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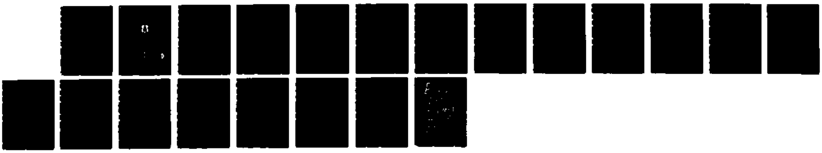

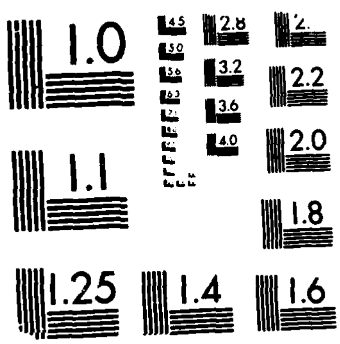

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FOREIGN TECHNOLOGY DIVISION

DETERMINING THE LOCAL COEFFICIENTS OF HEAT EMISSION OF A DISK WHICH IS ROTATING IN A HOUSING WITH JET BLOWING OFF WITH AIR

by

A.L. Kuznetsov

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HUMAN TRANSLATION

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By: A.L. Kuznetsov

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Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

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Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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DETERMINING THE LOCAL COEFFICIENTS OF HEAT EMISSION OF A DISK WHICH IS ROTATING IN A HOUSING WITH JET BLOWING OFF WITH AIR

A.L. Kuznetsov, candidate of technical sciences,

The article sets forth the results of tests for determining the local coefficients of heat emission of a rotating disk in the case of jet blowing off with air.

The results of tests on the heat emission of a disk, rotating in a housing with jet flow around, the description of the experimental installation, method and system of measurements were given in work [1]. However, subsequent processing of the test data prompted the necessity of making certain changes in them. These are covered in this article.

For example, in work [1] it was pointed out that the average dimensionless coefficient of heat emission Nu, for a ring with width ℓ (Figure 1), with an average radius R is determined from the expression

$$Nu_l = a_l Re_c^{0.8}\left[1 + b_l\left(\frac{u}{c_0}\right)^{0.8}\right], \qquad (1)$$

where $Nu_l = \frac{\alpha_l d}{\lambda}$; $Re_c = \frac{G_c}{0.785 z d \mu g}$; α_l - average coefficient of heat emission from the surface $f = 2\pi R \ell$; G_C - flow rate of air through the nozzle; d

- diameter of the nozzle; z - number of nozzles; R - radius of mounting of the nozzles; $a_l = 0{,}054 z^{0.85} \frac{d}{R} e^{-0{,}032 \frac{l}{d}}$; $b_l = \frac{0.27}{x^{0.3} e^{50x}}$; $x = \frac{zd^2}{Rl}$;

$u=\omega R$ - peripheral velocity of the disk on the radius of mounting of the nozzles; c_0 - velocity of adiabatic discharge from the nozzle; μ and λ - physical parameters of the air in the case of the temperature of the air in front of the nozzle t_0.

The amount of heat removed from the disk from the surface by means of convection was determined using formula

$$Q = a_l f \Delta t, \qquad (2)$$

where $\Delta t = t_\partial - t_0$ - temperature head, determined as the difference between the temperature of the surface of the metal of the disk and the temperature of the air on the input to the nozzles.

In accordance with equation (1) the values of the coefficient of heat emission and the criterion Nu on the radius of mounting of the nozzles are found from the expressions

$$\left.\begin{aligned} a_R &= 0{,}054 z^{0.85} \frac{d}{R} \mathrm{Re}_c^{0.8} \frac{\lambda}{d}; \\ \mathrm{Nu}_R &= 0{,}054 z^{0.85} \frac{d}{R} \mathrm{Re}_c^{0.8}. \end{aligned}\right\} \qquad (3)$$

In this case α_R and Nu_R virtually do not depend on the simplex $(u/c_0)^{0.8}$. On the basis of the theory of heat exchange α_R and Nu_R are the averaged values of the coefficient of heat emission and the criterion Nu for the area of a ring with width ℓ=d with an average radius R.

