The Features of Design Calculation Stages of Parameters of Flow Path of Cascade Compressor of Twin Shaft Gas Turbine Engine Core on Base of 1D and 2D Dimensional Models of Their Working Process

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Abstract: The features of the stages of the design calculation of the parameters for the formation of the initial design of the flow path of the compressor cascade of a twin-shaft engine core of gas turbine engine are presented and described. The article describes recommendations for choosing values of load coefficient, efficiency and other important parameters for stages of medium-pressure and high-pressure cascades at the stage of thermodynamic calculation. At the stage of design gas-dynamic calculation of the compressor at the middle diameter, typical distributions of axial velocity component and reaction rate along the flow path of compressor cascades should be taken into consideration. At the same time, it is necessary to provide requirements for the level of flow braking and static pressure coefficients in the rotor wheels and stator blades, load and Stepanov's coefficients. The features of the design gas-dynamic calculation of the compressor along the radius of the flow path are a variety of flow twist laws at the inlet to the rotor wheels, distributions of the pressure increase and efficiency by the height of the blades. In conclusion, an example of three-dimensional model of compressor flow path formed taking into consideration features of design calculation of parameters of cascade compressors of twin-shaft engine core of gas turbine engine on the basis of the corresponding flow path scheme in the meridional plane is presented.

1 INTRODUCTION

Traditionally, the aerodynamic design of core compressors for aircraft engines, including core compressor cascades for bypass turbofan engines, involves the following steps (Kholshevnikov K.V., 1970, Belousov A.N., 2006):

- design of the flow path (FP) of compressor cascades in the meridional plane;
- design calculation of compressor cascade FP parameters using one- and two-dimensional models of their working process;
- definition of characteristics of compressor cascades in view of possible regulation and values of its parameters on the basic modes of the engine operation;
- computational aerodynamic refinement of the spatial form of a flow path of compressor cascades by means of modern methods of computational gas dynamics (Hirsch, C., 2007).

Before describing the features of the design calculation of the FP parameters of twin-shaft core compressors, it should be noted that it is a multi-level iterative process. This design calculation is one of the initial steps of the design and its results are subsequently adjusted significantly in the 3D modelling and strength-testing steps. It is nevertheless an important step to get the initial compressor configuration, which will be further

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refined in later steps using much more demanding and resource-intensive mathematical models. The efficiency and labour-intensiveness of the engine design and construction process as a whole also largely depends on the success of the initial design of the CORE compressor cascade flow paths in the three-dimensional formulation.

Approaches to the formation of FP shape of multistage axial compressors (MAC) of the main engine structural unit (core) are proposed in a number of works (Belousov A.N., 2006, Bykov, N.N., 1984, Gelmedov, F.S., 2002, Belousov A.N., 2003). In particular, they are considered by Matveev V.N. (2022) on design of FP in meridional plane, the work is devoted to the next step of design - design calculation of parameters of flow path of compressor cascades by means of one-dimensional and two-dimensional models of their working process.

In spite of the fact that considerable attention has been paid to these calculations in the known publications, the questions of their implementation methods are still topical. The fact is that as new generations of engines appear, there is a need to partially adjust algorithms for determining the parameters of the flow path of MAC and restrictions of regime, aerodynamic and structural-geometric nature. It is connected both with new approaches and information opportunities of gas turbine engine (GTE) design, and with new materials, production technologies and design expertise.

2 PURPOSE AND STEPS OF DESIGN CALCULATION OF CORE COMPRESSOR CASCADES

Design calculation of core compressor cascades is carried out after thermodynamic calculation of all engine and initial formation of a shape of a flow path of the core in a meridional plane. As a result of these steps in the first approximation for the medium and high-pressure compressor cascades the numbers of stages, characteristic diameters of FP and rotor speeds are determined.

The aim of the design calculation of a compressor is to determine all geometrical parameters required to form the initial three-dimensional appearance of its flow path.

The design calculation of the FP parameters of a core compressor cascade using one- and two-dimensional models of its working process is traditionally divided into the following steps (Belousov A.N., 2006).

- Step 1. Design thermodynamic calculation of the compressor.
- Step 2. Mid-diameter design aerodynamic calculation of the compressor.
- Step 3. Design aerodynamic calculation of compressor on radius of FP.
- Step 4. Estimation of geometric values of profiles and their grids in various cross-sections along the compressor FP height.

