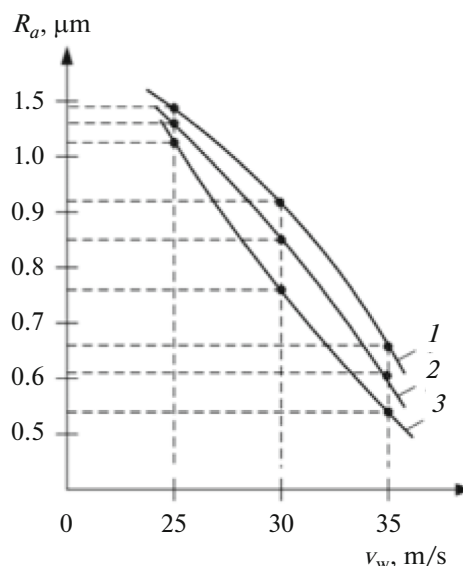


Fig. 4. Surface roughness versus abrasive wheel speed: (1) $v_{wp} = 0.15$ m/min; (2) $v_{wp} = 0.25$ m/min; (3) $v_{wp} = 0.35$ m/min.

($v_w = 25$ m/s; $v_w = 30$ m/s; $v_w = 35$ m/s) at various longitudinal feed rates yields the following values:

$$R_{a1} = 2 \times 10^4 \times \left[\frac{(0.15 \times 10^{-3})^{0.17} (2.5 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{25^{0.85}} \right] = 1.46 \mu\text{m};$$

$$R_{a2} = 2 \times 10^4 \times \left[\frac{(0.15 \times 10^{-3})^{0.17} (4.16 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{30^{0.85}} \right] = 0.92 \mu\text{m};$$

$$R_{a3} = 2 \times 10^4 \times \left[\frac{(0.15 \times 10^{-3})^{0.17} (5.8 \times 10^{-3})^{-0.6} (0.0025)^{0.6}}{35^{0.85}} \right] = 0.66 \mu\text{m}.$$

When machining FTLs using creep-feed grinding, the main drawbacks are wear and clogging of the abrasive wheels, which leads to thermal stress in the machining process and, consequently, low productivity. One method for eliminating these drawbacks is continuous dressing of the abrasive wheels with diamond rollers (DRs), as well as the properties and quantity of the supplied cutting fluids (CFs). The use of continuous dressing with DRs in both roughing and finishing passes is associated with the occurrence of additional vibrations in the process system.

The most widely used method is creep-feeding [1–3] grinding with continuous dressing of abrasive grinding wheels with diamond rollers in two working

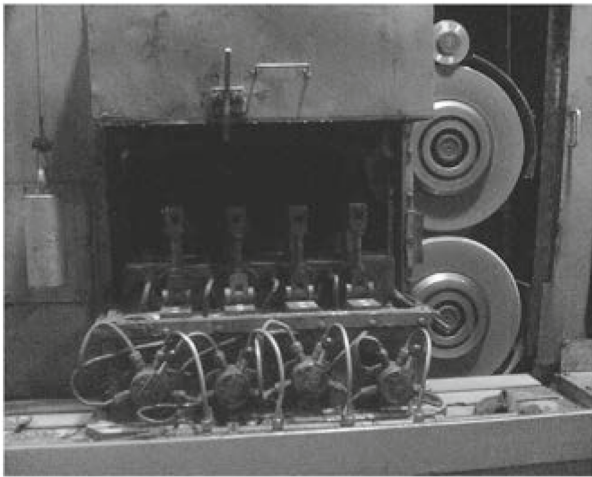


Fig. 5. View of the working area of the LSh233M machine.

passes on specialized CNC grinding machines: the single-spindle LSh183M and the dual-spindle LSh233M (Fig. 5).

The cutting tool used is highly porous 3P shaped wheels, $500 \times 25 \times 203$ in size, made of white fused alumina 25A, with a grain size of 10 (0.01 mm) 10P (increased content of fraction P of abrasive grains) VM212K5 PG, accuracy class A, unbalance class 1, with a cutting speed of 35 m/s. The workpieces are machined using the following process modes: $v_w = 35$ m/s; $v_{wp} = 200$ mm/min; with AKVOL-10M (water-oil composition) cutting fluid (CF).

Diamond dressing rollers (DRs) AC65T, AC82T, and AC-132 with a grain size of 10 were used as dressing tools. The turbocharger blades are made of hard-to-machine heat-resistant cast alloy ANV300 and heat-resistant steel 31Kh19N9, as well as nickel-based alloy KhN70VMTYu. Grinding and dressing modes for up and down rotation of the diamond dressing roller are given in [5, 6].

(A) Roughing pass.

