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Attainable accuracy of gas turbine engine housing ring machining

Достижимая точность обработки корпусных колец газотурбинных двигателей

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ABSTRACT

The problems of achievable accuracy of machining of casing rings of gas turbine engines are described. As a criterion for the machinability of the structure, geometric compliance is proposed. A model for machining the casing rings of gas turbine engines is developed. The values of geometric compliance of real body rings of gas turbine engines are calculated. The values of arising deviations in the processing of real casing rings of gas turbine engines and simulation results are compared. The critical value of geometric compliance has been determined, which reflects the boundary conditions under which it becomes necessary to use non-traditional technological solutions in the field of tools, cutting modes, equipment, etc. to achieve the specified accuracy.

KEYWORDS

Simulation model; cutting force; turning; accuracy; pliability; housing ring; produceability; modelling; rigidity; machining.

АННОТАЦИЯ

Описана проблема достижимой точности обработки корпусных колец газотурбинных двигателей. В качестве критерия обрабатываемости конструкции предложена геометрическая податливость. Разработана модель механической обработки корпусных колец газотурбинных двигателей. Рассчитаны значения геометрической податливости реальных корпусных колец газотурбинных двигателей. Сравнены значения возникающих отклонений при обработке реальных корпусных колец газотурбинных двигателей и результатов моделирования. Определено критическое значение геометрической податливости, которое отражает граничные условия, при которых возникает необходимость применения с целью достижения заданной точности нетрадиционных технологических решений в области инструмента, режимов резания, оборудования и т.д.

КЛЮЧЕВЫЕ СЛОВА

Математическая модель; сила резания; точение; точность; податливость; корпусное кольцо; обрабатываемость; моделирование; жесткость; механообработка.

Introduction

The lack of the reliable and checked techniques of creation of the technology processes allowing to achieve necessary quality of the processed surfaces and accuracy of their sizes with the minimum expenses and in the shortest possible time became the main problem for production. This problem is especially acute during the machining of parts of aircraft engines, the increased requirements of which determine the high cost of both serial production and increased costs at the stage of technological preparation of production [1]. Characteristics of the majority of parts of aviation engines are small rigidity and space and difficult geometry that is explained by aspiration to decrease in their weight on condition of maintaining utilization properties. In addition to traditionally expensive and difficult parts of the gas path in production high cost in modern aviation gas turbine engines (GTE) is got also by the case parts having the form of large-size thin-walled rings.

Shaping accuracy at edge cutting machining of metals substantially is defined by the system of forces operating on preparation in the course of cutting. It is expressed in emergence of elastic deformation of the processed surface at the chip formation which leads to emergence of the error of its geometrical sizes. In case of processing of nonrigid parts elastic deformation from influence of force of cutting can reach the value commensurable with tolerance zone size on the carried-out size that results in need of correction of process of fair processing. The additional difficulty is presented by processes of the relaxation of residual stresses which bring to loss of geometrical accuracy of the processed surfaces that is especially strongly shown on thin-walled parts [2].

1. Technology aspect of GTE housing ring machining

Determination of constructive criteria which more affect rigidity of the thin-walled part of large diameter will allow to estimate quickly technological effectiveness of the product in terms of the available accuracy of its machining. Rigidity – ability of the product to resist action of external loadings with the deformations admissible without violation of their working capacity. For convenience of calculations in the research the parameter of geometrical pliability C which in size is the return of rigidity and expressing the measure of abilities of the solid body or connection to elastic or elastoplastic deformations [3] was used:

$$C = \frac{\Delta}{F \cdot E}, \text{1/mm} \qquad (1)$$

where Δ – the size of lengthening, mm; *F* – the applied force, H; *E* – elastic modulus, H/mm2.

As the studied material corrosion-resistant alloy on the basis of AMS 5643 nickel which is often applied at production of case parts of the gas turbine engine [4] was accepted. The elastic modulus of this material matters E=1,930·10^{11} N/m^2. As the ring is the axially symmetrical body, as the method of edge cutting machining of parts of the similar design turning is, as a rule, applied. At the same time cutting force size on the fair modes of processing is F=1000 H. The analysis of design documentation of the considered group of parts of new aviation engines of average dimension showed that wall thickness size for them varies within 0.7–2.2 mm, wall height – 20–80 mm, diameter – 600–1450 mm. The specified values and intervals were accepted as input data and boundary conditions when modeling static power influence when machining.

