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Development of Effective Cooling Schemes of Gas Turbine Blades Based on Computer Simulation

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Abstract: In contrast to existing of calculation of temperature field of a profile part a blade with convective cooling which are not taking into account multi connective in a broad sense of this term, we develop mathematical models and highly effective combination (BIEM AND FDM) numerical methods from the point of view of a realization on the PC. The theoretical substantiation of these methods is proved by the appropriate theorems.

Keywords: multi coherent systems, method of the boundary integrated equations, singular operators, gas turbines

1. Introduction

FOR this purpose, were there developed converging quadrature processes and the estimations of errors in the terms of modules of a continuity A.Ziqmound are received. The offered technique of account of temperature fields is applied to cooled gas turbine blades. For visualization of structures is used peace-polynomial smoothing with automatic joining: a method of the least squares and smooth splines.

The repeated computing experiments with use BIEM on account of temperature fields and workers blades with various amount and arrangement of cooled channels having a difficult configuration at stationary and quasi-stationer modes, have shown increased reactive of the developed algorithms and their high accuracy.

The development of modern air engineering is stipulated, in main. development and refinement aviation gas turbine engines (AGTE) creation of perfect designs of flights vehicles (FV) with improved weight, strength, aerodynamic and dynamic characteristics, decreasing of harmful effects on an ecology of an environment (harmful lets, noise effects etc.), increase of a reliability, survival, acceleration characteristics, which conduct, as a whole, to increase of efficiency FV and growth of safety of flights.

What concerns development and refinement AGTE, at the present stage it is reached, in main assimilation of high values of temperature of gas in front of the turbine ($T_Г$) at simultaneous increase of a degree of recompression in the compressor. The attempts of use of other means, such as thickening of a thermal cycle, salvaging of a heat of exhaust gases and other well recommending in other branches gas-turbine engineering, in application to aircraft have not justified. The activities on increase $T_Г$ are conducted in several directions. The fist direction is a creation of new metal alloys with the more improved heat resisting and resisting properties. The second direction is a development of ceramic, cermet and sintering of materials. At last, the third direction is a cooling of hot parts of the turbine.

Therefore assimilation high $T_Г$ in AGTE at the present stage in main is reached in refinement of systems and schemes of cooling of hot details of turbines, and fist of all, nozzle and working blades.

Especially it is necessary to underline, that with increase $T_г$ of the requirement to accuracy of eventual results will increase. From the experimental and operational data it is known, what for of details of gas turbines the error calculation of temperatures should be very small, no more than 2-3%. In other words, at allowed (permissible) in AGTE to temperature of metal $T_{\lim} = (1100...1300^0\,K)$, t_0, intrinsic for heat resisting and heat resisting alloys on nickel or cobalt to the basis with various alloying by dopes, the absolute error of calculation of temperature should be in limits (20-30^{0}K).

To achieve it is difficult. Especially in skew fields of the difficult shape with various quantity and arrangement of cooling channels have a difficult configuration, in multiply connected areas with variables in time and or coordinates by boundary conditions even separate problem solving of heat conduction ramified hydraulic circuits and the definition of the intense condition is business not simple. Despite of a numbers of assumptions the solution of such problems requires application modern and perfect mathematical vehicle.

2. Problem Formulation

In classical statement a differential heat conduction equation circumscribing in common case non-stationary process of distribution of a heat in many – dimensional area in there is internal sources of the heat q_v , under difficult boundary conditions and relation of factors, included in an equation, to required temperature coordinates and time (an equation the Fourier-Kirchhoff) has a kind:

$$\frac{\partial(\rho C_v T)}{\partial t} = div(\lambda\, grad\,\mathrm{T}) + q_v, \qquad (1)$$

where ρ, C_v and λ - accordingly material's density, thermal capacity heat conduction, q_v - internal source or drain of heat, and T- required temperature.

