On the choice of in-process allowance for hardening

A S Bachurin$^{1,2}$ and N V Kourlaev$^1$

$^1$ Novosibirsk State Technical University, Karl Marx Avenue, 20, Novosibirsk, 630073, Russia
$^2$ Energozapas, Inzhenernaya Street, 26, Novosibirsk, 630090, Russia

E-mail: bachurin.a.s@yandex.ru

Abstract. The influence of allowance value on residual hardening stresses is researched. A new indicator is proposed to compare the effect of different values of the interoperative allowance for hardening on the workpiece leashes. The results of the change in the value of the allowance in the technological process of production of large-sized parts of modern civil interregional aircraft using the new indicator proposed by the authors are presented.

1. Introduction

The production of large-sized parts of great geometric complexity (parts containing surfaces of single, double curvature, many reinforcing elements, etc.) with a given accuracy is a complex technological task. One of the complex structural elements of modern passenger aircraft is the binding of the lantern. In this article, we consider the cover frame for the lantern of the SSJ family of aircraft. Such a frame is the largest and most complex binding detail, from a technological point of view: high requirements for surface quality, geometric complexity of the binding frame of a lamp (a large number of pockets, double curvature surfaces, etc.), requirements for the accuracy of the finished part. Limit deviations of the sizes on the processed frame thickness are -0.3 / + 0.2. The tolerance on the surface of the binding frame of the lantern overlooking the theoretical contour is -0.5 / + 0.5.

Figure 1. Binding of a lantern of the SSJ family aircraft: 1) a side binding frame; 2) a central rack; 3) binding beams.

2. Changing the inter-operative hardening allowance in order to reduce the leash

Residual process stresses arising during the part production have a significant impact on the characteristics of the finished part [1]. Residual hardening stresses have a significant level, and their
distribution significantly depends on the interoperalional stock [2]. Figure 2 presents a picture of residual equivalent stresses with the applied contours of the finished part [2].

**Figure 2.** Equivalent residual stresses: a) uniform allowance of 4 mm; b) uniform allowance of 8 mm; c) uniform allowance of 12 mm; d) uneven allowance from 8 mm to 18 m; e) blank rectangular shape with uneven allowance.

It can be seen that the contours of the part include zones of significant residual stresses and are characterized by significant irregularity. Reducing the allowance value leads to a decrease in the penetration depth of maximum stresses (195-60 MPa). With a decrease in the allowance value, the average value of stresses in the workpiece also decreases. In this context, we consider figure 3, which presents the results of modeling the cooling process during hardening for each of the sections. It can be seen that the temperature difference in the cross section is higher, the higher the value of the allowance. From figure 2 it can be seen that the higher the allowance, the higher the voltage, on average, in the area limited by the contour of the finished part. It would be logical to conclude that minimizing the tempering allowance will lead to minimizing the leash. However, we are not interested in the leashes of the workpiece, but the finished part, and therefore there is a need to fit the part into the workpiece and the presence of a sufficient allowance for this.
Figure 3. Changing of $\Delta T(t)$ over time in different cross sections: cross-section with a uniform allowance of 4 mm; 2) cross-section with a uniform allowance of 8 mm; 3) cross-section with a uniform allowance of 12 mm; 4) cross-section with an uneven allowance of 8 mm to 18 mm; 5) rectangular cross-section with an uneven allowance.

It is obvious that the nature of the residual stress distribution affects the distortion of the shape of the finished part. In addition to the ego, the geometric characteristics of the section are also important, the higher the stiffness of the element, the less it is subject to leashes, other things being equal [3]. Clearly, each section, with a different allowance, has a different geometric moment of inertia (as a stiffness characteristic). And the larger the allowance, the greater the geometric moment of inertia, but given the fact that a larger allowance increases the average stress, we can conclude that there should be a point of their optimal ratio, which determines the size of the allowance at which the hardening leashes will have the least value and influence on the finished part.

Based on the considerations described by the authors, an empirical indicator is proposed to determine the value of the interoperative allowance for hardening for large-sized parts of complex geometry made of aluminum alloys:

$$P_v = \frac{J_x}{S \cdot \Delta t_{max}}$$

(1)

where $J_x$ is the geometric moment of inertia with respect to the axis perpendicular to the axis of immersion "y", $S$ is a cross-sectional area, $\Delta t_{max}$ is the maximum temperature difference observed when cooling the workpiece with this allowance.

