Features of grinding surfaces of double curvature with cylindrical flap wheels

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Abstract. In the manufacture of the panels and sheaths of outer-forming parts, after milling operations or shot peen forming, grinding the surface with flap wheels is widely used. Surface grinding is often performed with flap wheels, which may have a cylindrical or profiled surface. Since profiled flap wheels are designed to handle surfaces with a specific curvature, cylindrical flap wheels are more universal and more often used. The main task of technological operation of grinding the complex surfaces is to ensure a same removal over the entire part surface. In this paper, an analytical study of the interaction features of the flaps of the cylindrical flap wheel along the width of the flap wheel when grinding the surfaces of double curvature is carried out. The analysis of possibilities for leveling the degree of influence of the flaps of the cylindrical flap wheel on the treated surface by re-overlapping the processing surface to ensure uniformity of grinding is carried out. A variant of grinding the surfaces of outer-forming parts with a cylindrical flap wheel with overlapping passages, which provides uniform treatment of the surface of double curvature, is proposed.

1. Introduction

In the manufacture of the panels and sheaths of outer-forming parts, after milling operations or shot peen forming, grinding the surface with flap wheels is widely used [2-12]. The results of numerous experiments have shown that the material removal linearly depends on the deformation value (the bend value of the flaps from pressing the flap wheel to the treated surface) of the flaps of flap wheel within the studied limits [1, 6, 7]. Therefore, in order to obtain a uniform (same) material removal from the treated surface of the panel and sheaths, it is necessary to ensure a constant value of deformation while maintaining the remaining operating parameters. However, due to the curvature of the panel and the cylindrical shape of the flap wheel, the same deformation is not possible across the entire width of the contact of flaps with the treated surface. Thus, it is necessary to find a compromise solution that will minimize the uneven removal along the width of the flap wheel. The way out in this case is to re-pass (partially overlapping) the trace of the previous processing at the next passage. In the repeated (following) passage, the amount of overlapping is chosen so that the sum of flap deformation in the overlapping zone of the two passages was approximate equal to the maximum flap deformation in the central zone of the flaps of each passage that will minimize the deviation of flap deformation across the width of the processing and thereby to provide more same material removal from the machined surface (fig.1a).
2. Formation of flap deformation during grinding panels of double curvature with straight profile flap wheels

The Let's consider a general case of grinding with the flap wheels with overlapping of the flap wheel passages for a panel that has a variable curvature in transverse direction. In this case, we assume that the largest amount of deformation $T$ (approximately in the center of the flap wheel) is constant for each passage.

Fig. 1 shows the model of flap deformation when grinding the panel with different radius of curvature, where after the first passage of grinding the section with a radius of curvature $R_1$ with the deformation $T$ (position 2 in fig. 1a) the flap wheel proceeds to perform the second passage of the other section with a radius of curvature $R_2$ with the same deformation $T$ without changing other operating parameters (position 3 in fig. 1a) with an overlapping of width $bb$.

![Figure 1](image)

**Figure 1.** Grinding the aircraft panel with flap wheel, where: a) the position of the flap wheel during grinding, b) to determine the width of the processing, 1 - panel, 2 - flap wheel with width of $b$, 3 - the position of the flap wheel in the next passage with an overlapping with width of $bb$.

From Fig. 1b it is not difficult to notice that the width of processing $b_0$ for one passage of the flap wheel at the flap deformation value of $T$ is determined by the following expression:

$$b_0 = AD = 2\sqrt{R^2 - (R - T)^2} = 2\sqrt{2RT - T^2},$$

where: $T$ is the maximum deformation of the flaps in the central zone of the flap wheel, $R$ is the radius of curvature in the panel grinding zone of this passage.

Fig. 2 shows the model of the overlaying of deformation curvature of the flaps of the second passage $L_2$ on the deformation curvature of the flaps $L_1$ obtained in the first passage, since the radius of curvature (more 4m) is much higher than the value of flap deformation ($\leq 4$mm) and during grinding the flap wheel is directed normal to the panel surface in the contact zone, so for the convenience of analysis of the interaction of the flap wheel with the processing surface the model of overlapping passes conditionally constructed in a straight line AH (Fig.2).
Figure 2. Formation of flap deformation during grinding with overlapping passages.