Machining allowance, mm	$Z = 1.4-1.8$
Wheel speed, m/s	$v_w = 25$
Machine table feed speed with workpiece, mm/min	$v_{wp} = 80$
Roller feed per wheel, mm per 10 revolutions of the ground wheel	0.006

(B) Finishing pass.

Machining allowance, mm	$Z = 0.1-0.16$
Wheel speed, m/s	$v_w = 26-28$
Machine table feed speed with workpiece, mm/min	$v_{wp} = 200-400$
Roller feed per wheel, mm per 10 revolutions of the ground wheel	0.004

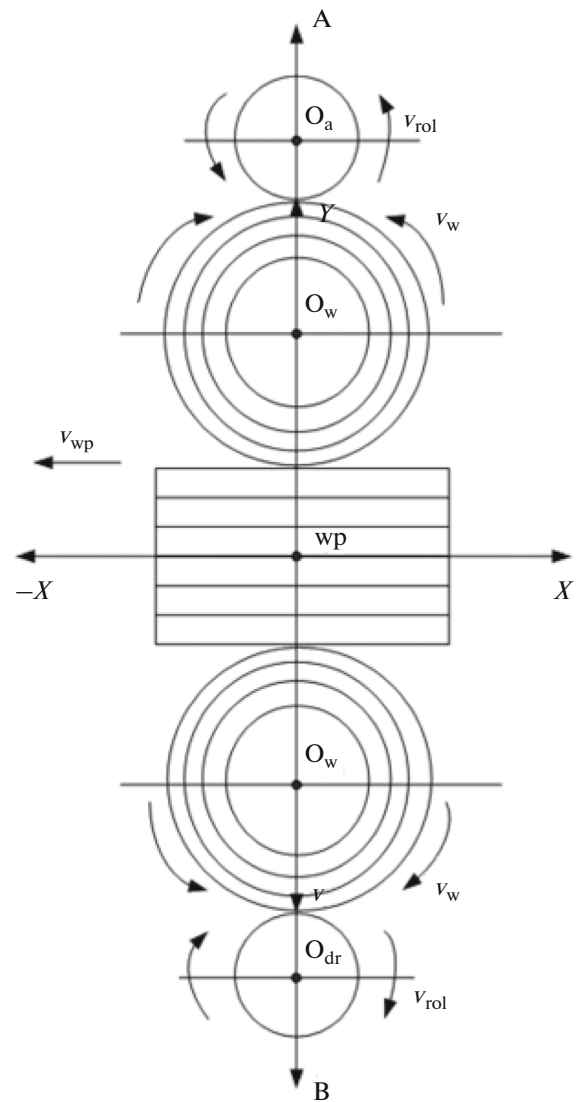


Fig. 6. Schematic diagram of blade locking joint processing under counter and concurrent rotation of abrasive wheels and diamond rollers.

With counter-rotating roller and wheel:

(A) Roughing pass.

Machining allowance, mm	$Z = 1.5-2$
Wheel speed, m/s	$v_w = 27$
Machine table feed rate with workpiece, mm/min	$v_{wp} = 100$
Roller feed rate per wheel, mm per 10 grinding wheel revolutions	0.004

(B) Finishing pass.

Machining allowance, mm	$Z = 0.05-0.1$
Wheel speed, m/s	$v_w = 27-30$
Machine table feed rate with workpiece, mm/min	$v_{wp} = 300-500$
Roller feed rate per wheel, mm per 10 grinding wheel revolutions	0.002

Figure 6 shows a diagram of the machining of a blade lock joint with counter and up-cut abrasive wheels and diamond rollers.

An analysis of the research results showed [33] that, depending on the number of teeth (4, 5, 6) and the machining allowance ($Z = 1.5\text{--}2\text{ mm}$), continuous dressing with diamond rollers ensures high cutting performance of the abrasive wheel. However, the oscillation amplitude increases during down-dressing due to variations in the wheel-to-roller speed ratio within the range of 0.8–0.9. Consequently, the surface roughness (R_a) and waviness (W_z), as well as the waviness pitch (S_{mwave}), will be higher than with a counter-rotating grinding wheel. In this case, the cutting force components P_z and P_y and their dispersion increase.

A comparison of the roughness value using the R_a criterion, based on the above relationships and under production conditions, showed that the relative error does not exceed 10–12%, indicating sufficient accuracy of the roughness calculation using the proposed formula (1).

CONCLUSIONS

The resulting formula for the roughness dependence on the process parameters of deep grinding allows for the determination of surface roughness and the consistent quality of the surfaces of the turbine blade fir-tree lock joint.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

USE OF AI

The authors of this work declare that artificial intelligence technologies were not used in the preparation of this article.

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