Index 1 allows to take into account the characteristic of the stiffness of the cross-section with respect to the inhomogeneity of the thermal field arising during hardening. Thus determining the most favorable ratio, which is achieved at the point of maximum value of the indicator. To test the indicator, a detailed of increased geometric complexity was selected, namely the frame of the lantern binding of the SSJ 100 family aircraft. The frame is made of forging material AK6 OST 1 90073-85 dimensions 275h1090h1855 mm. the Technological process, before the changes, assumed the presence of an overlap to the size of the cross section 100mm by 120mm as in figure 4.

After cutting the workpiece from the forging, heat treatment was carried out, that is, hardening and aging. This resulted in a substantial leash of the workpiece. The greatest floods were observed after hardening. There the magnitude of reached 4.7 mm. In the course aging leashes declined, but marginally.

At the end of the manufacturing process, the frame of the lantern binding had deviations from the reference geometry above the permissible ones. The deviation reached 0.9 mm.
Figure 4. 3D model of the workpiece and the workpiece on the machine table, before changing the allowance.

In the course of determining the value of the allowance, based on the indicator proposed by the authors, 5 characteristic sections were allocated in the frame of the lantern binding as in figure 5. For each section were obtained graphs $P_v$ depending on the value of the allowance (shown in figure 6), if analyzed, it can be concluded that the values of allowances should be in the range from 4.8 mm to 6.7 mm.

Figure 5. Sketch frame cover of the lamp and typical cross sections.

Figure 6. The $P_v$ value depending on the allowance value: a) section No. 1; b) section No. 2; C) section No. 3; d) section No. 4; e) section No. 5.
As a new working interoperative allowance for hardening, an allowance of 6 mm was chosen. According to the authors, this value of the allowance seems to be the most advantageous based on the conditions of machining of this particular part [4] and reduces the risks during testing. To control the geometry after hardening, special surfaces were provided on the surface of the workpiece, namely bosses as in figure 7 a, b, c. The coordinates of the boss data centers were measured before and after hardening.

![Figure 7](image).

**Figure 7.** a) the bosses as checkpoints b) cross-sectional view of the lantern binding frame c) batch of blanks with a uniform allowance on the pallet, after hardening.

3. Results

The value of the leash, on the control surfaces (bosses), is shown in figure 8. Leashes after hardening the workpiece decreased more than twice, 4.8 mm before the change and 2.04 mm after.

![Figure 8](image).

**Figure 8.** Deviations in geometry of the workpiece after hardening.

A total of 12 of 12 workpieces were underwent changes. Further measurements of the workpieces were not made, for reasons of reducing the production time, by eliminating the time spent on measuring the workpiece before and after hardening.
Upon completion of the subsequent stages of production, the frame of the lantern binding passed the necessary geometry control and was compared with the 3D model. The results of the comparison are presented in figure 9. The frame of the cover of the lantern, after the change of in-process stock, from the point of view of manufacturing precision, was to satisfy all design requirements. The maximum deviations from the theoretical contour were 0.14 mm, while the permissible 0.5 mm, the thickness tolerances were also maintained with a sufficient margin.

![Figure 9. Deviations of the finished frame from the electronic model.](image)

4. Conclusion
The obtained results confirm the efficiency of the indicator proposed by the authors. The change in the value of the allowance in favor, determined by the proposed indicator, allowed to reduce the hardening leashes and to improve the accuracy of manufacturing the frame of the lantern binding.

The modified workpiece after reducing the leashes, allowed to simplify the process of fitting the part into the workpiece on the CNC machine, to facilitate the process of fixing the workpiece in machine tools, to exclude additional alignment decreased the exposure time in an electric furnace for heating for hardening. In addition, the stage of coordination of frame geometry deviations from the construction documentation was excluded. All this allowed to reduce the production time of the lantern binding frame and ensure its proper quality.

References
[1] Yashcheritsyn P I, Ryzhov E V, Averchenko V I 1977 Technological heredity in mechanical engineering, Minsk Science and Technology, 256 p.
[2] Bachourin A S, Bobin K N, Matveev K A, Ryngach N A, Kourlaev N V 2013 Metal processing (Novosibirsk: Novosibirsk State Technical University)
[3] Arendarchouk A V, Astafyev A A, Bashnin Yu A 1980 Heat treatment in mechanical engineering (Moscow: Mechanical Engineering)
[4] Kharlamov G A and Tarapanov A C 2006 The machining allowances (Moscow: Mechanical Engineering)