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EXPERIMENTAL STUDIES OF THE GRINDING PROCESS BY PLANETARY GRINDING HEAD

Об'єктом дослідження є процес глибинного шліфування деталей авіаційних двигунів із важкооброблюваних матеріалів. В авіаційній галузі з таких матеріалів (сталь 4Х5МФ1С, ХН53КВМТЮБ та ін.) виробляють лопатки та диски турбін, сегменти соплових апаратів, сектори вхідних направляючих апаратів, плунжери, поршні, зубчаті колеса і т. д. Лезові методи оброблення не є дуже ефективними при створенні подібних деталей. Підвищений знос технологічного обладнання, інструменту призводить до росту температури у зоні різання, що негативно впливає на показники якості і знижує ресурс виробу в цілому. Постійне заточення, правлення або зміна інструменту на новий, додаткове налаштування технологічного обладнання призводить до збільшення собівартості виготовлення деталей з важкооброблюваних матеріалів. Впровадження глибинного шліфування у технологічні процеси дозволяє уникнути зазначених вище негативних факторів. Збільшення технологічних режимів шліфування знижує час оброблення, але стає причиною виникнення в поверхневих шарах припікань і пошкодження оброблюваної поверхні. Експериментальні дослідження процесу глибинного шліфування проводили з метою визначення температур у підповерхневих шарах деталі в процесі її оброблення і подальшого порівняння з теоретично отриманими результатами розробленої математичної моделі. Оброблення виконували на плоскошліфувальному верстаті Jotes SPD-30b (Польща). Температуру замірювали контактним методом (вимірювачем ОВЕН МВА 8, Росія) і безконтактним (пірометром CT 3M, Німеччина). Результати отриманих експериментальних значень температур наведені у вигляді таблиць. За результатами виконаних досліджень було встановлено, що застосування планетарної шліфувальної головки для технології глибинного шліфування деталей машинобудівної і авіаційної галузей з важкооброблюваних, корозійностійких матеріалів приводить до зниження енергосилових показників процесу. Крім цього спостерігається поліпшення класу чистоти поверхні (шорсткість оброблюваних поверхонь Ra знаходиться в межах 1,25–1,8 мкм). Отримані результати свідчать, що технологію глибинного шліфування слід впроваджувати у технологічні процеси замість операцій фрезерування, зовнішнього протягування і традиційного шліфування.

Ключові слова: *планетарна шліфувальна головка, глибинне шліфування, температура шліфування, підповерхневі шари деталі.*

1. Introduction

Development of modern engineering, light and aviation industries is accompanied by the development of new structural, heat-resistant and wear-resistant steels and alloys with high strength properties. These materials are used in the production of critical parts such as blades, shafts, gears, providing high strength characteristics, thereby increasing the life of products operating at high temperatures with alternating cyclic loads. Processing such materials is very time consuming, and the use of blade processing methods is unproductive [1]. One of the ways to improve the efficiency of machining is the introduction of the technology of creep feed grinding. The process of creep feed grinding provides minimal damage to the treated surface, more productive compared to milling and pulling. It is also characterized by high cost-effectiveness compared to traditional processing methods. The technology of creep feed grinding allows to reduce the processing time, to increase the quality and accuracy of indicators of processed surfaces of parts. This is possible only on the basis of the description of the temperature state of the subsurface layers of the workpiece for the set processing modes, taking into account the geometrical parameters of the shape of the grinding wheels, as well as the kinematics of the process [2, 3]. As *the object of research*, the process of creep feed grinding of parts of aircraft engines with difficult-to-work materials is selected. *The aim of research* is ensuring the quality parameters of the surfaces of parts of general engineering, light and aviation industry by the method of creep feed grinding.

2. Methods of research

Experimental studies of flat planetary grinding are carried out on a surface grinding machine of the Polish machine-building enterprise Jotes, model SPD 30-b [4], using an adapter, a planetary grinding head (PGH) mounted on its spindle [5, 6].

PGH speed is adjusted in the range $n_{PGH}=0–800$ rpm by including the Lenze ESV752N04TXB (Germany) frequency converter into the main working motion motor circuit [7]. In the course of experimental studies on the PGH, 100×20×32 abrasive wheels of a straight profile (SP) are installed with the following characteristics: 38A25BM28K35A3; 24A40M36K6. The diameter of the planetary head (together with abrasive circles) $D_{PGH}=350$ mm, the gear ratio $i=3.5$. The longitudinal feed of the part S_{long} is changed in the range of 0.1–0.8 m/min, and the grinding depth is $t=1–7$ mm. The treatments are carried out with the associated rotation of the PGH grinding wheels (Fig. 1) [8].

