Sborník vědeckých prací Vysoké školy báňské - Technické univerzity Ostrava
číslo 2, rok 2006, ročník LII, řada strojní
článek č. 1529

Milan DURDÁN*, Marek LACIAK, Karol KOSTÚR*****

THE ESTIMATION OF THERMO-PHYSICAL QUANTITIES OF THE MATERIALS IN INDIRECT TEMPERATURE MEASUREMENT OF CHARGE

STANOVENIE TEPLOFYZIKÁLNYCH VLASTNOSTÍ MATERIÁLOV PRI NEPRIAMOM MERANÍ TEPLOTY VSÁDZKY

Abstract

In the system of indirect temperature measurement in the charge, input parameters of model are very important. These parameters are thermo-physical quantities of the charge. The paper describes estimation of the heat conductivity λ and specific heat capacity c by means of optimization method – iterative dynamic programming (IDP). The material was heated in the laboratory electric furnace. The temperature was measured directly by the thermocouples. The system of indirect temperature measurement calculates temperatures indirect. The setting of thermo-physical quantities was realized by means of minimization of deviation between direct and indirect measured temperature in the iteration loop of the method, continual in time.

Abstrakt

V systéme nepriameho merania teplôt v ohrievanej vsádzke sú veľmi dôležité vstupné parametre modelu. Medzi tieto parametre patria aj teplofyzikálne vlastnosti ohrievaného materiálu. V príspevku je popísané stanovenie tepelnej vodivosti λ a mernej tepelnej kapacity c pomocou optimalizačnej metódy iteratívneho dynamického programovania (IDP). Realizácia priameho merania teploty materiálu bola prevedená v laboratórnej elektrickej peci. Teplota bola meraná priamo termočlánkami. Systém nepriameho merania teploty (model) nám poskytuje nepriamo namerané teploty. Pri stanovovaní teplofyzikálnych vlastností dochádza v iteračnom cykle metódy k ich nastaveniu za účelom minimalizácie odchýlky priamo a nepriamo nameraných teplôt v čase.

1 INTRODUCTION

The basic task of the system for indirect temperature measurement (SITM) is the prediction of heat material temperature based on direct measured temperatures. One of the models in the system for indirect measurement is based on the direct measured temperature with thermocouples (known boundary condition I. type) and solution of Fourier partial differential equation with elementary balance method

* Ing., Department of Applied Informatics and Process control, Faculty BERG, Technical University of Košice, Boženy Němcovej 3, Košice, tel. (+421) 55 602 5175, e-mail Milan.Durdan@tuke.sk
** Ing., Department of Applied Informatics and Process control, Faculty BERG, Technical University of Košice, Boženy Němcovej 3, Košice, tel. (+421) 55 602 5175, e-mail Marek.Laciak@tuke.sk
*** Prof., Department of Applied Informatics and Process control, Faculty BERG, Technical University of Košice, Boženy Němcovej 3, Košice, tel. (+421) 55 602 5191, e-mail Karol.Kostur@tuke.sk

$$\frac{\partial (t, c, \rho)}{\partial \tau} = \frac{\partial \left(\lambda \frac{\partial t}{\partial x} \right)}{\partial x} + \frac{\partial \left(\lambda \frac{\partial t}{\partial y} \right)}{\partial y}, \tag{1}$$

where:

c – specific heat capacity $\left[\frac{\text{J}}{\text{kg.K}} \right]$,

E – heat conductivity $\left[\frac{\text{W}}{\text{m.K}} \right]$,

ρ – density $\left[\frac{\text{kg}}{\text{m}^3} \right]$.

The elementary balance method goes out from the decomposition of entity into the elementary blocks. Each elementary block has got balance equation. We can create explicit or implicit algorithm of temperature area solution. The decomposition of entity into elementary blocks can be equidistant or non-equidistant. In the figure 1 is shown scheme of entity decomposition into the equidistant blocks [1, 2] Δx - scale of elementary block in side axis x, Δy - scale of elementary block in side axis y, Δz - scale of elementary block in side axis z.

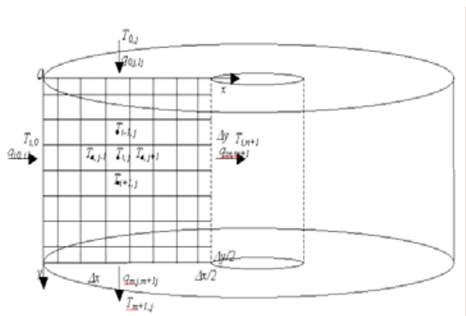

Fig. 1 The elementary blocks

2 THE PRINCIPLE FOR THE ESTIMATION OF THERMO-PHYSICAL QUANTITIES

The system for the indirect measurement must predict quantitative information with the accuracy such as we can measure directly. In the case of the quantitative limitations of system (simulation model), it is possible to eliminate undefined inputs of the model. These inputs are thermo-physical quantities (λ, c) of the material. The calculating of thermo-physical quantities in literary resources isn't possible, because for discontinuous entities aren't know appropriate equations. The equations for λ_{ef} (effective heat conductivity) not respond experiments with the required accuracy.

