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FEATURES OF GAS FLOW IN RADIAL CLEARANCES OF UNBANDERING BLADES WITH HONEYCOMB SEALS

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Abstract

On the basis of experimental research of turbine stage radial clearance honeycomb seals some physical phenomena were studied when flowing blade tip areas and the design procedure of energy losses was suggested.

Keywords: radial clearance, honeycomb seal, turbine stage, blade, flow in stage, diameter of honeycomb cell, depth of honeycomb cell, leakage.

The analytical calculation of radial clearances influence on efficiency of the turbine stage is connected with large mathematical difficulties. Learning of physical essence of happening effects in blade tip areas and confirmation of outcomes by appropriate experimental data has a great significance.

The structure of three-dimensional flow and the mechanism of tip losses origin in many respects depend on size of the radial clearance.

By increasing a radial space the intensity of blade tip vortexes considerably rises. Besides, together with the growth of the intensity of the vortex development the area surrounded by vortex motion of a flow is dilated [1].

On the one hand, the process of flow in near wall layer at the limiting surface is determined by friction, and on the other – by dynamic interaction with the basic flow. The part of near wall layer will be carried away by this flow because of the effect of overflowing through the butt end of a blade (under the influence of pressure difference on the concave and convex parts of a blade).

A considerable proportion of the heat transfer medium overflowing through the butt end of a blade is involved by the vortex at the blade back into the main flow deeply enough within the blade channel limits.

If the size of a clearance is significant, the part of near wall layer will be dilated in an axial direction under the influence of pressure differential in a lattice.

The registration of physical essence of the phenomenon in a clearance allows to analyze test data uniformly and to recommend semiempirical dependences.

One of the perspective directions of increasing profitability and reliability of gas turbine activity can be reduction of radial clearances of working and guide vanes with the help of honeycomb seal installation.

The presence of cellular structure on the radial clearance wall requires research of its influence on the flow of overflowing over the butt ends of blades.

The honeycomb surface creates additional resistance in the case of particular geometrical parameters of cells and particular ratio of honeycomb seal sizes: shape of cells, size of their diameter, and also depth in relation to the size of a clearance, width of a profile in cross-sections etc.

Gas pressure in cells periodically changes because of the pressure difference on surfaces of a profile in rotor bladings when moving them relative to the honeycomb surface. Thus in cells there is a pressure oscillation with frequency of rotor bladings passing relative to the space of a cell.

In this connection, quantity of gas pulsing in cells of honeycomb seal is eliminated from the general consumption of a flow determining useful work of the turbine. It entails appropriate reduction of the turbine efficiency.

Besides, the pulsing gas mixing with the basic flow considerably deforms fields of parameters of the heat transfer medium in peripheral sections of blades, specially at resonant effects also influencing vibrational conditions of aggregates.

Research of the three-dimensional flow structure in a honeycomb cell volume [2] has shown essential interaction interference of the flow in space of a honeycomb cell and flow in a channel under a cell. This interaction of flows specially appears in model of a hexahedral cell in comparison with a rectangular one.

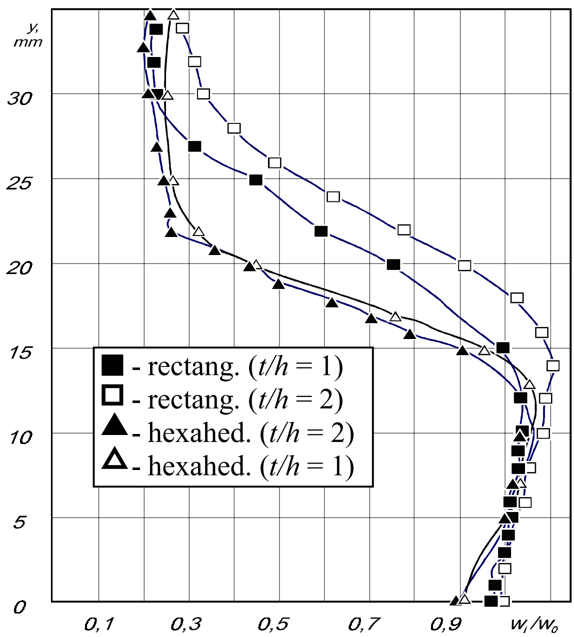

Fig. 1. Matching of hexahedral and rectangular cells on value of relative velocity W_i / W_0

