Technological quality maintenance of finishing robotic machining in mechanical engineering

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Abstract. Give consideration to development of robotic systems in modern mechanical engineering, as well as the advantages of their introduction into production to perform mechanical machining of work-piece. Schemes of operations using robots are given, as well as the main types of robotic systems used in mechanical engineering. Description provided to the experimental setup for finishing robotic machining. The results of field research to find the optimal cutting conditions that provide the required surface quality after processing are described.

1. Incorporation of robotic systems in modern industry

High requirements for efficiency and flexibility in modern industrial production and a significant increase in the share of low-volume and multiproduct manufacture, have led to an increase in the number of automated and high-precision mechanical operations. The active build-up of instrumentation, micro- and optoelectronics, as well as the ever wider use manufacturing methods of the precision work of parts and assemblies, have significantly increased the share of finishing machining operations. Given this trend, the use of industrial robots for processing is an attractive solution based on its flexibility, versatility and relatively low investment cost, compared to the cost of CNC machines [1, 2].

Robots have long proved effective in operations such as welding and painting car bodies, but in operations requiring high precision and toughness, the use of robots has so far been limited. The main problem involves is the occurrence of vibrations during mechanical operation due to the not high toughness of the robot, but the technological development and the occurrence of new robots of increased toughness made it possible to solve the problem, which makes robotic systems more effective for use in most machining operations. However, there is a reserve for further vibration reductions - these are cutting parameters. Optimum parameters open up the trade dynamically developing area of robotic finishing machining [3, 4].

Technological strengths of robots:
- purchase and maintenance costs are lower than CNC machines;
- good kinematic ability;
- higher speeds;
- great ability for readjustment, which makes it possible to use robots in multiproduct manufacture.

Technological weakness of robots:
Industrial experience shows that in multiproduct manufacture, CNC machines have a low coefficient of technical use (about 50%). Long delay increases the input requirements and time of recovery of outlay of such equipment, in turn robotic systems due to the wide possibility of reconfiguration and their versatility have several strengths, as well as a higher time factor and are better adapted to change parts and new operations. When this happens, robots require relatively low capital investments, as well as lower operating costs, in doing so pay back faster. The limited working area and kinematics of CNC machines make it necessary to machining one part in many operations and perform several remounts, which increases the production cycle. Due to the configuration, robotic systems can process in one placing. For these reasons, manufacturers are increasingly starting to think about using robots instead of CNC machines [2, 3, 5].

2. Modification of robotic system
At present time, most of the used robotic systems without force feedback control on the work-piece, such systems are programmed to simply move from point A to point B. These robots are great for painting and transferring goods, but they cannot provide the necessary dimensional accuracy and used to level of a surfaces for three reasons:

- tool deterioration causes a deviation from the required size dimension;
- the size and placing chatter marks on the surface of the work-piece are unpredictable;
- the shape of the work-piece can be very complex, which makes programming the robot difficult.

Force feedback control devices make it possible to ensure constant efforts during machining, which will allow us to adapt the system to deviations between the programmed and actual contour on the surface of the work-piece. For example, the casting process gives large limit and effective machining of such surfaces is not possible without a system of adaptation to these workpiece imprecisions. The process of polishing the surface requires high quality after machining, which cannot be achieved without a fixed-force between the tool and the parts and a fixed feed velocity. Fixed feed velocity is not a problem for modern robots, while obtaining accurate force on the work-piece is a limitation. Force feedback control during machining will improve output rate and quality. Tool deterioration can be minimized and tool breakage can be avoided. Given the need of modern industry, more and more robot manufacturers offer various options for using force feedback control [6, 7].

The next step is to choose the configuration of the robotic cell. There are two main technical solutions: 1) the work-piece is fixed on the robot (Figure 1) [8], and the tool is fixed on a fixed base. This method is used when the workpieces are small and the tool is dimensional, which requires a powerful drive to ensure its high speed. A similar solution is also used in the case of polishing tapes.

![Figure 1. Machining with fixing the workpiece to the robot.](image_url)
2) As a rule, an axial tool of small diameter, together with the spindle, is mounted on the output link of the robot (Figure 2), and the work-piece has large size (for example, external covers, welded structures). This method provides greater flexibility, due to the possibility of access to a larger number of surfaces of the work-piece, including internal or angled.