By results of researches is established [2], that the temperature condition of a profile part of a blade with radial cooling channels can with a sufficient degree of accuracy determined, as two-dimensional. Besides if to suppose a constancy of physical properties, absence of internal sources (drains) heat the temperature field under fixed conditions will depend only on the shape of a skew field and from distribution of temperature on a boundaries skew field. In this case equation (1) will look like:

$$\Delta T = \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \qquad (2)$$

For allocation from a set of the possible solutions it is necessary to supplement one, circumscribing a particular temperature field given a differential equation by conditions of uniqueness. In practice of problem solving temperature fields, connected to determination in elements of gas turbines washed by a flow of high – enthalpy gas more often set boundary conditions of the third kind describing heat exchange between a skew field and an environment because of a hypothesis of a Newton- of the Riemann. In that case these boundary conditions will be recorded as follows:

$$\alpha_0 (T_0 - T_{\gamma_0}) = \lambda \frac{\partial T_{\gamma_0}}{\partial n} \qquad (3)$$

Characterizes quantity of heat transmitted convection from gas to unit of a surface of a blade and assigned by heat conduction in a skew field of a blade:

$$-\lambda \frac{\partial T_{\gamma_i}}{\partial n} = \alpha_i (T_{\gamma_i} - T_i) \qquad (4)$$

Characterizes quantity of a heats assigned by a convection of the chiller, which is transmitted by heat conduction of a material of a blade to a surface of cooling channels; where T_0 – temperature of environment at i=0; T_i – temperature of environment at $i = \overline{1, M}$ (temperature of the chiller), where M- quantity of outlines; T_{γ_0} -- temperature on an outline γ_i at $i = 0$, (outside outline of blade); T_{γ_i} -- temperature on an γ_i at $i = \overline{1, M}$ (outline of cooling channels); α_0 - heat transfer factor from gas to a surface of a blade (at $i = 0$) α_i - heat transfer factor of environment from a blade to a cooling air at ($i = \overline{1, M}$); λ-- thermal conductivity of a material of a blade; n-external normally on an outline of researched area.

3. Problem Solution

As of today for the solution of this boundary value problem (2)-(4) most broad distributions have received four numerical methods – methods of final differences (MFD), finite element method (FEM) , probabilistic method (or method Monte-Carlo) and method of boundary integral equations (BIEM) (or it discrete analog a method of boundary element (BEM). Let's consider application BIEM for the solution of a problem (2)-(4).

3.1. The function T=T(x,y) , continuous with the derivatives up to the second order satisfying to an equation of the Laplace in considered area , including it an outline $\Gamma = \bigcup_{i=0}^{M} \gamma_i$ is harmonic. A corollary of the integral formula Grin for a researched potential function T=T(x,y) is the ratio;

$$T(x, y) = \frac{1}{2\pi} \int_\Gamma [T_\Gamma \frac{\partial(\ell nR)}{\partial n} - \ell nR \frac{\partial T_\Gamma}{\partial n}] ds \qquad (5)$$

Where R – variable at an integration of a distance between a point K(x,y) and "running" on an outline k- point; T_Γ - temperature on an outline Γ. The value of temperature in some k t_0 a point lying on the boundary, is received as limiting at approach of a point K(x,y) to the boundary

$$T_k = \frac{1}{2\pi} \left[\int_\Gamma T_\Gamma \frac{\partial(\ell nR_k)}{\partial n} ds - \int_\Gamma \frac{\partial T_\Gamma}{\partial n} \ell nR_k ds \right] \qquad (6)$$

With allowance for of entered boundary conditions (2)-(3), after a collecting terms of terms and input of new factors the ratio (6) can be presented as a linear algebraic equation, computed for the point R:

$$\begin{aligned} &\varphi_{k1} T_{\gamma_{01}} + \varphi_{k2} T_{\gamma_{02}} + \ldots + \varphi_{kn} T_{\gamma_{0m}} - \\ &- \varphi_{k\gamma_0} T_0 - \varphi_{k\gamma_i} T_i - 2\pi T_k = 0 \end{aligned} \qquad (7)$$

where n-quantity of sites of a partition of an outside outline of a blade $\ell_{\gamma_0} (\ell_{\gamma_i} on\, i = 0)$ on small sections $\Delta S_0 \; (\Delta S_i \; at \; i = 0)$, m-quantity of sites of a partition of outside outlines of all cooling channels $\ell_{\gamma_i} (i = 1, M)$ on small sections ΔS_i.

