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David KLIMÁNEK*, Bohumil ŠULC**

IMPROVEMENT OF CONTROL LOOP FUNCTION BY CONTROL VARIABLE SENSOR DISCREDIBILITY DETECTION

VYLEPŠENÍ FUNKCE REGULAČNÍHO OBVODU DETEKCÍ DISKREDIBILITY SENZORU REGULOVANÉ VELIČINY

Abstract

The gradual loss of the credibility of sensors measuring control variables in control loops (so-called control variable sensor discredibility) may cause serious difficulty detectable problems in control. If such a sensor produces biased data, which are not correct but not totally wrong, then there is a danger that the controlled variable exceeds limits of a tolerance range without displaying any difference from the set point. However, this is not the only negative consequence, sometimes, undesirable side effects may occur and they remain unrecognized. The problem of these indirect unrecognized impacts becomes important especially in combustion processes. In case of a pilot stoke-fired boiler, which has been used for experiments in the CTU labs, the sensor discredibility problem is related with function of the oxygen probe used for accurate control of the burning air. Discredibility of this sensor will affect hidden increase of penalized gaseous emissions, above all CO and NOx. The discredibility of the oxygen probe is very difficult to reveal because the main (temperature) control loop seems to be working without any problems. The usual way of discredibility detection (but sometimes expensive) is to use more measuring equipments (so-called hardware redundancy). The aim the research is to replace this expensive way of the hardware redundancy with the use of software tools. In this paper, a comparison of software evolutionary model-based methods (genetic algorithm and simulated annealing) will be shown.

Abstrakt

Postupná ztráta kredibility senzorů měřicích regulované veličiny v regulačních obvodech (tzv. diskredibilita senzorů regulačního obvodu) může způsobit při regulaci vážné, obtížně detekovatelné problémy. Pokud senzor poskytuje zkreslené údaje, které nejsou správné, ale také nejsou zcela špatné, vzniká nebezpečí, že skutečná hodnota regulované veličiny překročí limity tolerančního pásma, aniž je přístroji signalizovaná odchylka od žádané hodnoty. Toto není jediný negativní důsledek; v některých případech se mohou vyskytnout také nežádoucí vedlejší efekty, které zůstanou nerozpoznány. Problém vedlejších nerozpoznaných důsledků se stává závažný zejména u spalovacích procesů. V případě pilotního tepelného roštového kotle, který je k dispozici pro experimenty v laboratořích ČVUT v Praze, je problém diskredibility senzoru spojen s funkcí kyslíkové sondy použité pro přesnou regulaci spalovacího vzduchu. Diskredibilita tohoto senzoru ovlivní skryté zvýšení penalizovaných emisí zejména CO nebo NOx. Diskredibilita kyslíkové sondy je velmi obtížně odhalitelná, protože hlavní (tepelný) regulační obvod pracuje bez jakýchkoliv problémů. Obvyklý způsob detekce diskredibility (ale někdy nákladný) je použit více měřicích zařízení (tzv.

* Ing., Department of Instrumentation and Control Engineering, Faculty of Mechanical Engineering, Czech Technical University in Prague, Technicka 4, Prague, tel. (+420) 22435 2896, e-mail David.Klimanek@fs.cvut.cz

** Doc., Ing., CSc., Department of Instrumentation and Control Engineering, Faculty of Mechanical Engineering, Czech Technical University in Prague, Technicka 4, Prague, tel. (+420) 22435 2531, e-mail Bohumil.Sulc@fs.cvut.cz

hardwarová redundance). Cílem výzkumu je nahradit tento drahý způsob hardwarové redundance s použitím softwarových nástrojů. V příspěvku je ukázáno porovnání softwarových modelových metod s pomocí evolučních algoritmů (genetického algoritmu a simulovaného žíhání).

1 INTRODUCTION

When operating a control loop, unrecognized hidden inaccuracy of the control loop operation may be present. This control loop inaccuracy arises due to so-called discredibility of the controlled variable sensor. Notion of the sensor discredibility means, that the sensor is not faulty, but its properties have changed (or they have been changing gradually), and thus the sensor has started to provide biased data. As follows from the following, this notion has a special sense if linked with controlled variable sensors. The problem of sensor discredibility detection is usually not so important until side effects on the controlled process are negligible and they need not be taken into account.