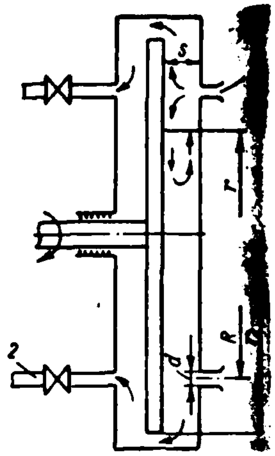

Figure 1. Layout of the installation: 1 - jet input of cooling air; 2 - removal of air.

As was pointed out in work [1], such a treatment of the test data also makes it possible to find the distribution of local coefficients of heat emission over the radius of the disk under the assumption of a symmetry of their profile relative to $R\left(\alpha\big|_{R+\frac{l}{2}}=\alpha\big|_{R-\frac{l}{2}}\right)$.

However, further processing of the test data showed that when rotation is present and there is a relatively small z there is considerable asymmetry of the profile of local coefficients of heat emission over the radius of the disk. However, a calculation of the temperature field of the disks of specific gas-turbine installations, cooled by jet blowing off, showed that disregard of the asymmetry α on the radius of the disk leads to a noticeable difference between the calculated distribution of temperature and actual. It follows from what has been said that the processing of test data has to be carried out while taking into account the local coefficients of heat emission separately for the radii of the disk r < R and for r > R.

Results of the tests for determining the local values of heat emission. The characteristics of the tests which were used for determining the local values of the coefficients of heat emission on the radius of a disk in the case of jet blowing off are given in the table.

d, мм	z	s в мм	R в мм	$y = \frac{r-R}{d}$	$y = \frac{R-r}{d}$	Re_c	u/c_0
8	2; 4; 8	8; 12,3; 32	207	4,5	4,625	$2{,}56\cdot10^4 \div 2{,}23\cdot10^5$	$0{,}0036 \div 0{,}965$
6	2; 4; 8	8; 12,3; 32	170; 207; 243	6,0; 6,17; 12,17	6,0; 6,17; 12,17	$2{,}46\cdot10^4 \div 2{,}175\cdot10^5$	$0{,}0037 \div 0{,}555$
4	4; 8	8; 12,3; 32	207	9,0	9,25	$2{,}66\cdot10^4 \div 8{,}9\cdot10^4$	$0{,}0039 \div 0{,}363$

The results of the tests were processed in criteria of similarity

$$Nu \frac{\alpha d}{\lambda} \quad \text{and} \quad Re_c = \frac{G_c}{0{,}785 z d g \mu}.$$

The structure of the criterial dependence was selected similar to equation (1)

$$Nu = a\, Re_c^{0,8} \left[1 + b \left(\frac{u}{c_0} \right)^{0,8} \right], \qquad (4)$$

where a and b - coefficients, just as in formula (1), depending on the magnitudes z, d, R, relative distance of the calorimeter from the radius of mounting of the nozzles y=(R-r)/d for r < R and y=(r-R)/d for r > R, and the width of the gap s.

The local value of the coefficient of heat emission α on the average radius of the calorimeter r was found from equation

$$\alpha = \frac{Q_K}{2\pi r b\,(t_\partial - t_0)},$$

where Q_K - amount of heat, removed from the calorimeter by means of convection; b - width of the calorimeter.

The influence of the magnitude of the gap on local heat emission in the case of a change of its values from s=d to s=8d $\left(\frac{s}{r_1} = 0{,}0267 \div 0{,}107\right)$

turned out to be negligible.

The nature of change in the local values of the coefficient of heat emission on the radius of a disk can be found conveniently and in a methodically correct manner in a comparison with the coefficient of heat emission on the radius of mounting of the nozzles, i.e., based on the ratio $(\alpha/\alpha_R)=(Nu/Nu_R)$.

The magnitudes of α_R and Nu_R are found by using equation (3).

