Paths of Improving the Technological Process of Manufacture of GTE Turbine Blades

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Abstract. The article provides an analysis of the problems at manufacture of blades of the turbine of gas-turbine engines and power stations is provided in article, and also paths of perfecting of technological process of manufacture of blades are offered. The analysis of the main systems of basing of blades in the course of machining and the control methods of the processed blades existing at the enterprises with the indication of merits and demerits is carried out. In work criteria in the form of the mathematical models of a spatial distribution of an allowance considering the uniform distribution of an allowance on a feather profile are developed. The considered methods allow to reduce percent of release of marriage and to reduce labor input when polishing path part of a feather of blades of the turbine.

1. Introduction

The modern gas-turbine engines (GTE) and gas-turbine installations (GTI) incorporate several thousands of details and assembly units. However the most loaded, responsible and technologically composite details of any GTE and GTI are blades which define reliability, a resource, cost and labor input of manufacture of the engine.

In the considered work as an object of research turbine GTE rotor blades (figure 1) as the high-loaded figurine details received by a molding method with a directional crystallization from express materials were. Therefore, preparations of blades – non allowances with a high operational properties [1].

Figure 1. Turbine GTE rotor blades.
The development stage and realization of technological process of manufacture of blades of the turbine is characterized by a number of research and production problems significantly influencing labor input, efficiency and accessible quality of turbine blades. It is caused by the following features of their manufacture [2, 3]:

1. Blades of GTE are the most responsible details in the engine to a great extent defining reliability and non-failure operation of work of GTE in general. Therefore, the manufacturing techniques and monitoring of blades have to provide stability of quality of their production and exclude a possibility of installation in the engine of blades with deviations by the geometrical sizes, quality of a surface, with metallurgical and other defects.

2. Complexity of geometric forms and requirements of a high precision of manufacture of blades, and also, the increased accuracy of orientation of a feather of a blade in space by relation to the blade lock. Accuracy of manufacture of a feather is in limits 0.05 … 0.15 mm. The latch part by means of which blades fasten to disks is produced with an accuracy of 0.01-0.02 mm.

3. Mass character of manufacture of blades. Even when releasing test pieces of engines manufacture of blades has serial character.

4. Use of expensive and scarce materials for manufacture of blades. In this regard the technological process of manufacture of blades has to guarantee minimum percent of marriage.

5. The poor workability of the materials applied to manufacture of blades. Blades of the turbine produce from the alloys on a nickel basis having rather larger hardness at high viscosity.

The combination of the specified factors also defined specificity of production of blades [4, 5, 6].

2. Description of the models

To judge uniform of distribution of an allowance, it is necessary to have criterion of this uniform of distribution, in other words – criterion of an optimality [7].

Let's provide the formal description of a problem of a spatial distribution of an allowance.

We will explain substance of the developed criterion of an optimality by means of an example of distribution of an allowance at preparation of a turbine blade in space (figure 2).
The analysis of figure 2 allows to draw a conclusion that the contour of preparation of a blade has 6 degree of freedoms: movements on axes X, Y, Z and turn (rotations) on corners $\alpha$, $\beta$, $\gamma$ rather corresponding axes. The task consists in that by movement on these degree of freedoms of a contour of preparation to reach the most favorable relative positioning of a contour of preparation and a contour of a detail of a blade, i.e. in mathematical statement it is necessary to achieve keeping of identity: $AB=A_1B_1=A_2B_2$.

Three types of criteria of an optimality (K) were developed for the solution of an objective in the considered statement.

Serves as the first criterion of an optimality (K1) equation (1) maximal of the distances taken on a normal to a shovel detail contour. Let's designate this distance through $\delta_i$. Measurement to be taken in $n$ blade detail contour points. Then, the optimality criterion has an appearance:

$$K_1 = \max_{(i)} \delta_i = \max_{(i)} \delta_i(X,Y,Z,\alpha,\beta,\gamma); \quad (i=1, \ldots, n).$$

The problem of optimum installation of a contour of preparation of a blade concerning a contour of a detail of a blade will consist in such choice of values of the $X, Y, Z$ variables, $\alpha$, $\beta$, $\gamma$ at which the size $K_1$ minimum equation (2) is provided:

$$\min K_1 = \min_{(X,Y,Z,\alpha,\beta,\gamma)} \left\{ \max_{(i)} \delta_i(X,Y,Z,\alpha,\beta,\gamma) \right\}; \quad (i=1, \ldots, n).$$

As the second criterion of an optimality (K2) equation (3) it can be accepted minimum of deviations $\delta_i$:

$$K_2 = \min_{(i)} \delta_i = \min_{(i)} \delta_i(X,Y,Z,\alpha,\beta,\gamma); \quad (i=1, \ldots, n).$$

The problem of management consists in that change of the $X, Y, Z$ variables, $\alpha$, $\beta$, $\gamma$ to provide the maximal value of criterion $K_2$ equation (4):

$$\max K_2 = \max_{(X,Y,Z,\alpha,\beta,\gamma)} \left\{ \min_{(i)} \delta_i(X,Y,Z,\alpha,\beta,\gamma) \right\}; \quad (i=1, \ldots, n).$$

From the practical point of view, the criterion of K2 often is the most successful as at installation of preparation of a blade by this criterion preparation moves away from dangerous provisions in which the allowance can be the negative.

