NOTATION

T, temperature; p, pressure; V, volume; ρ, density; R, gas constant; B, second virial coefficient; H, enthalpy; U, internal energy; r, intermolecular distance; $\mathcal{U}$, intermolecular potential function.

LITERATURE CITED

1. A. Schaber, "Zum thermischen Verhalten fluider Stoffe," Dissertation, Karlsruhe (1965).
2. V. I. Nedostup and E. P. Gal'kevich, Teplofiz. Vys. Temp., 14, No. 5 (1976).
3. A. Michels, H. Wouters, and J. De Boer, Physica, 1, 587 (1934); 3, 585 (1936).
4. J. Saurel, J. Rech. Centre Nat. Rech. Scient., 42, 21 (1958).
5. L. P. Filippov, Similarity of Material Properties [in Russian], Moscow State Univ. (1978).
6. V. I. Nedostup, Zh. Fiz. Khim., 44, No. 9 (1970).
7. E. Holleran, J. Phys. Chem., 73, No. 1, 167 (1969).
8. V. I. Nedostup, Author's Abstract of Candidate's Dissertation, Lomonosov Odessa Technological Institute (1966).
9. A. Michels, H. Wijker, and H. Wijker, Physica, 15, 627 (1949); A. Michels, J. Levelt, and G. Wolkers, Physica, 24, 769 (1958).
10. V. A. Rabinovich, A. A. Vasserman, V. I. Nedostup, and L. S. Veksler, Thermophysical Properties of Neon, Argon, Krypton, and Xenon [in Russian], Standartov, Moscow (1976).

TEMPERATURE DISTRIBUTION IN A ROTATING HOLLOW CYLINDER

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The temperature distribution in a hollow cylinder rotating with a given angular velocity is found for steady-state boundary conditions of the first kind.

We consider an infinitely long cylinder whose radial cross section is a doubly connected region S bounded on the outside by contour L (a circle of radius R) and on the inside by contour L_0 (a circle of radius R_0). A certain portion of the outer surface of the cylinder is in contact with a strip of hot metal translating with a velocity V. As a result of the contact with the moving strip the cylinder rotates about a fixed axis with an angular velocity $\omega = V/R$. The cylinder receives heat by contact, convective, and radiant heat transfer. At time $t = 0$ when the thermal process begins, a liquid enters the channel of the cylinder under turbulent conditions and maintains the temperature of the inner surface constant. The temperature on contour L at $t = 0$ is established instantaneously and does not change with time in the XOY system (Fig. 1); the initial temperature in the volume of the cylinder is assumed constant. It is required to find the temperature distribution in the cylinder at any time $t > 0$.

The temperature at the boundary is a continuous periodic function of points on contour L, and can be represented in the XOY system by a Fourier series:

$$\Theta(1,\ \varphi) = \bar{\Theta} + \sum_{n=1}^{\infty} [\beta_n \sin(n\varphi) + \gamma_n \cos(n\varphi)], \tag{1}$$

$$\Theta(\rho_0,\ \varphi) = \Theta_1;\ \Theta(\rho,\ \varphi,\ \mathrm{Fo})|_{\mathrm{Fo}=0} = \Theta_2. \tag{2}$$

The required temperature which satisfies boundary condition (1) and the initial condition (2) is determined by solving the heat-conduction equation

$$\frac{\partial^2\Theta}{\partial\rho^2} + \frac{1}{\rho}\frac{\partial\Theta}{\partial\rho} + \frac{\partial^2\Theta}{\rho^2\partial\varphi^2} = \mathrm{Pd}\frac{\partial\Theta}{\partial\varphi} + \frac{\partial\Theta}{\partial\,\mathrm{Fo}}. \tag{3}$$

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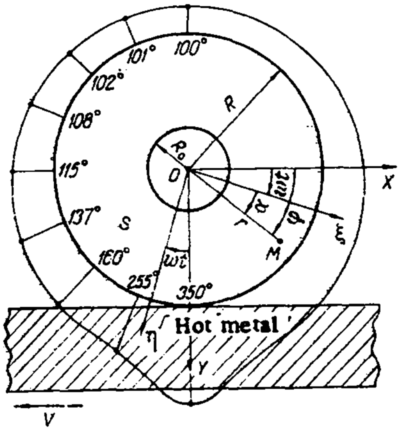

Fig. 1. Measured values of the temperature along outer contour L of roller.