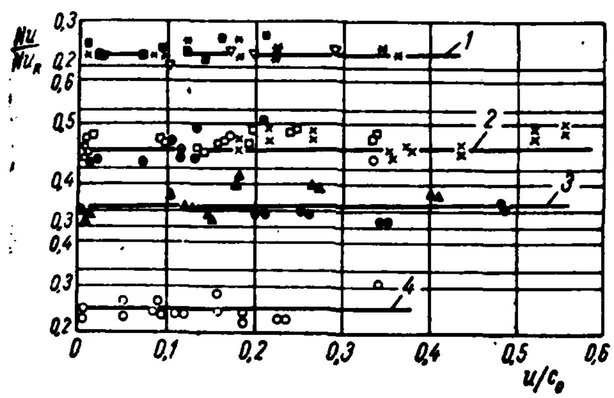

Figure 2. Dependence of Nu/Nu_R on u/c_0 for $r < R$:

1 – $y = \frac{R-r}{d} = 9{,}25$, $d = 4$, $z = 8$, $s = 8 \div 32$ мм; 2 – $y = \frac{R-r}{d} = 4{,}625$, $d = 8$, $z = 4$, $s = 8 \div 32$ мм; 3 – $y = \frac{R-r}{d} = 6{,}17$, $d = 6$, $z = 8$, $s = 8 \div 32$ мм; 4 – $y = \frac{R-r}{d} = 9{,}25$, $d = 4$, $z = 8$, $s = 12{,}3$ мм

Local values of the coefficients of heat emission for $r < R$. In Figure 2 the ratio Nu/Nu_R is given as it depends on u/c_0 for $r < R$ with different combinations of z, d, R, r, s, y. As is evident from the graph, for calorimeters, the average radius of which is less than the radius of mounting of the nozzles, the rate of rotation of the disk has virtually no influence on heat emission. This is explained by the fact that the flow, induced by the rotation of the disk, presses out toward the periphery that part of the jet flow which is flowing toward the center. Consequently on the surface of a disk lower than R there should be a lowering of heat emission, conditioned by jet blowing off. With an increase in the rate of rotation there is an increase in heat emission, caused by the rotation of the disk. Apparently these two factors compensate each other and the Nu number virtually does not depend on the ratio u/c_0. Evidently this result cannot be extended to a zone which is more removed from the radius of mounting of the nozzles than existed in the test, i.e., by $y=\frac{R-r}{d}>12{,}17$.

In connection with the fact that for $r<R$ the variable u/c_0 does not influence heat emission, the criterial dependence (4) is simplified considerably and

$$\mathrm{Nu}=a\,\mathrm{Re}_c^{0.8}, \qquad (5)$$

and the ratio

$$\frac{\mathrm{Nu}}{\mathrm{Nu}_R}=\frac{a}{0{,}054z^{0.85}\frac{d}{R}}. \qquad (6)$$

In expressing the test values of $\mathrm{Nu}/\mathrm{Nu}_R$ in a dependence on $y=(R-r)/d$, it is possible to establish in semilogarithmic coordinates (Fig. 3) that this dependence is determined by the equation

$$\frac{Nu}{Nu_R} = e^{-0.1836\,(y-0,5)} \approx e^{-0,18\,(y-0,5)}. \tag{7}$$

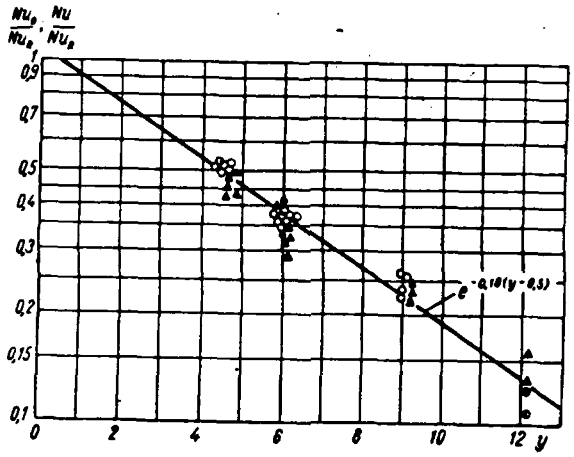

Figure 3. Dependence of the ratio Nu/Nu_R and Nu_0/Nu_R on y for $r < R$ (▲) and for $r > R$ (○).

