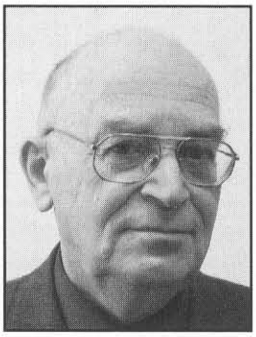
Krzysztof PIETRUSEWICZ, Paweł BIAŁY, Stanisław SKOCZOWSKI
TECHNICAL UNIVERSITY OF SZCZECIN, INSTITUTE OF CONTROL ENGINEERING,

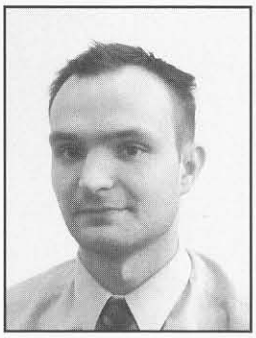
MFC/IMC system for processes with varying time-delay exemplified by a 4 MW steam boiler

Prof. Stanisław SKOCZOWSKI



He was born in 1936. Since 1963 he has been employed at the Technical University of Szczecin. In 1969 he received his Ph.D. degree, and in 1973 the Habilitation degree. In 1978 he became a Full Professor. He is an author of 5 monographs, about 140 papers and has supervised 13 Ph.D. thesis. His research interest include temperature control, process modeling and identification, as well as industrial and adaptive control systems.

Mgr inż. Paweł BIAŁY



He was born in 1976. In 2000 he received his Master of Science degree at Technical University of Szczecin – Engineering Sciences at the Institute of Control Engineering. Currently he is attending Ph.D. course there. He specializes on control and optimization of regulation processes. For last 5 years he has been focusing on optimization processes in most modern steam and water boiler houses.

Mgr inż. Krzysztof PIETRUSEWICZ

He was born in 1977. Since 1997 he has been student in Engineering Sciences at the Institute of Control Engineering, Technical University of Szczecin. In 2002 he received his MSc degree. Currently he is attending Ph.D. course. His interests are focused on soft computing, visualization and industrial applications of PLCs.

Abstract

The paper deals with robust model-following control of a process with varying time-delay. The proposed MFC/IMC structure offers more robustness to plant parameter perturbations and less sensitivity to disturbances, as compared with classic single-feedback loop with PID controller.

On the basis of presented results of oxide content control in a 4 MW steam boiler one can compare properties of the proposed structure with properties of the classic single-loop system with PID controller.

Also, the use of PD/PI fuzzy-logic controller as a part of MFC/IMC system confirms its flexibility.

Streszczenie

Artykuł prezentuje wyniki badań nad odporną strukturą regulacji MFC/IMC dla obiektów ze zmiennym opóźnieniem. Proponowana struktura charakteryzuje się małą wrażliwością na perturbacje nominalnego modelu sterowanego obiektu, oraz znacznym tłumieniem zakłóceń wejściowych oraz tych sprowadzonych do wyjścia obiektu. Wyniki badań symulacyjnych dla obiektów aperiodycznych z opóźnieniem z użyciem struktury MFC/IMC sprawdzone zostały na przykładzie procesu doregulowywania zawartości tlenu w kotłach parowych mocy 4MW, i porównane z klasyczną strukturą jednopętlową z regulatorem PID.

Dodatkowo, wykorzystanie logiki rozmytej w realizacji części algorytmu MFC/IMC potwierdza elastyczność układu regulacji typu model-following.

Key words: Robust PID control, Fuzzy-logic, Model-Following Control.
Słowa kluczowe: Regulacja odporna, regulacja PID, logika rozmyta, regulacja typu model-following.

1. Introduction

PID controllers are encountered in almost 95% of industrial control applications [1-3]. The amount of publications devoted to this algorithm still arises [4, 5] because of simplicity and virtues of lasting value the PID algorithm offers.

Since the first rules for tuning the PID controllers were given [6], development of digital-control and microprocessor enabled great impact to research work on structures that could not be used in practice before [7-13].

Over the past few years the methods of artificial intelligence in general and fuzzy-logic in particular, are strongly applicable in industrial controllers.

By the use of fuzzy-logic one can find a simple way to take account on experience gathered during the plant operation [8-15].

The system to control the oxide content in steam boilers provides optimal fuel-air mixture for burning process. This kind of system gives great savings of fuel. The oxide content is measured in fumes blown from the boiler. Air dampers are the actuators in a compared control structures.

The paper proposes MFC/IMC system described in [12, 18, 19] as a solution of control the oxide content in the steam boilers.

Presented results show many virtues, yielding increased robustness and control performance at the same time.

