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ANALYSIS OF THE SELECTED INVERSE PROBLEMS OF HEAT CONVECTION.

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Abstract. *In the paper, selected inverse problems of heat convection are presented. The main focus is put on the sensitivity coeffcients idea. The formulation and evaluation of sensitivity coefficients are presented for several cases. The are shown in 2D and 3D geometry. Two ways of eveluation of sesnsitivity coefficients are shown.*

1 INTRODUCTION

In the paper, the problems which contain convectional term in its mathematical description are taken under consideration. The convectional term can appear in cases with fluid flow, or in cases with moving solid. It can also be found in the case, when the heat source moves in the domain. Here, two cases were considered: heat transfer in fluid flow and welding case, where heat source (electric arc) moves along solid material.

Forced and natural convection have been taken under consideration by the researchers working with the inverse problems techniques. A number of papers are devoted to this problem, several recent works can be found in references. They deal with the estimation of steady state inlet temperature profile [5], transient inlet temperature profile [2], estimation of axial variation of the wall heat flux in laminar flow [3], transient wall heat flux [6], simultaneous estimation of spacewise and timewise variations of the wall heat flux [7], inlet velocity estimation based on the velocity measurements [9, 10] or on the temperature measurements for the potential flows [13]-[11]. In the number of cited papers, the simulated measurements have been employed. Simulated measurements based on the solution of the direct problem with the a priori assumed values for the unknown values of the parameters or functions to be estimated. The solution of such defined direct problem is treated as exact measurements, and is used as the input data in the inverse procedure. But real measurements contain measurement errors. In order to simulate them, the random error is added to the exact measurements. Standard statistical hypotheses generally assumed for the measurement errors include them as being regarded as additive, uncorrelated, normally distributed with zero mean and with constant and known standard deviation. Employing such prepared input data in the inverse procedure should result in stable recovery of a priori established values of the unknown functions or parameters. This approach allows also to examine the influence of the number and location of measurement sensors to the stability of solution, as well as to examine the maximum measurement error which provides stable results of the inverse scheme.

In this paper, two cases are studied. In the first, the sensitivity of the fluid internal temperature with respect to the entry fluid flow velocity is investigated. If this sensitivity is strong enough, it gives the possibility of recovering the information regarding the velocity of fluid from the measurements of temperature field. Convection phenomena consist of two conjugate transport mechanisms: mass transport and energy transport. Determination of temperature distribution in the considered region requires the knowledge of the velocity field. Effective evaluation of this field is possible after the suitable assumption of boundary conditions, what can be a source of serious troubles. The proper values of boundary fluid flow conditions can be taken from measurements, but it is commonly known, that measurements of fluid velocities are difficult, expensive and sometimes even impossible to perform. On the other hand, fluid flow meaningfully perturbates the temperature distribution in the nonisothermal region (e.g. with the presence of external or internal heat sources). So, the temperature distribution of the fluid contains the information about the fluid velocity and about its boundary value. Referring to the fact, that temperature measurements are much easier and cheaper than velocity measurements, the procedure of velocity determination from the temperature measurements seems to be of a great practical importance.

The second case shows the sensitivity of temperature of plate with moving heat sorce to the thermal conditions on the opposite side of the plate. The knowledge about the thermal conditions is essential in the processes of arc welding or padding. Namely, the value of heat resistance at the bottom of the plate should be known. Its value cannot be measured directly. There is one quantity which can be easily measured: the surface temperature. Thus, the procedure which allows to evaluate the air gap resistance basing on measurements of the surface temperature seems to be of great practical importance. In the paper, the formulation of the sensitivity coefficients is presented. The whole inverse algorithm can be found in [4].

2 DIRECT PROBLEM

The analyzed convective heat transfer problem is described by the set of partial differential equations that consist of the momentum equation (the Navier Stokes equations) formulated for each direction of space, continuity equation and the energy equation (the Fourier Kirchhoff equation). For the undertaken assumptions the governing set of equations can be presented in the form:

- potential flow

$$u_x = -\frac{\partial \phi}{\partial x} \tag{1}$$

and

$$u_y = -\frac{\partial \phi}{\partial y} \tag{2}$$

where u_x and u_y stand for the velocity vector components (Darcy's velocity), and ϕ denotes the velocity potential.
Continuity equation can be prescribed in the form:

$$\nabla^2 \phi = 0 \tag{3}$$

The set of equations (1) ÷ (3) describes mathematically the velocity field of the potential flow. The temperature distribution is linked with the velocity field via energy conservation equation:

$$\rho c \frac{\partial}{\partial x}\left(u_x T\right) + \rho c \frac{\partial}{\partial y}\left(u_y T\right) = k \frac{\partial}{\partial x}\left(\frac{\partial T}{\partial x}\right) + k \frac{\partial}{\partial y}\left(\frac{\partial T}{\partial y}\right) + q_v \tag{4}$$

where ρ stands for the mass density of fluid, c denotes its specyfic heat, T means the temperature, q_v stands for the internal heat source generation rate and k denotes the heat conductivity of the material

