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THE ANALYSIS OF TEMPERATURE FIELDS IN THE VICINITY OF SHAPED HEAT EXCHANGE SURFACES BY NATURAL CONVECTION

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Abstract: *The paper is focused on research into heat transfer in a vertical arrangement of shaped heat exchange surfaces. Regulating elements, whose task was to reduce the thickness of a thermal boundary layer and thus to increase the values of local heat transfer coefficients, were placed into freely flowing air in order to intensify heat transfer. A non-contact method of holographic interferometry was used to visualise temperature fields in the vicinity of a shaped heat exchange surface.*
Keywords: *heat transfer, interferometry, ribs*

1. INTRODUCTION

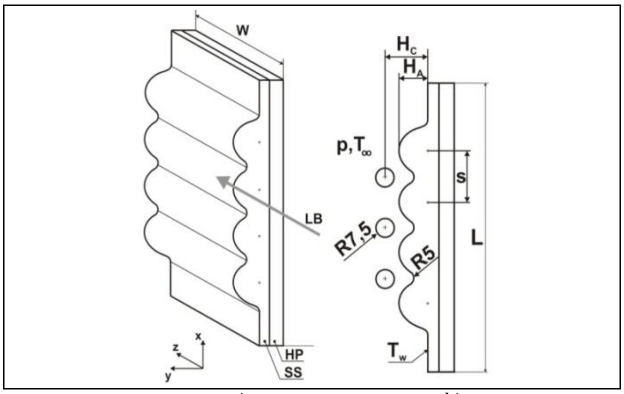
Several authors dealt with the issue of heat transfer in the vicinity of shaped vertically arranged heat exchange surfaces. Leong & Kooi [8] performed the experiments of temperature field visualisation by natural air convection in a transient flow mode from short vertical rectangular ribs using holographic interferometry. The succession of interferograms recorded in a heating mode of aluminium panels shows the influence of panels on local heat transfer coefficients. Viswatmula & Amin [13] studied qualitative data representing the natural air convection in vertical channels with two rectangular hindrances on the sides facing each other. Pavelek [11] dealt with research into heat transfer by natural air convection in a system of heated vertical plates with constant surface temperatures. He investigated natural convection heat transfer on vertical plates and in slots on a model by an interferometric method. Ambrosini & Tanda [1] experimented with natural air convection in vertical channels by means of holographic interferometry and a schlieren method to show the distribution of temperatures and local heat transfer coefficients. They aimed at a vertical smooth and grooved channel. The work of Lu et al. [9] presents experimental research of heat transfer by natural air convection in three thin rectangular channels with different gap distances. These vertical rectangular channels were composed of two stainless steel plates and heated electrically. Naylor and Lai [10] carried out an experimental study on natural air convection in a double glazed window with a between-panes Venetian blind. The Mach-Zehnder interferometer was used for the visualisation of temperature fields and the research of local and mean heat transfer values. The Venetian blind consisted of seventeen horizontal aluminium lamellas. The visualisation of a temperature field and measurements were made for three platesspacings and three angles of displacement of the Venetian blind lamella. A space was filled with gas. The results show that the between-panes Venetian blind has a strong influence on the local and mean heat transfer values.

2. HEAT TRANSFER IN THE VICINITY OFA VERTICAL PLATE

Natural air convection rises from the impact of different fluid density in a given volume. The difference of fluid densities caused by a different temperature near the surface of a heated wall and in its vicinity causes lift forces and therefore fluid ascends along the wall while cooler fluid from the vicinity flows in on its place. In the paper we deal with heat transfer in the vicinity of vertically heated plates by free air convection in unlimited space [7].

2.1 Geometry of designed and produced heat exchange surfaces

The research of heat transfer was carried out on vertically arranged heat exchange arc-shaped surfaces. Examined surface geometry is shown in Fig. 1 which also indicates the direction of laser beam transfer through the measuring space (Fig. 1a). The length and width of the examined heat exchange surface was L x W (200 x 200 mm).

