Methods and Algorithms for Computer-aided Engineering of Die Tooling of Compressor Blades from Titanium Alloy

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Abstract. The articles provides the calculation algorithms for blank design and die forming fitting to produce the compressor blades for aircraft engines. The design system proposed in the article allows generating drafts of trimming and reducing dies automatically, leading to significant reduction of work preparation time. The detailed analysis of the blade structural elements features was carried out, the taken limitations and technological solutions allowed to form generalized algorithms of forming parting stamp face over the entire circuit of the engraving for different configurations of die forgings. The author worked out the algorithms and programs to calculate three dimensional point locations describing the configuration of die cavity.

1. Introduction

It is known that the design of 3-D models of reducing and cutting dies for volumetric punching of blades is not a fully formalized process, which in many ways stands on the experience of the designer and technologist depending on the applied practice in production, and is not always amenable to automation [1-3]. In this connection, the purpose of this work is to generalize the experience of developing CAD die tooling, which would implement a balanced approach to the combination of a formalized automated process of die geometry determination with the possibility of its interactive correction based on production experience and the possibility of geometry optimization, for example, using CAD-systems (Deform 3D, Qantorform et al. [4-8]).

The worked out system consists of three consequential calculations of units: development of die forging, calculation of generic mathematical model (GMM) of final reducing die and unit of technological equipment engineering of the second kind (test pattern and others). The first unit provides for creation of standard drawing of die forging without 3-D model with the possibility to display it on hard copy. Such representation of calculation results allows, without violating the tradition of enterprises, to agree on the shape and dimensions of the forging with all interested services and industries. In order to increase the versatility of the program, the size of the allowances on all blade surfaces is not related to normative documents, which differ markedly in different enterprises. Therefore, allowances can vary within wide limits and are set by the user in the initial data. The necessary overall dimensions and point location of the blade section are entered from the design drawing of the blade in manual and automatic modes. To increase the visibility of input and reduce subjective errors, the system provides a series of slides. Assignment of allowances, stamping inclinations, alignment block (pad), and creation of forging drawing with all sizes are performed automatically.
The received dimensions of the forging design in automatic mode are transferred to the unit for calculation of generic mathematical model (GMM) of final reducing die. CAD has an “input validation” unit, which allows you to apply manual input, excluding the forging design block, to change any work size after automatic input, optionally enter the missing parameters. The described principles of CAD design of volumetric stamping of GTE blades are implemented in software.

2. Methods and algorithms of research

According to the results of the practice of using the system and its technical approbation, it is possible to single out several key points concerning the processes of formalized determination of the die geometry and construction of its GMM.

1. Select the shape of the gutter geometry. The form of the gutter linker along the blade edges in the system under consideration is adopted in the form of a natural extension of the profile in each section. In this case, the linker is tapering and does not have sharp pips along the edge with the forgings, which increases the durability of the die. The width of the linker and its final thickness are variables and are set in manual mode.

2. Solve the task of selecting a line of connector dies around the blade shank and alignment block (pad), which is the most complex and multivariate. The analysis of the large nomenclature of forgings has shown that, depending on the blade design, three basic variants of blade crossing with the tractor's shank surface can be distinguished. Algorithms and programs have been developed to implement each of these options.

In practice, three types of connector dies are used: parallel, stepped, inclined. Inclined and stepped connectors allow you to adjust the depth of the die cavity in the upper and lower liners. The stepped connector simplifies the manufacture and control of the stamp. The gradient of the step levels is carried out at a small angle - 5-7 degrees. However, this connector complicates the stamp setting and worsens the quality of the burr cut. A small gap in the vertical section of the connector (0.1 ... 0.3 mm) often leads to a collision of dies with a slight displacement.

The proposed algorithm provides for the use of only two kinds of connectors: parallel or inclined.

The end shank surface from the side of the input edge of the blade in the lower liner (control base) is formed by turning the forgings in the stamp by an angle of TAY3. A similar surface in the top liner is at an angle (ALNEY + TAY3), where ALNEY is the selected stamping gradient. In the calculations, this angle is assumed to be constant. This design of inclines leads to the formation of a “cover” on the forging of a variable width, which is partially removed when burring.