Shall remark, that by unknowns in an equation (7) except a unknown quantity of a true value T_k in a point to are also mean on sections of a partition of outlines ΔS_0 and ΔS_i of temperature $T_{\gamma_{01}}, T_{\gamma_{02}}, ..., T_{\gamma_{0m}}$ and $T_{\gamma_{i1}}, T_{\gamma_{i2}}, ..., T_{\gamma_{im}}$ (total number n+т).
From a ratio (7) we shall receive required temperature for any point, using the formula (5)

$$T(x,y)=\frac{1}{2\pi}[\varphi_{k1}T_{\gamma_{01}}+\varphi_{k2}T_{\gamma_{02}}+...+\varphi_{kn}T_{\gamma_{0n}}+ \\ +...+\varphi_{km}T_{\gamma_{im}}-\varphi_{k\gamma_0}T_{cp_0}-\varphi_{k\gamma_i}T_{cp_i}] \tag{8}$$

where

$$\varphi_{k1}=\int_{\Delta S_{01}}\frac{\partial(\ell nR_k)}{\partial n}ds-\frac{\alpha_{01}}{\lambda_1}\int_{\Delta S_{01}}\ell nR_k ds$$

$$. \quad . \quad . \quad . \quad .$$

$$\varphi_{kn}=\int_{\Delta S_{0m}}\frac{\partial(\ell nR_k)}{\partial n}ds-\frac{\alpha_{0m}}{\lambda_m}\int_{\Delta S_{0m}}\ell nR_k ds$$

$$\varphi_{k\gamma_0}=\frac{\alpha_{01}}{\lambda_1}\int_{\Delta S_{01}}\ell nR_k ds+...+\frac{\alpha_{0n}}{\lambda_n}\int_{\Delta Sn}\ell nR_k ds$$

$$\varphi_{k\gamma_{ii}}=\frac{\alpha_{01}}{\lambda_1}\int_{\Delta S_{i1}}\ell nR_k ds+...+\frac{\alpha_{im}}{\lambda_m}\int_{\Delta S_{im}}\ell nR_k ds$$

In activities [2] the discretization of an antline $\tilde{A}=\bigcup_{i=0}^{M}\gamma_i$ by a great many of a discrete point and integrals which are included in an equations as logarithmic potentials, calculated approximately was made, being substituted the following ratios:

$$\int_{\Delta S_{\gamma_i}}\frac{\partial(\ell nR_k)}{\partial n}ds\approx\frac{\partial(\ell nR_k)}{\partial n}\Delta S_{\gamma_i} \tag{9}$$

$$\int_{\Delta S_{\gamma_i}}\ell nR_k ds\approx \ell nR_k\Delta S_{\gamma_i} \tag{10}$$

(where $\Delta S_{\gamma_i}\in L=\bigcup_{i=0}^{M}l_i;\ \ l_i=\int_{\gamma_i}ds$)

3.2. In difference from [4] we offer to decide the given boundary value problem (2)-(4) as follows. We suppose that distribution of temperature T(x,y) we locate as follows:

$$T(x,y)=\int_{\Gamma}\rho\ell nR^{-1}ds \tag{11}$$

where $\Gamma=\bigcup_{i=0}^{M}\gamma_i$ -smooth closed Jordan curve; M-quantity of cooled channels;

$\rho=\bigcup_{i=0}^{M}\rho_i$ -density of a logarithmic potential uniformly distributed on γ_i $S=\bigcup_{i=0}^{M}s_i$.

Thus curve $\Gamma=\bigcup_{i=0}^{M}\gamma_i$ positively are oriented and are given in a parametric kind:

x=x(s), y=y(s), s∈[0, L]

Using BIEM and expression (9) problem (2)-(4) we shall put to the following system of boundary integral equations:

$$\rho(s)-\frac{1}{2\pi}\int_{\Gamma}(\rho(s)-\rho(\xi))\frac{\partial}{\partial n}\ell nR(s,\xi)d\xi= \\ =\frac{\alpha_i}{2\pi\lambda}(T-\int_{\Gamma}\rho(s)\ell nR^{-1}ds) \tag{12}$$

where

$$R(s,\xi)=((x(s)-x(\xi))^2+(y(s)-y(\xi))^2)^{1/2}$$

For an evaluation of the singular integral operators which are included in the discrete operators of a logarithmic potential simple and double layer (10) are investigated, their connection is shown and the evaluations in term of modules of a continuity (evaluation such as assessments are obtained A. Zigmound).Theorem (main).