![Figure 2. Machining with tool clamping on the robot.](image)

Given the size and configuration of the drum for the helicopter wheel, it is advisable to place it on the table, and conduct machining with a tool mounted on the robot. This will provide higher positioning accuracy, due to less load on the "arm" of the robot and higher machining quality.

The drum (Figure 3) is an integral part of the helicopter wheel. The casting is made of magnesium alloy ML5PC in one piece with the rim, hub and one flange. Bores are made on both sides of the hub where tapered roller bearings are mounted. A camera and a tire, which is a power element, are mounted on the drum. She perceives loads and transfers them to the wheel drum.

![Figure 3. Helicopter wheel drum.](image)
According to factory repair technology, the drum is subjected to bead blasting for which a shot of stainless steel with a diameter of 0.2 mm is used. This treatment allows you to get a value of Ra 6.3 microns. This surface finish value is final for most of the wheel surfaces and does not require further machining. However, the surface finish of the outer surfaces along which the wheel chamber adheres should be improved to a surface finish parameter Ra of 1.6 microns. For this goal, the use of industrial robots with high flexibility in production is an effective option, since the nomenclature consists of a larger number of wheels of various sizes, which provides a large reduced production program.

Considering the size of the machined surfaces and the type of fastening in the spindle, a grinding wheel is selected as the tool for machining, which is mounted on the support disc using a Velcro substrate. Such a system provides a quick change of circles of different grain sizes and instant continuation of work [9].

3. Experimental studies of the process of finishing robotic machining
To determine the optimal cutting parameters and ensure machining quality, an experimental assembly was created in the Industrial Robots laboratory of the Moscow Polytechnic University and experimental studies were conducted.

The experimental assembly was created on the basis of the ABB industrial robot IRB-140 (Figure 4, a). This is a universal robot, the positioning accuracy of which is ± 0.03mm; load capacity up to 6 kg; active radius 810 mm. For machining, the robot was equipped with a spindle model GDF65-24Z / 0.8. The spindle has the following technical characteristics: power 0.8 kW; torque 0.22 N*m; maximum speed is 24,000 rpm; current frequency 400 Hz; weight - 3 kg.

To clamping the spindle to the robot, special machine-tool attachment (Figure 4, b) was designed and manufactured. In addition to the spindle, a Schunk FT AXIA torque sensor was installed on the machine-tool attachment. This sensor has already found application in a number of technological problems, including grinding and assembly. Thanks to the sensor, it becomes possible to obtain online data on the cutting force and the influence of various factors on the process.

![Figure 4 (a, b). Experimental assembly in the laboratory "Industrial robots"](image_url)

As part of the study, a full factorial experiment (PFE) was conducted [10, 11]. For starters, factors that occurred during the machining were selected (Table 1).
Table 1. Factors affecting the finishing machining.

| Factors                | Designation |
|------------------------|-------------|
| Spindle speed $n$, (rpm)  | $x_1$       |
| Motion $S$, (m/min)     | $x_2$       |
| Cutting depth $t$ (mm)  | $x_3$       |
| Seediness              | $x_4$       |

Then, the output capacity is determined that characterize the flow of the process of finishing robotic machining: $Y_1 (P_x)$ – component of the cutting force along the X axis (H); $Y_2 (P_y)$ – component of the cutting force along the Y axis (H); $Y_3 (P_z)$ – component of the cutting force along the Z axis (H); $Y_4 (T_x)$ – moment acting on the X axis (H*m).

Levels of factors and variability intervals are presented in table 2:

Table 2. Levels of factors and variability intervals.

| Factors | Levels | Variability intervals |
|---------|--------|-----------------------|
|         | -1     | 0                     | +1         |
| $x_1$   | 9600   | 10800                 | 12000      |
| $x_2$   | 0,5    | 1,0                   | 1,5        |
| $x_3$   | 0,3    | 0,2                   | 0,1        |
| $x_4$   | 120    | 240                   | 320        |

The number of experiments depends on the number of factors and in this experiment was 16. With each set of factors, the experiment was carried out five times to determine the average value, which allowed to exclude the random influence of ambient conditions.

The mathematical model of the experiment looked like a polynomial of the first degree:

$$ y = b_0 + \sum_{i=1}^{n} b_i \cdot x_i + \sum_{i=1}^{n} b_{ij} \cdot x_i \cdot x_j \ldots \quad (1) $$

After analyzing the significance of the coefficients, it was revealed that the following coefficients are significant:

- for $y_1$: $b_0$, $b_3$, $b_{13}$, $b_{23}$;
- for $y_2$: $b_0$, $b_1$, $b_3$, $b_4$, $b_{12}$;
- for $y_3$: $b_0$, $b_1$, $b_{23}$, $b_{24}$;
- for $y_4$: $b_0$, $b_2$, $b_{23}$.

