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Artificial Neural Networks Approaches to Monitoring of Combustion in a Fluid Boiler

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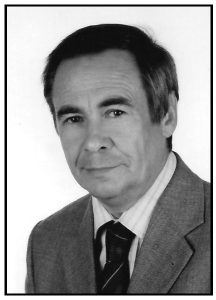

Abstract

The paper describes the applications of artificial neural network models to calculating the emission of exhaust gases and early detection of a steam leak in power fluid boilers. Both tasks are related to the monitoring of boilers operation necessary for fulfilling the ecological requirements (balancing and reduction of the contamination emissions) and limiting the damage results. The paper describes especially problems, that are of general character and are important for implementation of industrial applications similar to other industrial plants.

Keywords: artificial neural networks, virtual analyzers, fluid boilers diagnosis.

Monitorowanie kotłów fluidalnych z zastosowaniem neuronowych modeli spalania

Streszczenie

Opisano zastosowanie modeli neuronowych do wyliczania emisji zanieczyszczeń powietrza oraz do wczesnego wykrywania nieszczelności parowych w energetycznych kotłach fluidalnych. Oba zadania związane są z monitorowaniem pracy kotłów koniecznym dla spełnienia wymagań ekologicznych (bilansowanie i redukcja emisji zanieczyszczeń) oraz ograniczeniem skutków awarii. W artykule przedstawiono zwłaszcza te zagadnienia, które mają charakter ogólny i są ważne przy tworzeniu tego typu przemysłowych aplikacji dla innych obiektów przemysłowych.

Słowa kluczowe: sztuczne sieci neuronowe, wirtualne analizatory, diagnostyka kotłów energetycznych.

1. Introduction

In the described solutions, the models of processes are used for the monitoring tasks. The high and stable in time accuracy of these models is a condition for their practical usefulness in industrial applications. In many cases, only modelling in artificial neural networks structures, with the use of the archival measured data, can fulfil this condition [1, 2].

Calculation methods of estimation the exhaust fumes emission from power boilers and a method of early detecting the steam leak from boilers were examined.

In the first case, the purpose was to calculate the principal components of exhaust fumes (CO, CO_2, NO_x, dust) on the base of the combustion parameters. The systems implementing such calculations are named virtual analysers and often they are alternative solutions to the hardware analysers. In the industrial practice, the virtual analysers are used either in parallel with hardware analyser equipments since the former ensure the real continuity of monitoring, or they replace hardware analyser equipments. The second case exists usually when independent, continuous emission measurements are impossible or too expensive.

Virtual analysers could be the alternative solution on the condition that their accuracy is comparable with the accuracy of the hardware analysers. This is obtained when the accurate enough description of emission as the function of the process parameters is known.

The steam leakages cause especially strenuous and expensive damage of power boilers. Typical controlling arrangements detect leakages in a very advanced phase, when the destruction of the boiler is very extensive, and additionally is it usually necessary to switch out the power unit. Early detection and localization of leakages is the subject of many research implemented during many years. There were trials in which special measuring techniques sensible for the acoustic and optical effects were used. The main faults of such solutions are very high expenses related to the necessity of using the special apparatus that could work in extremely difficult conditions.

In last years, very interested methods of leakage detection by a very advanced analysis of the boiler operation were invented. The steam going out from the steam-water circuits changes the energetic balance and efficiency of particular steps and conditions of the combustion. Such changes are at the beginning not high, but it was tested and proved that with the use of especially efficient analysing methods, such changes could be detected and used for the diagnostic purposes. Chapter 3 presents results obtained during tests of that method for brown coal fluid boilers.

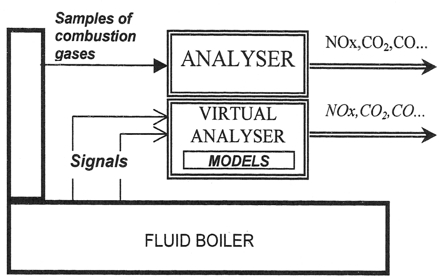

Fig. 1. Diagram of the research arrangement
Rys. 1. Schemat układu badawczego

All of the presented results come from the tests prepared using the arrangement shown in Fig. 1. Box described as a virtual analyser was used both for the emission of exhaust fumes estimation (primary task), and for testing the methods of the leakage detection.

2. Virtual analyser of combustion gases

Virtual analysers replace the hardware analysers in this way that they calculate the required value of the physical variable on the grounds of values of other available physical variables that most often come from measurements. Thus, one can avoid to apply additional hardware investments.