- laminar flow (2D)

  momentum equations:

$$\frac{\partial}{\partial x}\left(u_x u_x\right)+\frac{\partial}{\partial y}\left(u_y u_x\right)=\frac{\partial}{\partial x}\left(\frac{\mu}{\rho}\frac{\partial u_x}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\mu}{\rho}\frac{\partial u_x}{\partial y}\right)+g_x-\frac{1}{\rho}\frac{\partial p}{\partial x} \tag{5}$$

$$\frac{\partial}{\partial x}\left(u_x u_y\right)+\frac{\partial}{\partial y}\left(u_y u_y\right)=\frac{\partial}{\partial x}\left(\frac{\mu}{\rho}\frac{\partial u_y}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\mu}{\rho}\frac{\partial u_y}{\partial y}\right)+g_y-\frac{1}{\rho}\frac{\partial p}{\partial y} \tag{6}$$

  continuity equation:

$$\frac{\partial u_x}{\partial x}+\frac{\partial u_y}{\partial y}=0 \tag{7}$$

  energy equation:

$$\rho c\frac{\partial}{\partial x}\left(u_x T\right)+\rho c\frac{\partial}{\partial y}\left(u_y T\right)=k\left(\frac{\partial^2 T}{\partial x^2}\right)+k\left(\frac{\partial^2 T}{\partial y^2}\right)+q_v \tag{8}$$

  In the above equations u_x, u_y stand for the velocity vector components, p is the pressure, ρ means mass density of fluid, c denotes its specific heat, k is heat conductivity of fluid, q_v stands for the internal heat source generation rate and T means the temperature.

- solid with moving heat source (3D, semi steady state)

$$\begin{aligned}&\rho c\frac{\partial}{\partial x}\left(u_x T\right)+\rho c\frac{\partial}{\partial y}\left(u_y T\right)+\rho c\frac{\partial}{\partial z}\left(u_z T\right)=\\&=\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+q_v\end{aligned} \tag{9}$$

  In the equation (9), u_x, u_y, u_z stand for the components of the heat source movement velocity vector, q_v is the stationary heat source generation rate.

The above systems of equations can be solved using any numerical technique, home made or commercial software. Of course, presented equations should be supplemented by the boundary conditions appropriate for the geometry.

3 INVERSE FORMULATION

In this paper, inverse problem is defined in the following way:

- flow problems: **Estimate inflow velocity knowing the value of internal temperature.**
- moving heat source: **Estimation of thermal conditions on the lower surface basing on the measurements of the upper surface temperature**

This kind of problems, usually called Inverse Problems (IP) are mathematically classified as ill-posed in general sense, because their solutions may become unstable, as the results of the errors inherent to the measurements used in the analysis. Inverse problems were initially taken as not of physical interest, due to their ill-posedness [20]. However, some heuristic methods of solution for inverse problems, which were based more on pure intuition than on mathematical formality, where development in the 50s. Later most of the methods, which are in common use nowadays, were formalized in terms of their capabilities to treat ill-posed problems. They basis on implementation of regularization (stabilization) techniques, which provide the ill-posed problems to the well-posed ones. The first works dealing with the overcoming ill-posedness of Inverse Problems were presented by J.V.Beck, A.N. Tikhonov and O.M. Alifanow.

In the paper, for the solution of the inverse problem the idea of sensitivity coefficients was used. Sensitivity coefficients are defined as the first derivative of the measured quantity with respect to the estimated one.

In linear cases the sensitivity coefficient is not a function of the calculated field. Since it depends only on the problem geometry, the computations of the coefficient can be performed only once. However, in the nonlinear case, as the presented one, the sensitivity coefficients depend on the temperature field and should be calculated in each iteration of the inverse procedure [1, 8, 12]. Sensitivity coefficients show the regions, which are the best for carrying out measurements. When the coefficient is relatively large, it means a high sensitivity of the desired quantity to the changes of the measured one. On the other hand, when the values of the coefficients are relatively small our chances for a successful solution of the inverse problem are rather poor. There are several known ways of determining the sensitivity coefficient:

- *Direct analytic solution for determining the sensitivity coefficients.*

This method is utilized in the linear cases of heat transfer (mainly conduction) and when an analytical solution is known. The sensitivity coefficient is determined by differentiation of the analytic solution with respect to the desired quantity.

- *The boundary value problem approach for determining the sensitivity coefficients*

Here, the original boundary problem is differentiated with respect to the desired quantity in order to develop a boundary value problem describing the sensitivity coefficient. When the original problem is linear, this method leads to a simple and straightforward solution. When nonlinearity appears, the resulting systems of the equations can be much more complicated as the initial one.

-*Finite difference approximation for determining the sensitivity coefficients*

This method assumes an evaluation of the sensitivity coefficients in the sense of finite differences:

$$Z = \frac{Y(B+\varepsilon) - Y(B)}{\varepsilon} \tag{10}$$

where ε is a small number. One can easily notice, that this attempt requires double solution of the direct problem. Thus, this method can be efficiently used only if the direct solution is not too much time consuming, especially in nonlinear cases when the iterative procedure is employed. In the problem described herein, due to the fact, that a solution of the direct problem can be obtained relatively fast, the third approach was used.

