Grinding of aluminum alloy panels after shot peen forming on contact type installations

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Abstract. One of the key technological processes of production of the airframe of an aircraft is the manufacture of large-sized contour forming details such as “panel” and “fuselage shell”. To date, the most promising method of obtaining the required aerodynamic shape of such parts is the method of shot peen forming. It consists of processing the outer surface of a part with a stream of fast-moving shots, because of which a specific profile of micro roughness stays on the surface, characterized by numerous prints of fraction of different diameter and depth [1-5]. The grinding of the flap wheel is part of the forming process and improve the quality of the original surface. For the formation of large-sized surfaces, the scientists of INRTU have developed and introduced in the conditions of the Irkutsk aviation plant a unique installation for the shot peen forming – grinding of UDF-4 with CNC system [6, 7]. The primary, and the main difference of domestic development from foreign counterparts, is the division of the forming operation into smaller stages for easier process control. The development and improvement of grinding technology requires the development of appropriate methods and special software for it, which enables to automate the processing process.

1. Introduction
In the conditions of the Irkutsk aviation plant, for the implementation of an integrated technology for forming large-sized surfaces of panel and fuselage shell, the scientists developed and implemented a unique installation for shot peen forming – the grinding of panel and fuselage shell – UDF-4.

The development of the shaping technology required the installation of the UDF-4 with CNC system and the development of special software for it [8, 9]. In turn, there was a need for improvement of grinding technology and equipment. In terms of processing overall surfaces, there was necessity to solve a number of problems:

- for the convenience of processing surfaces of double curvature and reducing the auxiliary time for equipment changeover, there is a need to equip the installation for grinding with several tools;
- to implement highly accurate tool positioning control relatively to the surface to be machined;
- to provide uniform removal;
- to ensure a stable quality of the processed surface through the parameters of the control process of cutting.

2. Design engineering of the stripping head
To allow the use of several circles of different widths and grain sizes, the scientists designed and
manufactured a revolving grinding head [10-12]. The revolver-type grinding head (RGH) is a replaceable working body of the installation and provides a regulated surface roughness of parts. The design is a drum, inside which there are circumference flap wheels of the same diameter but different widths to ensure a higher productivity of the process. During its development, the principles of adaptive control during shot peen forming were taken into account (fig. 1) [8].

Figure 1. The revolver-type grinding head

As a tool for processing parts of complex aerodynamic shape the scientists used abrasive flap wheels, the processing of which is at high performance, low tool costs and the possibility of using both in single and in mass production [13-16].

An important task in grinding large-sized surfaces is the determination of the position of the flap wheel relative to the workpiece [17]. This condition ensures uniform removal of the stock from the surface to be treated. To solve this problem the scientists developed an adaptive control system for the position of the grinding head. It works using a pair of ultrasonic sensors installed in a seal at the ends of the working window. (fig. 2).

Figure 2. Adaptive grinding head control system

In the figure 2, numerals denote the following elements: 1 – work surface; 2 – ultrasonic sensors; 3 – resilient seal; 4 – flap wheel.

This system functions as follows (fig. 3).
Before processing, we fix the part (panel or fuselage shell) in a vertical position in the fixing device. Next, we set the required width of the abrasive flap wheel and control at the working position with the help of the corresponding positioning unit. After, at some distance, there is a coordination alignment of the center of the width of the flap wheel with the middle line of the processing band. Then, the grinding head is moving towards the surface to be treated, while using the sensor set 2 by the adaptive control system, the distances L1 and L2 to the surface 1 are continuously monitored (fig. 2). During processing, the sensors maintain constancy of distances, and, if necessary, correct it by tilting the housing from or to the surface at an angle $\alpha$ (fig. 3a). If necessary, there is the correction of the movements along the axis $\Delta Y$ and $\Delta Z$ (fig. 3b).