Features and possibilities of analysers will be presented with the use of the example of calculating the nitrogen-oxides (NO_x) contents in combustion gases. These oxides come from nitrogen existing in the air and in fuel, and the creation processes are of different kinds. Therefore the task of creating (NO_x) emission model is especially complex and adequate for presenting advantages of modelling in structures of artificial neural networks [3, 4].

The comparison of readouts obtained from the hardware equipment and a virtual analyser is presented in Fig. 2. Used model of NO_x emission was a multilayer feedforward perceptron structure with one hidden layer and 24 input signals (temperatures in burning chamber, flows of the air, combustion gases and fuel, etc.). Treating readouts of the hardware analyser as a pattern, the accuracy of virtual NO_x analyzer can be described as follows: error of the average value <0.5%, error of efficient value fluctuation component <1.5%.

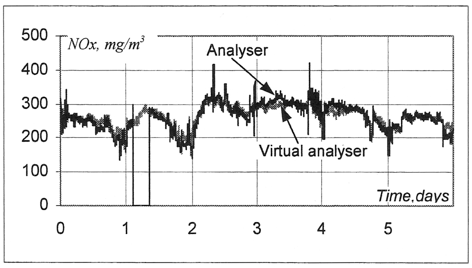

Fig. 2. Comparison of indications from the equipment and virtual analysers
Rys. 2. Porównanie wskazań analizatora sprzętowego i wirtualnego

For other components of fumes, the results were somewhat different. In the case of CO_2, a simpler model ensured higher accuracy, in the case of CO and dusts, the high accuracy of evaluating the mean value with bigger errors for estimating the instantaneous time values were obtained. The biggest difficulty in obtaining the required accuracy appeared during the calculation of the sulphur dioxide emission and was caused by the lack of measurement of the sulphur in fuel. Generally in every case the requirements for systems of monitoring and balancing of emission were fulfilled.

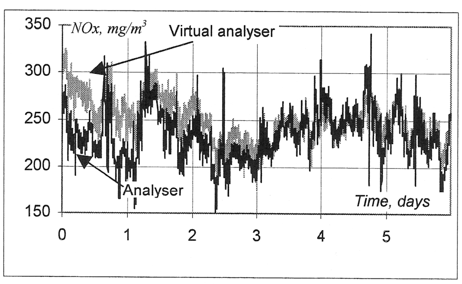

Fig. 3. Example of automatic correction of the model output
Rys. 3. Przykład automatycznej korekcji wyjścia modelu

Evaluating the results obtained during a couple of years of continued research conducted in industrial conditions, it is possible to ascertain that using the modelling with artificial neural networks structures is possible to build very accurate virtual analysers. Complication of the connections between variables of inputs and outputs is not important. The unique real limitation is the availability of obtaining measured signals that should be used in the model.

The initial accuracy of the virtual analyzer could become much worse if the process conditions will be changed. This is the problem common for the all systems supported by models of processes. Maintenance of virtual analyzers is prepared by the actualizations of models or correction of their outputs. In the case of an exemplary analyser of combustion gases, the second automatically implemented solution was applied (Fig. 3) so that the majority of models has worked well for more than two years.

An interesting development of the virtual analyser conception is fitting it with the possibility of solving the so called inverse task, i. e., the calculation of such input variable values that ensure the existence of the required output variable value. As a typical example of such operation, one can calculate such parameters of the combustion process that ensure the required emission levels with the simultaneous fulfilment of an additional requirement related to, e. g., efficiency.

The factor impeding spreading of industrial applications of virtual analysers is their troublesome implementation because in every case it is necessary to check if there exist suitable conditions for such undertaking. Generally it is possible to accept that virtual analysers are intended for industrial installations equipped with modern measurement and robotic systems. In such conditions, analyser utilises existing measurements data, and expensive equipment investments are not necessary.

3. Early steam leak detection

As it was mentioned in Section 1, the early steam leak detection is an unsolved and important problem of exploitation of the power boilers since the last year [5, 6, 7]. Using the experiences obtained during works on virtual analyzers of exhaust fumes, the tests are begun if technology of artificial neural networks could be used for solving this problem The conceptions of diagnostic deductions on the basis of exhaust fumes composition and on the basis of an analysis of leakage sensible variables were tested [8, 9, 10].

First let us assume that the steam leaking the combustion chamber directly influences the moisture of combustion gases, but indirectly also influences another combustion components (nitrogen oxide and coal oxide). Expected changes arising from leakages are not high and are completely masked by other changes from another reasons. Disclosing the influence of the leakages is possible by comparing the real concentration with the pattern concentration for the leakproof boiler. Difference (Residuum) is the symptom of the leakage appearance. The pattern exhaust fumes concentration must be counted on the grounds of model that uses signals not sensible for the steam leakages. For investigations, neuronal networks models were used similar to models of the virtual analyser of exhaust fumes.