Modeling of power influence when machining was carried out in the Solidworks Simulation system by means of the finite-element method (FEM). The main idea of FEM consists that any continuous size (in our case movement) can be approximated discrete model which is under construction on the set of the piecewise continuous functions defined on the finite number of elements [5]. As the point of application of loading the most nonrigid site of the part, namely the upper point of the thin wall of the ring which is subject to the maximum movements in the course of machining [6] was chosen.

Calculation results on FEM were analyzed by the technique of planning of the experiment which represents the complex of actions consisting in the choice of number and conditions of carrying out the experiences necessary and sufficient for the solution of the objective with the required accuracy. Planning of the extreme experiment – the special case at which optimal conditions of functioning of the object are looked for [7]. In this research planning of the experiment allowed to define criterion most of which affects pliability of the part.

2. Modeling of GTE housing ring pliability during machining

According to the rated scheme the lower edge plane of the ring is seal and imitates tightening adaptation. The concentrated load imitating power influence of the cutter when turning was put to the upper point of the ring on the cylindrical surface of the ring. The characteristic diagram received when calculating in the SolidWorks is presented on figure 1.

Results of modeling in the program Solidworks Simulation complex on the basis of the data on the maximum movement received in the analysis of diagrams were used for assessment of geometrical pliability of large-size thin-walled rings depending on three constructive criterion:

– from thickness of the wall of S (fig. 2);
– from diameter of the ring D (fig. 3);
– from height of the wall of the ring of h (fig. 4).

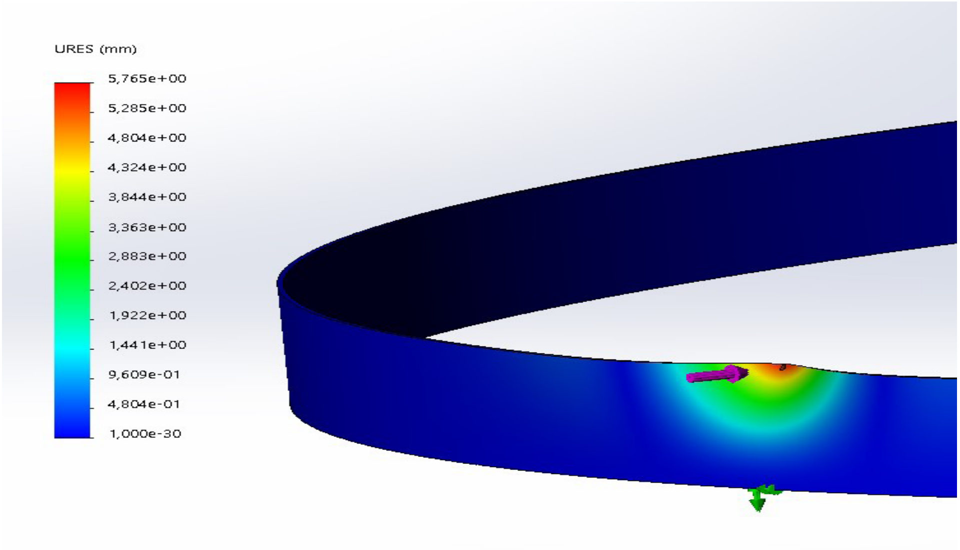


Fig. 1. The diagram of movements to areas of the point of influence of force of cutting of the processed part

Рис. 1. Эпюра перемещений в области точки приложения силы резания к обрабатываемой заготовке