Let

$$\int_0\frac{\omega_\xi(x)}{x}<+\infty$$

And let the equation (10) have the solution $f^*\in C_\Gamma$ (the set of continuous functions on Γ).Then $\exists N_0\in N=\{1,2\ldots\}$ such that $\forall N>N_0$ the discrete system, obtained by using the discrete double layer potential operator (its properties has been studied), has unique solution $\{\widehat{f}_{j_k}^{(N)}\},k=\overline{1,m_j};j=\overline{1,n};$

$$|f_{jk}^*-\widehat{f}_{jk}^{(N)}|\le C(\Gamma)(\int_0^{\varepsilon_N}\frac{\omega_\xi(x)\omega_{f^*}(x)}{x}dx+ \\ +\varepsilon\int_{\varepsilon_N}^{L/2}\frac{\omega_\xi(x)\omega_{f^*}(x)}{x}dx+\omega_{f^*}(\|\tau_N\|)\int_0^{L/2}\frac{\omega_{f^*}(x)}{x}dx+ \\ +\|\tau_N\|\int_{\varepsilon_N}^{L/2}\frac{\omega_{f^*}(x)}{x}dx),$$

where C(Γ) is constant, depending only on $\|\tau_N\|_{N=1}^{\infty}$ --the sequence of partitions of Γ; $\{\varepsilon_N\}_{N=1}^{\infty}$ -- the sequence of positive numbers such that the pair ($\|\tau_N\|,,\varepsilon_N$) satisfies the condition $2\le\varepsilon\|\tau\|^{--1}\le p$.

Let $\delta\in\left(0,d/2\right)$ where d-diameter Γ, and the splitting τ is those, that is satisfied condition

$$p'\ge\delta/\|\tau\|\ge 2$$

Then for all $\psi\in C_\Gamma$ (C_Γ - space of all functions continuous on Γ)

and $z\in\Gamma$, ($z=x+iy$)

$$\left|\left(I_{\tau,\delta}f\right)(z)-\bar{f}(z)\right|\le C(\Gamma) \\ \left(\|f\|_C\delta\ln\frac{2d}{\delta}+\omega_f\left(\|\tau\|\right)+\|\tau\|\ln\frac{2d}{\delta}+\|f\|_C\omega_Z\left(\|\tau\|\right)\right);$$

$$\left|\left(L_{\Omega,\Gamma}f\right)(z)-\widetilde{f}(z)\right|\le\left(C(\Gamma)\int_0^{\Gamma}\frac{\omega_f(x)\omega_l(x)}{x^2}dx+\right. \\ \left.+\omega_f\left(\|\tau\|\right)\int_{\Delta}^{d}\frac{\omega_l(x)}{x}dx+\|\tau\|\int_{\Delta}^{d}\frac{\omega_f(x)}{x^2}dx\right)$$

where

$$\left(L_{\tau,\varepsilon} f\right)(z) = \sum_{z_{m,e\in\tau(z)}} \left(\frac{f(z_{k,e+1}) + f(z_{k,e})}{2} - f(z) \right) \cdot$$

$$\frac{(y_{k,e+1} - y_{k,e})(x_{k,e} - x) - (x_{k,e+1} - x_{k,e})(y_{k,e} - y)}{\left|z - z_{k,e}\right|^2} + \pi f(z)$$

$\left(L_{\tau,\varepsilon} f\right)(z)$ -two parameter (depending on τ and δ parameters);

quadrature formula for logarithmic double layer potential; $\tilde{f}(z)$ - double layer logarithmic potential operator; with C (Γ) – constant, dependent only from a curve Γ; $\omega_f(x)$ a module of a continuity of functions f;

$$\left(I_{\tau,\varepsilon} f\right)(z) = \sum_{z_{m,e\in\tau(z)}} \frac{f(z_{k,j+1}) + f(z_{k,j})}{2} \cdot$$

$$\cdot \ln \frac{1}{\left|z_{k,j} - z\right|} \left|z_{k,j+1} - z_{k,j}\right|$$

