Increasing the shape accuracy of the hardened parts of the frame by technological methods

A A Makaruk, A A Pashkov, O V Samoylenko

Irkutsk National Research Technical University, 83, Lermontov St., Irkutsk, 664074, Russia

E-mail: makaruk@mail.ru; pashk0ff@mail.ru; olegsamoylenko1@gmail.com

Abstract. Aluminum alloy parts of the aircraft's power frame are usually ribbed longitudinally and transversely to increase rigidity. As a result, the cross-section of such parts is a complex, complex shape in the form of a brand, channel, I-beam, etc. with straight and inclined shelves. In the manufacturing of parts in the process of both mechanical processing and subsequent impact hardening, there is an undesirable deformation (leashes), which is expressed in the deviation from the plane and saber-like form. After milling, the leashes can be removed by local plastic deformation methods, such as rolling by rollers, or by pressing, and after hardening, mechanical treatment, including straightening by local plastic deformation methods, is not allowed by the industry standard technical procedure. Expansion of technological possibilities of manufacturing of low-rigid parts with application of technology of preventive deformation - introduction of pre-distortion of the form of a detail for compensation of the leashes arising on the subsequent strengthening operations by methods of surface plastic deformation.

1. Introduction

An important technological task in the manufacture of low-rigid large-size parts of the aircraft frame is the implementation of the operation of their straightening in order to eliminate the leashes of the contour, arising both in the mechanic processing and surface hardening [1,2]. It should be noted that the nature of the deviations after these operations are similar, the maximum values reach several millimeters with the permissible 0.2-0.4 mm - from the plane, ±0.15 - from the theoretical contour.

Pressing and local plastic deformation methods, such as roller-rolling, are used quite effectively in the process of straightening after machining [3-7]. After hardening, such machining is not regulated by industry regulations due to the possible introduction of undefined stresses into the hardened surface layer of the workpiece and the appearance of unhardened zones in it, which may adversely affect the operational properties. Application of shot peening does not allow to fully achieve the required result due to design features of parts and insignificant increase of cold-hardening in the previously hardened areas. [8].

Thus, the topical issue is the creation of a complex technology of straightening in order to eliminate the leashes of the contour, which includes the preventive deformation (introduction of pre-distortions of the form) of parts at the stage of straightening after machining and finishing the form by shot peening after hardening.

2. Design features of the parts to be machined

Figure 1 shows typical parts of the frame of "Frame rim" and "Frame Wall" type.
Figure 1. Typical frame parts: a) “Frame rim”, b) “Frame wall”

The main features of these parts are:

- Location of the centre of gravity of the cross-section outside the workpiece (see figure 2). As a result of this design feature, both ribbed (inner) and flat (outer) sides of the web are deformed with tensile forces from Fin and Fout, respectively, in a unidirectional deformation of the part under the influence of bending moments Min and Mout. This deformation is characterised by plane deviations at the edges of the workpiece, which can be eliminated by machining only the ribs, and the sheet will result in increased deflection;

Figure 2. Strength Factors Affecting the Workpiece Cloth

- large number of pockets formed by different combinations of curvilinear, longitudinal, transverse ribbing and cloth;
- comparable length and width of the wall, which requires elimination of flatness in two directions (longitudinal and transverse) after machining;
the need to eliminate, after the rim has been machined, the non-flatness (in the longitudinal direction) and the deviation from the theoretical contour characterized by a change in the radius of the curvilinear surface as a result of the elongation of the machined part in the longitudinal direction. If there are deviations from the plane when measuring with the help of the control table, the shape of the part in the form of a curved beam in two planes and the influence of its own weight should be taken into account (see Figure 3).

![Figure 3](image)

**Figure 3.** Schematic representation of deviations from the theoretical contour (Δz - clearance with respect to the control plate) and ways to eliminate them (rib rolling/shot peening)

3. **Methods for determining the deformation of parts arising from hardening**

Processing modes at preventive deformation of details are appointed taking into account the predicted deformation arising in the course of hardening. The following methods can be used to determine the method:

1. **Experimental.** In this case, on the basis of the available production experience on strengthening of parts of similar shape or construction-like samples in the same conditions (equipment, processing modes), the predicted deformation [9] is determined in the form of the difference in deflection arrows of the parts sections received after processing $f_1$ and the original one $f_0$:

   $$f_{con} = f_1 - f_0.$$  \hspace{1cm} (1)

   Deflection arrows in required planes $X, Z$ for $i$ the measured area $a_i$ are calculated by controlling the deviations with the help of a coordinate measuring machine, by probes from the control table or form template by three points (see Figure 4):

   $$f_{x(z)_i} = X(Z)_i - \frac{X(Z)_{i1} + X(Z)_{i2}}{2}.$$  \hspace{1cm} (2)

![Figure 4](image)

**Figure 4.** Determining the deflection arrow by three reference points

2. **Analytical.** An effective way to determine the predicted deformation of the parts after shot peening is to use finite element modeling methods using engineering analysis systems [10], such as LSTC LS-Dyna.