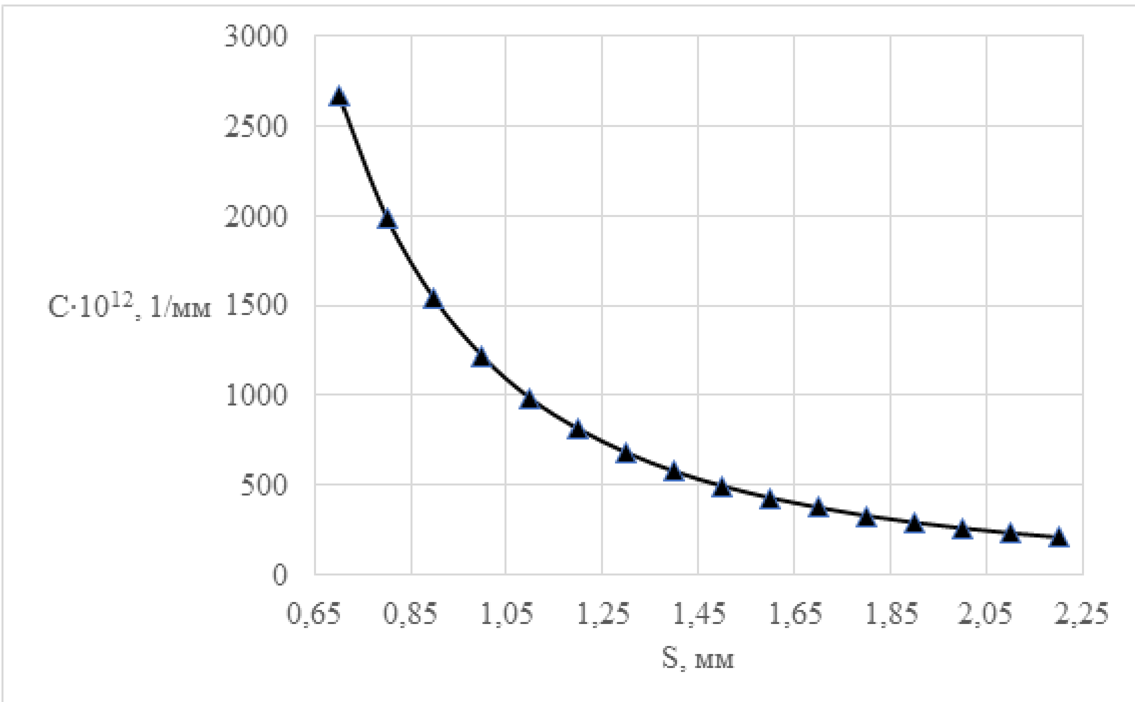


Fig. 2. The schedule of dependence of geometrical pliability of the large-size thin-walled ring with a diameter of D=1000 mm and mm h=50 wall height from S wall thickness

Рис. 2. График зависимости геометрической податливости крупногабаритного тонкостенного кольца диаметром D=1000 мм и высотой стенки h=50 мм от толщины стенки S