We bring the expressions to normal form:

$$ P_x = 54,7 + 3,56 \cdot t - 0,31 \cdot n \cdot t - 0,43 \cdot S \cdot t \quad (2) $$

$$ P_y = 38,6 + 9,5 \cdot n - 10,75 \cdot t - 6,2 \cdot z + 2,37 \cdot n \cdot S \quad (3) $$

$$ P_z = 316 + 7,31 \cdot n + 8,06 \cdot S \cdot t + 0,31 \cdot S \cdot z \quad (4) $$

$$ T_x = 2,6 + 0,06 \cdot S + 0,18 \cdot S \cdot t \quad (5) $$

The conducted PFE showed that with a probability of 0.95 a mathematical model can be considered adequate to experimental data, which means that based on these data, further decisions can be made and PFE can be used in the analysis of the process of finishing robotic machining.

After conducting a full factorial experiment and choosing the optimal cutting parameters for this material, which provided the smallest cutting forces and vibrations, the values of the parameter Ra
were measured. To determine the surface finish value, we used a portable MarSurf PS1 profilometer with an integrated surface finish gauge. The measurements showed that the stability of achieving the required value of the surface finish parameter is ensured by using cup grinder with a grain size index of P320 according to GOST 52381-2005.

4. Conclusion
Manual locksmithing is widespread in mechanical engineering, but increasing demands on working conditions, quality and flexibility of production leads to the active development of modern technologies, such as robotic systems. The trend towards the introduction of such systems takes place at various enterprises.

Studies similar to those presented in this article allow us to expand the field of use of robotic systems, as well as their technological capabilities in response to the needs of enterprises in the development of their production.

The performed studies showed the applicability of positional-force control of the robot based on the use of a force feedback control. However, for each technological operation, specialized algorithms should be developed according to the criterion of material removal rate or another criterion. The creation of such algorithms is the main scientific component of this work.

Regulation of cutting forces offers significant benefits, increasing productivity and improving the surface quality of parts. Promising at the present time is the management of material removal rate according to the evaluation of cutting forces and feed variation. Moreover, it is possible to use various control strategies, including the PID-controller, adaptive control and the use of fuzzy logic, depending on the technological features of the operation.

References
[1] Pilinevoch L 2016 Porous diamond tools with anisotropic pore structure for grinding and polishing Symp. BSUIR vol №3(97) pp 44 – 48
[2] Pandremenos J, Doukas C, Stavropoulos P and Chryssolouris G 2011 Machining with robots: a critical review - 7th Int. Conf. on Digital Enterprise Technology
[3] Vartanov M, Zinina I and Zotin D 2017 Technological capabilities of robotic finishing processing of parts in a multiproduct Bulletin of the Russian State Technical University vol №1(40) pp 190 – 193
[4] Zaghibani I, Lamraou M, Songmene V, Thomas M and Badaoui M 2011 Robotic High Speed Machining of Aluminum Alloys Proc. of the 4th edition of the Int. Conf. on High Speed Machining (ICHSM’2010)
[5] Sörnmo O, Olofsson B, Schneider U, Robertsson A and Johansson R 2012 Increasing the Milling Accuracy for Industrial Robots Using a Piezo-Actuated High Dynamic Micro Manipulator IEEE/ASME Int. Conf. on Advanced Intelligent Mechatronics (AIM)
[6] Krantz M and Andersson R 2010 Robotized Polishing and Deburring with Force Feedback Control Master Degree program in Robotics (Trollhättan, Sweden: University West, Department of Engineering Science)
[7] Mishurov M 2016 Power management of robots and its use for deburring industrial parts (Moscow: Young scientist) vol №3(107) pp 155 – 158
[8] Live demonstration at EMO 2015 from Delcam Professional Services
[9] Stepanov D 2015 Finishing of complex and thin-walled parts “New materials and technologies in mechanical engineering” vol №1 pp 122 – 124
[10] Belova N and Malinina O 2010 The use of a full factorial experiment in measuring gas flow parameters (Moscow: Young scientist) vol №4(15) pp 65 – 70
[11] Kristal’ M and Gorelova A 2019 Processing the results of planning an extreme experiment (Volgograd: VolGTU) p 70