Study of possibility to process the edges of the parts on the robot

D Podashev
Irkutsk National Research Technical University, 83 Lermontov street, 664074, Irkutsk, Russia.
dbp90@mail.ru

Abstract. The necessity to replace manual labour for mechanized and automatic is very actual for mechanical engineering. The possibility to implement the robot complex (RC) when processing the edges of the parts is studied in the report. Polymer-abrasive radial and end brushes were used as tools. Usage of processing of edges on RC by elastic polymer-abrasive brushes with different combination of surfaces on parts proved that such an operation can be implemented successfully with meeting all requirements on quality of processed edges.

1. Introduction
The mechanization and automatization of final operations for mechanical engineering enterprises is very acute.

The issues of evaluating the performance of the process and the quality of products after machining have been dealt with in many works, for example [1–8].

We consider the possibility of fulfillment of such operations on the parts of the aircraft MC-21 with use of industry robot with electrical spindle.

On figures 1, 2 and 3 there are drafts of samples in which the variety of combination of surfaces that can be met on parts including those of long-length types of profile is demonstrated.

The technology of processing of edges of parts with combination of different surfaces on these samples will be dependent on choice of tools and mode of processing. In the present work the elastic abrasive instrument is used.

![Figure 1. Sketch of the first sample with a different combination of surfaces.](image-url)
The researches were conducted on the RC shown on Fig. 4 and consisting of the following:
- robot KUKA KR 210 R2700 EXTRA (Germany) with control system KR C4, radius of action – 2696 мм, 6-axles, software - Windows XP;
- electric spindle made by "Elettromecanica Giordano Colombo" (Italy), model RC90 (Fig. 5) with rate of rotation – 240–24000 min\(^{-1}\), nominal output – 4 KW, with change of tool (several magazines with 3 tools per one magazine), with grips Ø2–16 mm, maximum tool diameter – 380 mm;
- table made by "Forster" (Germany) with dimensions 4000х1500 mm.

Figure 2. Sketch of the second sample with a different combination of surfaces.

Figure 3. Sketch of the third sample with a different combination of surfaces.
Taking into consideration fragility and vibration resistance of the robot with installed electric spindle balancing of the toll is provided on the module balance system Haimer TD2009 Comfort Plus (Germany) with operating rotations of the spindle – 300 – 1100 min\(^{-1}\), maximum length of the tool – 400 mm. The balancing was done in accordance with ISO 1940-1:2003 "Mechanical vibration — Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances" by class of accuracy of balancing G6.3.

When study the polymeric abrasive brushes made by 3M (Minnesota Mining and Manufacturing Company)(USA) of radial brands C BB-ZB were used with curved hairs (Fig. 6) and A BB-ZB – with straight hairs (Fig. 7) as well as end brushes Scotch-Brite™ BD-ZB (Fig. 8).

Brushes Scotch-Brite™ Bristle that are produced in the form of thin discs with curved hairs along the circle made out of polymer synthetic material produced by 3M (Minnesota Mining and Manufacturing Company).

A brush of almost any width can be constructed on the mandrel out of discs shown in Fig. 6 and 7.

The grains of abrasive material 3M Cubitron™ are evenly spread along all the capacity of the polymer abrasive instrument.

Let’s consider the case of processing of edges of parts by radial brushes on RC with curves along the radius including those in the holes, for example, of the flat part as on Fig.1.

On the long-length parts profile type the mandrel on which the brush is fixed is done lengthened and is placed at an angle \(\beta_{vc}\) (Fig. 9) to the processed surface to avoid its touching by the spindle head.
2. **Processing of the edge along the external radius**

The processing of the edges on the robot can be done by radial polymer abrasive brushes by two ways:

1. Processing with turn of spindle head along the required radius by developed program.
2. Processing without turn of spindle head. The operation is done in two stages (see Fig. 9).

\[ \beta = \beta_{\text{us}} + \gamma, \quad S_{BR} = S_B + (\Delta Y_R - \Delta Y_{\text{us}}), \]

where \( \Delta Y_R \) – brush deformation at \( \beta \) in direction of the radius \( R \) with current value \( \gamma \);
\( \Delta Y_{\text{us}} \) – brush deformation at setting value \( \beta_{\text{us}} \).

On the second stage the processing is done on part B-C after turn of the spindle head for 90°. At this the vertical feeding \( S_B \) and value of brush deformation \( \Delta Y \) shall be defined taking into consideration changes of angle \( \beta \).

\[ S_{BR} = S_B - (\Delta Y_R - \Delta Y_{\text{us}}). \]

3. **Processing of the edge in oval hole**

When processing of the oval hole it is necessary to avoid touching of the brush by opposite edge. For this it is important to define the allowed width of the hole \( B \) (Fig. 10) at the assigned brush deformation \( \Delta Y \), i.e. size \( B \) shall be \( B \geq M \).

![Figure 9. Scheme of processing radius edge.](image1)

![Figure 10. Scheme of processing the edge in oval hole.](image2)
\[ M = \frac{L}{2} + A, \quad (1) \]

where \( L = 2 \cdot \sqrt{2 \cdot \Delta Y \cdot R - \Delta Y^2} \);

\[ A = R \sin \alpha; \quad (2) \]

\[ \Delta Y = R - \sqrt{R^2 - 0.25L^2}. \]

By solving equation (1) and (2) jointly, we get the following:

\[ M = A + \sqrt{2 \Delta Y \cdot R - \Delta Y^2}. \quad (3) \]

As it is seen from equation (3) the allowed width of the oval hole depends on brush deformation \( \Delta Y \) and its radius \( R \). If it is impossible to change the brush radius then the tension \( \Delta Y \) should be change by the formula:

\[ \Delta Y = R - \sqrt{R^2 - (M - A)^2}. \]

Processing of the edge by radius should be done by turn of the spindle head (see Fig. 10) or process by the methodology examined on Fig. 9.

