Sborník vědeckých prací Vysoké školy báňské - Technické univerzity Ostrava
číslo 2, rok 2006, ročník LII, řada strojní
článek č. 1541

Karol KOSTÚR[*], Marek LACIAK[**], Martin TRUCHLÝ[***]

THE TYPES OF INDIRECT MEASUREMENT

TYPY NEPRIAMEHO MERANIA

Abstract

The control systems need information about relevant variables. Sometime, these relevant variables we are not know to measure in real technologies. In this case is suitable to use the indirect measurement. Authors try to describe the bases of theory of indirect measurement, the classification methods and structures of indirect measurement and briefly to describe some application.

Abstrakt

Riadiace systémy potrebujú informácie o relevantných procesných veličinách. Niekedy však tieto veličiny nevieme v reálnych technológiách priamo merať. V tomto prípade je vhodné použiť nepriame meranie. Autori sa v tomto príspevku pokúsili popísať základy teórie nepriameho merania, jeho klasifikácie a rôzne štruktúry a tieto následne ukázať na niektorých aplikáciách.

1 INTRODUCTION

In production competition two basic parameters of products decide. There are a quality and specific consumption of energy. In heating processes both parameters are linked by temperature. For example in hot work if the temperature will be higher as it is necessary, then the product quality will be good but an energy consumption high. In this case the internal temperature of hot working product direct to measure with out material destruction is the problem. This problem is topical of we have to control a variable or variables which are not measured. Usually, the reason of unmeasured variable does not exist suitable sensors. In these cases are necessary the systems of indirect measurement.

2 THE DIVIDING OF INDIRECT MEASUREMENT

The theory of indirect measurement is based on the mathematical modelling of a technological processes where relationships between inputs **x** and it outputs **y** are defined. Each y variable carries some part information about **x** and it's a deal on the contrary also. By task of indirect measurement is determine the unmeasured variable by help others directly measured variables. In other words told, some function (1) has to be found.

$$y = f\left(x_1, x_2, \ldots x_n, \tau\right) \tag{1}$$

where:

y – the indirect measured variable,

[*] Prof., Ing., CSc., Department of Applied Informatics and Process control, BERG Faculty, Technical University of Košice, B. Němcovej 3, Košice, tel. (+421) 556025191, e-mail Karol.Kostur@tuke.sk
[**] Ing., Department of Applied Informatics and Process control, BERG Faculty, Technical University of Košice, B. Němcovej 3, Košice, tel. (+421) 556025175, e-mail Marek.Laciak@tuke.sk
[**] Ing., Department of Applied Informatics and Process control, BERG Faculty, Technical University of Košice, B. Němcovej 3, Košice, tel. (+421) 556022477, e-mail Martin.Truchly@tuke.sk

τ – time,

$x_1, \dots, x_n$ – direct measured variables.

In this case variables $\mathbf{x_i}$ are some input variables only or $\mathbf{x_i}$ are some output variables only or $\mathbf{x_i}$ are both kind (input, output) variables – see Fig. 1.

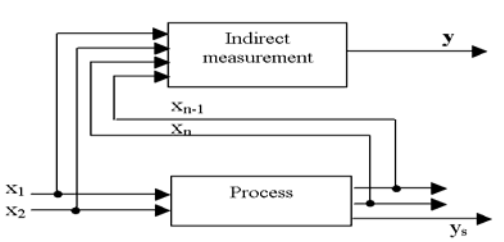

Fig. 1 Inputs and outputs variables in the indirect measurement

The problem of indirect measurement is not new, but it's still in the interest of technical professional workers. There are more ways how to do it. The indirect measurement we can divide from following standpoints [Kostúr at all 2005]:

- according the time,
- by type of transformation,
- according complexity,
- according the method access,
- by the realization.

2.1 Static and dynamic indirect measurement

If indirect measured variable (1) is time independence then this system of indirect measurement is steady slate. These systems are oldest and vide used. Each static characteristic of sensors belong to this group. If indirect measured variable depends on tine, then the system of indirect measurement is dynamic. For example the kinetic reaction first order is describes following equation.

$$\frac{dy}{d\tau} = k(x - y) \tag{2}$$

where:

y – product flow,

τ – time,

x – input flow,

k – speed constant.

In this case the speed constant is known and the input flow (x) is directly measured. The product flow (y) is possible to determine by help (2).

2.2 The types of the transformation

The aim of indirect measurement systems is known input directly measured variable/variables to transform on unmeasured variable/variables [Kostúr 2002]. The system of indirect measurement form this standpoint can be divided to three groups:

- first type of transformation $x(\tau) \rightarrow y(\tau)$,
- second type of transformation $\bar{x}(\tau) \rightarrow y(\tau)$,
- third type of transformation $\bar{x}(\tau) \rightarrow \bar{y}(\tau)$.