3 DESIGN THERMO-GAS-DYNAMIC CALCULATION OF COMPRESSOR CASCADES

A flow path diagram of the intermediate and high pressure cascades (intermediate pressure compressor (IPC) and high pressure compressor (HPC)) of a core compressor in the meridional plane, indicating the characteristic cross sections, is shown in Figure 1,a.

The design thermodynamic calculation of the MAC cascades is carried out by means of a one-dimensional model of the working process at the design mode, usually the cruising one. In this design process, several schemes of compressor cascades are considered, differing in number of stages and configuration of FP, from which the most promising variants are further selected according to various criteria.

The input data for thermodynamic calculation of compressor cascades are parameters, the values of which are obtained in the previous steps of design. They include pressure ratios, specific works, rotor speeds of IPC and HPC, total pressures and temperatures in characteristic sections, as well as design and geometrical parameters of compressor cascades, describing their appearance in meridional plane, such as number of stages z_{st} and characteristic diameters, in particular.

The design thermodynamic calculation of IPC and HPC can be characterised by the following points.

1. There are two ways of distributing the values of the head consumption coefficient $\bar{H}_{z\,st\,per} = H_{z\,st}/U^2{}_{per}$ by stages of IPC and HPC. At the first "classical" method this distribution has almost parabolic form, see Figure 1,b (Kholshevnikov K.V., 1970, Belousov A.N., 2006). When this method is used, the value of $\bar{H}_{z\,st\,per}$ in IPC increases from $\bar{H}_{z\,st\,per\,I}$ of the first stage, which is equal or slightly greater than 0.20, to the last stages up to 0.30...0.33.

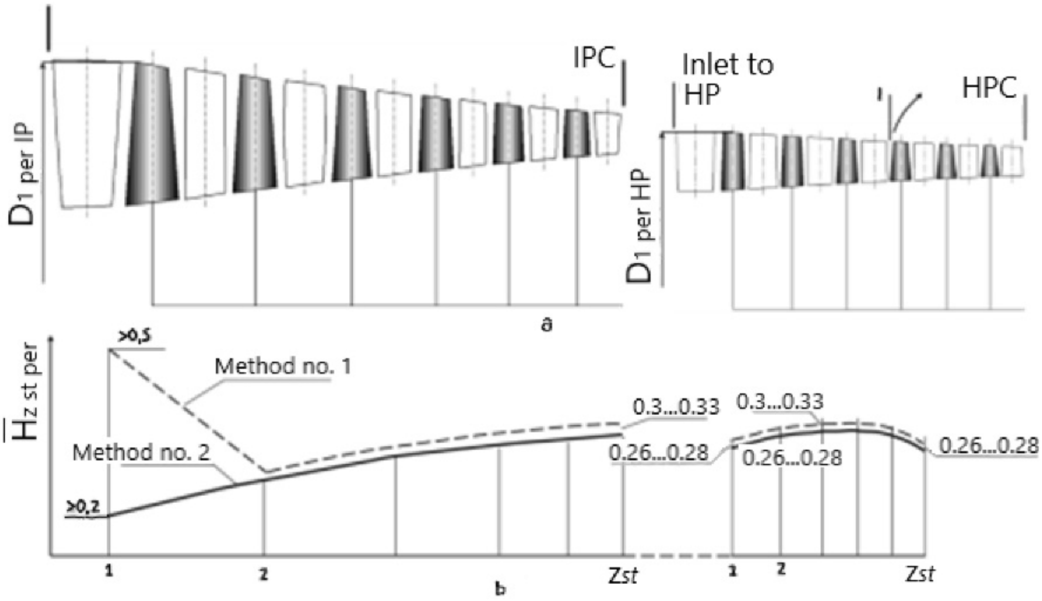


Figure 1: Flow path diagram of a twin-shaft core compressor with two ways of distributing the head coefficient values over the stages: a - flow path diagrams for IPC and HPC; b - head coefficient distributions.

In HPC the value of $\overline{H}_{z\,st\,per}$ increases from 0.26...0.28 in the first stage to 0.30...0.33 in the middle stages and decreases to 0.26...0.28 towards the exit from HPC.