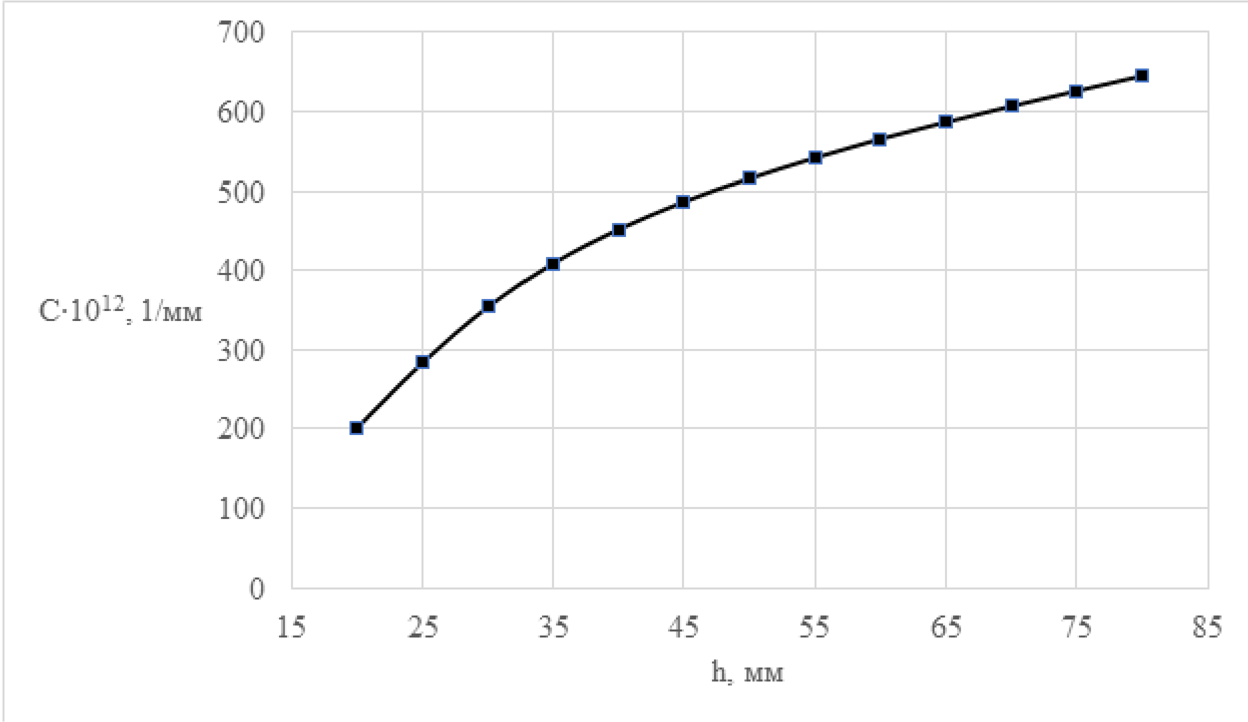


Fig. 3. The schedule of dependence of geometrical pliability of the large-size thin-walled ring with a diameter of *D*=1000 mm and mm *S*=1.5 wall thickness from *h* wall height

Рис. 3. График зависимости геометрической податливости крупногабаритного тонкостенного кольца диаметром *D*=1000 мм и толщиной стенки *S*=1,5 мм от высоты стенки *h*