To avoid undesirable side effects resulting from the controlled variable sensor discredibility, either hardware or software way of the sensor discredibility detection can be used. The hardware discredibility detection is usually achieved by means of adding another redundant sensor. This may be a costly solution. The cheapest solution is offered by the software way, which is under the current investigation and which is the main point of this presentation. Generally, the aim of research is to extend function of a standard controller, so it would be able, besides its normal control function, to discover impreciseness in the control loop operation.

Sensor discredibility detection is well demonstrable especially when we are interested in the combustion process control. In quest of producing the minimal achievable gaseous emissions and maintaining the steady fuel combustion, it is necessary to control the air factor (air excess) α, on its desired value [Bašta, J., et al., 2004]. The air factor α is expressed by the ratio

$$\alpha = \frac{Q_a}{Q_{a\,min}} > 1 \quad [-] \tag{1}$$

where

Q_a – actual burning air $\left[\frac{\mathrm{m}^3}{\mathrm{s}}\right]$,

Q_{amin} – the necessary burning air $\left[\frac{\mathrm{m}^3}{\mathrm{s}}\right]$.

The topical value of the air factor α in the running combustion process is acquired via oxygen concentration measurement in the flue gases at the end part of the boiler.

In Fig. 1 an optimal range of the air factor is depicted. If the air factor is between α_{min} and α_{max}, then emissions of CO and NO_x will not exceed a maximal level. However, the problem is that oxygen probes are vulnerable to faults [Neuman, P., Šulc, B., Zítek, P. & Dlouhý, T, 2000]. If the oxygen probe starts to provide -biased information about the oxygen content in flue gasses, emissions of CO and NOx will exceed given limited values and penalties for the undesirable side environment impacts can follow. Thus it is necessary to avoid an unrecognized increase of emissions particularly of CO and NOx. To the avoid penalised side effect resulting from oxygen probe faults, we suggest to prevent this state by a software tool which would be able to detect changes of the controlled variable sensor at its beginning. Such a task is referred to the sensor discredibility detection.

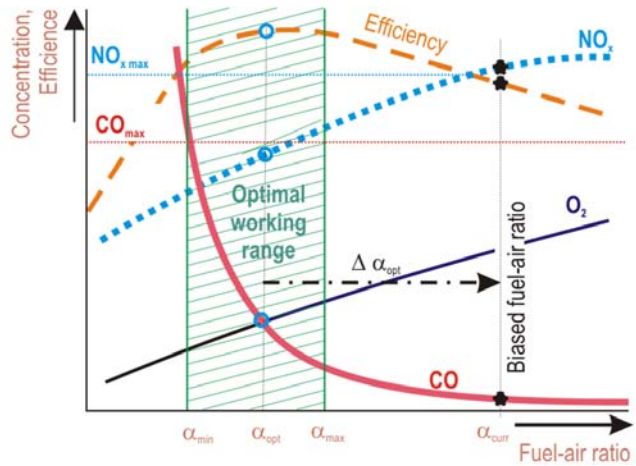

Fig. 1 Optimal operating range in dependence on the fuel - air ratio

The sensor discredibility detection is considered to be applied to a pilot stoker-fired boiler (Fig. 2), available for experiments in the CTU labs. In spite of the fact that usually the hardware redundancy is preferred, this solution is not suitable for the used oxygen probe because of the expected additional costs. Our aim is to implement the software sensor discredibility detection into the controller unit.