Stamping incline in the lower liner on the shank end from the side of the blade output edge is always assumed to be constant (ALNEY). To control the displacement of dies in the transverse direction, the stamping gradient in the upper liner is assumed to be overestimated.

Here and further all profile surfaces and die connector surfaces are calculated taking into account the “hot” dimensions of forgings, which are determined by the coefficient of linear expansion in the range of forging temperatures.

The key problem in the system of die tooling is to choose die lines around the blade root and alignment block (pad), which is the most complicated and multivariate. The analysis of a great number of forging showed that depending on the blade construction it is possible to point out three main variants of blade intersection with path surface of shank end. There are algorithms and programs for realization each of these variants.

The design of parting face starts from the side of input edge of the blade (Fig.1).
Figure 1. Choosing parting of a die along route and shank end from the side of input blade edge: A – the surface of lock edge, 1,2,3 – the variants of blade crossing the route surface of lock.

1 variant. Limiting points of die impression blade stay within the surface of the shank end (surface A, (fig.1)). In this case the connector along route is set as parallel to middle plane of shank end and break the surface A in the point of a1 (lower insert) and b1 (upper insert). The further direction of a connector lies in axis of the stamp.

2 variant. Limiting points of die impression blade exceed the limits of the surface of the shank end. In this case the connector along route (points a2 и b2) lies at the intersection of A surface.

3 variant. Limiting points of die impression blade exceed the limits of route. This is the most complex variant of connector. In order to upload the configuration of the shank, it is provided for reduce the blade width, while ensuring the necessary allowance along the edge. The connector along the route runs parallel to the axis of the shank at the points of a3 and b3.

For all variants of connector there is the same thickness of flash gutter linker (MOST), accepted in the initial stamp design data.

In practice, three types of connector dies are used along the shank end between rout and foot: parallel (variant 3), stepped (variant 2), inclined (variant 1). Inclined and stepped connectors allow you to adjust the depth of the die cavity in the upper and lower liners. The stepped connector simplifies the manufacture and control of the stamp. The gradient of the step levels is carried out at a small angle of 5-7 degrees. However, this connector complicates the setting of the stamp and worsens the quality of the burring. A small gap in the vertical section of the connector (0.1 … 0.3 mm) often leads to a collision of dies with a slight displacement. While burring it is practically impossible to provide optimized gap and the form of cutting edge, especially from the side of a top die.

The proposed algorithm provides for the use of only two kinds of connectors: parallel or inclined. Using an inclined connector allows solving two problems: create a sufficient surface (control base) on the end face of the lock, which the forging to be reliably set in the control device; ensure a greater depth of the die cavity in the lower insert compared with the top one.

The end surface of the shank in the lower insert (control base) forms a natural draft due to the turn of the forging in the stamp by an angle of TAY3. In this case side surface of a shank in the top insert is formed at an angle (ALNEY + TAY3) to axis of a shank, where ALNEY is the selected stamping gradient (fig. 3). In the calculations, this angle is taken as constant for route surface of a shank. This design of inclines leads to the formation of a "visor" on the forging of a variable width, which is partially removed when burring.

Then a connector of dies is formed along the shank end from the side of the leading edge of the blade.

The variants of intersection of a blade with the surface of shank end from the side of trailing edge are similar to those examined earlier for leading edge. Figure 2 schematically shows three possible options. Unlike the leading edge, parting of a die along route and further in flash gutter is formed parallel to the die axis, i.e. at the angle of TAY3 to the shank axis. Thus, the output of the connector
on the lock end is determined by the points of a4 - b4 (variant 1), a5 - b5 (variant 2), a6 - b6 (variant 3). The position of connector die along the shank end i.e. connector output to the foot is selected from the following conditions:
- if connector die along the shank end is located over the shank axis (for example, variants 2 and 3 at the figure 2), then connector at the end is parallel;
- if connector die is lower the shank axis, then connector is inclined opening onto the shank axis at the point of c4 (for example, variant 1 at the fig.2).

**Figure 2.** Choosing parting of a die on the shank end from the side of trailing edge of a blade airfoil: Б – the surface of shank lock, 1’,2’,3’ – variants of intercrossing blade and route surface of a lock.