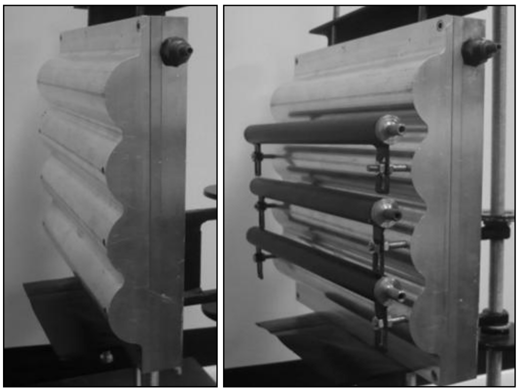


a) b)

Fig. 1 Geometry of examined heat exchange surface
a) indicated direction of laser beam transfer in measured space
b) arrangement of regulating elements toward the surface
W, L – width and length of heat exchange surface, H_C – height of regulating elements (ducts), H_A – height of the arc ridges, s – spacing between arc ridges, T_w – surface temperature, T_∞ – ambient temperature, p – ambient pressure, LB – laser beam, HP – heating plate, SS – shaped surface

The height of each arc-shaped surface was H_A = 20 mm and the height of regulating ducts placement toward a basic plate was H_C = 28 mm. The spacing between the arc contours was s = 40 mm (Fig. 1b).

Shaped surfaces and heating plates are made of aluminium alloy and their real pattern is shown in Fig. 2.



a) b)

Fig. 2 Produced heat exchange surfaces
a) arc contour without regulating ducts
b) arc contour with regulating ducts

For the uniform heating of shaped surfaces the heating plates have meandering inner surface (Fig. 3) and therefore uniform heat flow from the heating plates into the shaped surfaces is provided [2].

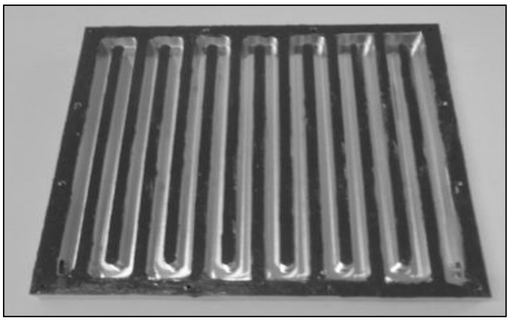


Fig. 3 Meandering inner surface of the heating plate

3. VISUALISATION OF TEMPERATURE FIELDS BY HOLOGRAPHIC INTERFEROMETRY

The analysis of temperature fields in the vicinity of vertical surfaces was carried out by holographic interferometry which enables to visualise inhomogeneity in fluids due to their different refractive index [5]. The research was conducted on the assembled holographic variant of Mach-Zehnder interferometer (Fig. 4).

Interferometry belongs to the most accurate optical methods for visualizing temperature fields. An observed action can be directly qualitatively evaluated from the obtained records. For the quantitative evaluation it is first necessary to determine the distribution of the refractive index in the object and then to calculate the distribution of required physical quantities from it [3]. For ideal gases it is possible to express the refractive index as a function of density from the Gladstone-Dale relation:

$$n = 1 + K \cdot \rho \qquad (1)$$

where, K – Gladstone-Dale constant [-], ρ – ambient density [kg.m^{-3}].

An interference method of the research of phase objects is based on the interaction of two coherent waves, one of which is distorted by passing through an optical inhomogeneity and the other passes through an optically undisturbed area. The alternating maxima and minima of luminous intensity, interference fringes from which changes of a refractive index in a monitored area can be determined might then be seen on the ground glass.

A holographic interferometer can operate in real time or by a double-exposure method. By this method two different states of the same transparent object are recorded on one holographic plate. A more suitable method is the method in real time when only one reference state of the transparent object is recorded on the holographic plate. In the reconstruction it consequently interferes a reconstructed object beam with a real object beam passing through the monitored object in a different state and that all happens in real time.

Fig. 4 shows a holographic variant of the Mach-Zehnder interferometer. A light beam from the laser (1) after the reflection on the mirror is divided on the beam splitter (2) into an object beam and a reference beam. The object beam is by means of a system – micro-objective lens and spatial filter (3) and objective lens (4) modified to a parallel beam of a larger diameter, passes through the measuring space and falls on the holographic plate – hologram (9).

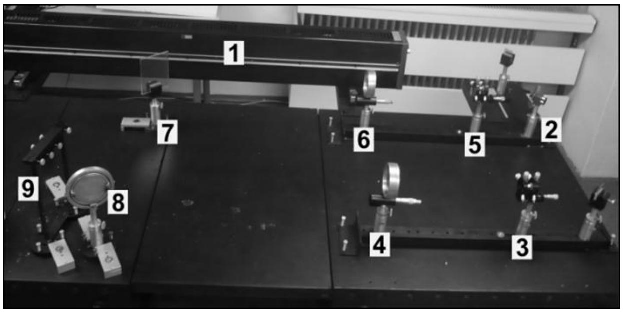


Fig. 4 A system of a holographic variant of the Mach-Zehnder interferometer
1 –laser, 2 – beam splitter, 3 and 5 – micro-objective lens and spatial filter, 4 and 6 – objective, 7 and 8 – mirror, 9 – holographic plate

The reference beam modified by the system (micro-objective and spatial filter (5) and objective (6)) to a parallel beam of a larger diameter is consequently reflected from the mirrors (7 and 8) and also falls on the holographic plate (9). If we want to use the device for transparent objects, we will perform a holographic record of the object beam without inhomogeneity in the measuring space.