The proposed structure can be used instead of Siemens gain-scheduled PID control system actually employed in the adjusting of oxide content.

2. MFC/IMC structure

The MFC/IMC structure is shown in Fig. 1. It considers all constraints in control signals.

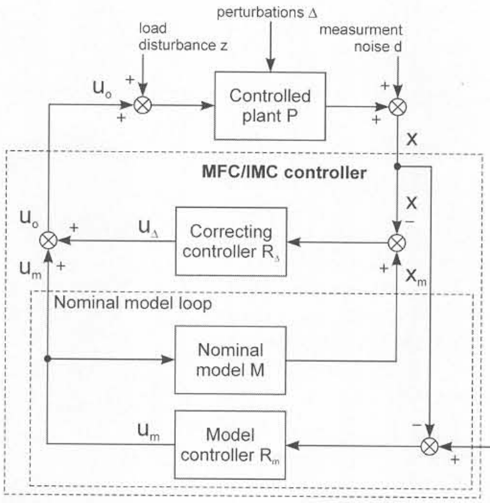


Fig. 1. MFC/IMC structure
Rys. 1. Struktura MFC/IMC

In a classic single-loop system the controller has been designed using the process model as the base in full consciousness that the model M(s) may differ from the process P(s) by the unknown, but limited multiplicative perturbation Δ(s), as shown in eq. (1)

$$P(s)=M(s)\left[1+\Delta(s)\right]$$
$$\left|\Delta(s)\right|\leq \Delta_{max}<1, s=j\omega, \omega\in\left[0,\infty\right) \quad (1)$$

The presence of perturbations Δ(s) makes that the process P(s) is to be treated as unknown.

The control system of Fig. 1 is described by the eq.(the s argument is omitted)

$$x=x_0\left[1-\frac{1+R_\Delta M(1+\Delta)}{(1+R_m M)(1+R_\Delta M(1+\Delta))+R_m M\Delta}\right]+$$
$$+d\frac{1}{(1+R_m M)(1+R_\Delta M(1+\Delta))+R_m M\Delta}+ \quad (2)$$
$$+z\frac{M(1+\Delta)}{(1+R_m M)(1+R_\Delta M(1+\Delta))+R_m M\Delta}$$

where:
x_0 - reference signal
d - disturbances at the plant output (e.g. measurement noise)
z - disturbances at the plant input (e.g. load disturbances)

3. Output sensitivity

Proposed MFC/IMC system provides lower sensitivity to disturbances at the input and output of the controlled plant than in the case of a classic single-loop structure [9, 12, 18, 19]. It is shown in the following numerical example.
The process is described by the eq. (3)

$$P(s)=\frac{e^{-10\cdot s}}{(1+s10.0)(1+s33.3)(1+s111.11)} \quad (3)$$

while its nominal model (4)

$$M(s)=\frac{1}{(1+s10.0)(1+s20.0)(1+s40.0)} \quad (4)$$

Model and corrective controllers in compared structures are tuned by the phase margin method given in [12, 18, 19]

$$R_m(s)=\frac{(1+s20.0)(1+s50.0)}{s50.0} \quad (5)$$

$$R_\Delta(s)=25.0\frac{(1+s30.0)(1+s200.0)}{s200.0} \quad (6)$$

Figure 2 shows the sensitivity functions $|S_d(\omega)|$, $|S_z(\omega)|$ in the frequency domain.

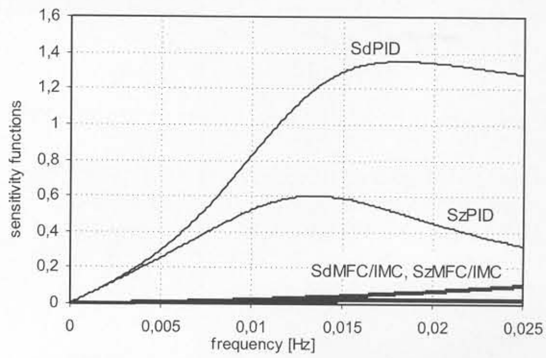


Fig. 2. Output sensitivities
Rys. 2. Wrażliwości zakłóceniowe

The main conclusion from results presented in Fig. 2 is that the proposed MFC/IMC structure suppresses the disturbances much better (it means a lower sensitivity) than the classic single-loop system with PID controller tuned for the nominal model of the controlled process.

4. Parallel PD/PI Fuzzy Inference System

Examples of parallel PD/PI Fuzzy Inference System shown in Fig. 3 can be found in [8-11, 14-17].