The angle of inclination $\alpha$ and corrective movements is calculated by the following formulas:

$$\alpha = \arctg \left( \frac{S_1 - S_2}{H} \right)$$  \hspace{1cm} (1)

$$\Delta Z = - \frac{R \cdot \sin \alpha \cdot \sin \left( \frac{\alpha + \beta}{2} \right)}{\cos \left( \frac{\beta}{2} \right)}$$  \hspace{1cm} (2)

$$\Delta Y = - \frac{R \cdot \sin \alpha \cdot \cos \left( \frac{\alpha + \beta}{2} \right)}{\cos \left( \frac{\beta}{2} \right)}$$  \hspace{1cm} (3)

where $S_1$ и $S_2$ – readings of the upper and lower ultrasonic sensors, $H$ – distance between sensors, $R$, $\beta$ – polar coordinates of the center of seal.

Depending on the width of the circle used, the corresponding pairs of signals from the sensors are processed, and the angle is determined, by which the grinding head should be turned.

A change in the radius of curvature during the transition from one section to another characterize the surface of the panels and fuselage shell. One of the options for surface treatment with a curvature in the transverse direction can serve as a profiled flap wheel processing, while reducing the overlap zone of one band by another.

After analyzing the curvature of the real surfaces of the panels in the transverse direction, we can talk about the feasibility of profiling flap wheels of 300 and 400 mm width. For circles of 100, 200 mm width, profiling is not required, since a small width will allow processing a sufficiently large range of radii of curvature, with a small amount of overlap. The use of profiled flap wheels will ensure uniform grinding of the surface with varying curvature.

The main technological parameters of the traditional equipment for grinding the flap wheel are the rotational speed, feed rate, upset distance, as well as the number of working process. The double
curvature of the machined surface, the inconstancy of the geometric dimensions of the circle and the need to simultaneous control several processing parameters greatly complicate the task of ensuring uniform removal and roughness over the entire surface of the part. If the control and regulation of rotational speed, feed rate and number of passes is not difficult, then upset distance on the contact surface of the circle with the workpiece when processing is variable and difficult to control. The way out of this situation can be the use of effective power to control the cutting process, which is necessary to implement the grinding process [18-20].

For the installation UDF-4, power is one of the registered parameters of the CNC system and reflects on the control panel. Depending on the load on the motor while the unit is running, the user can monitor the process performance in real time. The provision of the necessary amount of upset distance along the entire length of the processing strip occurs by monitoring it during processing. With a changing curvature of the surface profile, the areas divide the length into some parts where cutting power varies within acceptable limits. The range of change of cutting power is determined by the allowable limits of change in the magnitude of the removal. That is, we divide the surface into sections (processing bands), on which the amount of metal removal per unit of surface is determined by measuring the curvature of the surface profile of this section (which in turn depends on the mode of shot-impact shaping).

To test the possibility of control with the help of experiments, we carried out the experiments on KK751 flap wheels with a diameter of 350 mm and width of 100, 200, 300 and 400 mm at different rotational speeds (600, 800, 1000 and 1200 rev/min), which confirmed the linear dependence of the effective power on upset distance (fig. 4).

![Diagram showing the relationship between effective power and upset distance for different speeds](image_url)

**Figure 4.** The graphs of the magnitude of the effective power in relation to upset distance at different values of speed: a) width LK 200 mm; b) width LK 400 mm. Functional diagram of working out the inclination of the body of the stripping head relative to the treated surface.
Thus, the design of the revolving type of grinding head allows processing surfaces of single and double curvature due to the inclination of the flap wheel relative to the surface. At each site, feedback adjusted the draft value on the power displayed on the control panel. The program controlled the power read by the sensor and converted it into movement of the grinding head in the transverse direction.

3. Conclusion

Equipping the installation UDF-4 with a revolver-type grinding head significantly expanded its technological capabilities. It became possible, without stopping the grinding process, to change the working tool in accordance with technological need or change its position in space depending on the curvature of the surface grinded.

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