Here

$$\Theta=\frac{T-T_{\min}}{T_{\max}-T_{\min}};\ \beta_n=\frac{\bar{T}a_n}{T_{\max}-T_{\min}};\ \gamma_n=\frac{\bar{T}b_n}{T_{\max}-T_{\min}};\ \rho=r/R,\ \rho_0=R_0/R;\ \mathrm{Pd}=\frac{a}{R^2}\omega;\quad \mathrm{Fo}=\frac{R^2}{a}t; \quad (4)$$

T is the running dimensional temperature; T_{max} and T_{min}, maximum and mimimum temperatures; Θ_1 and Θ_2, respectively, the dimensionless values of the temperature of the inner surface and the initial temperature of the cylinder; a_n and b_n, coefficients in the Fourier series for the dimensional temperature on L; r, running radius; a, thermal diffusivity; Pd, Predvoditelev number; Fo, Fourier number.

Since the required temperature $\Theta(\rho,\ \varphi,\ \mathrm{Fo})$ is a continuous, single-valued function of the points of the cross section S, and satisfies Dirichlet conditions, it can be expanded in a Fourier series:

$$\Theta(\rho,\ \varphi,\ \mathrm{Fo})=\frac{1}{2}A_0(\rho,\ \mathrm{Fo})+\sum_{n=1}^{\infty}A_n(\rho,\ \mathrm{Fo})\cos[n(\varphi-\mathrm{Pd\,Fo})]+\sum_{n=1}^{\infty}B_n(\rho,\ \mathrm{Fo})\sin[n(\varphi-\mathrm{Pd\,Fo})]. \quad (5)$$

The coefficients $A_0(\rho,\ \mathrm{Fo})$, $A_n(\rho,\ \mathrm{Fo})$, $B_n(\rho,\ \mathrm{Fo})$ are functions to be determined.

The problem is more conveniently solved by writing Eqs. (1) and (5) in complex form:

$$\Theta(1,\ \varphi)=\frac{1}{2}a_0+\sum_{n=1}^{\infty}a_n^0e^{in\varphi}+b_n^0e^{-in\varphi}, \quad (6)$$

$$\Theta(\rho,\ \varphi,\ \mathrm{Fo})=\frac{1}{2}A_0(\rho,\mathrm{Fo})+\sum_{n=1}^{\infty}A_n^0(\rho,\ \mathrm{Fo})\,e^{in(\varphi-\mathrm{Pd\,Fo})}+\sum_{n=1}^{\infty}B_n^0(\rho,\ \mathrm{Fo})\,e^{-in(\varphi-\mathrm{Pd\,Fo})}, \quad (7)$$

where

$$A_n^0=\frac{1}{2}(A_n-iB_n);\ B_n^0=\frac{1}{2}(A_n+iB_n);\quad a_0=2\bar{\Theta};\ a_n^0=\frac{1}{2}(\gamma_n-i\beta_n);\ b_n^0=\frac{1}{2}(\gamma_n+i\beta_n). \quad (8)$$

Since the coefficients A_n^0 and B_n^0 are complex conjugates, it is sufficient to find one of them. Because of the linearity of problem (1)-(3) each term of series (7) must satisfy Eq. (3). Substituting successively the terms of series (7) into Eq. (3), we obtain the following two problems:

$$\frac{\partial^2A_0}{\partial\rho^2}+\frac{1}{\rho}\frac{\partial A_0}{\partial\rho}=\frac{\partial A_0}{\partial\,\mathrm{Fo}}, \quad (9)$$

$$A_0(1,\ \mathrm{Fo})=2\bar{\Theta},\ A_0(\rho_0,\ \mathrm{Fo})=2\Theta_1,\ A_0(\rho,\ 0)=2\Theta_2 \quad (10)$$

and

$$\frac{\partial^2A_n^0}{\partial\rho^2}+\frac{1}{\rho}\frac{\partial A_n^0}{\partial\rho}-\frac{n^2}{\rho^2}A_n^0=\frac{\partial A_n^0}{\partial\,\mathrm{Fo}}, \quad (11)$$

$$A_n^0(1,\ \mathrm{Fo}) = a_n^0 e^{in\,\mathrm{Pd\,Fo}},\quad A_n^0(\rho_0,\ \mathrm{Fo}) = 0,\quad A_n^0(\rho,\ 0) = 0. \tag{12}$$