In *Fig. 1* the diagrams of relative axial speeds on the altitude of a clearance are adduced. One of the walls is made as a rectangular or a hexahedral cell (*Fig.2*)

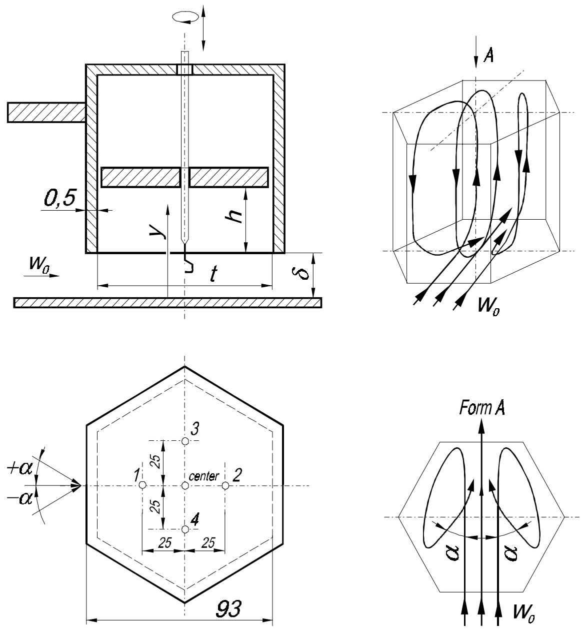

Fig. 2. Model of hexahedral cell and scheme of flow in it

with the different size t/h, where t – width of a cell, h – depth of a cell.

At the bottom of a clearance ($y = 10$ mm) we may consider the concurrence of diagrams of speeds for all versions of honeycombs designs as satisfactory. The considerable reduction of speed (with $y = 15 \ldots 30$ mm) in hexahedral honeycombs in comparison with rectangular ones is explained by interaction of vortex flows in a cell and in a clearance because of change of angles in a horizontal plane (*Fig.2*).

It is necessary to mark different interactions of flows by change of geometrical parameter t/h.

Further researches of a three-dimensional flow structure in channels with honeycomb walls allow to establish capability for optimization of honeycomb structure for detection of influence on the ratio process of geometrical parameters of such seals.

In *Fig. 3* some outcomes of leakage dependence in honeycomb seal are given at different combinations of diameter sizes and depth of a honeycomb cell, and also size of a radial clearance.

The executed researches have allowed to present values of hydraulic resistance of channels with honeycomb walls as an extending relation $\xi = c \cdot \mathrm{Re}^n\,(\delta/d_c)^m\,(h_c/d_c)^\ell$, where ξ – drag coefficient of a channel, δ – quantity of a clearance, d_c – diameter of cell honeycombs, h_c – depth of cell honeycombs, c – coefficient.

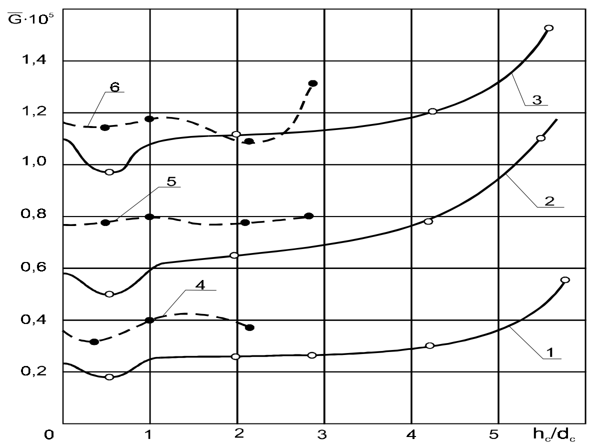

Fig. 3. Experimental relations of reduced rate to relative depth of cells of honeycomb seal at different clearances: $1 - \delta = 2$ mm, $d_c = 3.5$ mm, $(\delta/d_c = 0.57)$; $2 - \delta = 4$ mm, $d_c = 3.5$ mm, $(\delta/d_c = 1.14)$; $3 - \delta = 6$ mm, $d_c = 3.5$ mm, $(\delta/d_c = 1.71)$; $4 - \delta = 2$ mm, $d_c = 7.0$ mm, $(\delta/d_c = 0.29)$; $5 - \delta = 4$ mm, $d_c = 7.0$ mm, $(\delta/d_c = 0.58)$; $6 - \delta = 6$ mm, $d_c = 7.0$ mm, $(\delta/d_c = 0.86)$.