Let's assume that after the 1st passage of the flap wheel with the deformation value of $T$, a processing stripe with the width $AD$ is obtained (Fig. 2). It is obvious that in the center of the flap at the highest $T$, the impact of the flap wheel on the surface of the part is greatest, and when moving away from the flap center to the edges, it decreases to a minimum and the value of material removal decreases accordingly. To align the removal of the next passage of the flap wheel, the grinding should be carried out with the overlapping of the traces of processing of the previous passage, so that the degree of impact on the treated surface was with the smallest deviations. Since the amount of removal during grinding is proportional to the flap deformation [1,6], we assign a point $N$ (the intersection of the circles $R_1$ and $R_2$) at a distance of $T/2$ from the line $AD$ (see Fig. 2). In this case, the total amount of deformation at point $N$ will be equal to $T$. When you move from the line $NK$ to points $F$ and $D$, the sum of the deformation values will decrease, approaching the value $T_1$ and forms the line $L_3$, which is the arc of the sector $L_3$. Accordingly, arcs $R_1$ and $R_2$ with a line drawn at a distance $T_1$ parallel to $AD$ also form sectors (shaded). The distances of the arcs $L_1$, $L_2$, and $L_3$ from this straight line represent fluctuations in the amount of deformation $t$, which in accordance with [1,6] are proportional to the amount of removal and characterize the uniformity of grinding.

The width of the overlapping for the subsequent passage in accordance with Fig. 2 is defined as follows:

$$b_{ov} = FK + KD = (FH-KH) + (CD-CK)$$

From Fig. 2 it follows that:

$$b_{ov} = FD = \left( \sqrt{R_1^2 - (R_1 - T)^2} - \sqrt{R_1^2 - \left( R_1 - \frac{T}{2} \right)^2} \right) + \left( \sqrt{R_2^2 - (R_2 - T)^2} - \sqrt{R_2^2 - \left( R_2 - \frac{T}{2} \right)^2} \right) - \sqrt{R_2 T - \frac{T^2}{4}} - \sqrt{R_2 T - \frac{T^2}{4}}$$

(2)

Then the width of the main stripe (the stripe processed without overlapping the stripe of first passage), taking into account the radius of curvature $R_1$ and the smooth change of the radii of curvature to $R_2$, can be determined by the following expression:

$$b_{06} = 2(CD - FD) = 2 \left( \sqrt{R_1 T - \frac{T^2}{4}} + \sqrt{R_2 T - \frac{T^2}{4}} - \sqrt{2R_2 T - T^2} \right)$$

(3)
Similarly, you can calculate the width of the main processed stripe (without overlapping) for the second and subsequent passages with different curvature radii.

Thus, due to an overlapping in point with flap bend value equated to 1/2 of the deformation \( T \) for subsequent passages, we obtain a more smoothed treated surface with a profile bounded by the curvature curves of the panel and curves in the overlapping zones with a maximum deviation proportional to \( t \) (see the shaded areas in Fig. 2).

The maximum amount of deformation deviation \( t \) (Fig. 2) is defined as follows:

\[
t = T - T_1
\]

At the same time:

\[
R_1 - T + T_1 = \sqrt{R_1^2 - CF^2},
\]

so:

\[
R_1^2 - \left( \sqrt{2R_1T - T^2} - \sqrt{2R_1T - T_1^2} - \sqrt{2R_2T - T^2} - \sqrt{2R_2T - T_1^2} + \sqrt{R_1T - \frac{T^2}{4}} + \sqrt{R_2T - \frac{T^2}{4}} \right)^2,
\]

It means that:

\[
t = R_1 - \left( \sqrt{R_1T - \frac{T^2}{4}} + \sqrt{R_2T - \frac{T^2}{4}} - \sqrt{2R_2T - T^2} \right)^2. \tag{4}
\]

It is easy to see that the curves \( L_1, L_2, \) and \( L_3 \) (Fig. 2) change in shape close to the sinusoidal law, then the height of the segment of these curves is expressed by the following general formula:

\[
t_i = t \sin \alpha,
\]

where: \( t \) is the maximum deviation, \( \alpha \in (0; \pi) \).