3.1 The boundary value problem approach - potential flow

In the considered problem one can define two types of sensitivity coefficients:

- potential sensitivity coefficient:

$$Z_\phi = \partial\phi/\partial u_n \tag{11}$$

- temperature sensitivity coefficient

$$Z_T = \partial T/\partial u_n \tag{12}$$

where u_n stands for the sought-for boundary velocity.

One way to obtain sensitivity coefficients values is to differentiate equation (4) with respect to the inlet velocity u_n. After differentiating eq. (4) one can obtain:

$$\frac{\partial^2 \left(\partial T/\partial u_n\right)}{\partial x^2} + \frac{\partial^2 \left(\partial T/\partial u_n\right)}{\partial y^2} = \frac{\rho c}{k}\left(u_x \frac{\partial \left(\partial T/\partial u_n\right)}{\partial x} + u_y \frac{\partial \left(\partial T/\partial u_n\right)}{\partial y}\right) + S_A \tag{13}$$

So, after utilization eq. (12):

$$\frac{\partial^2 \left(Z_T\right)}{\partial x^2} + \frac{\partial^2 \left(Z_T\right)}{\partial y^2} = \frac{\rho c}{k}\left(u_x \frac{\partial \left(Z_T\right)}{\partial x} + u_y \frac{\partial \left(Z_T\right)}{\partial y}\right) + S_A \tag{14}$$

In the above equations S_A has a meaning of a source term. It should be noted that the structure of eq. (14) is the same as the eq. (4). It means, that the same computer code can be readily utilized for evaluating Z_T field.

Source term S_A is described by the following formula:

$$S_A = \frac{\rho c}{k}\left(\frac{\partial u_x}{\partial u_n}\frac{\partial T}{\partial x} + \frac{\partial u_y}{\partial u_n}\frac{\partial T}{\partial y}\right) \tag{15}$$

and after introducing eq. (11):

$$S_A = \frac{\rho c}{k}\left(-\frac{\partial Z_\phi}{\partial x}\frac{\partial T}{\partial x} - \frac{\partial Z_\phi}{\partial y}\frac{\partial T}{\partial y}\right) \tag{16}$$

As the above equation shows, the knowledge of the potential sensitivity coefficients is essential.

The formula describing quantity Z_ϕ can be derived from eq. (3). Differentiating this equation with respect to u_n leads to the relation:

$$\nabla^2\left(\partial\phi/\partial u_n\right) = 0 \tag{17}$$

so

$$\nabla^2 Z_\phi = 0 \tag{18}$$

It is worth noting, that boundary problems (3) and (18) have not only the same structure, but the superposition principle can be applied solving velocity fields versus inflow velocity u_n. Moreover, the potential sensitivity coefficient field Z_ϕ does not depend on the inflow velocity and on the temperature field, but only on geometry of the domain. Hence, for the selected case, it is calculated only once, and the velocity field can be computed basing on this solution. These facts reduce computational cost.

3.2 The boundary value problem approach - laminar flow

Differentiating governing energy balance equation (8) with respect to the normal component of inflow velocity, one arrives at:

$$\frac{\partial}{\partial x}\left(k\frac{\partial Z_T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial Z_T}{\partial y}\right) + S_A = \rho c\frac{\partial}{\partial x}\left(u_x Z_T\right) + \rho c\frac{\partial}{\partial y}\left(u_y Z_T\right) \tag{19}$$

where

$$Z_T = \frac{\partial T}{\partial \tilde{u}_n} \tag{20}$$

is the sensitivity coefficient of temperature with respect to the normal component of inflow velocity. S_A is the term coming from nonlinearity of energy balance equation. Normal component of velocity acting in the definition of coefficient , $\tilde{u}_n$ can be a uniform inflow velocity, a nodal one, derivative of nodal velocity depending on an estimated boundary quantity. Here, for the sake of simplicity, the uniform inflow velocity is assumed. The term S_A coming from the nonlinearity of energy balance can be shown as:

$$S_A = \frac{\rho c}{k}\left(\frac{\partial u_x}{\partial \tilde{u}_n}\frac{\partial T}{\partial x} + \frac{\partial u_y}{\partial \tilde{u}_n}\frac{\partial T}{\partial y}\right) \tag{21}$$

Partial derivatives $\partial u_x/\partial \tilde{u}_n$ and $\partial u_y/\partial \tilde{u}_n$ acting in equation (21) are the sensitivity coefficients of horizontal and vertical components of velocity with respect to the normal component of boundary one. For the sake of clarity, new parameters can be introduced:

$$Z_u = \frac{\partial u_x}{\partial \tilde{u}_n} \tag{22}$$

$$Z_v = \frac{\partial u_y}{\partial \tilde{u}_n} \tag{23}$$

Introducing the above definitions to the equation (21) one can get:

$$S_A = \frac{\rho c}{k}\left(Z_u \frac{\partial T}{\partial x} + Z_v \frac{\partial T}{\partial y}\right) \tag{24}$$

