METHODS OF PROCESSING OF GAS TURBINE ENGINE (GTE) IMPELLERS FLOWPATH

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Here are considered the research results of processing flowpaths of open and semi-open impeller of GTE. Here are presented, developed by the author, method of monowheel interscapulum processing and technological processing schemes. Here are proposed the recommendations for processing conditions for machining centers by Hermle model 40 U and by Micron model 710 U.

Keywords: aeroengine manufacturing, gas turbine engine, impeller, monowheel, milling, processing

Conference participant

The processing of flowpath of open and semi-closed impellers is a serious technological problem in the production of GTE. The main operating characteristic of monowheel flowpath is to ensure the same natural frequency of each of the blades that make up the flowpath. Providing this condition is only possible with the highest frequency of the shape and size of each element of the flowpath. Obtaining of such level of frequency of machined surfaces is provided by the stock removal schemes, when the workpiece always remains in balance during machining, that is, the "warping" of the workpiece, uneven deformation of individual monowheel blades are excluded during processing.

Processing on CNC machining centers is a well known processing technology of monowheel flowpath, which allows to treat all blades in a single setup. [1] The implemented flowsheets include preliminary (rough) and final (finishing) processing. During roughing interscapular grooves are cut on the disc shaped workpiece, and then during the finishing the interscapulum is finally formed. Disc or end mill are used for roughing and end mills with the cone cutting end conversing into sphere. Meanwhile the process is held by "leaning" a tool to the generator of blade profile over the entire profile height, ie the straight part of a mill is involved in cutting of a blade flowpath and its radial part in cutting of radius of blade transition into the hub of monowheel.

In the described method, the ratio between the width of processing (line width) and the milling depth is not specifically regulated. However, this ratio determines the elastic deformation level of the work surface, ie determines the accuracy of the processing. During stock removal from the workpiece it’s regidity continuously decreases. The workpiece is deformed due to violation of its equilibrium state caused by the heterogeneity of the removing stock. And the "warping" occurs as during roughing (grooves cutting), occurring usually at unbalanced formation of interscapular grooves and as finishing the individual blades, usually due to uneven stock removal from the convex and concave parts of the profile.

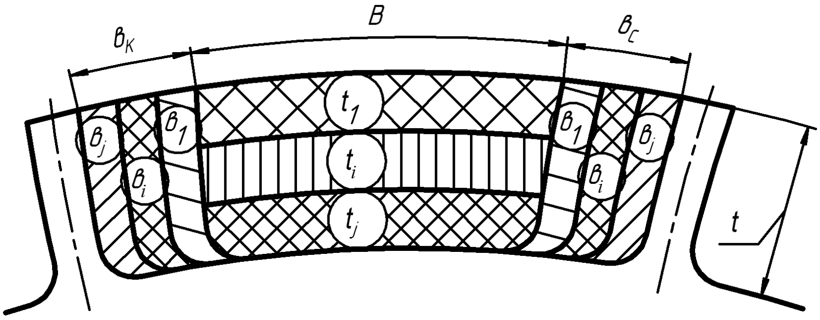

Fig.1. The scheme of stock removal in interscapulum of a monowheel

RSATU by P.A. Solovyov has developed and implemented to NPO “Saturn” monowheels processing circuit, which highly regulates stock removal procedure. [2] The interscapulum processing scheme decribing this method is shown in Figure 1.

According to this scheme, during the pre-processing stage interscapular grooves width *B* are cut in the disk shaped monowheel blank. Grooves are cut by disc or end mill for several passes, that is, the total depth of the groove profile *t* is formed by sequential remove of allowances t_1 in the first pass; t_i in *i*-th pass; t_j in *j*-th pass. However, after the first groove cut width *B* and depth t_1, a diametrically opposite to him groove is cut, that is, the symmetry principle is followed during the processing. After cutting through all interscapulum grooves depth t_1, the whole cycle monowheel processing repeats but with a depth of t_i. It is of great significance the ratio of all allowances, i.e. the correlation between t_1, t_i, t_j , generally it is $t_1 > t_i > t_j$. This correlation between the quantities of removed allowances is due to the fact that in the surface layer formed after groove machining the residual stress should be less than in the groove formed by the previous pass. On the other hand, allowance removed during groove cutting should be sufficient to delete deformed strained layer from the workpiece wich is formed by the previous treatment. Therefore formed on the bottom of the groove a new deformed layer should be less in depth than the last, and have less stress. Guarantees of this state is the gradual cutting depth reduction as height of formed profile approaches to its final value, that is, to *t*.