This distribution of $\overline{H}_{z\,st\,per}$ occurs because there is an increased flow irregularity at the inlet to the first stage and its efficiency is not high. In addition, the choice of higher $\overline{H}_{z\,st\,per}$ values in the first stages is hindered by the desire to ensure a uniform head over the blades' height. At the small values of the relative hub diameter typical to the first stages, excessively large flow turning angles can occur in the hub sections.

In the last stages of the HPC, due to the reduced blade height, the efficiency of the stages decreases as a result of increased relative values of radial clearances and an increased proportion of secondary losses.

In addition, at the HPC outlet, in order to ensure stable (without a stall) operation of the combustion chamber, it is desirable that the reduced flow speed λ_{HPC} should not exceed 0.30...0.32. In this regard, in the last stages of HPC the flow rate coefficient $\bar{C}_a = C_a/U_{ave}$ is sharply reduced (sometimes up to 0.39...0.41) and the Stepanov load coefficient $\overline{H}_T/\bar{C}_a$ increases (Stepanov, G.Yu., 1958). In order to keep the latter from exceeding the limit value of 0.65, it is necessary to reduce the head at the last stages.

Reducing the head in the first and last stages of the compressor cascade also has a beneficial effect on providing the required gas-dynamic stability margin of the MAC in off-design modes.

At the second method of coefficient values distribution of consumed head by stages at the first stage of IPC it is proposed by Gelmedov, F.S. (2003), Matveev V.N. (2022) to increase significantly coefficient $\overline{H}_{z\,st\,per}$ up to the value exceeding 0.50 (Fig. 1,b) by using high head (transsonic) wide-chord stage. The nature of distribution of $\overline{H}_{z\,st\,per}$ values over the other stages of the IPC and HPC remains practically the same. Only due to an increase in air temperature behind the transonic stage, while maintaining the same velocity level in relative motion at the inlet to the λ_{w1} rotor wheels, the $\overline{H}_{z\,st\,per}$ values, starting from the second stage of the IPC, can be slightly increased.

The second method of distributing $\overline{H}_{z\,st\,per}$ over the stages can in some cases reduce the number of stages, the axial dimensions and the mass of the MAC, but its efficiency is usually reduced.

Any distribution of $\overline{H}_{z\,st\,per}$ values over the stages must respect the equilibrium (1) and (2):

$$L_{K\,IP} = \sum_{i=1}^{z_{k\,IP}} \overline{H}_{z\,st\,per}\, U^2{}_{i\,per\,IP} \tag{1}$$

$$L_{K\,HP} = \sum_{i=1}^{z_{k\,HP}} \overline{H}_{z\,st\,tip}\, U^2{}_{i\,per\,HP} \tag{2}$$

where $U_{i\,per\,IP}$ and $U_{i\,per\,HP}$ are circumferential speeds on the periphery of i-*th* rotor wheels of the IPC and HPC.

2. The initial distribution of the efficiency values for the IPC and HPC stages is based on the considerations outlined in point 1.

At the middle and last stages of the IPC, as well as at the middle stages of the HPC, the highest stage efficiencies are assigned from the range $\eta'_{st\,ave\,max}$= 0.900...0.910. For the first subsonic and transonic stage, the efficiency value decreases in comparison with $\eta'_{st\,ave\,max}$ by 1.5...2.0 %, for the second stage by 0.7...1.0 %, and for the third stage by 0.3...0.5 %. If the first stage is supersonic, its efficiency value decreases by 3.0...4.0% relative to $\eta'_{st\,ave\,max}$.

At the penultimate stage of HPC value of efficiency decreases by 0.3...0.5 % in comparison with $\eta'_{st\,ave\,max}$, and at the last stage - by 0.7...1.2 %.

Thus, each i-*th* stage of IPC and HPC is assigned in the first approximation to the efficiency value $\eta'_{st\,ave\,max}$.

3. Stage-by-stage thermodynamic calculation of each compressor cascade, from the first stage to the last stage, is carried out in the usual way, for example, as proposed by Belousov A.N. (2006) using $\pi - i - T$-functions (Dorofeev, V.M., 1973) to take into account the change in the specific heat capacity of air as its temperature changes.

Usually, this calculation of the IPC and HPC is carried out in several iterations in order to clarify the pressure ratio and the efficiency of each stage of the MAC.