After photochemical processing of the holographic plate it is necessary to place it back to the system and illuminate it by the reconstructed beam which should be identical with the reference beam. A reconstructed object beam identical with the original one is created. This reconstructed beam interferes with the real one. Resulting interference, which is the image of inhomogeneity in the measuring space, can be traced using a CCD camera. The objective lens and a ground glass which allow recording the image of a temperature field to the CCD camera are behind the holographic plate.

3.1 Determination of heat transfer parameters

Within the quantitative analysis local values of heat transfer coefficients at locations x (in Fig. 2 and 3 indicated as sections) along the vertical surface were determined from the images of holographic interferograms:

$$\alpha_x = \lambda \left| \frac{\partial T}{\partial y} \right|_{wx} \frac{1}{T_{wx} - T_\infty} \qquad (2)$$

where, λ – coefficient of thermal air conductivity [$W.m^{-1}.K^{-1}$], T_{wx} – surface temperature at location x [K], T_∞ – fluid temperature (vicinity) [K], [11].

Heat transfer from the vertical heat exchange surface can be solved after applying the local Nusselt and Grashof number:

$$Nu_x = \left| \frac{\partial T}{\partial y} \right|_{wx} \frac{x}{T_w - T_\infty} \qquad (3)$$

$$Gr_x = \frac{g \cdot x^3 \cdot \beta \cdot (T_w - T_\infty)}{\nu^2} \qquad (4)$$

where, β – volume expansion coefficient [K^{-1}], ν – kinematic viscosity of air [$m^2.s^{-1}$], [12].

Mean values of the Nusselt and Grashof number can be expressed in the form [11]:

$$Nu_m = \frac{\alpha_m \cdot L}{\lambda} \qquad (5)$$

$$Gr_m = \frac{g \cdot L^3 \cdot \beta \cdot (T_w - T_\infty)}{\nu^2} \qquad (6)$$

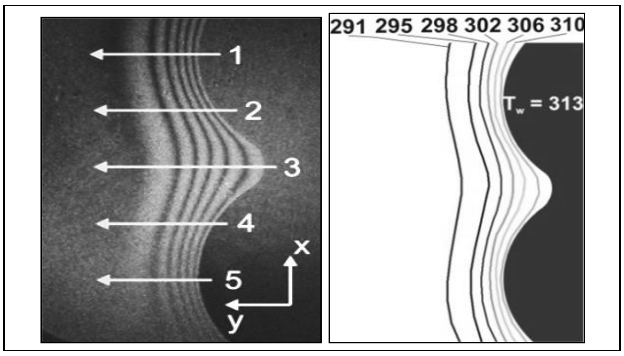
where, L – length of heat exchange surface [m].

The shape and size of a body, body surface temperature and fluid temperature as well as physical properties of fluid, in case of forced convection the mode of flow, have an influence on the process of heat transfer and therefore also on the values of heat transfer coefficients [7].

4. EVALUATION OF IMAGES OF HOLOGRAPHIC INTERFEROGRAMS

In Fig. 5,6 there is a demonstration of interferograms of temperature fields in one of the heat exchange surface parts where the effect of a regulating duct on local values of heat transfer coefficients $\alpha_x$was analysed.

It was first evaluated the shaped surface without regulating elements and consequently regulating elements with a diameter of 15 mm were placedover the heat exchange surface.