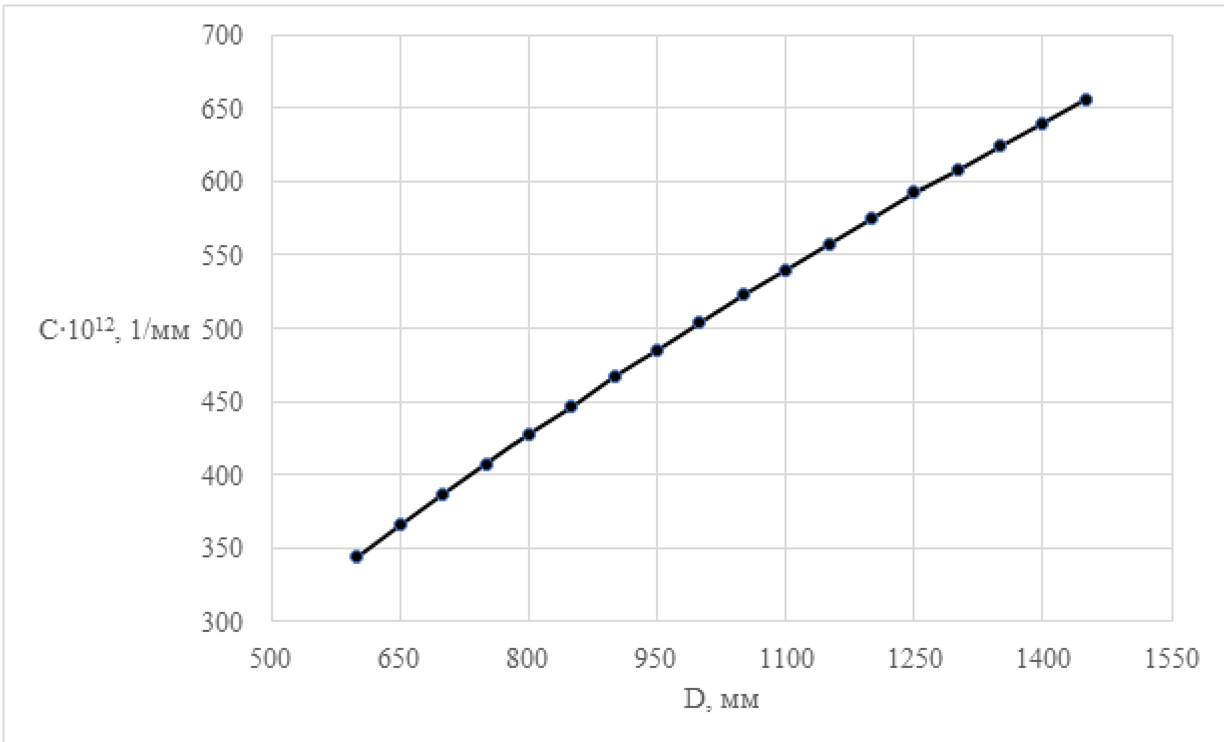


Fig. 4. The schedule of dependence of geometrical pliability of the large-size thin-walled ring with thickness of the wall of *S*=1.5 of mm and height of the wall of *h*=1.5 of mm from diameter *D*

Рис. 4. График зависимости геометрической податливости крупногабаритного тонкостенного кольца с толщиной стенки *S*=1,5 мм и высотой стенки *h*=1,5 мм от диаметра *D*

The schedules presented on fig. 3–5 assume the power characteristic of geometrical pliability from each of criteria in the explored area. The specified fact defined the choice of mathematical model for calculation of pliability in the following form:

$$Pl=C_0 \cdot S^{a1} \cdot h^{a2} \cdot D^{a3}, \text{ 1/mm} \quad (2)$$

It should be noted that in the considered range of change of thickness of the ring the size of geometrical pliability changes more, than by 10 times. At the same time the sharp growth of pliability is observed at reduction of thickness of the wall less than 1 mm that allows to speak about emergence of considerable difficulties of edge cutting machining of rings in the specified thickness range. By other criterion of dependence have more monotonous character.

For assessment of extent of influence of each constructive criterion on the accuracy of edge cutting machining of the part the matrix of planning of the mathematical experiment in the natural form which is provided in table 1 was made.

On the basis of the provided plan of the experiment the analysis of FEM by means of the Solidworks Simulation system for calculation of size of movement under the set conditions is carried out. Results of the mathematical experiment are also provided in table 1.

The planning matrix in the logarithmic form which will allow to receive degree model of geometrical pliability of large-size thin-walled rings is provided in table 2.

Table 1

Таблица 1

The matrix of planning of the mathematical experiment in the natural form and its results

Матрица планирования математического эксперимента в натуральной форме и его результаты

Experiment No	Diameter, X1 mm	Height, X2 mm	Thickness, X3 mm	Movement, Y mm
1	1450	80	2.2	1.798
2	600	80	2.2	0.9195
3	1450	20	2.2	0.3469
4	600	20	2.2	0.3159
5	1450	80	0.7	21.99
6	600	80	0.7	11.46
7	1450	20	0.7	8.776
8	600	20	0.7	5.765

Table 2

Таблица 2

The matrix of planning of the mathematical experiment in the logarithmic form and its results

Матрица планирования математического эксперимента в логарифмической форме и его результаты

Experiment No.	log(X1)	log(X2)	log(X3)	log(Y)
1	0.34242	1.90309	3.161368	14.5403
2	0.34242	1.90309	2.77815125	14.2491
3	0.34242	1.30103	3.161368	13.8258
4	0.34242	1.30103	2.77815125	13.7851
5	− 0.1549	1.90309	3.161368	15.6278
6	− 0.1549	1.90309	2.77815125	15.3447
7	− 0.1549	1.30103	3.161368	15.2289
8	− 0.1549	1.30103	2.77815125	15.0464

The linear logarithmic regression model in the natural form received on the basis of the made experiment has the following appearance:

$$\log(Y)=\log(a0)+a1*\log(s)+a2*\log(h)+a3*\log(D), \quad (3)$$

where $\log(a0)=C_0$ from expression (2).