4. In case of air intake behind e.g. I-stage of HPC (Fig. 1,a) for turbine cooling, the cascade efficiency value is found by the formula (3):

$$\eta_K = \frac{G_{in\,HP-I}(i^*_{Is} - i^*_{in\,HP}) + G_{I-out\,HP}(i^*_{out\,HPs} - i^*_I)}{G_{in\,HP-I}(i^*_I - i^*_{in\,HP}) + G_{I-out\,HP}(i^*_{out\,HP} - i^*_I)} \quad (3)$$

where $G_{in\,HP-I}$ is the air flow rate from the inlet of the HPC to the outlet of the I-stage;

$G_{I-out\,HP}$ - air flow rate from the inlet of the (I+1)-stage to the HPC outlet;

$i^*_{in\,HP}$ - total enthalpy of the flow at the inlet to HPC;

i^*_{Is} and i^*_I - total enthalpies of the flow in isoentropic and real compression process after the I-stage of HPC;

$i^*_{out\,HPs}$ and $i^*_{out\,HP}$ - total enthalpies of the flow in isoentropic and real compression process at the HPC outlet.

Thus, as a result of thermodynamic calculation of the compressor cascade, taking into account the noted features, values of pressure ratio and efficiency of its stages, efficiency of the whole cascade, as well as the total pressures and temperatures of air flow in all inter-row gaps are determined.

4 DESIGN AERODYNAMIC CALCULATION OF THE COMPRESSOR AT MID-DIAMETER

The aim of the design aerodynamic calculation of the stages of IPC and HPC core is to determine the kinematic and thermodynamic parameters in the characteristic sections of the flow path of the stages at the mid-diameter (Figure 2). In this case parameters characterizing working process of elementary blade rows of cascades at this diameter are also determined.

The input data for the design calculations of the MAC are energy and flow rates, thermodynamic and aerodynamic, as well as geometric parameters, the values of which are obtained from the previous steps of the design calculation.

The design aerodynamic calculation of the mid-diameter MAC stage is carried out by means of a one-dimensional model of its working process, taking into account the following features:

1. Based on the values of the axial velocity components at the inlet and outlet of the MAC $C_{in\,a\,ave}$ and $C_{out\,a\,ave}$, the distribution of the $C_{a\,ave}$ value at the inlet and outlet of each blade row of the compressor is carried out:

- in the case of IPC, it is usually assumed that $C_{out\,a\,ave} = C_{in\,a\,ave}$ and the axial component of the flow velocity $C_{a\,ave}$ along the entire compressor flow path remains unchanged;
- in case of HPC $C_{out\,a\,ave}$ is smaller than $C_{in\,a\,ave}$ and then two variants of $C_{a\,ave}$ distribution along the compressor's flow path are possible. In the first variant, the $C_{a\,ave}$ decreases from the inlet to the outlet of the MAC from $C_{in\,a\,ave}$ to the value of $C_{out\,a\,ave}$. In the second option, the $C_{a\,ave}$ value in the first few stages remains unchanged and equal to $C_{in\,a\,ave}$, and in the subsequent stages $C_{a\,ave}$ gradually decreases from the value of $C_{in\,a\,ave}$ to the value of $C_{out\,a\,ave}$. At the same time the decrease of $C_{a\,ave}$ in one blade row should not exceed 10...12 m/s (Belousov A.N., 2006).