The solution of problem (9)-(10) is known [1] to have the form

$$A_0(\rho,\ \mathrm{Fo}) = 2\left[(\Theta_1 - \bar{\Theta})\frac{\ln\rho}{\ln\rho_0} + \bar{\Theta}\right] + \sum_{n=1}^{\infty} A_n V_0(\lambda_n\rho)\, e^{-\lambda_n^2 \mathrm{Fo}}, \tag{13}$$

$$A_n = \frac{2\pi J_0(\lambda_n)}{J_0^2(\lambda_n\rho_0) - J_0^2(\lambda_n)}\left[(\Theta_2 - \bar{\Theta}) J_0(\lambda_n\rho_0) + (\Theta_1 - \Theta_2) J_0(\lambda_n)\right], \tag{14}$$

$$V_0(\lambda_n\rho) = J_0(\lambda_n\rho) Y_0(\lambda_n\rho_0) - J_0(\lambda_n\rho_0) Y_0(\lambda_n\rho), \tag{15}$$

$J_0(x)$ and $Y_0(x)$ are zero-order Bessel functions of the first and second kind, and the λ_n are the roots of the characteristic equation

$$J_0(\lambda) Y_0(\lambda\rho_0) - Y_0(\lambda) J_0(\lambda\rho_0) = 0. \tag{16}$$

We seek the solution of problem (11)-(12) as the sum of two functions [2]:

$$A_n^0(\rho,\ \mathrm{Fo}) = A_n^{00}(\rho,\ \mathrm{Fo}) + A_n^{0*}(\rho,\ \mathrm{Fo}), \tag{17}$$

where $A_n^{00}(\rho,\ \mathrm{Fo})$ satisfies Eq. (11) and boundary conditions (12), and $A_n^{0*}(\rho,\ \mathrm{Fo})$ satisfies the same equation with zero boundary conditions. Omitting intermediate calculations, we write the final solution of problem (11)-(12) in the form

$$A_n^0(\rho,\ \mathrm{Fo}) = \left[C_n^{(1)} J_n(\sqrt{-in\,\mathrm{Pd}}\,\rho) + C_n^{(2)} Y_n(\sqrt{-in\,\mathrm{Pd}}\,\rho)\right] e^{in\,\mathrm{Pd\,Fo}} + \sum_{k=1}^{\infty} A_{nk} V_n(\lambda_{nk}\rho)\, e^{-\lambda_{nk}^2 \mathrm{Fo}}. \tag{18}$$

The definition of $V_n(\lambda_{nk}\rho)$ is analogous to (15), and the λ_{nk} are the roots of the equation

$$J_n(\lambda_n) Y_n(\lambda_n\rho_0) - Y_n(\lambda_n) J_n(\lambda_n\rho_0) = 0. \tag{19}$$

The constants $C_n^{(1)}$ and $C_n^{(2)}$ are determined from the equations

$$\begin{aligned} &C_n^{(1)} J_n(\sqrt{-in\,\mathrm{Pd}}) + C_n^{(2)} Y_n(\sqrt{-in\,\mathrm{Pd}}) = a_n^0, \\ &C_n^{(1)} J_n(\sqrt{-in\,\mathrm{Pd}}\,\rho_0) + C_n^{(2)} Y_n(\sqrt{-in\,\mathrm{Pd}}\,\rho_0) = 0. \end{aligned} \tag{20}$$

Satisfying the initial condition (12) and taking account of the orthogonality of the functions $V_n(\lambda_{nk}\rho)$ in the interval $[\rho_0,\ 1]$, we obtain from (19) the coefficient

$$A_{nk} = \frac{\pi^2\lambda_{nk}^2 J_n^2(\lambda_{nk})}{2}\ \frac{\int_{\rho_0}^{1}\left[C_n^{(1)} J_n(\sqrt{-in\,\mathrm{Pd}}\,\rho) + C_n^{(2)} Y_n(\sqrt{-in\,\mathrm{Pd}}\,\rho)\right]\rho V_n(\lambda_{nk}\rho)\, d\rho}{J_n^2(\lambda_{nk}) - J_n^2(\lambda_{nk}\rho_0)}, \tag{21}$$