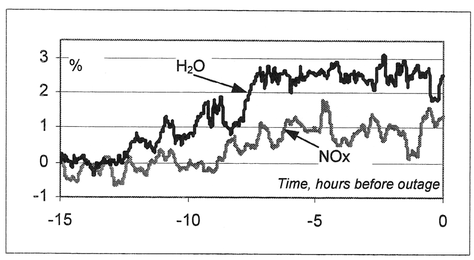

Fig. 4. Examples of the residuum changes
Rys. 4. Przykładowe przebiegi residuów

The changes in time of residues of exhaust fumes moisture and concentration of nitrogen and coal oxides in combustion gases were checked for a dozen registered time periods before the boiler stopped working due to the leakages.

Depending on the placement of the steam leakage, the reactions of different values are different, but usually the exact and lasting residuum growth could be observed only for a few hours before the boiler work stop due to outage (Figure 4), so for a relatively big leakage. Works for the use of the method of residuums are still continued.

Much better results were obtained by using the analysis of variables sensitive to the leakage. A set of such variables is created by the measurement signals (or their functions), which values or mutual relations are changeable when the steam leakage appears. A selection of sensitive variables is a separate problem, which will be not presented here in details. In later investigations concerning a fluid boiler, sets containing from 8 to 18 sensitive variables were applied.

Conception of the leakage detection is supported here using an assumption that the courses of sensitive variables treated jointly have features really changeable by the steam leakage. If such assumption is fulfilled, then it is also possible to create an algorithm of leakage detection by qualifying the features of the set of sensitive variables.

For checking this conception, patterns of sensitive variables from the period directly preceding the outage stopping the boiler (the phase of leakage developing) and from periods of correct working condition were prepared. Such patterns of dates were tested in classifying tasks using the Kohonen net. The results were not satisfying, what caused the beginning of trials with artificial neural nets teaching with a teacher. This time much better results were obtained. For all patterns of data over 90% of cases were correctly recognised. Such quality models can be used just for the leakage recognition. A result of one of the tests of verification of such opinion is presented in Fig. 5. It presents the course-averaged output from the model during 12 days preceding boiler stop from the steam leakage. The values 1 and –1, respectively, denote the correct working condition and the condition with the leakage.

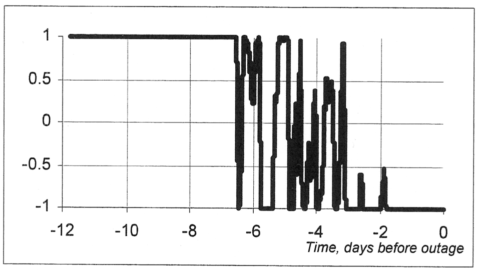

Fig. 5. Averaged output of leakage model.
1 – correct working condition, -1 –leakage
Rys. 5. Uśredniony sygnał wyjściowy modelu nieszczelności.
Poziom 1- stan poprawny, poziom –1- nieszczelność

The presented results show that just in 7 days before the boiler outage, the model shows changeability what should be interpreted as features typical for the steam leakage. At the beginning of the third day before the stop, the averaged output from the model constantly takes negative values, what univocally certifies the leakage. In comparison with the before presented method of residuals, the effectiveness of early detection of the damage is here considerably higher.

In the described examinations, only the possibility of an early detection of the leak without the effort of its isolation was tested. According to such defined task, numerous sensitive variables and teaching data for the leakage model were taken from different outages causes. Localisation of the leaking place could be done using the artificial neural networks models with sets of locally sensitive input variables.

At recapitulation of this part of the article, it is possible to affirm that using technology of artificial neural networks will allow for early detection of steam leakages in power boilers. Obtained results let us predict that the development of the analysis of sensible variables will enable also localization of leakages.

4. Conclusion

Described works confirm the advantages of modelling in structures of artificial neural networks. On the grounds of archival measurement data, it is possible to obtain models of even very complicated processes, what allows us to create advanced industrial applications based on models of processes.

With the use of the example of monitoring the emission from power boilers, it was proved that virtual analysers can effectively replace or be additional to the hardware analysers. Such ascertainment is especially important because there are ecological demands and resulting from them requirements of exhaust fumes emission monitoring in industry.

Described investigations related to the detection of leakages in power boilers are now in an initial phase but obtained results are very encouraging.

It seems adequate to say that an advanced and well-directed analysis of processes let us solve many difficult diagnostic problems. Advantages of modelling in structures of artificial neural networks are in this case very clear and valuable.

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