After differentiating the Navier-Stokes (5,6 equations come to the form:

$$\frac{\partial}{\partial x}\left(u_x Z_u\right) + \frac{\partial}{\partial y}\left(u_y Z_u\right) = \frac{\partial}{\partial x}\left(\frac{\mu}{\rho}\frac{\partial Z_u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\mu}{\rho}\frac{\partial Z_u}{\partial y}\right) - \frac{1}{\rho}\frac{\partial^2 p}{\partial \tilde{u}_n \partial x} - S_u \tag{25}$$

and

$$\frac{\partial}{\partial x}\left(u_x Z_v\right) + \frac{\partial}{\partial y}\left(u_y Z_v\right) = \frac{\partial}{\partial x}\left(\frac{\mu}{\rho}\frac{\partial Z_v}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\mu}{\rho}\frac{\partial Z_v}{\partial y}\right) - \frac{1}{\rho}\frac{\partial^2 p}{\partial \tilde{u}_n \partial y} - S_v \tag{26}$$

In the above equations terms S_u and S_v result from the nonlinerarity of momentum equation. The pressure terms in the equation (25) can be reorganized in the following manner:

$$\frac{\partial^2 p}{\partial \tilde{u}_n \partial x} = \frac{\partial}{\partial x}\left(\frac{\partial p}{\partial \tilde{u}_n}\right) = \frac{\partial Z_p}{\partial x} \tag{27}$$

Similar operation can be performed with pressure term taken from the equation (26). Z_p can be treated as another sensitivity coefficient which describes sensitivity of internal pressure distribution with respect to the normal component of inflow velocity. Namely:

$$Z_p = \frac{\partial p}{\partial \tilde{u}_n} \tag{28}$$

Finally:

$$\frac{\partial}{\partial x}\left(u_x Z_u\right) + \frac{\partial}{\partial y}\left(u_y Z_u\right) = \frac{\partial}{\partial x}\left(\frac{\mu}{\rho}\frac{\partial Z_u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\mu}{\rho}\frac{\partial Z_u}{\partial y}\right) - \frac{1}{\rho}\frac{\partial Z_p}{\partial x} - S_u \tag{29}$$

and

$$\frac{\partial}{\partial x}\left(u_x Z_v\right) + \frac{\partial}{\partial y}\left(u_y Z_v\right) = \frac{\partial}{\partial x}\left(\frac{\mu}{\rho}\frac{\partial Z_v}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\mu}{\rho}\frac{\partial Z_v}{\partial y}\right) - \frac{1}{\rho}\frac{\partial Z_p}{\partial y} - S_v \tag{30}$$

The Z_p coefficients can be derived using differentiated continuity equation.
Additional source terms, which appeared in the equations (29) and (30) are the result of nonlinearity of momentum equations. They can be presented in the form:

$$S_u = \rho \left(Z_u \frac{\partial u_x}{\partial x} + Z_v \frac{\partial u_x}{\partial y} \right) \tag{31}$$

and

$$S_v = \rho \left(Z_u \frac{\partial u_y}{\partial x} + Z_v \frac{\partial u_y}{\partial y} \right) \tag{32}$$

Presented terms are the functions of both Z_u and Z_v coefficients. Solution of (29) and (30) set requires solving all the equations simultaneously, or treat them as additional source term and keep the structure of equations similar to the original Fourier-Kirchhoff equations. The derivatives acting in the equations (31) and (32), as well as sensitivity coefficients and can be evaluated basing on the magnitudes of these quantities taken from previous iteration. So, the structure of additional source terms imposes iterative character of solution procedure. But this approach allows to use the same numerical program, which was used for original direct problem solution. Only redefinition of the source term is required.

4 RESULTS OF EXEMPLARY COMPUTATIONS

The exemplary computations were performed for the each of mentioned types of flow. The potential and laminar flow were investigated in the geometry presented in the figure 1, while the case of moving heat source were calculated for the geometry presented in the figure 2.

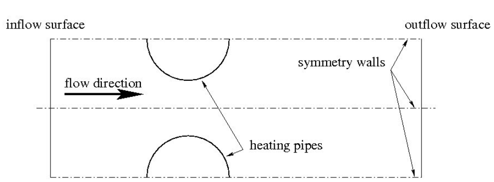

Figure 1: Geometry of the problem

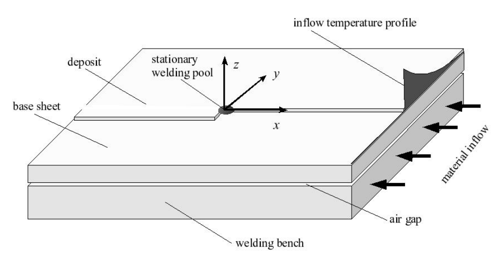

Figure 2: Geometry of pseudo steady state approximation

4.1 Potential flow

In order to investigate how the value of the inflow velocity influences the shape of the sensitivity coefficients, the calculations for two Reynolds numbers, Re=0.1 and Re=1.0 were performed.