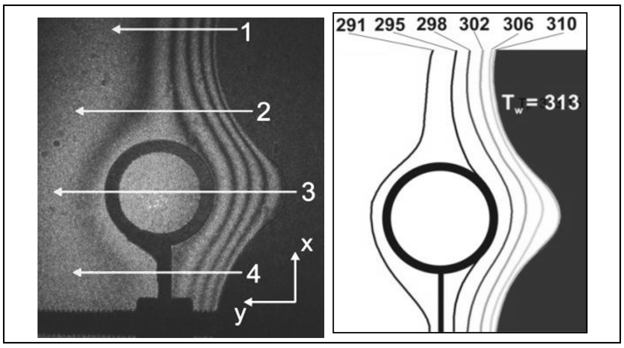


a) b)

Fig. 5 Part of theheat exchange arc surface
a) interferogram of the temperature field with indicated sections
b) temperature distribution in the vicinity of the arc contour in Kelvin

Section	1	2	3	4	5
α_x [$W.m^{-2}.K^{-1}$]	3.89	3.57	2.15	3.39	4.08

Tab. 1 Values of local heat transfer coefficients along the shaped surface without regulating ducts



a) b)

Fig. 6 Part of the heat exchange arc surface with a regulating duct
a) interferogram of the temperature field with indicated sections
b) temperature distribution in the vicinity of the arc contour in Kelvin

Section	1	2	3	4
α_x [$W.m^{-2}.K^{-1}$]	4.69	3.82	2.93	3.81

Tab. 2 Values of local heat transfer coefficients along the shaped surface with regulating ducts

The temperature at the heated plate surface was 313 K and the ambient temperature was 291 K.The results of local heat transfer coefficients along the arc contour without a regulating duct and with the regulating duct are graphically shown in Fig. 7.

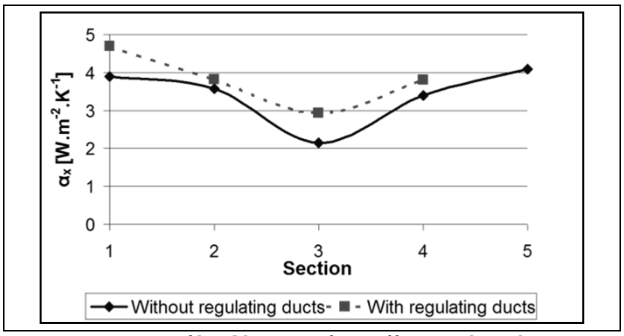


Fig. 7. Comparison of local heat transfer coefficients along the arc contour without a regulating duct and with a regulating duct

From the graph it is obvious that the regulating element affected the values of local heat transfer coefficients along the observed heat exchange surface.

5. VISUALISATION OF TEMPERATURE FIELDS BY THERMOVISION

Temperature fields in the vicinity of shaped heat exchange surfaces were also visualised by the thermovision camera FLIR i7 (Fig. 8). An infrared camera can be used for visualizing the temperature fields and on the basis of gained thermal images even the smallest temperature differences at the surface of the measured object can be detected. The surface temperature of a heat exchange surface was 323.15 K. A key element which affected the accuracy of measurement and the sensitivity of immediate temperature changes was a visualised element with required emissivity. Thin paper with the emissivity of 0.5 which thanks to its low thermal conductivity and density responds immediately to the change of the ambient temperature was used as a visualised element [4].

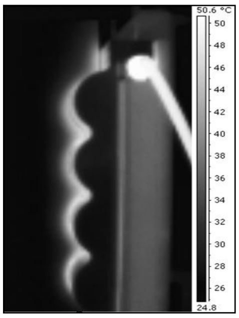


Fig. 8 Demonstration of a temperature field in the vicinity of an arc contour of vertical heated plates by natural air convection

Temperature fields copy the shape of a heat exchange area but on the ridges of the heat exchange area the thickness of a boundary layer decreases and therefore thermal resistance also decreases. All the factors affecting the accuracy of measurement were observed during the measurements by a thermovision camera. A temperature deviation of a monitored surface of a visualised element from the ambient temperature is the most significant factor. Several different factors, which need to be taken into consideration when making thermovision measurements, have an influence on the measurement by a thermovision camera. These are mainly the size of a recorded body, segmentation of a recorded body surface, properties of a recorded surface, as well as the influence of external sources of infrared radiation [4, 6].

6. CONCLUSIONS

The paper is focused on research into a convective component of heat transfer in the vicinity of shaped heat exchange surfaces. An interferometric method was used for visualizing the temperature fields in the vicinity of heat exchange surfaces. We tried to increase the local values of heat transfer coefficients by placing the regulating elements over the shaped surface. From the calculated local heat transfer coefficients along the shaped surface it is clear that the regulating elements have an influence on more intensive heat transfer. In the area where sections 1 and 3 are indicated an increase in local heat transfer coefficients with the use of regulating ducts was the most significant. Knowledge from the experiment can be used in devices for taking heat away for the purpose of cooling.

7. ACKNOWLEDGEMENTS

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