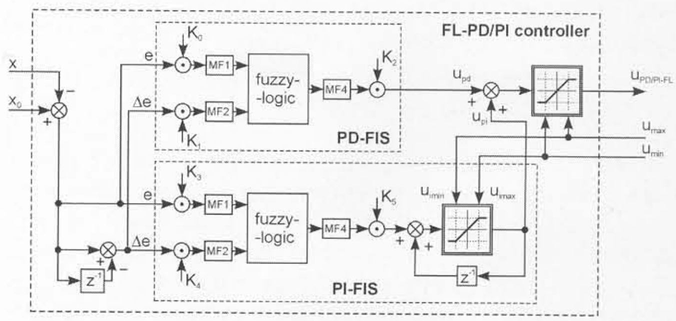


Fig. 3. FL-PD/PI controller structure
Rys. 3. Struktura rozmytego regulatora PD/PI

A three-term PID algorithm realized by means of fuzzy-logic has been used as a corrective controller in the MFC/IMC structure of Fig. 1. Rules for choosing the scaling factors K0-K5, membership functions MF1-MF6, and control surfaces of PD/PI parts in the way used here are described thoroughly in [8-11].

5. Controlled process - steam boiler 4MW

The research work on robust MFC/IMC system has been carried out in the boiler house of about 36 MW power.

Figure 4 shows two 4 MW power steam boilers with air dampers pointed out. The proposed MFC/IMC structure has been used to adjust the oxide content in one of the steam boilers.

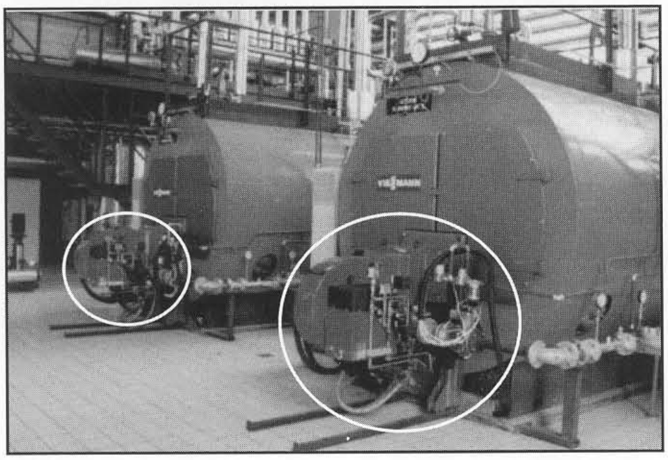


Fig. 4. Steam boilers – 4 MW power
Rys. 4. Kotły parowe mocy 4 MW

The presented boiler house is a full HMI system. It contains 3 water boilers 8 MW power each, and 3 steam boilers 4 MW power each.

The control of oxide content is subjected to many different disturbances (e.g. varying climatic conditions) and perturbations (e.g. varying time-delay as a consequence of varying steam demand).

Nowadays the gain-scheduled PID system realized by Siemens controls the oxide content in the described steam boilers.

The proposed MFC/IMC system has been used to solve the problem of tuning PID controllers for 16 values of steam demand. Replacing the gain-scheduled PID system by the presented model-following control structure also much more suppresses the disturbances.

6. Results of the oxide content adjustment

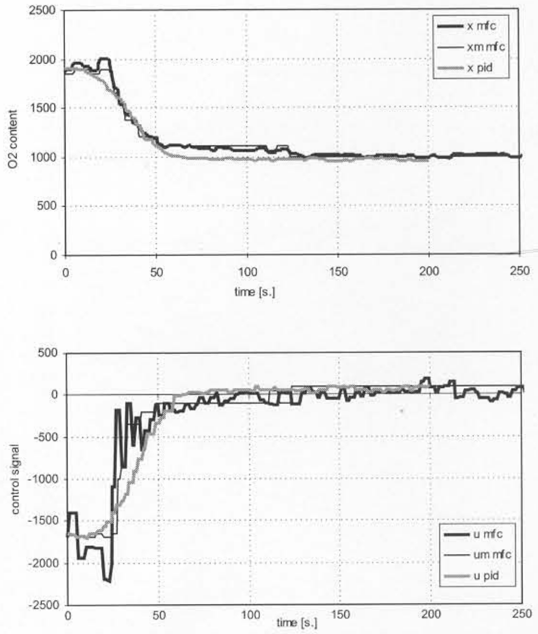
The proposed MFC/IMC system has been tested in practical examination. In experiments described below robustness and control performance for the perturbed plant time-delay and time constant, in the presence of load disturbances, assuming constant parameters of both controllers have been compared with the classic control system with PID controllers tuned for each steam demand point.