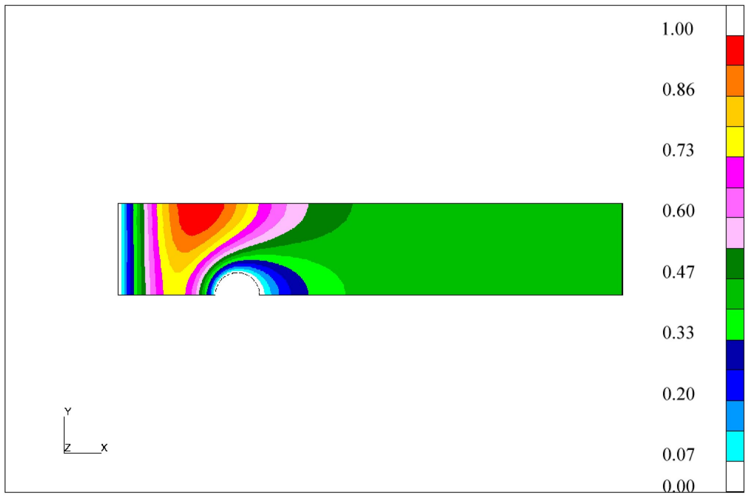

Figure 3: Distribution of the nondimensional sensitivity coefficient $\tilde{Z}_T$ for the Reynolds number Re = 0.1

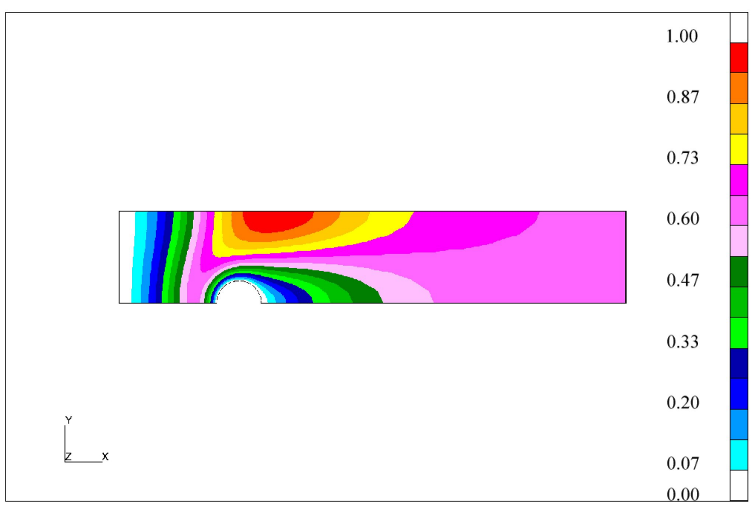

Figure 4: Distribution of the nondimensional sensitivity coefficient $\tilde{Z}_T$ for the Reynolds number Re = 1.0

It is interesting, that in the region situated next to the inflow boundary, the sensitivity coefficient have very low values. As a result, location of the sensors close to the inflow boundary can involve worse estimation of the inflow velocity.

4.2 Laminar flow

The laminar flow was tested for two cases: for the geometry presented in the figure 1 and for the domain containg two rotating cylinders. For the first case the sensitivity of temperature with respect to the uniformly distributed inflow velocity was investigated. Uniform distribution of inflow velocity causes, that only one parameter is estimated. The calculations were performed in the geometry shown in the figure 1 for the Reynolds number equal to 200. Results of calculations are shown in the figures 5-7.

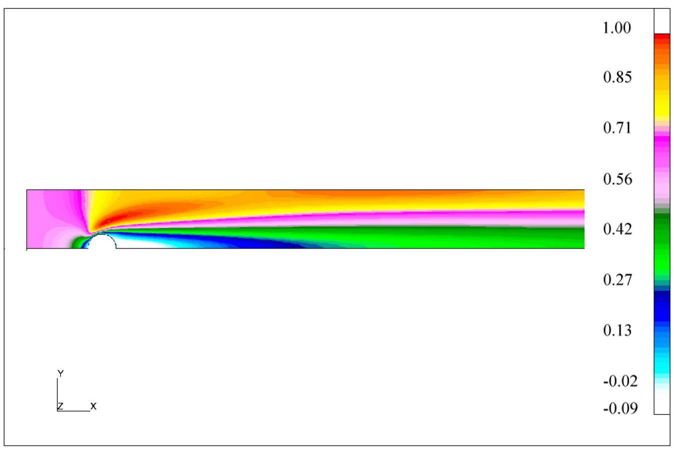

Figure 5: Distribution of the nondimensional sensitivity coefficient $\tilde{Z}_u$ for the Reynolds number Re = 200 for the external flow around the circular profile

In the second case the sensitivity of temperature with the respect to the rotational speed of the cylinder acting in the computational region is evaluated. The considered domain consist of two reverse rotating isolated cylinders. The Dirichlets boundary for temperature is assumed on the left and right wall, while top and bottom ones are isolated. The rotating cylinders involve the fluid motion in the domain which perturbates the temperature distribution in the fluid. Distributions of the sensitivity Z_u, Z_v and Z_T and are presented in the figures 8-10.

4.3 Moving heat source

In this case the influence of the value of the thermal resistance on the bottom of the analysed plate on the magnification and distribution of the sensitivity coefficients were investigated. The effect of the velocity of the surfacing head on the sensitivity coefficients has also been checked.