The test values of the ratio Nu/Nu_R for each combination of z, d, R, y were determined from the expression

$$\frac{Nu}{Nu_R} = \frac{\sum_1^n \frac{Nu}{Nu_R}}{n},$$

where n - number of tests for a fixed combination of z, d, R, y, from which the coefficient a with respect to equations (6) and (7) turned out to be equal to

$$a = 0,054 z^{0,85} \frac{d}{R} e^{-0,18\,(y-0,5)}. \tag{8}$$

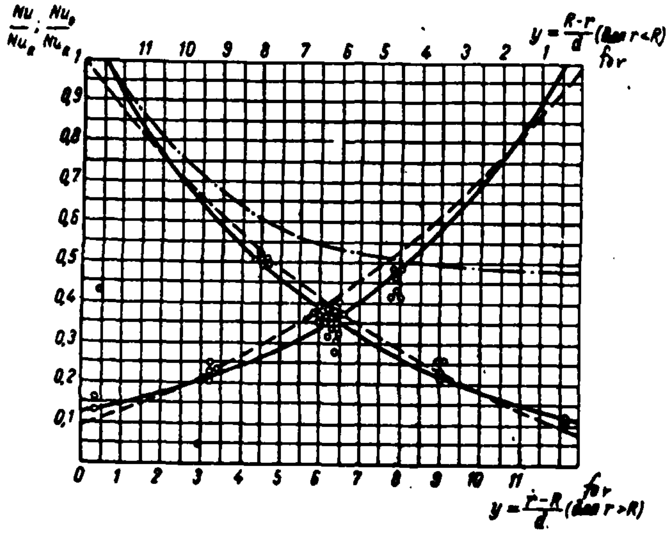

Figure 4. Dependence of the ratio Nu/Nu_R on y for radii which are greater and lesser than the radius of mounting of the nozzles: ________ - $Nu/Nu_R=e^{-0.18(y-0.5)}$; - - - - $Nu/Nu_R=(1-0.064y)e^{-0.064y}$ - local values of Nu/Nu_R, obtained from equation (1) with $u/c_0=0$; - · - - Nu/Nu_R - according to equation (4) with $u/c_0=0.5$; z=4; r > R.

Local values of coefficients of heat emission for r > R. In this case the ratio Nu/Nu_R depends on y and u/c_0, as a result of which the coefficients of heat emission are determined rationally in conformity with equation (4).

Coefficient a was found from tests, in which the influence of u/c_0 was negligible ($u/c \approx 0$). Plotting the test values of Nu_0/Nu_R in a dependence on y in the semilogarithmic coordinates (Figure 3), it can be established that this dependence is described by the equation

$$\frac{Nu_0}{Nu_R} = e^{-0,1736\,(y-0,5)} \approx$$

$$\approx e^{-0,18\,(y-0,5)}, \qquad (9)$$

where $Nu_0 = Nu|_{\frac{u}{c_0} \approx 0}$.

The test values of Nu_0/Nu_R for each combination of z, d, R, y were determined from the expression

$$\frac{Nu_0}{Nu_R} = \frac{\sum_1^n \frac{Nu_0}{Nu_R}}{n},$$

where n - number of tests for a given combination of z, d, R, y and $(u/c_0) \approx 0$.

The magnitude of coefficient a when $z > R$ in accordance with equations (6) and (9) is obtained equal to

$$a = 0,054 z^{0,85} \frac{d}{R} e^{-0,18\,(y-0,5)}. \qquad (10)$$

Thus for the case $r < R$ - when rotation is present and absent, and for $r > R$ - when rotation is absent, the profile of the local coefficients of heat emission turned out to be symmetric relative to R.

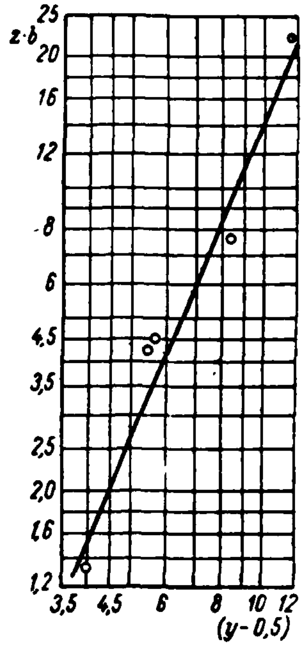

Figure 5. Dependence of zb on (y-0.5): ________ - $zb=0.05\ (y-0.5)^{2.45}$ (the points correspond to zb, averaged from 30-60 tests).