In the research of stages with honeycomb seals the particular features of gas flow in peripheral sections of rotor bladings were detected.

So, in *Fig. 4* the outcomes of traversing of a flow behind an impeller of a turbine stage with smooth and honeycomb seal are shown.

In *Fig. 5* the scheme of a flowing part of a turbine stage and points of measurements of flow parameters are shown.

The geometrical parameters of a stage are given in *Table 1*.

A considerable variation of flow parameters and presence of large axial speeds are observed by sealing ‘the smooth wall’ in the peripheral part of a blade and in the zone of a radial clearance. This explains additional leakages of a propulsive mass and, therefore, growth of losses. For stages with honeycomb seals these effects are not observed. This explains much higher efficiency in such stages.

In *Fig. 6* the dependence of relative efficiency $\overline{\eta}_{0i} = \frac{\eta_{0i}}{\eta_{0i\delta=0}}$ on the size of a relative radial clearance $(\overline{\delta} = \delta/l)$ is shown with particular parameter $u/C_0 = 0.65$ for versions of sealing (smooth and honeycomb).

There is a higher pace of efficiency reduction when increasing radial clearance for the stage with smooth seal. This feature of honeycomb seals should be taken into consideration when defining the influence of the increased radial clearances, generating during plant operation.

The structure of three-dimensional flow in blade channels of the turbine nozzles explains the mechanism of tip losses due to influence of the radial clearance.

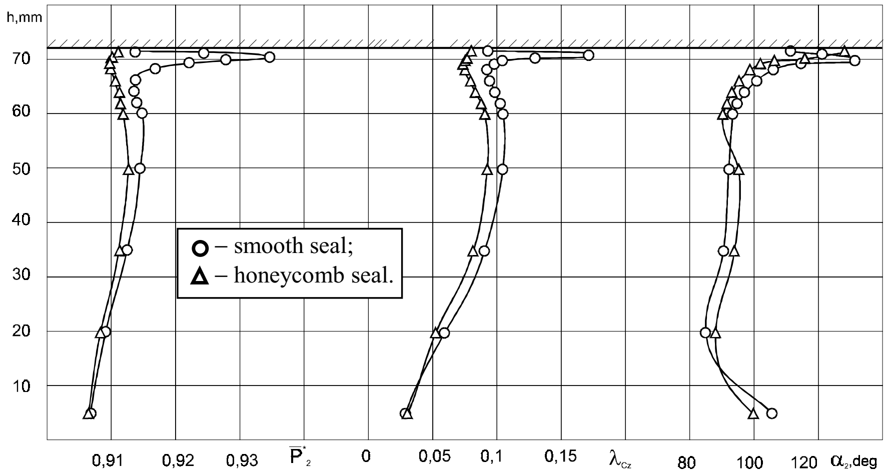

Fig. 4. Distribution of the basic parameters of a flow ($\overline{P}^*_2, \lambda_{Cz}, \alpha_2$) behind the impeller

Table 1. The geometrical parameters of a stage

No	Parameter	Measure	Stator	Impeller
1	Diameter of mean circle, D_m	mm	383.3	382.5
2	Altitude of a blade, l	mm	70.3	71.5
3	D_m/l	–	5.45	5.35
4	Chord of a blade, b	mm	60	23.2
5	l/b	–	1.17	3.08
6	Number of blades, z	p.	36	70
7	Blade spacing, t	mm	33.44	17.16
8	$(t/b)_m$,	–	0.56	0.74
9	Width of an output edge, y_{outp}	mm	0.25	0.3
10	y_{outp}/b	–	0.004	0.013

The executed researches demonstrate that energy losses in a nozzle considerably increase at the expense of a radial clearance in root section of guide vanes. Thus the influence of a clearance on overall performance of a stage is much more than radial clearance in an impeller, and, unlike an impeller, it spreads on all altitudes of a blade, that causes considerable reduction of stage efficiency.