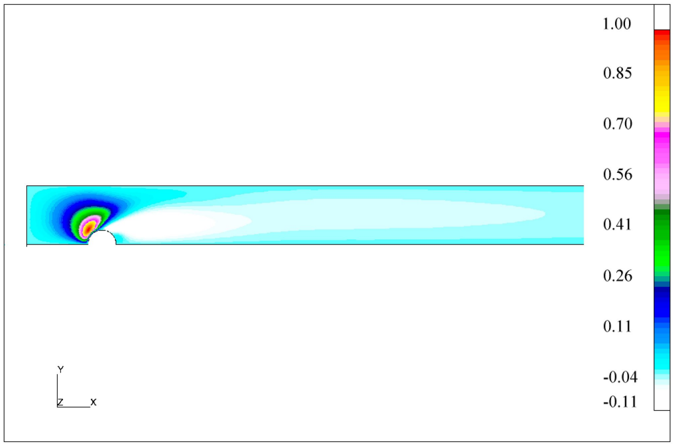

Figure 6: Distribution of the nondimensional sensitivity coefficient $\tilde{Z}_v$ for the Reynolds number Re = 200 for the external flow around the circular profile

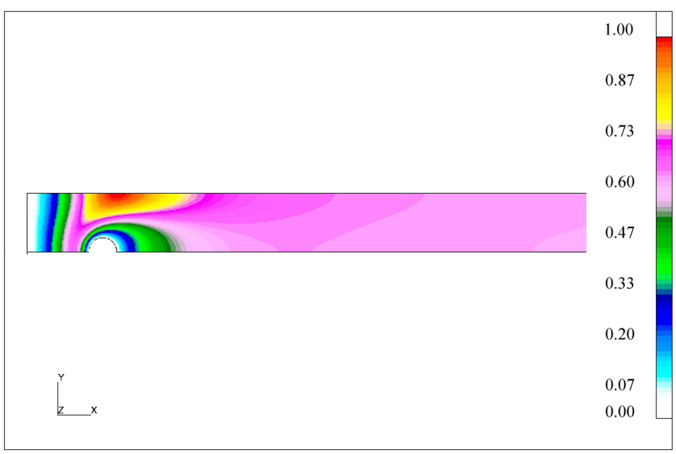

Figure 7: Distribution of the nondimensional sensitivity coefficient $\tilde{Z}_T$ for the Reynolds number Re = 200 for the external flow around the circular profile

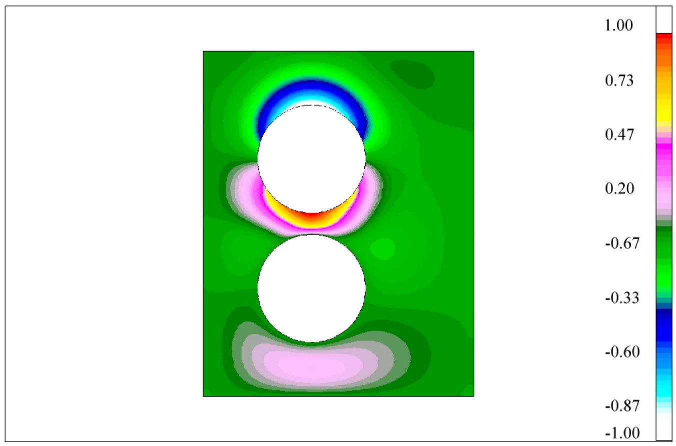

Figure 8: Distribution of the nondimensional sensitivity coefficient $\tilde{Z}_u$ for the Reynolds number $\mathrm{Re} = 100$ for the external flow around the rotating circular profile, calculated with respect to the rotational speed of profile

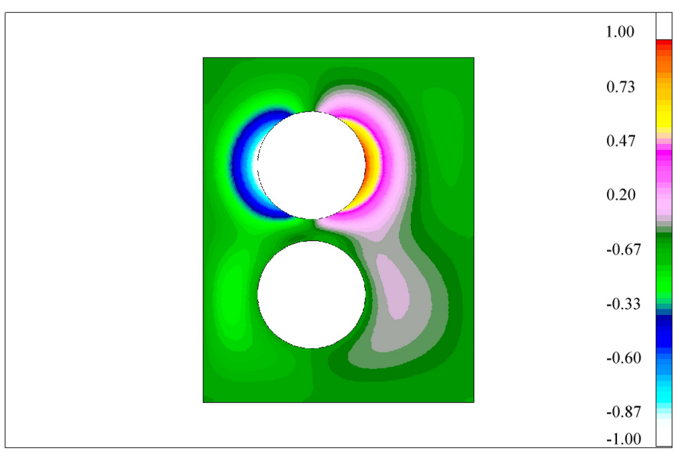

Figure 9: Distribution of the nondimensional sensitivity coefficient $\tilde{Z}_v$ for the Reynolds number $\mathrm{Re} = 100$ for the external flow around the rotating circular profile, calculated with respect to the rotational speed of profile