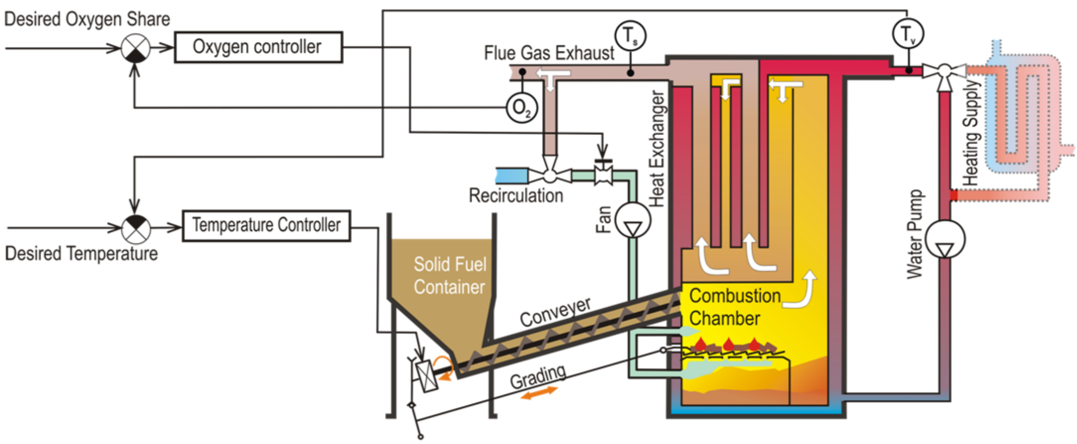

Fig. 2 Stoker-fired boiler for biomass combustion

Before any implementation to a control loop, it is necessary to test proper function of the designed procedures by simulation. Therefore, the methods have been applied to a simulated example of a control loop. In this example, the controlled object is a cascade of two tanks and the controlled variable is the level in the second tank. For modelling Matlab–Simulink is used. In the developed methods of the sensor discredibility detection a linear model of the controlled variable sensor is used and the real sensor behaviour was limited to a linear relation between sensor's input and output. Results of a suitability comparison and a time consuming of both model based methods will be shown.

2 DISCREDIBILITY DETECTION TESTING

Model based software methods for sensor discredibility detection (namely the method of simulated annealing – SA and the method of genetic algorithm – GA) has been presented i.e. in

[ŠULC, B., KLIMÁNEK, D., 2005 B]. The general requirement of successful application of any of the methods is to design so - called objective function. In terms of the sensor discredibility detection, this function is called a residual function or a residuum.

For testing and application the methods a Graphical User Interface (GUI) has been developed (Fig. 3). It offers choice of the methods for testing. Both of the methods are implemented with the use of Matlab S-function, because results computed by means of the S-functions are obtained faster than by standard M-functions blocks.

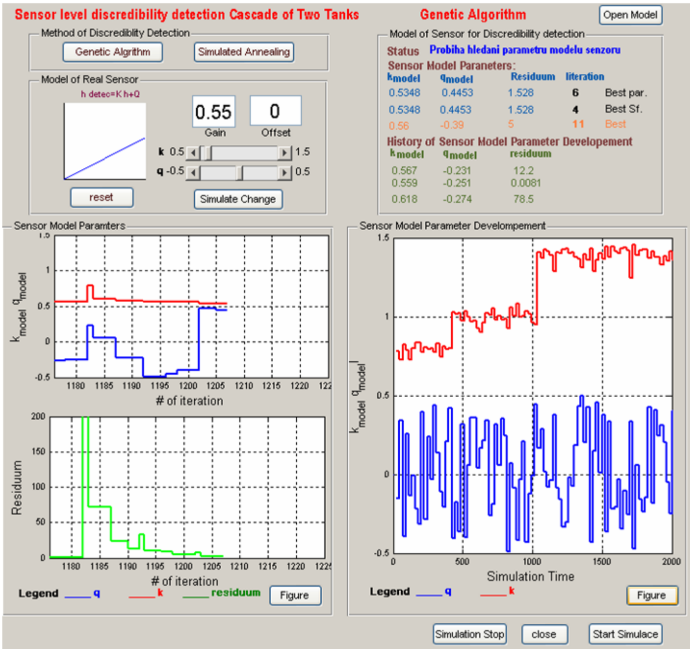

Fig. 3 Matlab GUI dialog window provides selection of discredibility detection methods, sensor discredibility simulation and sensor model parameter development.