2.2.1 The indirect measurement of first type

These methods are oldest and very simple. One directly measured variable (x) is transformed on one indirect measured variable (y) through known relationship -see Fig.2

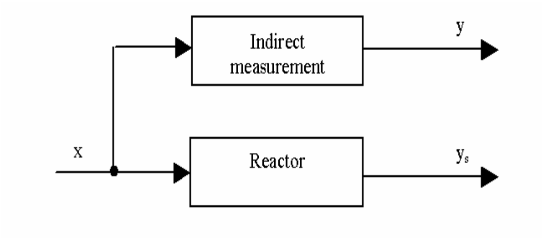

Fig. 2 The principle scheme of the indirect measurement of I. type

Example

The production of CaO is technology, which is based on chemical reaction of first order.

$$Ca\,CO_3 \rightarrow Ca\,O + CO_2$$

The direct measured variable is the mass flow Ca CO_3 and by relationship (2) is possible to compute CaO mass flow as y.

2.2.2 The indirect measurement of second type

Indirect measured variable y is computed from more direct measured variables.

$$y(\tau) = f(x(\tau)),$$
$$x = [x_1, x_2, ..., x_n],$$

where:

$x_1, ..., x_n$ – direct measured variables.

This method is suitable for systems which are described by simple differential equations.

Example

System of indirect measurement (SIM) is based on decarbonization model in steel making.

$$\frac{dC}{d\tau} = k_1 \cdot x_1 (x_2 + k_2 \cdot x_3) \qquad (3)$$

where:

τ – time,
C – % content of carbon in liquid steel,
x_1 – the oxygen volume flow blasted to melt,
x_2 – % content of CO in converter gas,

x_3 – % content of CO_2 in converter gas,
k_1,k_2 – constants.

The principle scheme SIM of carbon percentage is shown on Fig. 3, where 1 – is the converter, 2 – is the cover, 3 – is the oxygen flow meter, 4 – is the exhausting of converter gas.

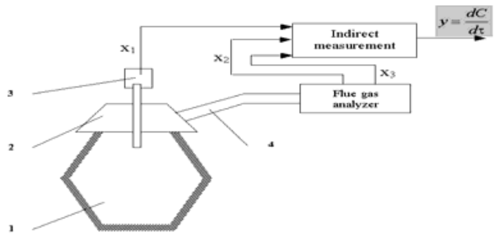

Fig. 3 The principle scheme of the indirect measurement of the carbon content in the melt

Inputs of SIM oxygen volume flow (x_1), percentage CO (x_2), percentage CO_2 (x_3), measured by the flue gas analyzer. The output from SIM is the decarbonization speed and from this indirect measured variable is possible to determine percentage of the carbon.

2.2.3 The indirect measurement of third type

This type is complicated and *it's* structure is following:

$$y_i(\tau) = f_i(x_j(\tau)), \quad i = 1,2,\ldots,\mathbf{s} \tag{4}$$

Input vector ***x*** are direct measured variables and SIM j = 1, ..., n computes vector of indirect measured variables – see Fig. 4. By essence of SIM is to find functions f_i .

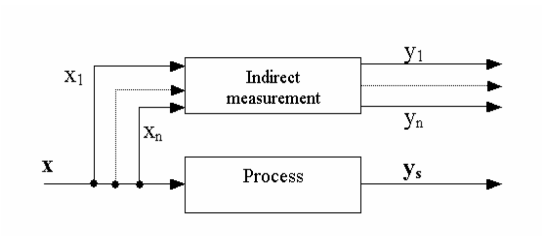

Fig. 4 The scheme of the indirect measurement of III. type

2.3 Indirect measurement according complexity

On base of research SIM for steelmaking process [Kostúr 2002, Laciak 2002] has been proposed following dividing:

- simple,
- complicated,
- feedback.

2.3.1 Simple indirect measurement

The input direct measured variables can be divided on uncontrolled **x** and control input **u**. But it is not substantial. Indirect measurement from the first type until the third type (chapter 2.2) belong to this group also. The task of SIM projector is to create the model which determines indirect measured variables **y** from direct measured **x** and **u** / see Fig. 5.