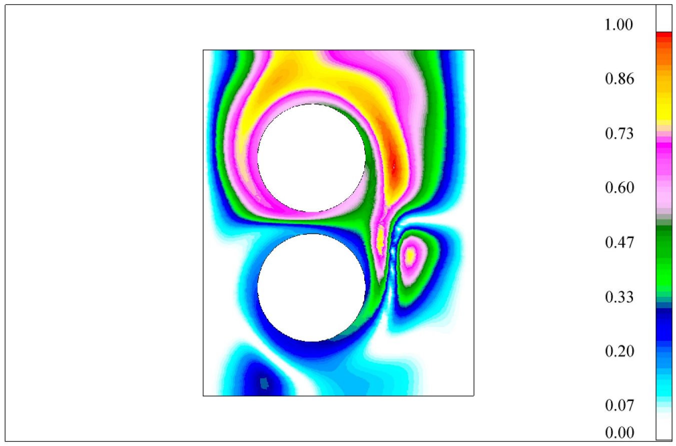

Figure 10: Distribution of the nondimensional sensitivity coefficient $\tilde{Z}_T$ for the Reynolds number Re = 100 for the external flow around the rotating circular profile, calculated with respect to the rotational speed of profile

4.3.1 Influence of the thermal resistance on the sensitivity coefficients

In order to estimate the influence of the thermal resistance on the sensitivity coefficients, computations were preformed for the following values of the resistance:

- R=0.00002 m^{2}K/W
- R=0.001 m^{2}K/W
- R=0.02 m^{2}K/W

The first value describes the case when the resistance is so small, that it can be practically neglected. Results of the mentioned computations are presented in the figures 11 $\div$ 13.

4.3.2 Influence of the heat source velocity on the sensitivity coefficients

The calculations were performed for the value of the thermal resistance $R = 0.004$ m^{2}K/W and the velocity w:

- w=0.002 m/s
- w=0.00156 m/s

The results of these investigations are presented in Figures 14 and 15. It is to be noticed, that when the heat source slows down, the region of maximum values of the sensitivity coefficients approaches the heating zone. The values of the sensitivity coefficients grow in this case. It can be explained by increase of the convective term with the velocity.

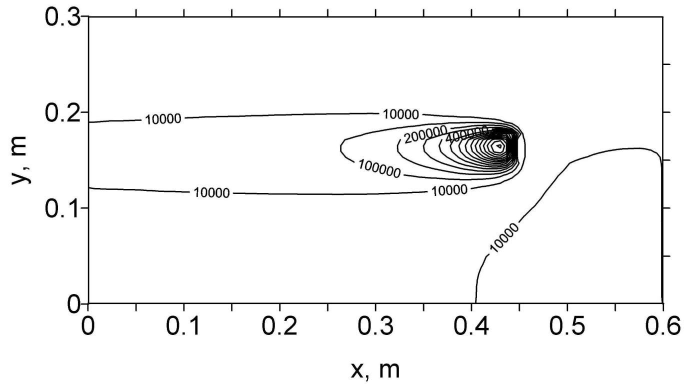

Figure 11: Distribution of the Sensitivity Coefficients [W/m^2] for the thermal resistance of the air gap $R = 0.00002\text{m}^2\text{K/W}$

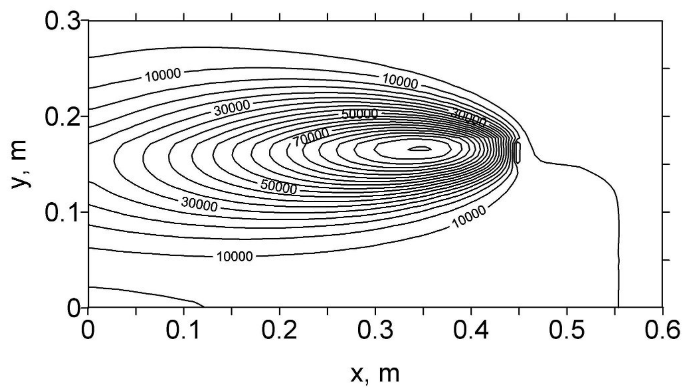

Figure 12: Distribution of the Sensitivity Coefficients [W/m^2] for the thermal resistance $R = 0.001\text{m}^2\text{K/W}$

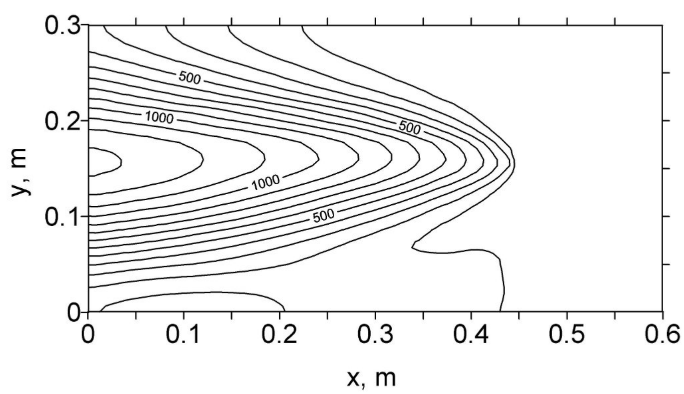

Figure 13: Distribution of the Sensitivity Coefficients [W/m^2] for the thermal resistance $R = 0.02\text{m}^2\text{K/W}$