and from Eq. (8) the expressions for the coefficients

$$A_n(\rho,\ \mathrm{Fo}) = 2\,\mathrm{Re}\, A_n^0(\rho,\ \mathrm{Fo}),\quad B_n(\rho,\ \mathrm{Fo}) = -2\,\mathrm{Im}\, A_n^0(\rho,\ \mathrm{Fo}), \tag{22}$$

where Re and Im denote the real and imaginary parts of the expressions on the right-hand sides of these equations. Introducing the notation

$$\begin{aligned} &J_n(\sqrt{-in\,\mathrm{Pd}}\,\rho) = \mathrm{ber}_n(\rho) - i\,\mathrm{bei}_n(\rho), \\ &Y_n\sqrt{-in\,\mathrm{Pd}}\,\rho) = \mathrm{ver}_n(\rho) - i\,\mathrm{vei}_n(\rho), \\ &C_n^{(1)} = -(\delta_n^{(1)} - i\delta_n^{(2)}),\quad C_n^{(2)} = \gamma_n^{(1)} - i\gamma_n^{(2)}, \\ &A_{nk} = \omega_{nk}^{(1)} - i\omega_{nk}^{(2)} \end{aligned} \tag{23}$$

and using well-known expansions for $J_n(z)$ and $Y_n(z)$ given, e.g., in [3] and separating real and imaginary parts, we obtain

$$\mathrm{ber}_n(\rho) = \sum_{k=0}^{\infty} \frac{(-1)^k (\sqrt{n\,\mathrm{Pd}})^{2k+n} \cos\frac{\pi}{4}(2k+n)}{k!\ (n+k)!}\left(\frac{\rho}{2}\right)^{2k+n},$$

$$\mathrm{bei}_n(\rho) = \sum_{k=0}^{\infty} \frac{(-1)^k (\sqrt{n\,\mathrm{Pd}})^{2k+n} \sin\frac{\pi}{4}(2k+n)}{k!\,(n+k)!}\left(\frac{\rho}{2}\right)^{2k+n},$$

$$\mathrm{ver}_n(\rho)=\frac{2}{\pi}\,\mathrm{ber}_n(\rho)\ln\frac{C_1\sqrt{n\,\mathrm{Pd}}\,\rho}{2}-\frac{1}{2}\,\mathrm{bei}_n(\rho)-$$

$$-\frac{1}{\pi}\sum_{k=0}^{n-1}\frac{(n-k-1)!\,(\sqrt{n\,\mathrm{Pd}})^{2k-n}\cos\frac{\pi}{4}(2k-n)}{k!}\left(\frac{\rho}{2}\right)^{2k-n}-$$

$$-\frac{1}{\pi}\,\mathrm{ber}_n(\rho)\left(1+\frac{1}{2}+\cdots+\frac{1}{n+k}+1+\frac{1}{2}+\cdots+\frac{1}{k}\right),$$

$$\mathrm{vei}_n(\rho)=\frac{2}{\pi}\,\mathrm{bei}_n(\rho)\ln\frac{C_1\sqrt{n\,\mathrm{Pd}}\,\rho}{2}+\frac{1}{2}\,\mathrm{ber}_n(\rho)-$$

$$-\frac{1}{\pi}\sum_{k=0}^{n-1}\frac{(n-k-1)!\,(\sqrt{n\,\mathrm{Pd}})^{2k-n}\sin\frac{\pi}{4}(2k-n)}{k!}\left(\frac{\rho}{2}\right)^{2k-n}-$$

$$-\frac{1}{\pi}\,\mathrm{bei}_n(\rho)\left(1+\frac{1}{2}+\cdots+\frac{1}{n+k}+1+\frac{1}{2}+\cdots+\frac{1}{k}\right). \tag{24}$$

Here $C = \ln C_1$ is Euler's constant.