As the third criterion of an optimality (K3) equation (5) the difference between maximal and minimum of deviations can serve:

$$K_3 = K_1 - K_2 = \max_{(i)} \delta_i - \min_{(j)} \delta_j = \max_{(i)} \delta_i(X,Y,Z,\alpha,\beta,\gamma) - \min_{(j)} \delta_j(X,Y,Z,\alpha,\beta,\gamma); \quad (i=1, \ldots, n) \quad (j=1, \ldots, n).$$

The problem of optimum distribution of an allowance is reduced to minimization of this criterion:

$$\min K_3 = \min_{(X,Y,Z,\alpha,\beta,\gamma)} \left\{ \max_{(i)} \delta_i(X,Y,Z,\alpha,\beta,\gamma) - \min_{(j)} \delta_j(X,Y,Z,\alpha,\beta,\gamma) \right\}; \quad (i=1, \ldots, n) \quad (j=1, \ldots, n).$$

Shortcomings of criterion of this kind is need of formation of $K_3$ in the form of a difference of two rather larger sizes. This difference at an approximation to a minimum becomes small and commensurable with the hindrances complicating a possibility of use of criterion of K3.

3. Results and discussion
The manufacturing techniques of blades are improved, mainly, in the direction of increase of mechanization and automation now. The exception of manual skills (a subjective factor) allows not
only to reduce labor input, but also to increase quality of manufacture of blades [8, 9].

Increase of effectiveness of technological process of manufacture of blades of the turbine GTE, first of all, has to solve a problem of increase of economic indexes of process, namely: increases in the material capacity factor (MCF); decrease in labor input of an manufactures; reductions of a production cycle of manufacture of details and decrease of costs of technological preparation of production [10].

Let's carry out a qualitative analysis of the technological process of manufacture of the rod (cooled) turbine GTE blade existing at the enterprise.

Today in mechanical engineering it is accepted to make turbine blades of the preparations received by investment casting with an accuracy, whenever possible, the blade (so-called non allowance molding) excluding the subsequent machining of a profile of a feather. According to the carried-out statistical analysis by production of shovels of the turbine of the 1st step of GTE to 30% it is rejected in connection with existence of pouring defects (blisters, blockages, multidirectional crystalline structure); to 10% makes marriage on discrepancy of geometrical parameters of a blade of design documentation and non-optimum distribution of an allowance in path part of a blade. In spite of the fact that blades of gas-turbine engines make under constant technological conditions, using the same expendables, the geometry of cast preparations of blades of the turbine is not stable. It is bound to individual conditions, a subjective factor and the modes of melting filling of each mold piece [11, 12].

Available geometrical accuracy of blades of the turbine is defined by the terminating finishing operations of polishing realizing a method of trial passes and measurements. In these operations an iterative successive approximation to the given design documentation of geometry of a blade by means of measurement and partial completion is supposed. On a set of serial productions, for measurement of a profile of a feather of a blade the specialized adaptation realizing a sample method of measurement is used (figure 3).

![Figure 3. The simplified scheme of the sample appliance.](image_url)

The part of the blades arriving after molding are often rejected because of shortage of an allowance in certain areas of section of a profile of a feather (have, a so-called, negative allowance). Therefore preparation of a blade is rejected. However, similar preparations can be allowed for further machining as deviations which have blades allow to enter a theoretical profile of a feather by its best placement in limits of tolerance set by design documentation.

Let's carry out the analysis of the control methods existing in machine-building enterprises and checks of a profile of a feather of blades of GTE:

- a sample method (measurement is carried out between a surface of a back and a trough of a feather an express template in this section of a feather of a blade);
- the method based on use of the device of the optical-mechanical monitoring of blades (DOMMB);
- the method based on use of contact measuring TESA, LK cars which compare an actual surface of preparation of a detail to its mathematical model in particular points, the given programmatically;
– the method based on use of noncontact laser "OPTEL" instruments.

From the given control methods of blades of GTE the first two are most widespread in serial production today, and the DOMMB appliance is used for monitoring of a feather of compressor blades, and adaptation of sample type is intended for monitoring of blades of the turbine [13].

The third and fourth control methods of a profile of blades as the most modern and perspective instrument of monitoring only begin to introduce recently on the enterprises of machine-building branch. Their rather sluggish introduction and use is bound, first of all, to the high cost of installations and need of a highly skilled engineering upkeep as installations of a similar class demand express conditions at their placement on temperature, environmental purity, vibration.