The set-point of oxide content has been varied from 4% to 2.5%. Plant load has been treated as a perturbation.

The model controller Rm of Fig. 1 has been tuned in experimental conditions with 75% of steam demand. The plant output and control signals have been recorded. Then the nominal model and model controller was derived.

The corrective controller RDis a nonlinear PID realized by means of fuzzy-logic in the way shown in Fig. 3 [8-11, 14-17].

Figure 5 shows the plant output and the control input for the classic and the MFC/IMC system in the nominal case (i.e. for 75% of steam demand).

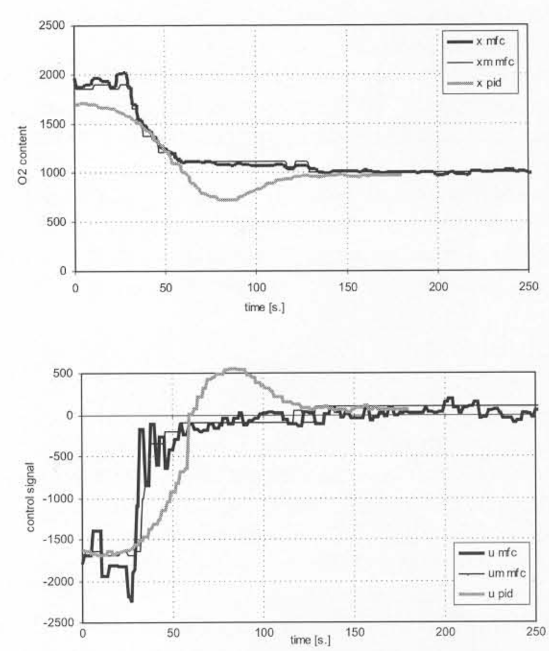


a)

b)

Fig. 5. Oxide content (a) and control signals (b) in compared structures in nominal case (i.e. for 75% of steam demand; identified time-delay about 15 seconds)
Rys. 5. Zawartość tlenu (a) oraz sygnały sterujące (b) w badanych strukturach przy założonych nominalnych warunkach pracy (75% obciążenia - poboru pary z kotła; zidentyfikowane opóźnienie około 15 sekund)

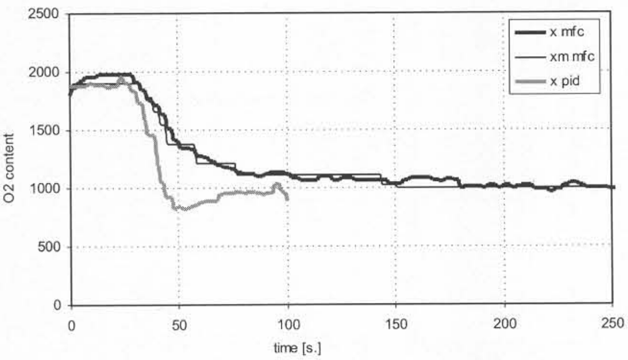
In Fig. 6 it is shown how compared systems manage with perturbed plant time-delay caused by the change in load signal.



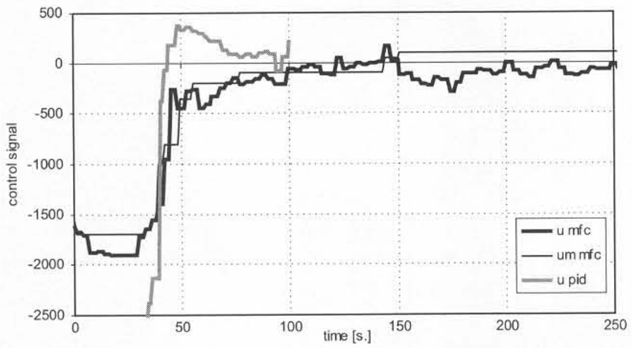
a)

b)

Fig. 6. Oxide content (a) and control signals (b) in compared structures for full load (i.e. 100% of steam demand; identified time-delay about 10 seconds)
Rys. 6. Zawartość tlenu (a) oraz sygnały sterujące (b) w badanych strukturach przy całkowitym obciążeniu (zidentyfikowane opóźnienie około 10 sekund)



a)



b)

Fig. 7. Oxide content (a) and control signals (b) in compared structures for 43% of steam demand (biggest time-delay; identified time-delay about 30 seconds)

Rys. 7. Zawartość tlenu (a) oraz sygnały sterujące (b) w badanych strukturach przy 43% obciążenia (przypadek, gdy opóźnienie jest największe; zidentyfikowane opóźnienie około 30 sekund)

As shown in Figs. 6 and 7 varying time-delay as a consequence of change in steam demand makes no difference for the proposed MFC/IMC structure, as compared with the classic single-feedback loop, tuned for each case of steam demand.