The estimation of thermo-physical quantities is based on the principle of optimization method. The task of the methodology is to minimize the criterion function, which is sum of the deviations quadrates between measured temperatures on real object and temperatures calculated by SITM (simulation model). The form of the criterion function by one measured temperature of steel coil is following:

$$F = \sum_{i=1}^{\tau_k} \left(T^i{}_{measur} - T^i{}_{SITM} \right)^2 , \tag{2}$$

where:

$T^i{}_{measur}$ – the measured temperature in the charge (steel coil) $[\mathrm{K}]$,

$T^i{}_{SITM}$ – the model temperature calculated by SITM $[\mathrm{K}]$,

i – the time step $[\text{-}]$.

The criterion function for three measured temperatures on steel coil is following:

$$F = \sum_{i=1}^{\tau_k} \sum_{j=1}^{3} \left(T^i{}_{jmeasur} - T^i{}_{jSITM} \right)^2 , \tag{3}$$

In each simulation step the sum of three temperatures deviations is calculated (parameter j). The kernel of thermo-physical quantities estimation is optimization algorithm, which is modification of the known algorithm - iterative dynamic programming (IDP). The principle of this method is following. The process is divided in the p – temperature parts. In first part quasi optimum is found and optimization continues in the next part, where parameters are known for first part. This sequence is repeated until last time part. The found trajectory of parameters is initial trajectory for the next iterations.

The modified algorithm for the estimation of the heat conductivity λ and specific heat capacity c is following:

1. Initial values of heat conductivity and specific heat capacity are loaded for each temperatures interval ΔT. These parameters are saved in input text file.
2. The process is divided in the p – temperature parts.
3. The temperature of the SITM model is calculated by initial values of vector λi a ci. These temperatures are saved dynamically.
4. The criterion function for the initial status is evaluated after the end of simulation.
5. The change of the parameters in first part. These parameters are changed in each temperature part within the allowed region.
6. Simulation by SITM and calculation of the criterion function.
7. Transition in the second parameter after simulations with all values of the first parameter in the temperature part.
8. Repeat points 5. and 6.
9. Selection of the best values λi and ci from the first part on based of the minimal value of the criterion function.
10. Transition to next part (part=part+1) and repeating points 5. - 9.
11. In the case of last part (part=p) we obtain new initial values of the thermo-physical quantities for the next iteration step for the optimization method.

By the each new iteration it give out to the decreasing of the region for both parameters [3].

3 THE RESULTS OF THE THERMO-PHYSICAL QUANTITIES ESTIMATION

The methodology for the estimation of the thermo-physical quantities was verified in two variants:

a.) one measured temperature in steel coil,

b.) three measured temperatures in steel coil.

The heating process was divided to the seven temperature parts for both variants (ΔT=100°C). The estimation of the thermo-physical quantities was realized up to temperature 700°C. Initial values was obtained from tabular data for the steel.

Results after estimation of the thermo-physical quantities for both variants and initial values are in table 1. The values of both parameters (λi a ci) are considerably differing from tabular data (initial state).

Tab. 1 Results after estimation of the thermo-physical quantities for variant a) and b)

	Temperature [°C]	0/ 400	100/ 500	200/ 600	300/ 700
Initial values	λ[W/m.K]	65,1	60,2	55,6	50,9
	c [J/kg.K]	476	494	532	565
	λ[W/m.K]	46,5	41	37,4	34
	c [J/kg.K]	611	682	770	857
Variant a)	λ[W/m.K]	27,5	24,2	18,7	21,5
	c [J/kg.K]	573	575	532	449
	λ[W/m.K]	46,5	95,3	86,9	79,0
	c [J/kg.K]	351	682	770	857
Variant b)	λ[W/m.K]	21,9	9,2	6,3	12,5
	c [J/kg.K]	570	620	532	449
	λ[W/m.K]	28,5	79,5	202	183
	c [J/kg.K]	358	356	770	857

The result of the criterion function-F (3) and values of the average relative deviation between direct and indirect measured temperature in the steel coil are in table 2. Four iteration steps and improvement of the deviation is minimal was realized in the variant a).

Eight iteration steps, that help to decrease value of the criterion function was realized in the variant b). The relative deviation decreased after the IDP algorithm down to the value 0,5%.

Tab. 2 Results of criterion function and relative deviation between temperatures

		Criterion function	Relative deviation [%]
Variant a)	Initial	1249119	3,68
	After IDP	1223109	3,48
Variant b)	Initial	3746135	4,14
	After IDP	3632057	3,67

Courses of the estimation of heat conductivity λ before and after IDP-algorithm are shown in the figure 2. The diametric difference is between initial values and values after IDP-algorithm by higher temperatures (500-700°C). The values of the heat conductivity after IDP-algorithm are higher quadruple near the temperatures 600 and 700°C. This increasing can be caused by the incorrect measurement of the higher temperatures, therefore it is necessary to verify the methodology on the larger set of measurements.