Preparation of the calculation model is performed using standard preprocessor capabilities of the selected modeling environment as follows. We carried out optimization of the geometry of the part (see figure 5) by averaging the thickness of the canvas of the part in the presence of a large number of transitions within a single pocket of the part, the elimination of technological roundings, fillets, chamfers and other elements that prevent the division of the part into a grid consisting of hexahedral (rectangular) elements. The choice of this type of elements is conditioned by the aspiration to provide sufficient accuracy in combination with an acceptable number of nodes of the finite element grid, which determines the "weight" of the model and the duration of the calculation.
Figure 5. Preparation of the calculation model: a) CAD model of a detail segment, b) the optimized model broken down on a grid of final elements

Part loading is carried out by applying a load equivalent to the force factors occurring during blasting [11-13]. These force factors are determined experimentally in the following sequence:

- simulators of typical rim elements are made: curvilinear longitudinal rim with changing angle of inclination, and pocket consisting of web sections, two longitudinal and two transverse ribs;
- simulators with fixed samples are processed at the UDP-2-2.5 shot peening machine on standard shot peening modes of this type of parts;
- samples are measured and the deflection arrows obtained during processing are calculated taking into account the initial ones;
- the specific (per unit of width) tensile force acting after processing on the structural element under study is determined by the formula (3):

\[
F_l = \frac{3EfH^3}{4a^2(H - z_c)}
\]  

(3)

where \(E\) – modulus of elasticity of the 1st kind; \(f\) – the bending deflection of the sample obtained during processing; \(a\) – bending measurement base; \(H\) – sample thickness; \(z_c\) – distance from the point of application of tensile force to the treated surface (they can be neglected in the calculation, since the maximum initial stresses are close to the surface during impact hardening).

The distribution of the tensile force resulting from the machining of the "curved edge" element depending on the angle of inclination is shown in Figure 6.

Figure 6. Dependence of the tensile force caused by the processing of a curved edge element on the angle of inclination of the part's edge

Creation of a surface load by a method of force influence on a surface layer of a detail equivalent to
internal force factors of process of shot peening is carried out as follows. All structural elements (longitudinal, transverse, curvilinear ribs and a cloth) are broken into sections (shown in bold lines in Figure 7) with length 250±100 mm by means of preprocessor.

![Figure 7. Component groups of structural element section](image)

Each section is divided into a set of boundary nodes lying on the surface, united into groups. The groups of elements for each section shall be a closed contour and shall lie in mutually perpendicular directions. Groups of elements shall be divided into all areas of structural elements, both from the outer and inner sides [14-17].

Segment boundaries are applied to the force distributed along the length of the segment with the possibility of following movement, when the force vector is rotated during bending and continues to operate normally to the application plane. Выбираются Three points of the tracking force application planes are selected (points 1, 2 and 3 form the tracking force application planes F₁, точки 1, 2, 4 – points 1, 2, 4 form the tracking force application planes F₂ (see Figure 8) for the boundary zones of the structural element sections.

![Figure 8. Selection of the tracking force application planes](image)

The value of specific tensile force for a site of a constructive element is appointed depending on an angle of rotation of considered constructive element. For this purpose in the center of masses of the party of a site the system of coordinates X'Y' concerning which the corner of rotation of an internal and external site of a constructive element is calculated and the corresponding specific force is appointed Fsp.

The distributed force value for the selected group of elements is calculated by formula (4). The force is set by the loading curve with a smooth increase within 15-20 seconds and the stabilization stage within 20 seconds:

\[ F_i = \frac{F_{pl} l}{n}, \]  

(4)
where $l$ – section length, $n$ - number of nodes in the group of this section.

The results of modeling are the distribution of displacements and deformations relative to two mutually perpendicular planes (Figure 8), on the basis of which it is possible to predict the possible deformation of the part after shot blasting.