7. Conclusions

Results obtained from experiments carried out on the adjustment of oxide content in steam boiler using the PLC with the implemented MFC/IMC system with nonlinear corrective controller realized by the means of fuzzy-logic lend great support to the validity of theoretical considerations.

The proposed structure exhibits a substantial robustness to plant parameter changes, e.g. varying time-delay.

The presented MFC/IMC system can be implemented on PLCs and PACs available on the market. So the proposed control system presents an effective alternative to control algorithms employed so far.

The use of MFC/IMC system with constant parameters and scaling factors of controllers and internal model of the controlled plant instead of gain-scheduled PID control proposed by Siemens proved it perfectly.

8. References

[1] K.J. Åström, P. Albertos, J. Quevedo: PID control. Control Engineering Practice 2001, No. 9, pp. 1159-1161.

[2] K.J. Åström, T Hägglund: The future of PID Control. Control Engineering Practice 2001, No. 9, pp. 1163-1175.

[3] K. K. Tan, Q.-G. Wang, C.-C. Hang, T. Hagglund: Advances in PID control. Springer-Verlag, London, 1999.

[4] M. Lelić, Z. Gajić: A reference guide to PID Controllers in the nineties. In: Proc. IFAC Workshop on Digital Control, Past, Present and Future of PID Control, Terrasa 2000, Spain, pp. 73-82.

[5] A. O'Dwyer: A summary of PI and PID controller tuning rules for time delay: Part 1 and Part 2. In: Proc. IFAC Workshop on Digital Control, Past, Present and Future of PID Control, Terrasa 2000, Spain, pp. 175-180, 242-247.

[6] J. Ziegler, N. Nichols: Optimum settings for automatic controllers. Trans. ASME, 64, 1942, pp. 759-768.

[7] S. Skoczowski, K. Pietrusewicz, B. Broel-Plater: Model following PID control and its implementation on PLC. Proc. MMAR, 2002, pp. 1225-1230.

[8] S. Skoczowski, S. Domek, K. Pietrusewicz, B. Broel-Plater: Robust model following PID control and its implementation on PLC. Proc. CD of 4th IFAC Symposium on Robust Control Design, Milano, Italy, 2003

[9] K. Pietrusewicz, S. Skoczowski: A robust MFC-PID temperature controller and its implementation on PLC (in Polish). Proc. of Automation 2004, Warsaw 2004, pp. 113–122.

[10] B. Broel-Plater, K. Pietrusewicz, S. Skoczowski: New results in robust fuzzy-logic PID controller design. Accepted for 10th IEEE MMAR Conference, 2004.

[11] B. Broel-Plater: Utilization of a fuzzy logic algorithm for industrial TC controllers (in Polish). Proc. of 4th Symposium on Measurements and Control in Industrial Processes, 1999, pp.N1-N8, Zielona Góra.

[12] S. Skoczowski: Control system structures and their robustness. Pomiary Automatyka, Kontrola.No. 6, 2003, pp. 5-9.

[13] S. Skoczowski: A robust control system utilizing plant model (in Polish). Pomiary Automatyka, Kontrola. No. 9, 1999, pp. 2-4.

[14] R. Ketata, D. De Geest, A. Titli: Fuzzy controller: design, evaluation, parallel and hierarchical combination with a PID controller. Fuzzy Sets and Systems, 71, 1995, pp. 113-129.

[15] J. Carvajal, G. Chen, H. Ogmen: Fuzzy PID controller: Design, performance evaluation, and stability analysis. Information Sciences, 123, 2000, pp. 249-270.

[16] Z.-W. Woo, H.-Y. Chung, J.-J. Lin: A PID type fuzzy controller with self-tuning scaling factors. Fuzzy Sets and Systems, 115, 2000, pp. 321-326.

[17] J.-X. Xu, C.-C. Hang, C. Liu: Parallel structure and tuning of a fuzzy PID controller.Automatica, 36, 2000, pp. 673-684.

[18] S. Skoczowski: Technika regulacji temperatury. Wydawnictwo Miesięcznika Naukowo-Technicznego PAK, Warszawa-Zielona Góra 2000.

[19] S. Skoczowski: Deterministyczna identyfikacja i jej wykorzystanie w odpornej regulacji PID temperatury. Wydawnictwo Uczelniane Politechniki Szczecińskiej, Szczecin 2001.

Tytuł: Układ MFC/IMC w regulacji procesami o zmiennym opóźnieniu na przykładzie kotła parowego mocy 4 MW

Artykuł recenzowany