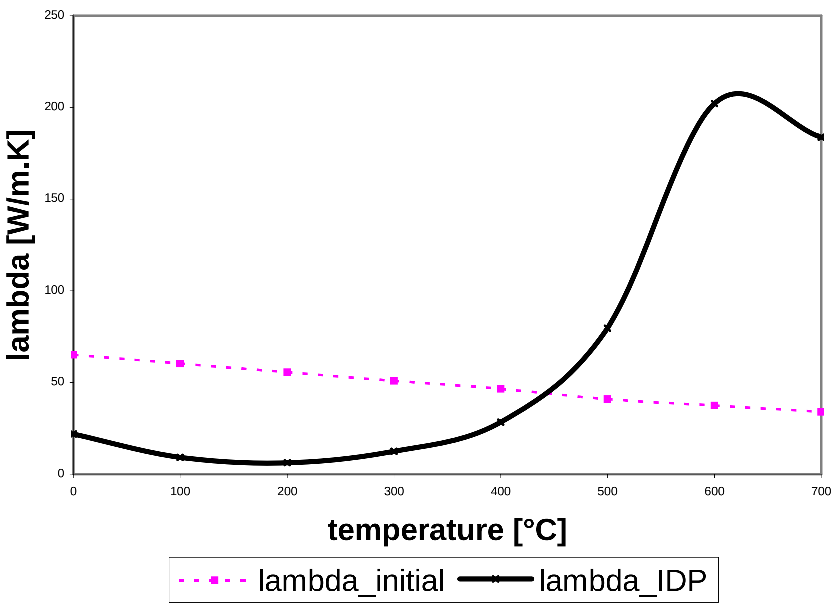

Fig. 2 The courses of heat conductivity

Courses of specific heat capacity c before and after IDP - algorithm are shown in the figure 3. The specific heat capacity for initial state is plotted by the interrupted line and has increasing character. The course of specific heat capacity after IDP-algorithm is plotted by solid line. This values (unlike from course of heat conductivity) is by higher temperatures equal with values of specific heat capacity for initial state. The biggest change of this parameter is by temperatures 400 and 500°C.

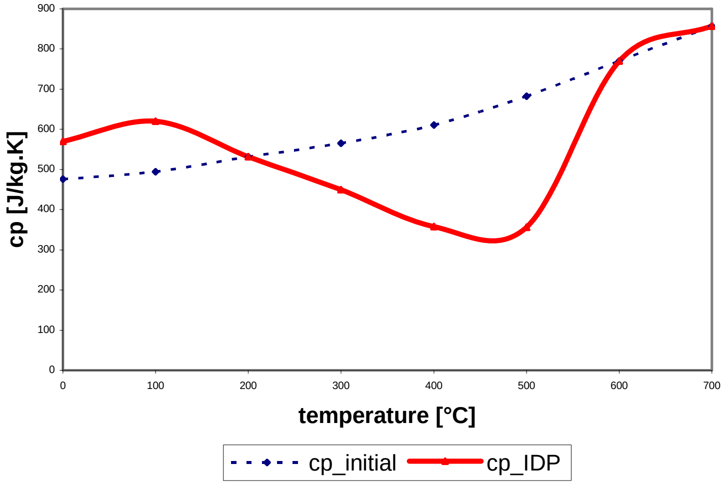

Fig. 3 The courses of specific heat capacity

4 CONCLUSIONS

The mainly purpose of the thermo-physical quantities estimation of the heated material is the increasing of these parameters accuracy. The methodology, described in this paper, should have created in final result the autonomous module of the complex system for indirect temperature measurement. The first results demonstrate the increasing of the accuracy of system for indirect measurement. It is very important to verify the methodology for the estimation of thermo-physical quantities on the larger data set.

5 ACKNOWLEDGEMENTS

This work was partially supported by grants VEGA 1/3346/06, VEGA 1/2179/05 and AV 4/0016/05 from the Slovak Grant Agency for Science.

REFERENCES

[1] KOSTÚR, K., LACIAK, M., TRUCHLÝ, M., *Systémy nepriameho merania*. 1st ed. Košice : Reprocentrum, 2005. 173 pp. ISBN 80-8073-273-6.

[2] KOSTÚR, K & DURDÁN, M., *Adaptation of indirect measurement system for measuring temperatures inside material*. Proceedings of 15th International Conference on Process Control 05, Štrbské Pleso, High Tatras, June7-10 2005, 214 pp., 189 in CD ISBN 80-227-2235-9.

[3] KOSTÚR, K. et all, In *Inteligentný systém nepriameho merania*. URVP TU Košice, 2005, 134 pp.

Reviewer: prof. Ing. Jiří Tůma, CSc., VŠB-Technical University of Ostrava