In *Fig. 7* the distribution of flow parameters behind a nozzle of one of turbine jets is given.

The reduction of a radial clearance in root section of a nozzle or usage of its effective sealing is a great enough reserve of increase of stage profitability.

The application of honeycomb seals on ends of blades butt of nozzles allows

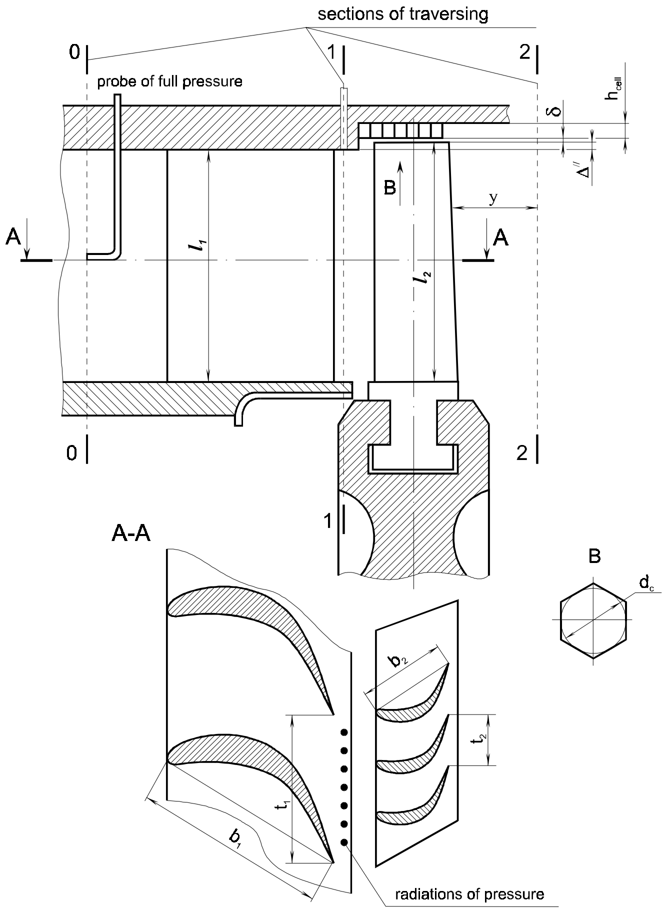

Fig. 5. The scheme of a flowing part and measurements

to decide profitability of a power plant successfully. The reduction of a radial clearance is not accompanied by destruction of a blade in case of grazing by a curl of honeycomb structure as a result of thermal extensions of a turbine casing. However, experimental researches of flow in honeycomb seals are necessary for inserting amendments into empirical relations on influence of radial space in nozzles of turbines on overall performance of stages.

The detected features of gas flow in honeycomb seals allow to correct physical picture of effects and to make some methodical corrections to the known relations on influence of radial spaces on overall performance of the turbine.

So, the following physical flow pattern of a flow in a radial clearance with honeycomb seal influencing losses from overflow of the heat transfer medium in a radial space is represented. In a cavity of a radial clearance there is a composite

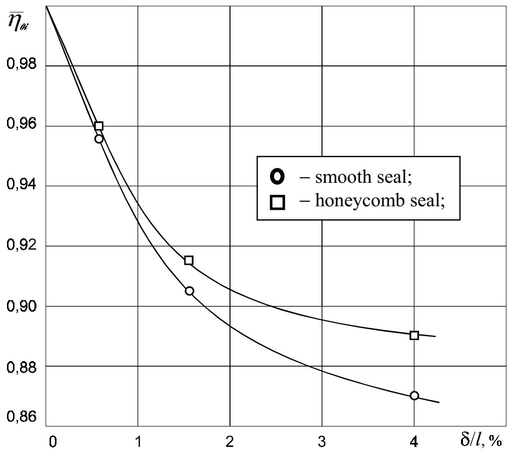

Fig. 6. The dependence of efficiency $\overline{\eta}_{0i}$ on the size of a radial clearance if $u/C_0 = 0.65$