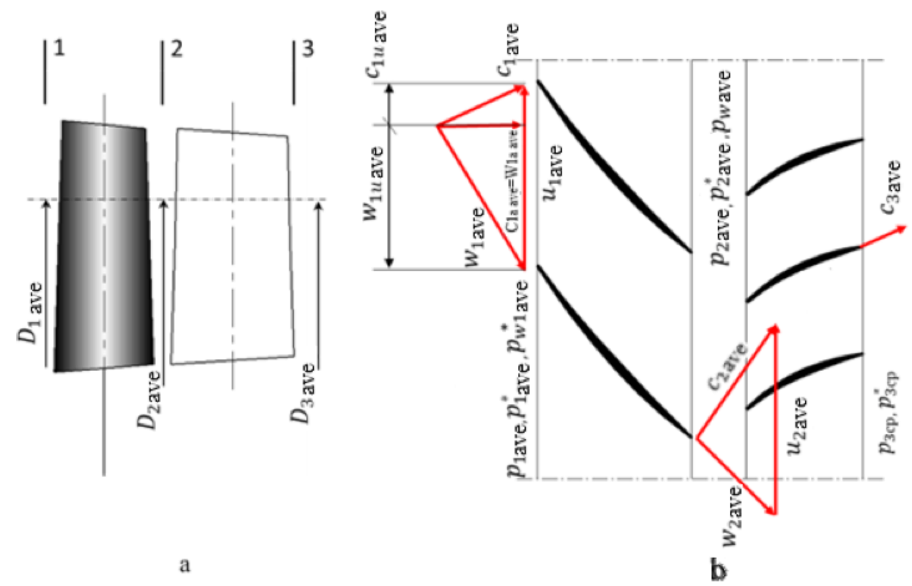


Figure 2: Compressor stage scheme: a - in the meridional plane; b - in the circumferential plane.

Further, during aerodynamic calculation in different cross-sections along the blade height the distribution of $C_{in\,a\,ave}$ along the blade rows can be changed and specified, in particular in order to provide acceptable values of flow angles in relative motion β_1, flow turning angles $\Delta\beta_1$ and reduced flow speed in relative motion at the inlet to the rotor wheels (RW).

2. Initial distribution of $\rho_{st\,ave}$ degree of reactivity by MAC stages is made taking into account the recommendations of Table 1 (Belousov A.N., 2006).

At the subsequent steps of aerodynamic calculation distribution of $\rho_{st\,ave}$ values by stages is specified in accordance with rational values of static pressure ratio in RW grids $C_{p\,RW} = (p_2 - p_1)/(p_{w1}^* - p_1)$ and guide vanes (GV) $C_{p\,GV} = (p_3 - p_2)/(p_2^* - p_2)$ at different radii of FP (Koch, C.C., 1981).

Table 1: Range of $\rho_{st\,ave}$ values depending on the type and position of stage in the MAC.

Stage type	Position of stage in the MAC		
	first	middle	last
Subsonic	0.50….70	0.50…0.70	0.65…0.80
Transonic	0.65…0.75	-	-
Supersonic	0.70…0.80	-	-

After that, aerodynamic calculation of stages of IPC and HPC at the middle diameter is carried out in the traditional sequence, presented, in particular, by Belousov A.N. (2006).

In order to obtain an efficient and stable compressor, attention must be paid to the values of the following relative parameters that characterise its operation.

1. Flow braking in relative motion in RW $W_{2/1} = W_{2\,ave}/W_{1\,ave}$ and in absolute motion in GV $C_{3/2} = C_{3\,ave}/C_{2\,ave}$ (De Heller criterion). In order to avoid increased hydraulic losses in the RW and GV, the values of these ratios must be greater than 0.70 (Kampsti, N., 2000). Otherwise, it will be necessary to change the $\rho_{st\,ave}$ value. If the required $W_{2/1}$ or $C_{3/2}$ cannot be achieved in this way, it will be necessary to reduce the required head and redistribute the $\overline{H}_{z\,st\,per}$ values across the MAC stages.

2. Formulas (4) and (5) for static pressure ratio in RW and GV:

$$C_{p\,RW\,ave} = \frac{p_{2ave} - p_{1ave}}{p_{w1\,ave}^* - p_{1ave}} \tag{4}$$

$$C_{p\,GV\,ave} = \frac{p_{3ave} - p_{2ave}}{p_{2\,ave}^* - p_{2ave}} \tag{5}$$

In order to avoid increased hydraulic losses in the RW and GV, these coefficients must not exceed 0.40 (Koch, C.C., 1981). The values of $C_{p\,RW\,ave}$ and $C_{p\,GV\,ave}$ can be influenced by changing the degree of reactivity $\rho_{st\,ave}$. In subsonic compressor stages it is advisable to ensure an approximate equality of $C_{p\,RW\,ave}$ and $C_{p\,GV\,ave}$ coefficients.

3. Theoretical head coefficient $\overline{H}_{T\,per} = H_T/U_{1\,per}^2$ calculated from the peripheral circumferential speed of the RW $\eta D_{1\,per} n/60$.

The value of this coefficient must not exceed 0.33 (Kholshevnikov K.V., 1970, Belousov A.N., 2006). Otherwise, it is necessary to reduce the consumed head of the stage or to increase, if it is possible under the condition of limiting the value of reduced relative flow velocity in relative motion at the RW inlet $\lambda_{w1\,ave}$, circumferential velocity $U_{1\,per}$.