Figure 4 shows the ratio Nu/Nu_R when $r < R$ and Nu_0/Nu_R when $r > R$ depending on y. It is evident from the drawing that a satisfactory agreement of the test values is attained both with the dependences (8) and (9) and with the dependence obtained from equation (1) (broken line).

The dependence Nu/Nu_R according to equation (4) produces a concept about the nature of the increase in heat emission from rotation of the disk for the case $r > R$.

During rotation of the disk in conformity with equation (4) the test values of coefficient b, taking into account the increase of heat emission due to rotation, were found from expression

$$b = \frac{\sum_{1}^{n} \frac{\frac{Nu}{Nu_0} - 1}{\left(\frac{u}{c_0}\right)^{0,8}}}{n}, \qquad (11)$$

where n - number of tests for the fixed combination of z, d, R, y.

The dependence of coefficient b on the number of nozzles z for fixed combinations of d, R, y is described satisfactorily by equation

$$b \approx \frac{1}{z}. \qquad (12)$$

It follows from here that it is advisable to conduct further processing of the test data in the form of the dependence

$$zb = f(d, R, y).$$

It turned out that the variable zb depends only on y=(r-R/d). The influence of the radius of mounting of nozzles R and their diameter d on the variable zb could not be established.

Figure 5 gives in logarihtmic coordinates the test dependence of zb on (y-0.5), which is approximated satisfactorily by the expression

$$zb = 0{,}05\,(y - 0{,}5)^{2.45}, \qquad (13)$$

where the constant coefficient and the exponent were determined by the method of least squares.

The generalizing dependence for coefficient b has the form

$$b = 0{,}5\,\frac{(y - 0{,}5)^{2.45}}{z}. \qquad (14)$$

All the test data for heat emission of a disk, rotating in a housing with jet blowing off of air, and depending on the number Re_c, are given in Figure 6, from which it is evident that the test points in both cases agree with a curve which is proportional to $Re_c^{0.8}$.

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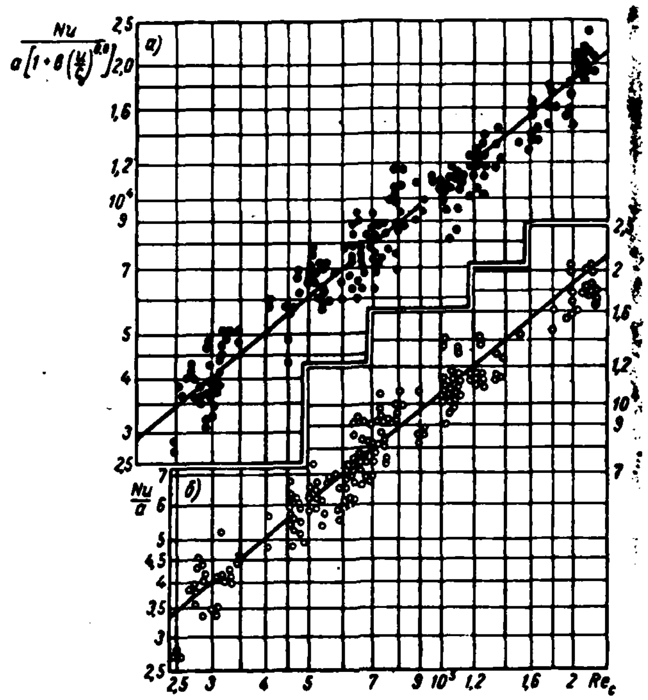

Figure 6. Dependence of heat emission of a dis[illegible] rotating in a housing with jet blowing off by air, on the Re_c number:

$$a - \frac{Nu}{a\left[1 + b\left(\frac{u}{c_0}\right)^{0,8}\right]} = f(Re_c) \text{ for } r > R; \quad б - \frac{Nu}{a} = f(Re_c) \text{ for } r < R$$

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