Finishing of interscapulum is consistent removal from each of the flowpath blades allowances b_c - from the back and the b_k - from the pressure side. In this case, these allowances are cut for several passes, during each of which allowances b_1, b_i, b_j are subsequently removed. During the processing cutting tool “leans” to the entire height of the blade profile, that is the height *t*. This is possible only when processing monowheels, for which generator of blade flowpath does not match the linear tool generator. A lot of monowheels with such a shape of flowpath generators are used in GTE.

During finishing the flowpath of monowheel blade first removed is allowance b_1. Processing is performed along a closed path equidistant to the part profile, i.e. mill "runs" the profile from the

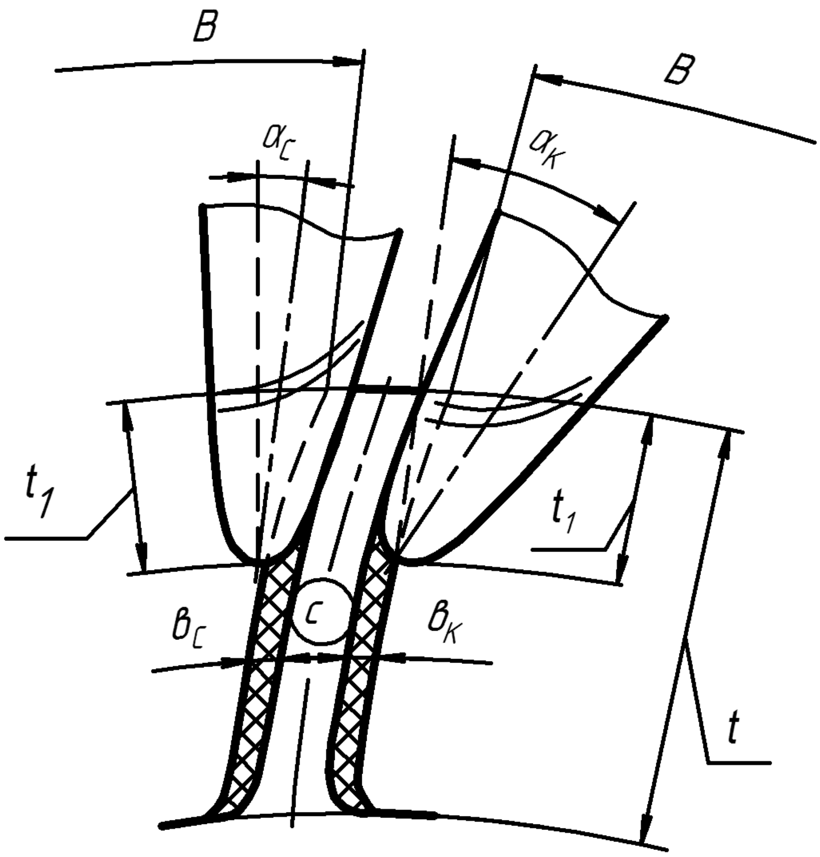

Fig. 2. Machining pattern (stock removal) on the first milling pass around the processing blade profile

back and pressure side. The process is then repeated with successive blade until the allowance b_1 be removed from all blades of a wheel. The order of processing blades with allowance removal can be arbitrary, i.e. the symmetry principle is not required. After the removal of the allowance b_1 from a blade flowpath the entire cycle is repeated with removal of the allowance b_i, then b_j.

Values b_1, b_i, b_j, set for each stage of finishing, are calculated on basis of the maximum allowable strain of the interscapular space defined by the following expression:

$$\delta_{\max} = \frac{(B+2\text{в}_i)\,\sigma_t \cdot \delta_t}{2E(h-t)}\left[1+\frac{3(h+t)}{(h-t)^2}\right]^2,$$

where: δ_{max} - the maximum allowable strain of the interscapular space, mm; h - thickness of monowheel flowpath (blade chord), mm; t - blade height, mm; E - elasticity modulus of the material, Pa; σ_t - the value of the residual stresses in the surface layer of the blade, Pa; δ_t - the depth of residual stress in the surface layer of the blade, mm, b – width of interscapulum after i - passes, mm; b_i - thickness of removable stock at i - pass, mm.

Use of this processing technology for flowpath monowheels significantly increases accuracy. This is due to the fact that the setting up milling, particularly setting milling depth, includes elastic deformation of the part during processing.