4. Flow rate coefficient calculated from the peripheral circumferential velocity of the RW $\bar{C}_a = C_{1a\,ave}/U_{1\,per}$.

Statistics show that at the inlet to the first stage of the IPC the $\bar{C}_a$ value is usually in the range of 0.45...0.55, and at the inlet to the first stage of the HPC it is in the range of 0.45...0.50. At the IPC outlet, $\bar{C}_a$ = 0.45...0.55, and at the HPC outlet, $\bar{C}_a$ = 0.40...0.45 (Kholshevnikov K.V., 1970).

5. Stepanov load coefficient $\bar{\bar{H}}_T = \bar{H}_{T\,per}/\bar{C}_a$.

In order to ensure the highest stage efficiency, it is advisable that the value of this coefficient does not exceed 0.65. Rational range of Stepanov load coefficient values is 0.55...0.65 (Stepanov, G.Yu., 1958).

5 DESIGN AERODYNAMIC CALCULATION OF THE COMPRESSOR ALONG THE RADIUS OF THE FLOW PATH

The purpose of the design aerodynamic calculation of MAC stages along the radius is to determine kinematic and thermodynamic parameters in characteristic sections of the stage flow path at different radii - from the hub to the peripheral one. Besides, at the same radii it is reasonable to find values of parameters characterizing working process of elementary blade rows and stages as a whole, such as static pressure ratio coefficients, flow braking in RW and GV, coefficients of theoretical head and flow rate, calculated by circumferential speed at RW periphery, Stepanov load coefficients.

As input data for the calculation geometrical parameters of the flow path in the meridional plane, parametric diagrams (total pressure and temperature as well as flow angle) along the radius at the IGV inlet and values of flow parameters at average diameters of the MAC stages are used.

Design aerodynamic calculation of the MAC stage at different radii is carried out in the traditional way using two-dimensional axisymmetric model of the working process and is accompanied by the following features.

1. When determining the distribution of static pressure, static temperature and flow density at the inlet to the IGV of IPC it is necessary to take into account the unevenness of the total pressure and total temperature and flow angles in this section, for which the equation of radial equilibrium with the curvature of the current lines in the meridional plane is used.

This problem is solved discretely on axisymmetric circles, by which the whole cross-section plane at the IGV inlet is divided into m ($m \geq$ 16...20) ring sections of equal area, located from hub diameter to middle diameter, and the same number of ring sections of equal area, located from middle diameter to peripheral diameter (Figure 3).

The calculation circles at the RW inlet and outlet sections, as well as at the GV outlet of each stage of the IPC and HPC, are then formed in a similar way.

It should be noted here that, due to the presence of boundary layer on the hub and peripheral FP surfaces, the axisymmetric model does not allow obtaining reliable calculation results in this area. Therefore, it is reasonable to determine the values of flow parameters in the 2D model at the circumferences corresponding to the hub and periphery by extrapolating the values of the related parameters at the preceding circumferential cross-sections.

2. The flow swirl law at the RW inlet $C_{1u} = f(C_{1u\,ave}; r_1)$ can be set not only analytically, but also with corrections to the selected $C_{1u} = f(C_{1u\,ave}; r_1) + \Delta C_{1u}$ pattern.

3. Pressure ratio of the stage π^*_{st} can be set not only constant, but also variable along the radius, taking into account its value at the average diameter $\pi^*_{st} = f(\pi^*_{st\,ave}; r_1)$.

4. Distribution of values of relative efficiency of the stage $\bar{\eta}_{st\,j} = \eta_{st\,j}/\eta_{st\,ave}$ (j - number of the calculation circle) over the height of the flow path is carried out as follows. At value of relative hub diameter $\bar{d}_{hub} = D_{hub}/D_{per} = r_{hub}/r_{per}$ of the stage in the range 0.65...0.92, typical for HPC (Belousov A.N., 2006), in the first approximation over all height of the blade is taken $\bar{\eta}_{st\,j}$=1.