$\left(I_{\tau,\varepsilon} f\right)(z)$ - two parameter (depending on τ and δ parameters); quadrature formula for logarithmic potential simple layer; $\ddot{f}(z)$ - simple layer logarithmic potential operator;

$$z_{k,e} \in \tau,\ z_{k,e} = x_{k,e} + iy_{k,e}$$

$$\tau(z) = \left\{ z_{k,e} \ \left|z_{k,e} - z\right| > \varepsilon \right\}$$

$$\tau_k = \{z_{k,1}, \ldots, z_{k,m_k}\},\ \ z_{k,1} \le z_{k,2} \le \ldots \le z_{k,m_k}$$

$$\|\tau\| = \max_{j=1,m_k} \left|z_{k,j+1} - z_{k,j}\right|$$

are developed effective from the point of view of realization on computers the numerical methods basing on again constructed, converging two-parametric quadratute processes for the discrete operators logarithmic potential of a double and of a simple layer (the regular errors are appreciated and mathematically the methods quadratures for the approximate solution Fredgolm I and II boundary integral equation are proved –is made regularization on Tihonov and the appropriate theorems are proved.

3.3. The given technique of calculation of a temperature field of a blade can be applied and to blades with the plug – in splash plate. By their consideration in addition to boundary conditions III kinds adjoin also conditions of interfaces between segments of a partition of an outline as equalities of temperatures and heat flows

$$T_v(x,y) = T_{v+1}(x,y) \qquad (13)$$

$$\frac{\partial T_v(x,y)}{\partial n} = \frac{\partial T_{v+1}(x,y)}{\partial n} \qquad (14)$$

Where - number of segments of a partition of an outline of section of a blade; x,y- coordinates. At finding of best values T(chiller), it is necessary to decide a return problem of heat conduction. For it is necessary to find at first solution of a direct problem of heat conduction under boundary conditions III kinds from a leg of gas and boundary conditions I kinds from a leg of a cooling air

$$\mathrm{T_v(x,y)}\big|_{\gamma_0} = \mathrm{T}_{\mathrm{i}_0} \qquad (15)$$

Were $\mathrm{T}_{\mathrm{i}_0}$ -unknown optimum temperature of a wall of a blade from a leg of a cooling air.

3.4. The developed technique for the numerical decision of a stationary task heat conduction in cooled лопатках can be distributed also on cvazistasionare case.

Let's consider a third regional task for cvazilines of the equation heat conduction

$$\frac{\partial}{\partial x}\left(\lambda(T)\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda(T)\frac{\partial T}{\partial y}\right) = 0 \qquad (16)$$

$$\alpha_i(T_{ci} - T_{\gamma i}) - \lambda(T)\frac{\partial T_{\gamma i}}{\partial n} = 0 \qquad (17)$$

For lines of a task (14) - (15) we shall take advantage of substitution Kirkov

$$A = \int_0^T \lambda(\xi) d\xi \qquad (18)$$

Then the equation (14) is transformed to the following equation Laplace:

$$\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2} = 0 \qquad (19)$$

For preservation lines converging composed in a regional condition (15) we shall accept in initial approximation constant λ (T) = lc. Then from (16) we have

$$T = A/\lambda c \qquad (20)$$

And the regional condition (15) will be transformed as follows:

$$\alpha_i(T_{ci} - A_{\gamma i}/\lambda_c) - \frac{\partial A_{\gamma i}}{\partial n} = 0 \qquad (21)$$

So, the stationary task (17), (19) method of the boundary integrated equations is decided. If the decision L (x, y) in a point (x, y) of a linear third regional task (17), (19) for the equation Laplace to substitute in (16) and after integration to decide (solve) the appropriate algebraic equation, which degree is higher unit than a degree of function λ (T), we shall receive meaning of temperature T (x, y) in the same point. Thus in radicals the algebraic equation of a degree above fourth is decided

$$a^0T^4 + a^1T^3 + a^2T^2 + a^3T + a_4 = A, \qquad (22)$$

That corresponds to the task λ(T) as the multimember of a degree above by third. In result the temperature field will be determined as a first approximation, as the boundary condition (17) took into account constant meaning heat conduction lc in convective thermal flows. According to it we shall designate this decision $T^{(1)}$ (accordingly $A^{(1)}$). For definition subsequent and $A^{(2)}$ (accordingly $T^{(2)}$) the function and A(T) is displayed in a number Taylor a vicinity $T^{(1)}$ and the linear members are left in it only. In result is received a third regional task for the equation Laplace concerning function And $A^{(2)}$. Temperature $T^{(2)}$ is determined by the decision of the equation (18).