However, this method cannot be used for flowpath processing of monowheels which profile generator does not match the linear tool generator. Moreover, the algorithm of calculating elastic strain during cutting does not include a number of geometric dimensions of the workpiece, in particular the thickness of the blade profile. These facts greatly restrict the use of the technology and reduce the accuracy of processing with normal mill conditions.

RSATU by P.A. Solovyov has developed a special technique and method of fine milling, supplementing the one above. The method applies only to the stage of finishing, that is, at the roughing stage it repeats the procedure described in [2].

At the end of the preliminary (draft) processing a monowheel workpiece is a disc with radial grooves width B and height t. In addition, each monowheel blade with a curved profile, convex from the "back" and concave from the "pressure side" has the final thickness C, closed by finishing allowances: b_c - from the back and the b_k - from the pressure side. The final stock removal b_c and b_k thick on each side of the blade and t overall height is done by moving a mill on closed paths equidistant to milled blade profile in several passes. Milling depth (line width) from pass to pass varies from t_1 to t_j. On the first pass milling is conducted at a speed V_p, with a depth equal to the allowance thickness b_c and b_k at the height t_1 determining the line width (Fig. 2).

On the one hand, value t_1 must not exceed the maximum possible length of contact of the tool generator with a curved blade surface generator. On the other hand, it must ensure less deformation of the workpiece than the permissible value of interscapulum B width. That is, the milling width t_1 may be less than the maximum possible length of a match of tool generator and the working surface. During the first pass with the line t_1 width a mill angle to work surface varies depending on the curvature of the working surface.

Milling conditions, namely: cutting speed V_p, feed S, the line width t_1, cutting depth b_c and b_k determine the value of the cutting force resultant R. The value of the cutting force resultant R and blades dimension, namely: profile height t, chord width h and thickness of blade profile C determine the magnitude of the elastic strains of a part δ during processing. Therefore, the line width t_1, as the most convenient parameter for regulation, is included in the part program based on the calculation of allowable deformation.

During the following passes (mill closed path) the working cycle is repeated, but with the lines t_i and t_j wide. The value of line width for each new pass is assigned according to the value of treated surface deformation, Fig. 3.

Each time elastic deformations are calculated in response to changing load conditions of treated surface, that is, according to the location of cutting force resultant on the blade profile height t, mill angle and mill position along the chord of the blade.

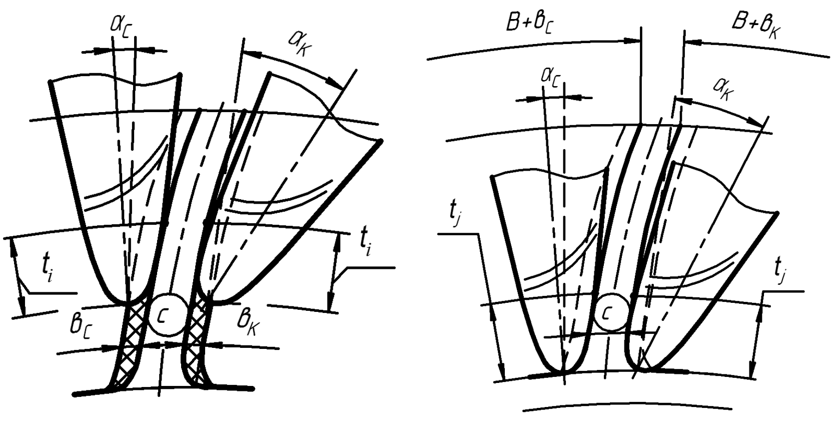

Fig. 3 Monowheel flowpath processing scheme

a) in the middle section of a blade (i-pass) b) during final pass (j-pass)

With each new line made by mill, the height of treated blade profile *C* increases from 0 during the first pass to the *t* at the end of the last, while treatment area become closer to the monowheel hub. These changes always need to recalculated the elastic deformation of the blade according to the one kind or another value of line width.

Line values t_i and t_j are set in the control program of the CNC machine as well as the mill angles α_C and α_K which values ensure the absence of collisions (infeeds) of spindle to the working surface.

Upon completion of the final pass, the width of interscapulum equals to $B+b_c$ from the back and to $B+b_K$ - from the pressure side. After it the finishing process is carried out on next to the treated blade, etc.