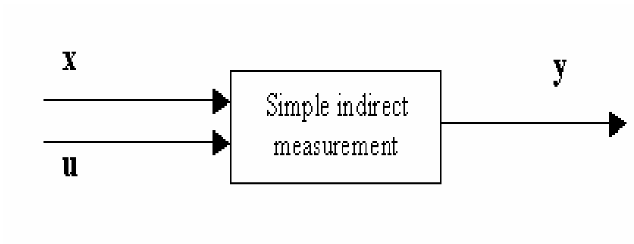

Fig. 5 The principle of the simple indirect measurement

2.3.2 Complicated indirect measurement

The common feature this group is the prediction input vector $\boldsymbol{x}^P$. There are following relationships:

$$y(\tau) = f\left(x^P(\tau)\right),$$

or

$$\boldsymbol{y}(\tau) = \boldsymbol{f}\left(\boldsymbol{x}^P(\tau)\right),$$

where:

$$\boldsymbol{x}^P(\tau) = \boldsymbol{f}'\left(\boldsymbol{x}^P(\tau - \Delta\tau), \boldsymbol{u}(\tau - \Delta\tau)\right)$$

for initial definable $\mathbf{x}^P(0)$**.**

Inputs $\mathbf{x}^P$ is possible to characterize as outputs from simple partial models $\boldsymbol{f}'$. The complicated indirect measurement consists form final model (function f_i) which computes indirect measured outputs **y** and from some partial models (functions f_j'), which compute inputs $\mathbf{x}^P$. Structure is shown on Fig. 6.

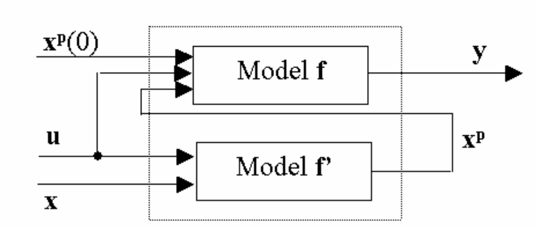

Fig. 6 The principle of complicated indirect measurement

2.3.3 Indirect measurement with feedback

Simple and complicated measurement can be widened about feedback. The meaning feedback means the input indirect measured variable y to indirect measurement from previously time step $(\tau - \Delta\tau)$. The principle both variant with feedback is shown on Fig.7.

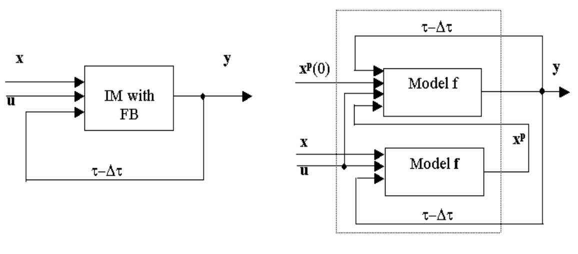

Fig. 7 The principle of indirect measurement with feedback

Example

This structure was been realized in SIM [Kostúr 2004, Laciak 2004, Tréfa 2004] for indirect measurement of a temperature and percentage carbon (y_1,y in melt from direct measured variables **x** =[pressure, temperature, % CO, % CO_2,...]. It is possible become general in following form:

$$y_1(k+1) = a_{10} + a_{11}y_1(k) + a_{12}y_2(k) + ... + a_{15}y_5(k) + \sum_{j=1}^{n} a_{1j+3}x_j(k) + \sum_{i=1}^{m} a_{1n+s+i}u_i(k)$$

$$y_s(k+1) = a_{S0} + a_{S1}y_1(k) + a_{S2}y_2(k) + ... + a_{S3}y_S(k) + \sum_{j=1}^{n} a_{Sj+3}x_j(k) + \sum_{i=1}^{m} a_{Sn+n+s+i}u_i(k)$$

where**:**

y_s – 5-th indirect measured variable,

x_j – j-th direct measured variable,

u_i – i-th direct measured control input,

k – the time step,

A – the matrix of coefficients.

3 CONCLUSIONS

Methods for creating of models processes and measurement are similar but the precision must to be high in case indirect measurement. It is possible to obtain because the number indirect measured variables is less as the number output variables in model some technological process.

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. The systems of indirect measurement. In *Proceedings of 3rd ICCC*. Ostrava : VŠB Ostrava, 2002, pp. 63-68. ISBN 80-248-0089-6.

[3] KOSTÚR, K. & LACIAK, M. Model for indirect measured of LD steelmaking process. *Metallurgy*. 2002, Nr. 2, pp. 113-116. ISSN 0543-5846.

[4] KOSTÚR, K. LACIAK, M. TRÉFA, G. Indirect measured temperature in LD converter. In *Proceedings of 2nd International & Exhibition on New Development In Metallurgical Process Technology*. Riva del Garda - Italy : Milano : Associazione Italiana di Metallurgia, 2004, pp. 63-68. ISBN 80-85298-51-6.

Reviewer: prof. Dr. RNDr. Lubomír Smutný, VŠB-Technical University of Ostrava