Introducing the notation

$$\Delta_n^{(1)}=\mathrm{ber}_n(\rho_0)\,\mathrm{ver}_n(1)-\mathrm{bei}_n(\rho_0)\,\mathrm{vei}_n(1)-\mathrm{ver}_n(\rho_0)\,\mathrm{ber}_n(1)+\mathrm{vei}_n(\rho_0)\,\mathrm{bei}_n(1),$$
$$\Delta_n^{(2)}=\mathrm{bei}_n(\rho_0)\,\mathrm{ver}_n(1)+\mathrm{ber}_n(\rho_0)\,\mathrm{vei}_n(1)-\mathrm{ber}_n(1)\,\mathrm{vei}_n(\rho_0)-\mathrm{bei}_n(1)\,\mathrm{ver}_n(\rho_0),$$
$$\Delta=2\{[\Delta_n^{(1)}]^2+[\Delta_n^{(2)}]^2\}, \tag{25}$$

we obtain from system (21) the following explicit expressions for $\delta_n^{(1)}$, $\delta_n^{(2)}$, $\gamma_n^{(1)}$, $\gamma_n^{(2)}$, $\omega_{nk}^{(1)}$, and $\omega_{nk}^{(2)}$:

$$\delta_n^{(1)}=\frac{\gamma_n[\mathrm{ver}_n(\rho_0)\,\Delta_n^{(1)}+\mathrm{vei}_n(\rho_0)\,\Delta_n^{(2)}]+\beta_n[\mathrm{ver}_n(\rho_0)\,\Delta_n^{(2)}-\mathrm{vei}_n(\rho_0)\Delta_n^{(1)}]}{\Delta},$$

$$\delta_n^{(2)}=\frac{\beta_n[\mathrm{ver}_n(\rho_0)\,\Delta_n^{(1)}+\mathrm{vei}_n(\rho_0)\,\Delta_n^{(2)}]-\gamma_n[\mathrm{ver}_n(\rho_0)\,\Delta_n^{(2)}-\mathrm{vei}_n(\rho_0)\Delta_n^{(1)}]}{\Delta},$$

$$\gamma_n^{(1)}=\frac{\gamma_n[\mathrm{ber}_n(\rho_0)\,\Delta_n^{(1)}+\mathrm{bei}_n(\rho_0)\,\Delta_n^{(2)}]+\beta_n[\mathrm{ber}_n(\rho_0)\,\Delta_n^{(2)}-\mathrm{bei}_n(\rho_0)\,\Delta_n^{(1)}]}{\Delta},$$

$$\gamma_n^{(2)}=\frac{\gamma_n[\mathrm{bei}_n(\rho_0)\,\Delta_n^{(1)}-\mathrm{ber}_n(\rho_0)\,\Delta_n^{(2)}]+\beta_n[\mathrm{ber}_n(\rho_0)\Delta_n^{(1)}+\mathrm{bei}_n(\rho_0)\,\Delta_n^{(2)}]}{\Delta},$$

$$\omega_{nk}^{(1)}=\frac{\pi^2\lambda_{nk}^2J_n^2(\lambda_{nk})}{2\,[J_n^2(\lambda_{nk})-J_n^2(\lambda_{nk}\rho_0)]}\cdot\int_{\rho_0}^{1}[\delta_n^{(2)}\,\mathrm{bei}_n(\rho)-\delta_n^{(1)}\,\mathrm{ber}_n(\rho)+\gamma_n^{(1)}\,\mathrm{ver}_n(\rho)-\gamma_n^{(2)}\,\mathrm{vei}_n(\rho)]\,\rho V_n(\lambda_{nk}\rho)\,d\rho,$$

$$\omega_{nk}^{(2)}=\frac{\pi^2\lambda_{nk}^2J_n^2(\lambda_{nk})}{2\,[J_n^2(\lambda_{nk})-J_n^2(\lambda_{nk}\rho_0)]}\int_{\rho_0}^{1}[\gamma_n^{(1)}\,\mathrm{vei}_n(\rho)+\gamma_n^{(2)}\,\mathrm{ver}_n(\rho)-\delta_n^{(1)}\,\mathrm{bei}_n(\rho)-\delta_n^{(2)}\,\mathrm{ber}_n(\rho)]\,\rho V_n(\lambda_{nk}\rho)\,d\rho. \tag{26}$$