3 COMPARISON OF METHODS

Representative simulation responses obtained via methods GA and SA are depicted in Fig. 4. In the simulation, the model of the real level sensor behavior is modeled by the same equation as the sensor model for discredibility evaluation part, it means that the real physical value of the controlled variable y_{real} is transmitted to the measured value y according to the equation $y = k\, y_{real} + q$. Evidently, if the sensor works properly the values of the parameters must be: the gain of the sensor $k = 1$, and the shift factor $q = 0$. The sensor model for discredibility evaluation part uses the estimated value of y_{real} marked as y_{est}. This value (y_{est}) is transmitted to the value marked as y_m according to equation $y_m = k_m\, y_{est} + q_m$. In principle, the discredibility detection algorithms try to find such parameters (k_m, q_m) of sensor model for discredibility evaluation part, which minimize a residuum e ($e = y_{real} - y_m$). The sensor discredibility detection is based on the continual evaluating of the sensor model parameters; because when no sensor discredibility occurs, the parameters do not change.

In the Fig. 4 there is depicted a simulation run when the sensor gain has increased from 100 % to 140 % (at the simulation time 2000 the sensor gain was decreased by 55 %). It is apparent that both algorithms were able to find the new gain k_m of the sensor model. From these responses, it is also evident that both methods are sensitive mainly to changes of the gain k of the sensor. Detection of the shift factor q changes at the sensor is not so important, because the control loop is mostly vulnerable to sensor gain changes (when the linear model of the sensor is considered).

Generally, from testing of algorithms follows, that the SA needs more evaluation time for one evaluation period – a period for SA required 60 iterations, while GA needed 10 iterations. This difference is because GA works with a group of potential solutions, while SA compares only two potential solutions and accepts better one. SA needs six times more of evaluation time to perform as much iteration as GA.

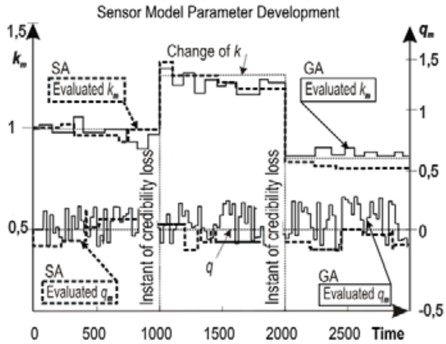

Fig. 4 Sensor model parameter detection

4 CONCLUSIONS

Both methods are able to indicate the sensor properties changes. Although the evolutionary algorithm generally required more time consumption in comparison with other optimizing procedures, this circumstance does not matter in the sensor discredibility detection. Because discredibility may not have any unacceptable impacts on the control results. The time needed for the detection does not affect the control process.

In order to apply methods for oxygen probe discredibility detection, future development will focus on estimation of the oxygen content in the flue gasses. A way that seems to be viable is depicted in Fig 5. This method is based on balancing the oxygen incomes to combustion process, determination the oxygen fixed in the unburned solid fuel and the oxygen fixed in the wet flue gasses. The value of the oxygen fixed in flue gasses can be obtained from the tabulated values for each component of the wet gasses based on the air factor.

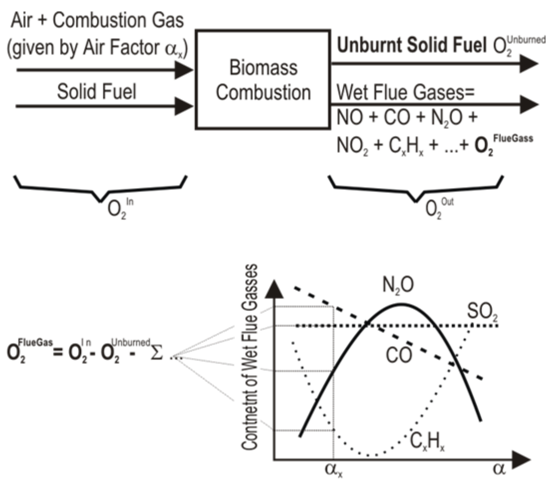

Fig 5 Schematic diagram depicting principle of estimation of the oxygen content in flue gases

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Reviewer: doc. Ing. Miluše Vítečková, CSc., VŠB – Technical University of Ostrava