In a range $\bar{d}_{hub}$ = 0.45...0.65, typical for IPC (Belousov A.N., 2006), in area of 10 % of blade height in hub and peripheral zones it is reasonable to reduce relative efficiency $\bar{\eta}_{st\,j}$ linearly to tract surfaces by $\Delta\bar{\eta}_{st\,j}$= 0.03...0.05. In this case in a range of change of relative blade height $\bar{h}_j = h_j/h = (r_j/r_{per} - \bar{d}_{hub})/(1 - \bar{d}_{hub})$ from 0 to 0.1 dependence $\bar{\eta}_{st\,j} = 1 + \Delta\bar{\eta}_{st\,j}(10\bar{h}_j - 1)$ should be used, and in a range $\bar{h}_j$ = 0.9...1.0 - $\bar{\eta}_{st\,j} = 1 + \Delta\bar{\eta}_{st\,j}(9 - 10\bar{h}_j)$.

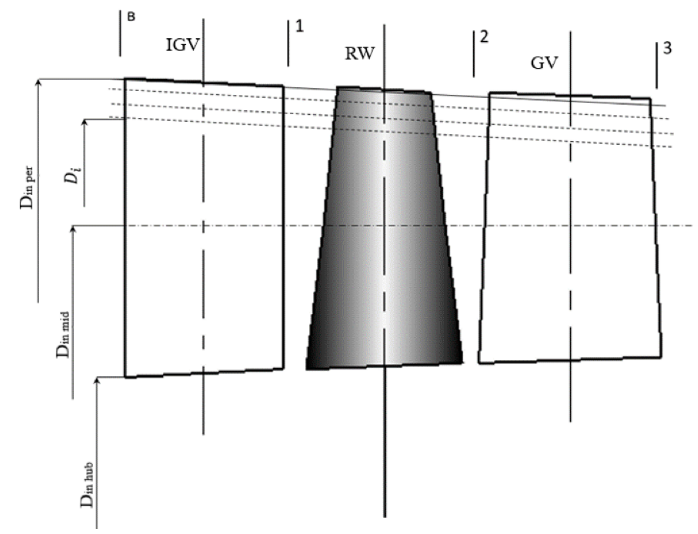


Figure 3: Two-dimensional axisymmetric flow scheme in the first compressor stage.

5. Values of axial component of flow velocity on design circles in interventional gaps are determined by means of connection equation of circumferential and axial components of flow velocity without taking into account curvature of current lines in meridional plane, but taking into account dependences $C_{1u} = f(C_{1u\,ave}; r_1) \pm \Delta C_{1u}$ and $\pi^*_{st} = f(\pi^*_{st\,ave}; r_1)$.

6 AN ASSESSMENT OF THE GEOMETRIC VALUES OF THE PROFILES AND THEIR GRIDS AT VARIOUS CROSS-SECTIONS ALONG THE HEIGHT OF THE COMPRESSOR FLOW PATH

Preliminary estimation of geometric profile values from the results of aerodynamic calculation of compressor stages along the radius is carried out using traditional methods, for example, the method presented by Belousov A.N. (2006), Bykov. N.N. (1984). Additionally, it is advisable to determine the values of diffusivity factor by S. Liebling's of RW and GV grids at all design j-*th* radii at the end of the calculation:

$$F_{D\,RW\,j} = 1 - \frac{W_{2j}}{W_{1j}} + \frac{(W_{1uj} - W_{2uj})}{2(\frac{b}{t})_{RW\,j} W_{1j}} \quad (6)$$

$$F_{D\,GV\,j} = 1 - \frac{C_{3j}}{C_{2j}} + \frac{(WC_{2uj} - C_{3uj})}{2(\frac{b}{t})_{GV\,j} C_{2j}} \quad (7)$$

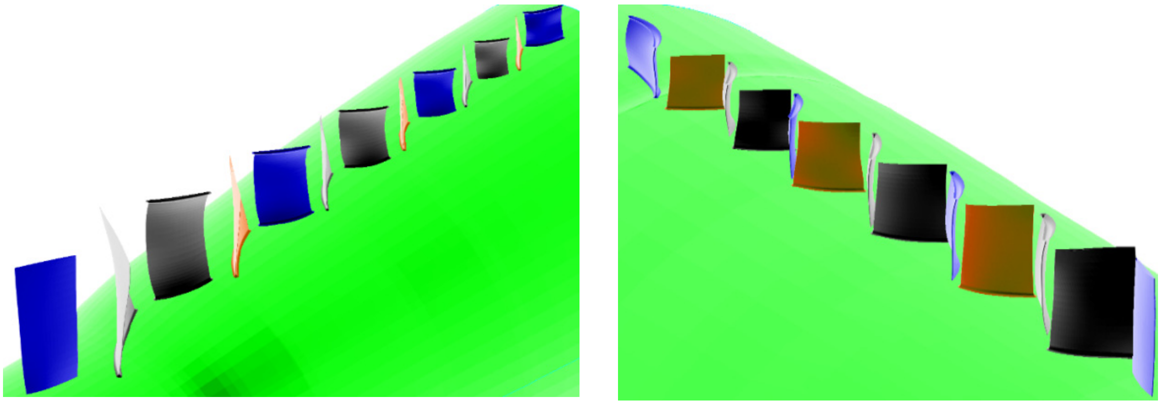
where $(\frac{b}{t})_{RW\,j}$ and $(\frac{b}{t})_{GV\,j}$ are the solidity of the RW and GV grids at the calculated j-th radii.