3.5. The repeated computing experiments with use BIEM on calculation of temperature fields nozzle and working blades with various quantity and arrangement of cooling channels have a difficult configuration have shown, that for practical calculations in the approach, offered us, the discretization of areas of an integration can be conducted with rather smaller quantity of discrete points. Thus the reactivity of the developed algorithms and accuracy of evaluations is increased. The accuracy of calculation of temperatures, required consumption of a cooling air, heat flows, losses from cooling margins of safety etc. essentially depends on reliability of boundary conditions, included in calculation, of heat exchange.

3.6. It is considered piece-polynomial smoothing of structures cooled gas-turbine blades with automatic conjecture: the method of the least squares, device spline and smooth is used.

3.6.1. Let equation of sites of a structure cooled blades is polynomial of the third order.

$$y(x)=a_0+a_1x+a_2x^2+a_3x^3 \qquad (23)$$

The equation of measurements of target coordinate has a kind:

$$Z_y=a_0+a_1x+a_2x^2+a_3x^3+\delta_y \qquad (24)$$

where $Zy=\|z_{1y}, z_{2y}, \ldots, z_{ny}\|^T$– Vector of measurements of target coordinate, n-quantity(n-amount) of points in a examined interval. For an estimation polynomial factors (23) the method of the least squares of the following kind is used

$$\hat{\theta} =(X^TX)^{-1}(X^TZ_y) \qquad (25)$$

$$D_{\hat{\theta}}=(X^TX)^{-1}\sigma^2 \qquad (26)$$

where

$$X=\begin{Vmatrix} 1 & x_1 & x_1^2 & x_1^3 \\ 1 & x_2 & x_2^2 & x_2^3 \\ 1 & x_3 & x_3^2 & x_3^3 \\ \ldots & \ldots & \ldots & \ldots \\ 1 & x_n & x_n^2 & x_n^3 \end{Vmatrix}$$ - Structural matrix;

$D_{\hat{\theta}}$ -dispersion a matrix of mistakes;

$\hat{\theta}=\|a_0, a_1, a_2, a_3\|^T$ - Vector of estimated factors.

Estimations of factors for the first site is received under the formula (25). Beginning with second, the components of a vector θ pay off on experimental data from this site, but in view of parameters found on the previous site. Thus, each subsequent site of a structure we shall choose with blocking. Thus it is expedient to use the following linear connections between the appreciated parameters of the previous site $\hat{\theta}_{N\ 1}$ and required $\hat{\theta}_N$ N-го of a site:

$$A\theta_N=V, \qquad (27)$$

$$A=\begin{bmatrix} 1 & x_e & x_e^2 & x_e^3 \\ 0 & 1 & 2x_e & 3x_e^2 \\ 0 & 0 & 2 & 6x_e \end{bmatrix}, \qquad (28)$$

$$V=\begin{bmatrix} \hat{a}_{0N-1}+\hat{a}_{1N-1}x_e+\hat{a}_{2N-1}x_e^2+\hat{a}_{3N-1}x_e^3 \\ \hat{a}_{1N-1}+\hat{a}_{2N-1}x_e+3\hat{a}_{3N-1}x_e^2 \\ 2\hat{a}_{2N-1}+6\hat{a}_{3N-1}x_e \end{bmatrix}, \qquad (29)$$

e=(N-1)(n-L); L- Number points of blocking.

The expressions (27)-(29) describe communications, which provide joining of sites of interpolation on function, first and second with derivative.

Taking into account accuracy of measurements, the task of definition of unknown factors of model in this case can be formulated as a task on conditional: minimization of the square-law form $(Z_y-X\theta)^T\sigma^2 I(Z_y-\theta)$under a limiting condition (27). Here I - individual matrix. For the decision of such tasks usually use a method of uncertain multipliers Lagrange. In result we shall write down the following expressions for estimation a vector of factors at presence of linear connections (27):

$$\tilde{\theta}^T=\hat{\theta}^T+(V^T-\hat{\theta}^TA^T)[A(X^TX)^{-1}A^T]^{-1}A(X^TX)^{-1} \qquad (30)$$

$$D_{\tilde{\theta}}=D_{\hat{\theta}}-(X^TX)^{-1}A^T[A(X^TX)^{-1}A^T]^{-1}A(X^TX)^{-1}\sigma^2 \qquad (31)$$

Substituting matrixes A, X and vectors Z_y and V in expressions (25), (26), (30) and (31), we receive an estimation of a vector of factors for a site of a structure cooled лопатки with number N, and also дисперсионную a matrix of mistakes of estimations.