Finally the required temperature takes the form

$$\Theta(\rho,\ \varphi,\ \mathrm{Fo})=\left[(\Theta_1-\bar{\Theta})\frac{\ln\rho}{\ln\rho_0}+\bar{\Theta}\right]+\frac{1}{2}\sum_{n=1}^{\infty}A_nV_0(\lambda_n\rho)\,e^{-\lambda_n^2\mathrm{Fo}}+$$

$$+2\sum_{n=1}^{\infty}\{[\delta_n^{(2)}\,\mathrm{bei}_n(\rho)-\delta_n^{(1)}\,\mathrm{ber}_n(\rho)+\gamma_n^{(1)}\,\mathrm{ver}_n(\rho)-\gamma_n^{(2)}\,\mathrm{vei}_n(\rho)]\cos(n\varphi)-$$

$$-[\delta_n^{(2)}\,\mathrm{ber}_n(\rho)+\delta_n^{(1)}\,\mathrm{bei}_n(\rho)-\gamma_n^{(2)}\,\mathrm{ver}_n(\rho)-\gamma_n^{(1)}\,\mathrm{vei}_n(\rho)]\sin(n\varphi)\}+$$

$$+2\sum_{n=1}^{\infty}\sum_{k=1}^{\infty}\omega_{nk}^{(1)}V_n(\lambda_{nk}\rho)\,e^{-\lambda_{nk}^2\mathrm{Fo}}\cos[n(\varphi-\mathrm{Pd\,Fo})]+2\sum_{n=1}^{\infty}\sum_{k=1}^{\infty}\omega_{nk}^{(2)}V_n(\lambda_{nk}\rho)\,e^{-\lambda_{nk}^2\mathrm{Fo}}\sin[n(\varphi-\mathrm{Pd\,Fo})]. \tag{27}$$

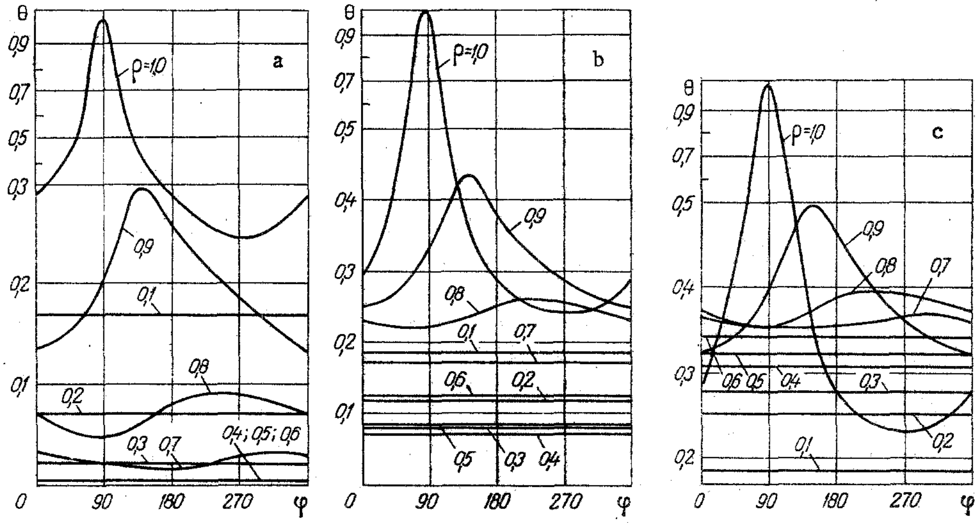

Fig. 2. Curves of the dimensionless temperature distribution in a radial cross section of roller: a) Fo = 0.01; b) 0.05; c) 0.5. φ is in deg.

To calculate the temperature distribution, the temperature was measured on the outer contour L of the cylindrical model with internal cooling, shown in Fig. 1.

It is expedient to write the boundary conditions on contour L as a finite sum instead of an infinite Fourier series. Experiments showed that the temperature distribution can be approximated with sufficient accuracy by the function

$$T_i(R,\ \varphi) = \bar{T}\left[1 + \sum_{n=1}^{m_1} a_{2n-1}\sin(2n-1)\varphi_i + \sum_{n=1}^{m_2} b_{2n}\cos(2n)\varphi_i\right], \tag{28}$$

where $\bar{T}$ is obviously the average temperature on the outer contour; $m_1 = m_2 = (s-1)/2$ if the number of points s at which the temperature is measured is odd; $m_1 = s/2$, $m_2 = (s-2)/2$ if s is an even number. The constants $\bar{T}$, a_{2n-1}, and b_{2n} are to be determined. We present the solution of system (28) for the temperature distribution shown in Fig. 1:

$\bar{T}a_1$	$\bar{T}a_3$	$\bar{T}a_5$	$\bar{T}a_7$	$\bar{T}b_2$	$\bar{T}b_4$	$\bar{T}b_6$	$\bar{T}b_8$	$\bar{T}$
84,00	—29,98	11,31	0,28	—49,60	20,00	—5,40	—1,87	151,87
β_1	β_3	β_5	β_7	γ_2	γ_4	γ_6	γ_8	$\bar{\Theta}$
0,2545	—0,0908	0,0343	0,0008	—0,1503	0,0606	—0,0164	—0,0057	0,3996

The coefficients $\bar{\Theta}$, β_n, and γ_n are found from Eqs. (4). The temperature of the channel wall T_1 is determined by the method described in [4].

TABLE 1. Roots of Characteristic Equations

k	n				
	0	1	2	3	4
1	3,3139	3,6077	4,0763	4,8619	5,9844
2	6,8576	7,0953	7,5518	8,3170	9,4100
3	10,3370	10,5830	11,0272	11,7720	12,8356
4	13,8864	14,0706	14,5027	15,2270	16,2613
5	17,3902	17,5582	17,9781	18,6821	19,6869

The following numerical values were used in calculating the temperature distribution: $T_1 = 82°C$ ($\Theta_1 = 0.1879$); $T_2 = 20°C$ ($\Theta_2 = 0$); R = 80 mm; R_0 = 8 mm; $\rho_0 = 0.1$; Pd = 350. The eigenvalues λ_n and λ_{nk} were obtained from the solution of the characteristic equations by using the McMahon formulas, given in [5]. Table 1 lists the roots of the present characteristic equations.

Figure 2a, b, c shows the distribution of the temperature Θ in a radial cross section at an angle φ for various Fo. It can be seen from the graphs that that for all practical purposes the steady state is reached for Fo ⩾ 0.5.

LITERATURE CITED

1. A. V. Lykov, The Theory of Heat Conduction [in Russian], Vysshaya Shkola, Moscow (1967).
2. É. Melan and G. Parkus, Thermal Stresses Arising from Steady Temperature Distributions [in Russian], Fizmatgiz, Moscow (1958).
3. G. N. Watson, A Treatise on the Theory of Bessel Functions, Macmillan, New York (1944).
4. M. A. Mikheev and I. M. Kikheeva, Fundamentals of Heat Transfer [in Russian], Énergiya, Moscow (1977).
5. A. Gray and G. B. Mathews, A Treatise on Bessel Functions and Their Applications to Physics, Macmillan, London (1952).

FLOW OVER BLUNT BODIES WITH SPIKES AND CAVITIES

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The influence of the shape of bodies of revolution with complicated generating lines on the coefficient of drag is investigated by the method of "large particles."

It is known that even a slight change in the shape of the generating lines of bodies of revolution has a strong influence on the aerodynamic coefficient of drag [1, 2]. The introduction of new elements of the generating lines, such as the presence of special features of the cavern or spike type on the front surface, can have all the more pronounced an influence on c_x.

"Bow" separation zones are characteristic of the flows around such bodies. Ever more attention is presently being paid to the investigation of separation flows [3, 4, and others]. The conducting of experiments at high velocities is connected with considerable, at times fundamental, technical difficulties, and such natural experiments are very costly, too. Therefore, it is desirable to use a numerical experiment for the solution of such problems [5]. The method of "large particles" [6] is used in the present report. Its use is desirable because it allows one to study nonsteady flows during streamline flow over blunt bodies having generating lines of complicated shape (including bends) without the isolation of any singularities. The spectrum of velocities of the oncoming stream is sufficiently wide, including sub-, trans-, and supersonic modes. The bodies of revolution with generating lines of arbitrary configuration, including sections with bends and concavities, were calculated by the method of "fractional cells" [7].

An analysis of the experimental and numerical results obtained allows us to make the following basic classification of modes with streamline flow over bodies with spikes (Fig. 1). We note that nonsteady modes were not considered.

The pattern of streamline flow over a cylindrical body of revolution with a "short" spike, when the distance of withdrawal of the shock wave from the body over which the flow occurs is greater than the length of the spike, is shown in Fig. 1a.

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