The current values of milling width (line width at a given pass) are put into the control program according to the calculation of the blade deformation, defined as the sum of the bending and torsional deformations of the blade under the action of the cutting force resultant (Fig. 4).

The maximum values of the blade deformation, according to the scheme are defined by the following expression:

$$\delta_{\max} = \frac{R\cos\beta\cdot t^3}{3EJ_x}\left(1+\frac{3EJ_x\cdot h^2}{GJ_k\cdot t^2}\right)^3$$

where: δ_{max} - the maximum possible value of the total blade deformation during processing, mm; *R* - cutting force resultant, N; *E, G* –the shear and elasticity modulus respectively, Pa; J_x J_k- - moment of inertia of blade profile during bending with respect to the x axis and torsion to the z axis respectively, mm^4; *β* - the angle of the cutting force resultant to the normal of working surface, rad; *t* - width (height) of blade profile, mm; *h* - chord length, mm.

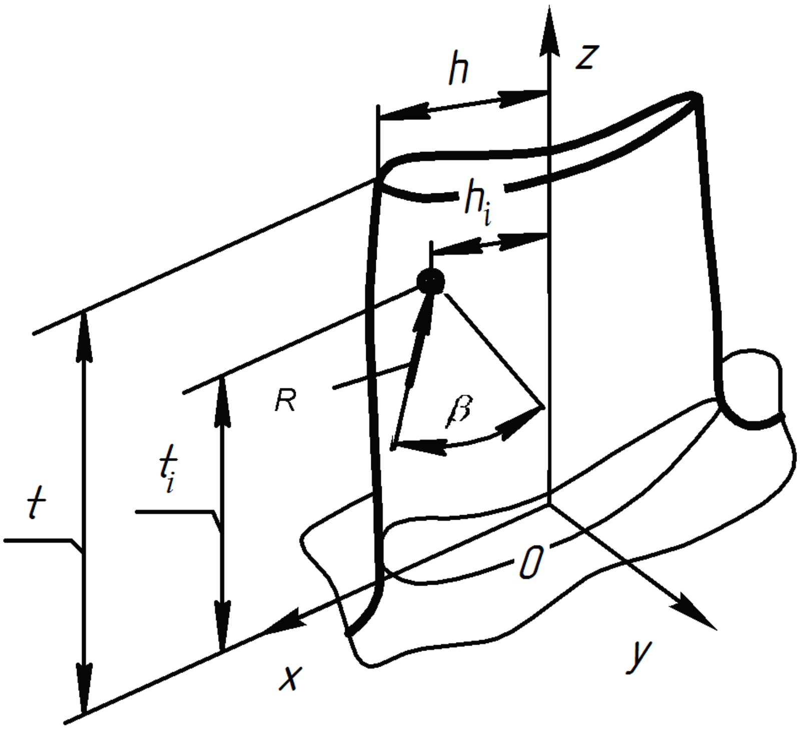

Fig. 4. Scheme for calculating the elastic deformations of a part during milling the monowheel blade flowpath

Calculation of the maximum blade deformation value during milling is made according to the condition that it should be smaller than dimensional tolerance of groove width or its part, which is determined by the expression $\delta_{max} = k$ • *T;* where *T* - manufacturing tolerances for processing, mm; *k* - factor of admission, which is often assumed to be 0.3.

The use of this method, which requires a constant recalculation of milling line width during the transition of the path from the back to the pressure side and during its moving along the profile height from the outer surface to the hub transition radius, is technically provided by control systems of NC unit 840D by Siemens. These control systems are widely used in machining centers with five simultaneously controlled axes, in particular in machining centers by Hermle model 40U; by Micron model 710 U, etc.

Abstracts

1. The processing flowsheets of monowheel flowpath must ensure uniform stock removal from each blade of monowheel at all stages of processing, including rough, pre- and finish (final) milling.

2. Cutting conditions for processing of individual surfaces and even patches of each monowheel blade must be constantly adjusted to ensure equal conditions of deformation. The deformation value should not exceed one third of dimensional tolerance of interscapulum of monowheel flowpath.

APPROXIMATION OF THE DENSITY FUNCTION OF THE WEIBULL DISTRIBUTION USING ANALYSIS CUMULANT

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The application of the cumulant analysis for research of the density of probability of distribution in a multiservice network is considered in this article. Possibility of its representation through cumulants allows to consider properties of self-similarity of a traffic.

Keywords: queuing system, the traffic, the moments of functions, cumulants, the distribution of «heavy» tail.