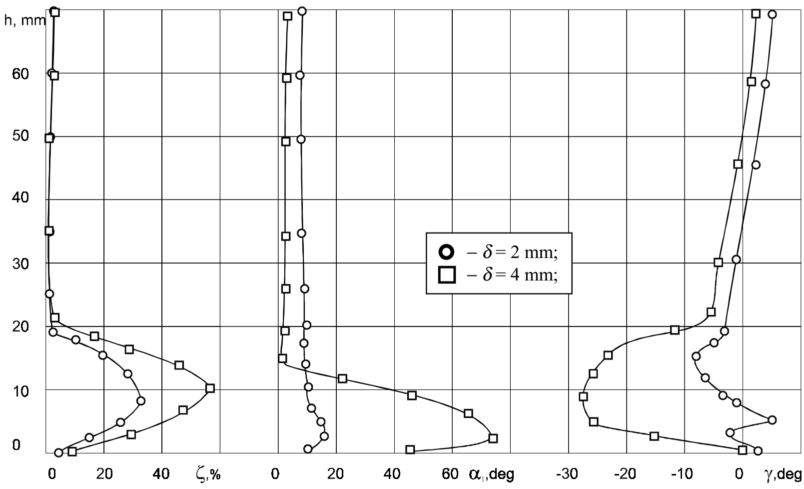

Fig. 7. Distribution of parameters of a flow $(\zeta, \alpha_1, \gamma)$ behind a nozzle

flow of gas when interacting with pair vortex [3]. Peripheral jets of gas leaving a nozzle are moving through ring section of a clearance. Besides through a radial clearance there is an overflow of gas from the concave part of a blade to the convex one.

If a wall of the turbine casing is smooth, to take into account losses in a radial clearance, the efficiency of stages calculated without a radial clearance should be reduced according to [3] to the value

$$\eta_c = 1 - \Delta\eta_c = 1 - \overline{\delta}\frac{\rho''}{\rho_m}\left[1 + \frac{0.3}{\sin\beta_2}\left(\frac{b}{t}\right)''\right],$$

where $\overline{\delta} = \frac{\delta}{h}\left(1 + \frac{h}{D_m}\right)$, ρ – density of gas, b – value of a chord of a profile, t – step of rotor bladings.

The value 0.3 is connected to a flow coefficient through a clearance. If for smooth sealing $\mu = 0.6$, for honeycomb seal the flow coefficient depends on very many factors, including conditional ones. According to our data (*Fig.6*) the efficiency for the honeycomb seal depending on increase of a clearance reduces to a less degree than for the smooth seal.

The phenomenon of 'latching' of a clearance in honeycomb seal determines the tendency of increasing the efficiency, which counteracts leakage increase in a radial clearance.

In a nozzle the influence of a radial clearance in the case of smooth seal is estimated by the formula [4]

$$\eta_T = \frac{\eta_T}{\eta_{T\delta=0}} = 1 - \frac{\kappa_\eta}{\eta_T}\left(3.2 - 0.0465\alpha_1\right)\overline{\delta},$$

where κ_η – an experimental factor; $\kappa_\eta \approx 0.9\ldots1.1$; α_1 – angle of exit of a flow from a nozzle; $\overline{\delta}$ – relative clearance; $\overline{\delta} = \delta/l$.

The value $(3.2 - 0.0465\alpha_1)$ depends on a ratio and flow coefficient through a clearance, which value is received for smooth seal $\mu = 0.5\ldots0.8$. For honeycomb seal the value should be determined for appropriate conditions, depending on geometrical parameters of honeycomb seal. The charts of relations $\overline{\eta_T} = f(\overline{\delta})$ for nozzles with radial clearances allow to forecast influence of a radial clearance changing on stream, and also to make decision on reduction of radial spaces in the cases of application of honeycomb seals.

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