As a result of consecutive application of the described procedure and use of experimental data we shall receive peace-polynomial interpolation of a researched site with automatic стыковкой.On the basis of the carried out experimental researches is shown, that optimum overlapping in most cases is the 50%-s' overlapping.

3.6.2. Besides peace-polynomial regression exist which represent polynomial (low odd degrees - third, fifth), continuity, subordinated to a condition, of function and derivative (first and second in case of cubic spinal in general(common) points of the next sites. If the equation of a structure cooled gas-turbine blades is described cubic spinal submitted in obvious polynomial a kind (23), the factors a_0, a_1, a_2, a_3 determining j-й spinal, i.e. line connecting the points $Z_j=(x_j, y_j)$ and $Z_{j+1}=(x_{j+1}, y_{j+1})$, calculate as follows:

$$\begin{aligned}
&a_0 = z_j;\\
&a_1 = z_j^{'};\\
&a_2 = z_j^{''}/2 = 3(z_{j+1}-z_j)h_{j+1}^{-2} - 2z_j^{'}h_{j+1}^{-1} - z_{j+1}^{'}h_{j+1}^{-1};\\
&a_3 = z_j^{'''}/6 = 2(z_j - z_{j+1})h_{j+1}^{-3} + z_j^{'}h_{j+1}^{-2} + z_{j+1}^{'}h_{j+1}^{-2};
\end{aligned} \tag{32}$$

где $h_{j+1}=|z_{j+1}-z_j|$, $j=\overline{1, N-1}$

3.6.3. Let's consider other way smooth восполнения of a structure cooled gas-turbine blades on the precisely measured meaning of coordinates in final system of discrete points distinct from method of spinal-function and also effective from the point of view of realization on computers. Let equation of sites of a structure cooled blades is described by the multimember of the third order of a type (23), then by taking advantage a method smooth supply (the conditions smooth of function are carried out and first by derivative) we shall define its factors

$$\begin{aligned}
&a_0 = z_j;\\
&a_1 = (z_{j+1}-z_j)h_{j+1}^{-1};\\
&a_2 = -((z_{j+2}-z_{j+1})h_{j+2}^{-1} + (z_{j+1}-z_j)h_{j+1}^{-1})h_{j+1}^{-1};\\
&a_3 = ((z_{j+2}-z_{j+1})h_{j+2}^{-1} - (z_{j+1}-z_j)h_{j+1}^{-1})h_{j+1}^{-2};
\end{aligned} \tag{33}$$

$j=\overline{1, N-1-S}$, $S=1$.

If it's required to perform a condition of function smooth first and second derivative, i.e. appropriate smooth of cubic splines, we shall deal with the multimember of the fifth degree (degree of the multimember is equal 2S + 1, i.e. S = 2).

The advantage of such approach (smooth supply) consists that it is not necessary to decide system of the linear algebraic equations, as in case of application spinal, though the degree of the multimember is higher on 2.

4. Conclusions

In view of extreme complexity of appearances determining regularities of heat exchange, value α_0 with an adequate accuracy purely theoretically to calcite usually it fails. Therefore practically they prefer to determine from an experimental data generalized because of the theory of a similarity. As per the last years there were activities, permitting to take into account influence to heat exchange of an initial degree of a turbulence, angle of attack, mass forces and radiation of gas, compressibility and acceleration of a flow, temperature non-stationary at increase and drop of a load etc.[5]. Between that, the recommendations, being available in the literature, at the best allow to determine factors α_0 with accuracy $\pm 15\%$ cooling of an air α_i with accuracy $\pm$ 10%. The latter does not mean, certainly, that the errors in definition of temperature of details also are calculated in tens interest. Therefore, the application of perfect methods of calculation of temperature fields of elements of gas turbines is one from actual problems of an air engine building. The efficiency of these methods in the total rends directs influence to operational manufacturability and reliability of elements of designs, and also on acceleration characteristics of the engine.

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