It is considered rational to provide values of S. Liebling's diffusivity factor in the range of 0.40...0.50 (Kampsti, N., 2000). An acceptable value of this parameter in the process of calculation is most often achieved by changing the density of the grid profiles.

Initial three-dimensional models of IPC and HPC (Figure 4) of perspective core have been created taking into account the above features of steps of design calculation of parameters of flow path cascades of compressor of two-shaft CORE. The schematic of these compressors in the meridional plane with observance of proportions in axial and radial directions has been presented earlier in Fig. 1,a.

7 CONCLUSIONS

In the article the revealed features of design calculation of FP parameters of cascade compressor of two-shaft core are resulted, which have allowed to supplement a matrix of requirements to one-dimensional and two-dimensional models of working process of multistage compressors with specific requirements to similar models of IPC and HPC, which are summarized in Table 2. In the same table, the requirements for the relative MAC parameters characterising the working process of stages and their blade rows, which are quite often discussed in textbooks and articles on compressor theory, but rarely used in published methods for their design calculations, are also presented.



Intermediate pressure compressor. High pressure compressor.

Figure 4: Three-dimensional models of IPC and HPC.

Table 2: Additional requirements for one- and two-dimensional IPC and HPC working process models.

No	Parameter	Required range of values or pattern	
		IPC	HPC
1	Coefficient of consumed head of the first subsonic stages $\bar{H}_{z\ st\ per}$	0.20…0.26	0.26…0.28
2	Coefficient of consumed head of the first transonic or supersonic stages $\bar{H}_{z\ st\ per}$	0.50…0.60	-
3	Coefficient of consumed head of the middle stages $\bar{H}_{z\ st\ per}$	-	0.30…0.33
4	Coefficient of consumed head of the last stages $\bar{H}_{z\ st\ per}$	0.30…0.33	0.26…0.28
5	Efficiency of the first subsonic or transonic stages	0.885…0.895	0.880…0.890
6	Efficiency of the first supersonic stage	0.865…0.880	-
7	Efficiency of the middle stages	0.905…0.910	0.900…0.905
8	Efficiency of the last stages	0.880…0.890	0.875…0.885
9	Regularity of the relative efficiency of the stage over the blade height at $\bar{h}_j$=0.1	$\bar{\eta}_{st\ j} = 1 + \Delta\bar{\eta}_{st\ j}(10\bar{h}_j - 1)$	$\bar{\eta}_{st\ j} = 1$
10	Regularity of the relative efficiency of the stage over the blade height at $\bar{h}_j$=0.1…0.9	$\bar{\eta}_{st\ j} = 1$	$\bar{\eta}_{st\ j} = 1$
11	Regularity of the relative efficiency of the stage over the blade height at $\bar{h}_j$=0.9…0.10	$\bar{\eta}_{st\ j} = 1 + \Delta\bar{\eta}_{st\ j}(9 - 10\bar{h}_j)$	$\bar{\eta}_{st\ j} = 1$
12	Flow rate coefficient of the first stages	0.45…0.55	0.45…0.50
13	Flow rate coefficient of the last stages	0.45…0.50	0.40…0.45
14	Allowable reduction in the axial component of the flow velocity in one blade row	10…12 m/s	
15	Flow braking in RW in relative motion and in GV in absolute motion	≥ 0.7	
16	Static pressure ratio in the RW and GV	≤ 0.4	
17	Stepanov load factor	0.55…0.65	
18	S. Liebling's diffusivity factor of the RW and GV grids	0.40…0.50	

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