The average deviation \( t_{av} \) in this case can be determined as follows:

\[
t_{av} = \frac{1}{\pi} \int_0^{\pi} t \cdot \sin \alpha = - \frac{1}{\pi} t \cdot (\cos \pi - \cos 0) = \frac{t}{\pi} \cdot 2 = 0,636 \cdot t \tag{5}
\]

For the second passage, the flap wheel must move to the next distance \( s \) (Fig. 2):

\[
s = KC + KH = \sqrt{R_1T - \frac{T^2}{4}} + \sqrt{R_2T - \frac{T^2}{4}} \tag{6}
\]

Fig. 3, 4, 5 and 6 showed the graphs of width change of main processed stripe, overlapping stripe width and offset of the flap wheel to complete the following passage depending on the radius of panel curvature and the magnitudes of flap deformation of flap wheel in the case of \( R_1 = R_2 \).
Figure 3. Dependence of width of overlapping stripe, width of main processed stripe and displacement of flap wheel depending on curvature radius at deformation value of 4mm, where: bottom curve - width of overlapping stripe, middle curve – width of main processed stripe, top curve- offset of flap wheel for following grinding passage.

Figure 4. Dependence of width of overlapping stripe, width of main processed stripe and displacement of flap wheel depending on radius of curvature at deformation value of 3mm, where: bottom curve - width of overlapping stripe, middle curve – width of main processed stripe, top curve- offset of flap wheel for following grinding passage.
Figure 5. Dependence of width of overlapping stripe, width of main processed stripe and displacement of flap wheel depending on radius of curvature at deformation value of 2mm, where: bottom curve - width of overlapping stripe, middle curve – width of main processed stripe, top curve- offset of flap wheel for following grinding passage.

Figure 6. Dependence of width of overlapping stripe, width of main processed stripe and displacement of flap wheel depending on the radius of curvature at deformation value of 1mm, where: bottom curve - width of overlapping stripe, middle curve – width of main processed stripe, top curve- offset of flap wheel for following grinding passage.

From Fig. 3, 4, 5 and 6 it should be noted that for processing the panel in areas with a small radius of curvature, it is recommended to use a wide flap wheel, since in this case the width of the flap wheel provides the maximum width of the main processed stripe per passage. This will reduce the number of passages when processing the entire part and, consequently, reduce the processing time. The specific width of the flaps required for processing in this way must be preliminarily calculated, taking into
account the condition that the maximum deviation of the value of the flap deformation in the zone of contact with the curved surface of the panel T in the transverse direction must be greater than or equal to the amount of needed deformation (according to the processing mode) set by the technologist.

Fig. 7 shows the dependence of the average deviation of the resultant deformation value on the radius of curvature for processing modes with a deformation of 1, 2, 3 and 4 mm during grinding with overlapping passages.

Figure 7. Dependence Average deviation of resultant deformation during grinding panel with different processing modes, where: bottom curve (curve 1) – for grinding with a deformation of 1 mm, curve 2 (above the curve 1) – for grinding with a deformation of 2 mm, curve 3 (above the curve 2) - for grinding with a deformation of 3 mm, top curve (curve 4) - for grinding with a deformation of 4 mm.

The results of the study of deviations of the resultant deformation during grinding with passage overlapping at a point with flap deformation equal to 1/2T showed that its deviation does not exceed 11% of the specified technological deformation of the central part of flap, which is expected to significantly improve the uniformity of material removal from the machining surface. Thus, the deviation of the surface shape should not exceed 11% of the thickness of the removed material, respectively.

3. Conclusion
To ensure a more uniform removal of material during grinding the double curvature panel with flap wheels in areas with a small radius of curvature, it is recommended to perform grinding with overlapping passages at the intersection of passages with the flap deformation equal to ½ of the flap deformation in central contact zone.

The developed method for calculating the width of the overlapping stripe, the width of the main processed stripe, and the necessary displacement of the flap wheel to perform the subsequent passage can minimize the uneven material removal from the surface of the double curvature panel for sections of the panel with a small transverse radius.

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