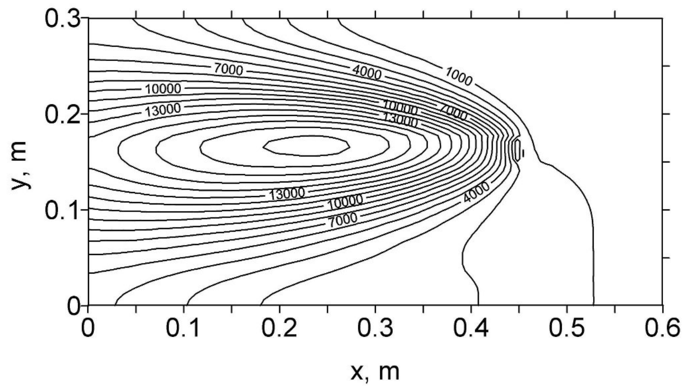

Figure 14: Distribution of the Sensitivity Coefficients [W/m^2] for the heat source velocity $w = 0.002$m/s

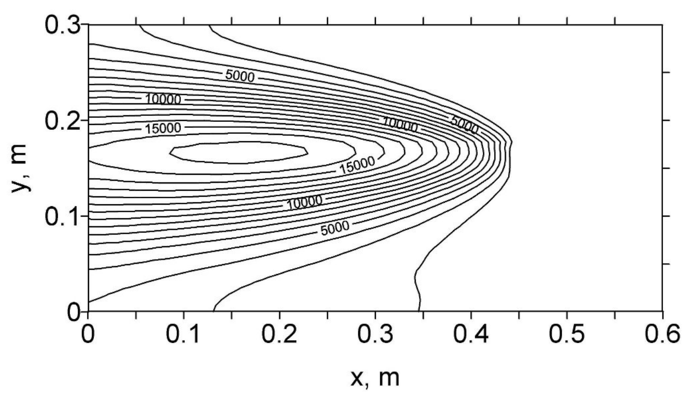

Figure 15: Distribution of the Sensitivity Coefficients [W/m^2] for the heat source velocity $w = 0.00156$m/s

5 FINAL REMARKS

In the paper the procedure of evaluating sensitivity coeficients for the convection problems is presented. Particulary, the cases with potential, laminar and moving heat source were chosen. The sensitivity coefficients can be easly utilized in inverse procedure for estimation of desired boundary quantity. They can be also used in the preparing of expriment due to the fact, thay can show the optimum regions for measurements. Two methods of coefficients evaluation were presented:

- boundary value approach,
- finite difference approximation for determining the sensitivity. coefficients

First approach is more complicated, but in some cases can provide to the mathematical description similar to the direct problem. It is much quicker the the second one. On the other hand second approach is easier in application and constitues attractive alternative for the lighter problems from the time of computations point of view.

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REFERENCES

[1] J. V. Beck et al. *Inverse Heat Conduction: Ill Posed Problems.* Wiley Intersc., New York, 1985.

[2] J. Bokar and M.N. Özisik. Inverse analysis for estimating the time varying inlet temperature in laminar flow inside a parallel plate duct. *Int. J. Heat and Mass Transfer*, 38:39–45, 1995.

[3] C.H. Huang and M.N. Özisik. Inverse problem of determining unknown wall heat flux in laminar flow through a parallel plate. *Numerical Heat Transfer*, 21:55–70, 1992.

[4] Szczygieł I., Fic A., and Sachajdak A. Estimation of thermal parameters describing surfacing by welding process. In *8th World Congress on Computational Mechanics WCCM8 and 5th European Congress on Computational Methods in Applied Sciences and Engineering ECCOMAS 2008*, Venice Italy, 30 June - 4th July 2008.

[5] F.B. Liu and M.N. Özisik. Estimation of inlet temperature profile in laminar duct flow. *Inverse Problems in Engineering*, 3:131–141, 1996.

[6] F.B. Liu and M.N. Özisik. Inverse analysis of transient turbulent forced convection inside parallel plates. *Int. J. Heat and Mass Transfer*, 39:2615–2618, 1996.

[7] H. Machado and H.R.B. Orlande. Inverse analysis of estimating the timewise and spacewise variation of the wall heat flux in a parallel plate channel. *Int. J. Num. Meth. Heat and Fluid Flow*, 7:696–710, 1997.

[8] M.N. Özisik and H.R.B. Orlande. *Inverse Heat Transfer*. Taylor and Francis, 2000.

[9] I. Szczygiel. Estimation of the boundary conditions in convectional heat transfer problems. In *Proceedings of National Heat Transfer Conference*, Baltimore, 1997.

[10] I. Szczygiel. Utilization of the algor packagein solution of the inverse heat convection problems. In *Advanced Computational Methods in Heat Transfer*, Cracow, 1998.

[11] I. Szczygiel. Identification of boundary velocity basing on internal temperature measurements - sensitivity analysis. In *Proc of the Inverse Problems in Engineering Symposium*, Tuscaloosa, USA, 2003.

[12] I. Szczygiel. Temperature-velocity coupling of the convective heat transfer - sensitivity analysis. *Numerical Heat Transfer*, 2005.

[13] I. Szczygiel and A. Fic. Identification of the boundary velocity velocity basing on the internal temperature measurements. In *proc of the CHMT 2001 Conference*, Rio de Janeiro, Brasil, 2001.