Stamping incline in the bottom insert in the shank end (fig. 3) is assumed to be constant (ALNEY), regardless the variant under consideration. To control the displacement of dies in the transverse direction during stamp setting, it is accepted that lower die cavity (point at the edge c in fig. 2) must lie in one vertical plane with upper die cavity (point at upper die d in fig. 2). In this case stamp draft in the upper die cavity will always be more than ALNEY. At the same time if connector of shank end is parallel, then the angle is constant, if it is inclined, then the angle is alternate.

The connector line runs along the foot of the shank. Taking into account the accepted conditions for the formation of the connector at the of the shank ends, we find out that the die connector at the foot in most cases is not parallel to the shank axis. However, the depth of the cavity in the lower die cavity will be greater than the corresponding depth in the upper die cavity. Considering this circumstance, the stamping gradient in the lower die cavity is assumed to be constant (ALNEY). When installing stamps, it is necessary to control the mutual displacement in the longitudinal direction. To make it easier to control, it is desirable that the cutting edges of the burr (B and H in Figure 3) are in a vertical plane. This is achieved by assigning a variable angle of the stamping bias in the top insert, which is larger than the preset one and smoothly changes along the die splitting line. The described algorithms for forming a die connector on the shank ends uniquely determine the connector on the foot: in all cases the depth of the cavity in the lower die will be greater than the corresponding depth in the upper one. Given this circumstance, the stamping gradient in the lower liner is assumed to be constant (ALNEY), and in the upper it is variable. This approach allows combining the stamp edges and using the foot of the forging shank to control the displacement of the liners in the longitudinal direction.

Let’s consider the formation of parting plane around a technological pad. The technological pad is situated outside the working part of a blade. To simplify the design of stamp the connector around the pad is made flat. However in this case it is necessary to apply vertical (stepped) connector moving from a blade to a pad, which has major deficiencies. When developing CAD-system for stamp another decision concerning the formation of connector surface is suggested and carried out. The key point lies in the fact that aerofoil of top section of blade is spread into the area of pad.
Using such method the stamp connector will be curvilineal, and its exit onto the side surface of pad will depend on the angle of top section turning. To obtain the estimated dimensions of the linker of the burring groove, it is necessary to make a reduction in the blade thickness around the pad due to suction or pressure side. The choice of the appropriate option depends on the size of l1 (Fig. 4), which determines the site of the forging control base. It is accepted that: if l1≤0.4K, where K is the thickness of the pad, then the thickness of the blade is reduced due to the suction side located in the lower liner. In this case, the profile of the pressure side without additional twist extends to the entire pad, and the profile of the suction side is built equidistantly, at a distance of the thickness of the linker (MOST). If l1> 0.4K, the profile of the suction side remains unchanged. The required linker thickness (MOST) is created by changing the profile of the t pressure side (Figure 5), which is constructed equidistantly to the profile of the suction side. To maximize the overlapping edges of the burr trim, it is possible to slightly reduce the width of the pad (C) by 1 ≤ 2 mm (Figure 4.5). To implement all the described conditions and limitations, appropriate algorithms and software tools have been developed.
improve the quality of the burr cut, it is provided to reduce the thickness of the blade around this structural element by truncating the profile from suction or pressure side. If the area of the forging control base on the pad is not sufficient, then the thickness of the blade is reduced due to the suction side. In this case, the profile of the pressure side without additional twist extends to the entire pad, and the profile of the suction side is built equidistantly, at a distance of the thickness of the linker (MOST). Otherwise, the profile of pressure side remains unchanged. The required thickness of the linker is created by changing the profile of the trough.

3. Conclusion
Analysis of the blade from titanium alloys [9, 10] structural elements features, taken limitations and technological solutions allowed to form the surface of parting of a die throughout the engraving contour. Algorithms and programs were developed for calculating the three-dimensional coordinates of points describing the configuration of the die cavity, the base surfaces for the installation of control templates, the shape and overall dimensions of the top and lower inserts of the stamp. As a result, a generic mathematical model of the final stamp was obtained in the form of a three-dimensional array of base points joined by edges in the form of straight lines or splines. This model is the basis for the creation of design documentation for technological equipment and its monitoring tools.

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