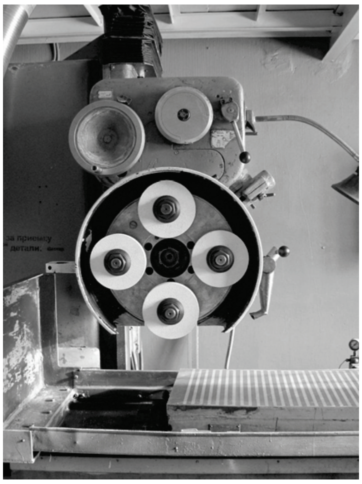
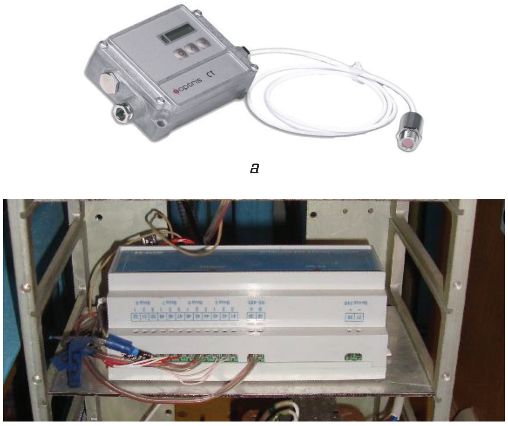


Fig. 1. General view of the planetary grinding head mounted on a surface grinding machine Jotes SPD-30b (Poland)

The temperature of the workpiece is measured in two ways – contact and contactless. The pyrometer CT 3M (Optris, Germany) carries out contactless measurement of the temperature on the surface of the grinding wheel in the cutting zone, as well as under the surface of the workpiece with a variable depth of measurements. Contact temperature measurements are carried out using thermocouples connected to the OBEH MBA8 meter (Russia), Fig. 2.



a

b

Fig. 2. Measuring complexes:
a – CT 3M pyrometer; *b* – OBEH MBA8 meter

Thermocouples with a diameter of 1.8 mm of type K are connected with free ends to the inputs of the measuring device with the observance of polarity in order to avoid serious errors. The connection of the OBEH MBA 8 meter to the computer itself is carried out using the adapter RS-485 interface OBEH AC3 (Russia). Further, using the software supplied with the measuring device, thermocouples are surveyed and the results were then output.

As samples for carrying out experiments for the purpose of describing the preliminary preparation procedure, rectangular billets with dimensions of 85×25×25 mm, made of tool die steel 4X5MΦ1C according to GOST 5950-2000 [9] and hardness of 49-51 HRC are chosen. From the installation plane of the workpiece, blind holes are made, providing a hermocouple depth of 2 mm below the processed surface. For this, a vertical drilling machine 2ЧС112 CΦ (Russia) and an electroerosive machine 4E723–01Φ1 (USSR) with a brass electrode RBS1D180×300 are used. The result is a holes with a diameter of 1.8–2 mm with a radial rounding of the end face of the hole and a roughness R_a=0.8 μm (according to the passport of the machine). The thermocouple termination circuit is shown in Fig. 3.

According to the established methodology for conducting experiments, 18 samples are prepared. Thermocouples are mounted in each of them, as shown in Fig. 4.

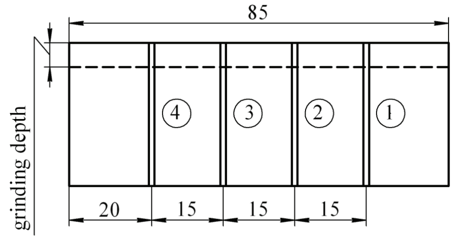


Fig. 3. Thermocouple laying scheme

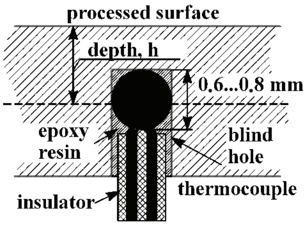


Fig. 4. Thermocouple laying

Experimental studies of temperature fields of workpieces from 4X5MΦ1C steel in their processing by SP circles 100×20×32 38A25BM28K35A3, installed on PGH, are carried out with the following grinding process parameters:
- grinding depth *t*, mm: 0.5; 1.0; 1.5; 2.5;
- rotation speed of circles V_{cr}, m/s: 12, 16, 20;
- longitudinal feed S_{LONG}, mm/s: 0.50; 0.75; 1,00; 1.50;
- grinding width *B*, mm: 20;
- trimming of circles is carried out by single-point diamond pencil.

A 5 % aqueous solution of $NaHCO_3$ («soda water») is used as a process coolant.

3. Research results and discussion

As shown in the Table 1, the experimental values demonstrate good agreement with the results of theoretical thermal analysis. Thus, the correctness of the thermal model has been tested for the process of creep feed grinding with the use of a PGH by a large number of experiments. In addition, the results show that the measured temperature is higher, the higher the speed of the workpiece and the greater the depth of cut. However, the temperature of the workpiece is not reduced, but, conversely, increases slightly with increasing speed of the circle. Despite this, this effect of lowering the temperature of the workpiece does not apply when using higher circle speeds. The ratio of thermal distribution shows that increasing the speed of the circle more effectively increases the share of heat transfer to the tool and coolant. Grinding energy also increases with increasing speed of the circle, with the result that a greater amount of thermal energy will flow into the workpiece and the temperature will become higher.