4. Definition of preventive deformation modes and machining of parts

Preventive rim deformation is based on the need for pre-stressing prior to hardening in two planes: to eliminate deviations from the flatness of the ribs and from the theoretical contour of the sheet rolling. Preventive deformation of the wall is limited to the introduction of pre-steps to eliminate deviations from the flatness by rolling longitudinal ribs (transverse ribs are virtually absent, as they can be taken edge areas of the curved rib, however, rolling rollers on them is impossible due to the presence of a large number of guide holes, so after hardening required to fine-tune the form by shot peening them).

With the help of a coordinate measuring machine, probes from the control table or form template, deviations in the control points in the required X, Z planes after machining the rim are determined. Initial deformation diagrams are drawn (see Figure 10, Line 1)).

**Figure 9.** Modeling results in the form of motion distribution: a - relative to the OZ axis; b) relative to the OX axis
Based on the results of a typical part hardening, a structural-like sample or a simulation, we draw diagrams of deviations (predicted deformation during hardening) of the part at the control points in the required X, Z planes (see Figure 10, Line 2).

The total deviations are calculated at the control points (taking into account the sign), which are to be corrected when rolling out the rollers:

\[ X(Z)_{\text{pack}} = X(Z)_{\text{out}} + X(Z)_{\text{con}}. \] (5)

The diagrams of the total part deviations in the required X, Z planes, which require elimination during rolling by rollers, are drawn (see Fig. 10, line 3). Taking into account the design features of the workpiece to be machined, the areas \( a_{x(z)}_{i} \), requiring correction after machining are determined. For each section \( a_{x(z)}_{i} \) the deflection rolls are to be eliminated at three control points accordingly (2).

The required tensile forces for the section are determined using the part rolling pattern shown in figure 11, which has a channel cross section \( a_{x(z)}_{i} \):

\[ F_{x(z)}_{i,\text{pack}} = \frac{8 \cdot f_{x(z)} E f_{x(z)}}{a_{x(z)}^{2} x(z)_{i}} \times 80\%; \] (6)

where \( x_{i}, z_{i} \) – distances from the tensile stress points to the centre of gravity of the i-th section; \( E \) - 1st type modulus of elasticity; \( f_{x}, f_{z} \) – moments of inertia in the part cross-section.

On the basis of the tensile forces obtained \( F_{x(z)}_{i,\text{pack}} \) for the parts required for machining \( a_{x(z)}_{i} \) the tightening torques of the power bolts are determined \( M_{x(z)}_{i} \) [18] of the used rolling devices by means of calibration schedules shown in Figure 12.

On the basis of the tensile forces obtained \( F_{x(z)}_{i,\text{pack}} \) for the parts required for machining \( a_{x(z)}_{i} \) the tightening torques of the power bolts are determined \( M_{x(z)}_{i} \) with the help of the calibration graphs shown in Figure 12.

**Figure 10.** Diagram of part deflection (1 - initial deformation, 2 - predicted deformation at hardening, 3 - total deformation, ah(z) - straightening section by rollers)
Figure 11. Rim type part unrolling pattern

Figure 12. Dependence of tensile force caused by rollers rolling parts made of 1933T2 alloy on the tightening torque of the power bolt of the ribs (1) and the cloths (2)

Rolling of the required part sections by rollers $a_{X(z)i}$ on the calculated modes. Diagrams of deviations in the required $X$ and $Z$ planes, taken with the opposite sign, are used to control the obtained shape. [19-21]. If necessary, the required section of the part is subjected to additional rolling by rollers with an increase in the torque of the power bolt by 10-20% with the control of obtaining the required deformations.

After hardening on the parts there is a decrease in deviations from the flatness from 6.8 mm to 0.4 - 1.8 mm, from the theoretical contour from 1.2 to 0.1 - 0.5 mm. If it is necessary to eliminate deviations exceeding the permissible values, the shot is processed locally.

5. Conclusion
1. Preventive deformation of parts of the power frame of aircraft allows minimizing the deviations of the shape, arising in the process of their hardening by impact methods. In order to increase productivity, it is more effective to make pre-distortion at the stage of part straightening after machining. The developed set of rolling tools is applicable for deformation of parts in two planes by machining both ribs and blades of parts.
2. The method of determining the internal force factors of the shot peening process is an integral...
part of the preparation of the initial data for the calculation of the predicted deformation.

3. CAE simulation of the shot peening process significantly reduces the cost of producing structurally-like samples when determining the predicted deformation of the parts to be hardened. It is also possible to analyze the effect of hardening modes on part deflection.

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