In calculation result the following mathematical model of dependence of geometrical pliability of the large-size thin-walled ring on diameter, height and thickness was received:

$$Pl=0.99 \cdot S^{0.34} \cdot h^{1.88} \cdot D^{3.12}, \quad (4)$$

These coefficients indicate extent of influence of criteria on pliability of the part, and it means that diameter of the processed part has the greatest influence on pliability size, and wall thickness the smallest.

3. GTE housing ring turning accuracy during production

Turning of different large-size case rings was carried out under Scientific and Production Association «Technopark of aviation technology» machining conditions. Diameters, thickness and heights nominal sizes of thin-walled elements are reflected in table 3. Statistics of deviations of the sizes when processing of the specified parts gathered by comparison of the nominal and actually received diameter of the considered thin-walled element on the basis of selection of 10 processed rings of each code.

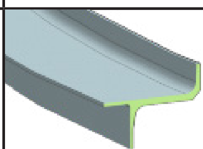
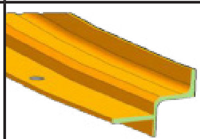
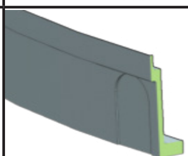
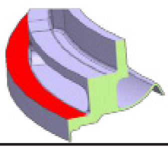
From the provided table 3 it is visible that the greatest deviation has the part with the greatest geometrical pliability of the element. At the same time for rings with proportional values of geometrical pliability to which comparable sizes of elements of the mode of cutting are applied almost linear relation of accuracy of processing from the geometrical pliability calculated on model (2) is observed. The lack of proportional growth of the error of processing when comparing rings with the values of geometrical pliability differing much is explained by use of other process parameters of cutting which allow to reduce efforts of cutting and to increase processing accuracy to acceptable values. Different rings machining analysis showed that geometrical pliability criterion value is $\approx 0.1 \cdot 10^{12}$ mm^{-1}. Housing rings which have geometrical pliability more than this value was machined firstly with insufficient accuracy by conventional technology.

Table 3

Таблица 3

Results of experimental large-size thin-walled rings processing

Результаты экспериментальной обработки крупногабаритных тонкостенных колец

№	Section of the ring sketch	Thickness of element S, mm	Height of element h, mm	Diameter of the element is D, mm	Theoretical geometrical pliability by (4), $\cdot 10^{12}$, 1/mm	Experimental average deviation by machining, mm
1.		0.863	12.5	1381.252	0.677	0.120
2.		1.752	10	1306.322	0.475	0.097
3.		0.939	6	843.127	0.0376	0.051
4.		1.143	5.3	748.538	0.0219	0.035

There are many technological decisions to reduce part bending and increase low rigidity parts machining accuracy. Some of them based on decreasing cutting force by changing speed, federate and depth of cut [8–10]. Another methods use special tool geometry [11–13]. Some methods allow to increase machining accuracy by toolpath and stock removal order [14–17]. Methods based on special fixtures and jaws are widely used too [18–20]. Developed model and proposed design benchmark allows defining the necessary to use this methods or to use conventional technology during new parts machining without waste losses.

Conclusion

Geometrical pliability can be use as machining accuracy criteria for large-size thin-walled aviation engine housing rings. The specified experimental data confirm reliability of the ring pliability mathematical model. Geometrical pliability criteria value for researched range of the rings (diameter is 600–1450 mm, height is 20–80 mm, thickness is 0.7–2.2 mm) is $0.1 \cdot 10^{12}$ mm^{-1}. This value shows the boundary parts design conditions when is necessary to use nonconventional technological decisions (tool, cutting mode, equipment, etc.) to provide required machining accuracy. Designers can use this value to detect the parts with bad produceability and make changes in advance to exclude problems during it production. Preliminary estimate of geometrical pliability of responsible elements of the large-size thin-walled ring on the basis of modeling of FEM allows to estimate technological effectiveness of the design in terms of edge cutting machining already at the stage of technology preparation of production and to take the appropriate measures for the defects exception.

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