Sample method – the most widespread way of monitoring and an assessment of an optimality of distribution of an allowance of a feather of a blade of GTE. It consists in use of express templates, i.e. for each blade there is a particular set of reference templates (figure 4): (a) – the 1st step of the turbine GTE; (b)– the 4th step of the turbine GTE. The blade on the technological bases located on half-internal and latch part is installed in the device and check a feather profile by serial combination of templates with surfaces of a back and a trough. In places of a deviation of a profile of a feather from a template carry out mechanical operational development by glazing by the abrasive tool.

![Figure 4. Sample equipments for monitoring of preparations of turbine blades.](image)

Now at the enterprise the sample equipments represented in figure 4 for monitoring of geometry of a profile of turbine blades of GTE are used [14].

Essential factor, at a similar method of measurement of a profile of a feather, limiting body height of efficiency and putting into dependence accessible quality on a subjective factor is lack of automatic keeping of the sizes.

It is possible to increase effectiveness of technological process of manufacture of blades of the turbine GTE the next ways: having increased quality of foundry processes (due to use of the reduction mix and a ligature, introduction of systems of computer model operation of foundry processes, etc.); application of original design decisions – use of the gravitational lock devices capable to reduce marriage on mold pieces of blades of the turbine; introduction in technological process of manufacture of blades of the additive technologies and methods of fast prototyping; modernization of operations of monitoring of a profile of a feather of blades. One of essential reserves is increase of level of operations of monitoring of path part of a blade which determine the reached accuracy, considering the method of trial passes and measurements realized in technology. This way is less expensive.

In the course of mechanical operational development of a profile of a feather of a turbine blade one of the most important questions is the choice of optimum system of basing for the uniform distribution of an allowance on a feather. The problem consists in the irregular space shape of a feather, lack of developed surfaces for precise basing when processing and monitoring, a small rigidity of thin-walled blades.
Because sample devices do not consider an optimum spatial distribution of an allowance on a feather of preparation of a blade, often there are situations bound to non-uniformity of distribution of an allowance which special case is existence of the negative allowance as it was said above that, in turn, leads to marriage.

Detailed studying of algorithm of monitoring of blades of the turbine on the sample device allowed to reveal a number of shortcomings of this method:

✓ at a similar control method it is very difficult to reveal the real size of shift of a contour of a back and trough in a Y direction – y as the result of an assessment of size of shift is influenced at the same time also by the shift of contours of a back and trough x dimension – x, an error of a corner of a curling of a feather and an error of a form of the checked contour;
✓ the small efficiency and poor objectivity caused by lack of a spatial distribution of an allowance on a blade feather and also
✓ influence on result of measurement of conditions of installation of measuring templates (a distortion of templates, size of effort of a clip of a template to a blade feather, etc.);
✓ existence of a subjective factor bound to a big share of application of manual skills on basing of a blade and the subsequent operations of grinding and glazing of a feather;
✓ need of application of unwieldy sample and measuring economy.

Thus, at a stage of monitoring of the received preparations of blades of the turbine there is a problem, the bound to basing of preparations and the subsequent uniform distribution of an allowance on a feather. In this regard, as it was told above, about 10% of preparations of blades are rejected because of existence of the negative allowance. Having resolved an issue of the uniform distribution of an allowance in preparations of blades by technological methods it is possible to increase percent of release of suitable production.

The schemes of basing of blades of GTE applied today can be divided into the following groups on a way of installation of preparation:

1) basing of preparation of a blade immediately on the machine;
2) basing of preparation of a blade, using the equipment readjusted on dimensions;
3) basing of preparation of a blade, using the unified equipment;
4) basing of preparation of the blade which is filled in a briquette.

Basing of preparation of a blade immediately on the machine allows processing only by methods, not the bound to the considerable efforts. Basing of blades with use of equipment or filling in a briquette allow to conduct processing by milling.

According to [15] at the engine-building enterprises apply the following schemes of basing of blades of GTE (figure 5).

![Figure 5. The existing systems of basing of blades in the course of manufacture. — technological bases, —— design bases.](image-url)
It is possible to solve a problem of the uniform distribution of an allowance in preparations of blades of the turbine GTE by design methods, in a path of perfecting of a design of the sample device, having added several degree of freedoms (in the form of the correcting screws) by means of which, preparation of a blade falling apart on three axes and gets an opportunity to rotate concerning each of axes.

4. Conclusion
Thus, authors of work made the following recommendations allowing to reduce labor input of operations of monitoring of a profile of a feather of turbine blades and to increase effectiveness of technological process of manufacture of blades:
1. On the basis of production statistics it is necessary to define the required quantity of degree of freedoms in the sample device for an optimum spatial distribution of an allowance in preparation of a blade.
2. To define less expensive design ways of realization of a problem of a spatial distribution of an allowance in industrial equipment.
3. Practical realization and the experimental approbation of the offered recommendations under production conditions the enterprises.

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