Table 1

Results of experimental and theoretical studies

№ of experiment	Technological processing modes				Heat flux, W/mm^2		R_W	Workpiece temperature, °C		
	V_{CR}, m/s	D_{CR}, mm	t, mm	S_{LONG}, m/min	Q_{CR}	Q_{TOT}		T_{EXP} (2 mm)	T_{THEOR} (2 mm)	T_{THEOR} (0 mm)
1	20	80.2	1.50	0.200	6.48	7.15	0.320	160.9*	183.1	250.5
2	20	79.6	1.50	0.075	6.42	6.24	0.310	72.5	74.2	86.0
3	20	79.4	1.50	0.060	6.34	5.28	0.292	69.5	68.5	79.1
4	20	79.0	1.50	0.045	6.38	4.61	0.280	65.2	63.7	73.8
5	20	78.6	1.50	0.030	6.24	4.20	0.272	59.5	61.8	69.4
6	20	78.4	1.00	0.090	7.05	5.73	0.332	69.5	65.8	78.4
7	20	78.2	1.00	0.075	7.14	4.87	0.326	63.5	61.0	70.8
8	20	77.8	1.00	0.060	7.13	4.26	0.316	59.4	56.7	64.1
9	20	77.4	1.00	0.045	7.03	3.79	0.296	55.5	52.9	60.7
10	20	77.0	1.00	0.030	7.03	3.47	0.288	51.9	51.7	57.7
11	16	76.8	2.50	0.090	4.97	6.17	0.311	230.9*	210.7	320.1
12	16	76.6	2.00	0.060	5.40	5.27	0.328	77.2	78.6	88.0
13	16	76.2	1.50	0.060	5.70	4.50	0.332	66.5	67.9	77.6
14	16	75.8	1.00	0.060	6.47	3.96	0.340	56.8	57.4	65.8
15	16	75.4	0.50	0.060	7.57	3.37	0.380	50.4	46.8	55.1
16	12	62.8	1.50	0.060	5.01	4.06	0.377	67.6	66.9	77.3
17	16	62.0	0.50	0.030	–	–	–	820.0*	–	–
18	16	74.0	0.50	0.030	7.54	3.25	0.369	48.2	47.0	54.2

Note: * – burn appearance

The grinding energy values q_{tot} in the Table 1 are above the critical grinding energy values q_{crit} for experiments No. 1 and No. 11. In addition, in both these cases, the maximum surface temperature of the workpiece T_{theor} (0 mm) is very close to the temperature of the bubble boiling point of the liquid. Burn of the workpiece does not occur at the beginning of the grinding process, but only after a certain length of movement of the grinding head. In addition, the transition from normal processing conditions to the burn formation is accompanied by a sudden (abrupt) increase in grinding force and a rapid increase in the temperature of the workpiece.

After this, burn on the surface of the workpiece is formed continuously. Let's note the conditions for the burn formation. For this, the vertical and horizontal component of the cutting force is determined by its average value. Determination of its value is performed for each discrete movement of the grinding wheel relative to the processed surface. As an example, let's take experiment No. 1, the beginning of the burn formation of the workpiece is thirty-eighth second of the grinding process. The calculation period of the average temperature values is from 16 to 32 seconds of the grinding process. Thus, the experimentally obtained temperature value at the second thermocouple at a depth of 2 mm T_{EXP} is decisive as the maximum measured temperature value. At this point in time, burn of the preform is not yet formed. Burn occurs at the time when the grinding wheel passes over the third thermocouple, even if it recorded a lower temperature than the second thermocouple.

As a result of the experiments performed for parts made of 4Х5МФ1С steel, the adequacy of the thermal model is confirmed, which makes it possible to predict the temperature of the workpiece and has good consistency with the experimental data. Moreover, the signals of the measured grinding power and temperature can set the burn appearance of the workpiece. Experimental results show that the transition from machining conditions without burn to machining with burn is accompanied by a sharp increase in grinding power and a further increase in the temperature of the workpiece when the grinding energy formed during the experiment exceeds the critical energy. Thus, the burn occurrence of the workpiece can be predicted in order to prevent it.

4. Conclusions

According to the research results, it is found that the use of PGH for creep feed grinding of machine-building and aviation parts [10] of difficult-to-work, corrosion-resistant materials leads to a decrease in the energy-power indices of the process while simultaneously improving the surface cleanliness class:

- temperature in the contact zone is reduced to values at which there are no phase transformations in the surface layers of the workpiece: 60–90 °C (except for experiments No. 1, 11 and 17);
- there is an improvement in the physical and mechanical properties of the processed surface (the roughness of the processed surfaces is within R_a 1.25–1.8 μm);
- multiple well cubic boron nitride circles allow to force grinding mode without compromising the accuracy and quality of processing;
- greatly reduces the coolant consumption, up to its absence in the process. In addition, the requirements for coolant properties may be less critical;
- stability of abrasive wheels is increased (at least 2 times).

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