Conference participants

In the modern telecommunication networks multiservice traffic is often described with the help of distributions with «heavy» tails, which allow to consider as a model system of mass service system type G/G/1.

In practice, in the study of real systems, are rarely known laws of distribution and service supplied to the input of the system of traffic. The study is based on representation of the distribution of time of service - a probability density function, which in turn presented with the help of approximation by means of cumulant analysis. This approach has a number of advantages, because cumulant functions are clear an independent statistical meaning and may be set to a certain extent independently of each other.

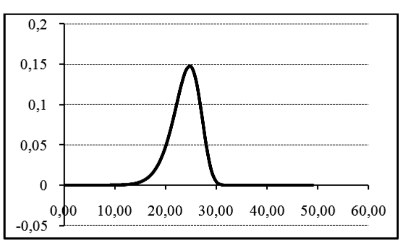

Fig. 1. The density function of the Weibull distribution withα=10andβ=25.

Consider the approximation of the probability density in a number of Edgeworth, the giver of decomposition of an arbitrary probability density for the derivative of a Gaussian distribution.

$$W(x) = W_G(x)-(\chi_3/3!)W_G^{(3)}(x) + (\chi_4/4!)W_G^{(4)}(x) - (\chi_5/5!)W_G^{(5)}(x)+ (\chi_6+10\ \chi_3^2/6!)W_G^{(6)}(x), \quad (1)$$

where $W_G^{(k)}$ - derivative of the density of normal function.

As a result collected probability density comparable with the known characteristics of the traffic that is being transmitted on multiservice network.

For the study will take a distribution function with «heavy» tail (Weibull distribution), according to the law which will come traffic to the input of the network element.

Function of the Weibull distribution has the form:

$$F(x) = 1-e^{-(x/\beta)\alpha}, x>0, \alpha> 0, \beta> 0, \quad (2)$$

whereα- shape parameter, β- scale parameter.

The density of the Weibull distribution is as follows (Figure 1):

$$f(x)=\alpha\beta^{-\alpha}x^{\alpha-1}e^{-(x/\beta)\alpha}. \quad (3)$$

It is known that the moments m_k random variable$x$Weibull distribution are as follows:

$$m_k= \beta^{k/\alpha}G(1+k/\alpha), \quad (4)$$

where$G(z)$ - gamma function.

For a complete description $W(x)$find the first six points of the expression (4).

The connection between cumulants and moments of distributions given by the relations:

$$\chi_1= m_1, \chi_2= m_2- m_1^2,\chi_3= m_3- 3m_1m_2+2m_1^3, \chi_4 = m_4 - 2m_2^2 - 4m_1m_3 + 12 m_1^2m_2 - 6m_1^4, \chi_5=m_5 - 5m_1m_1- - 10m_2m_3+20m_1^2m_3+30m_1m_2^2- 60m_1^3m_2+24m_1^5, \chi_6=m_6-6m_1m_5- 15m_2m_4+30m_1^2m_4-10m_3^2+120m_1m_3- - 120m_1^3m_3+ 30m_2^3- 270m_1^2m_2^2+ +360m_1^4m_2- 120m_1^6. \quad (5)$$

Based on the foregoing, we can expand the function in a number of Edgeworth (1). From expression (1) is directly visible to the special value of the cumulants in the evaluation of the probability density deviation from a Gaussian distribution.

For the selected values αandβtaking into account (4) and (5) we can obtain an approximation of the distribution (3) as shown in Figure 2.

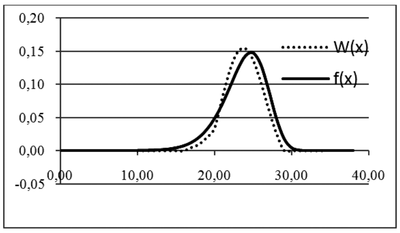

Fig. 2. Comparison of the two densities of the Weibull distribution

In the construction of the resulting density distribution (Fig. 2) takes into account that approximates the expression for the density must satisfy the normalization condition.

Thus, the resulting approximation of the density function of the Weibull distribution with cumulants can compare it with the theoretical distribution in the future to estimate the error variance.

Investigation of density function using cumulant analysis allows to take into account the properties of the self-similarity of traffic and service process. In practice, most simply realized the calculation of moments of time intervals between packets and time periods of service. After obtaining estimates of probability densities of the distributions of performance evaluation process unit may be obtained by a numerical (or approximate) solution of Lindley.

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