4. Processing of the edge in oval hole in the hard-to-reach spots

Such holes that are placed close to the part wall are demonstrated on Fig. 2. The processing should be done by the instrument that shall not touch the adjacent wall because it is impossible to process edges by polymer and abrasive brushes. Such instruments can be the following: grinding caps Hoffmann Group (Germany); grinding cones as per GOST 22774–77 or cone rotary files. The processing by the grinding cap is demonstrated on Fig. 11.

![Figure 11. Edge processing with grinding cap.](image1)

![Figure 12. Scheme of processing hard-to-reach straight edges.](image2)

Inclination of the cap (cone) allows to widen part of the instrument participating in the cutting.

All other edges that are on the sample (Fig. 2) can be processed by the radial brushes.

5. Processing of rectilinear edge in the hard-to-reach spots

The edge in the hole is such an edge on the sample (Fig. 3). It is impossible to process such an edge with radial brush. The usage of end polymer abrasive brush BD-ZB P50 (Fig. 12) allows to fulfill this operation successfully.

The processing of the narrow groove \((B = 22 \text{ mm})\) on the sample (Fig. 3) is possible by radial brush BB-ZB A P50 \(\varnothing 150 \text{ mm}\) (Fig. 13). For such a groove at \(\alpha = 0^\circ\) the allowed brush deformation \(\Delta Y\) when processing with this brush is equal to \(\Delta Y = 3.3 \text{ mm}\) that is quite acceptable.

It take \(\Delta Y = 2 \text{ mm}\) when processing of the groove by brush BB-ZB A P50 \(\varnothing 150 \text{ mm}\), then due to equation (3) at \(\alpha = 0^\circ\) the minimum allowed width of the groove shall comprise \(M = 17.26 \text{ mm}\).

When processing the groove by brush BB-ZB C P120 \(\varnothing 150 \text{ mm}\), then as per equation (3) at \(\alpha = 10^\circ\) the minimum allowed width of groove is equal to \(M = 30.23 \text{ mm}\).
When processing by brush RB-ZB C P80 Ø75 mm as per equation (3) at $\alpha = 10^\circ$ the minimum allowed width of the groove is equal to $M = 18.6$ mm. When processing by brush RB-ZB C P80 Ø50 mm the width of the groove is equal to $M = 14.14$ mm.

The variants of the processing of narrow grooves by different radial brushes are given in the Table 1.

![Figure 13. The scheme of processing a narrow groove with a radial brush.](image1)

![Figure 14. The scheme of processing inclined surface with radial brush.](image2)

**Table 1.** Minimum allowed widths of grooves when processing edges on V95pchT2 by radial brushes

| Brush   | Diameter, mm | $\beta^\circ$ | $\Delta Y$, mm | $\Delta Y_{cr}$, mm | $\alpha^\circ$ | $A$, mm | $M$, mm |
|---------|--------------|---------------|----------------|----------------------|---------------|---------|---------|
| BB-ZB A P50 | 150          | 0             | 2              | -9.287               | -12.104       | 5.101   |
|         |              | 3             | -7.641         | -9.973               | 11.027        |
|         |              | 4             | -4.983         | -6.514               | 17.652        |
| BB-ZB C P120 | 150         | 2             | 17.205         | 34.458               | 34.458        |
|         |              | 4             | 24.166         | 46.648               |
|         |              | 6             | 29.394         |
| BB-ZB C P80 | 75           | 2             | +22,912        | 26,682               |
|         |              | 3             | +17,242        | 25,812               |
|         |              | 4             | +11,485        | 24,319               |
| RB-ZB C P80 | 50           | 2             | +22,912        | 9,733                |
|         |              | 3             | +17,242        | 7,41                |
|         |              | 4             | +11,485        | 4,978               |
On sample (Fig. 3) there is a groove with inclined surfaces at $\beta > 60^\circ$ that touches the vertical wall. The variant of processing of such edges by radial brush BB-ZB A P50 $\varnothing 150$ mm is presented on Fig. 14. The rectangular section CD is processed at $\beta = 27^\circ 30'$, brush deformation at $\alpha = 0$ should be $\Delta Y \leq 1.5$ mm.

6. Conclusion
The researches of the technological possibilities of the processing of the edges on robot KUKA KR 210 R2700 EXTRA with electric spindle demonstrated that such final operation can be successfully implemented under industry conditions.

At this the following shall be taken into consideration:
1. The large variety of elastic abrasive instruments: circles, radial and end brushes, flap wheels, grinding caps and cones can be used as instruments.
2. Received in work [9] regressive equitations of size of the processed edge when usage of radial and end brushes allow to manage the effectiveness of the process depending on the processing mode.
3. To ensure the required accuracy of the positioning of the edge the system to detect the optimal position of the brush in regard of processed surface with usage of the equitation of regression of the accuracy parameter from the processing mode was developed during the work [10].
4. Developed in [10] equitations of regression of roughness of the processed edge from modes of processing allow foreseeing that parameter and, if necessary, managing it by modes of processing.
5. The analysis of the technological possibilities of the processing of edges on RC demonstrated that the majority of combination of surfaces (by external and inner radiuses, oval holes in the easy-to-reach and hard-to-reach spots for processing, rectangular edges in the hard-to-reach spots) can be successfully processed.
6. For industry conditions it is possible to make special equipment for final processing of the parts.

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