Development of Software for Fuel Combustion Control System Based on Frequency Regulator

Artur Zaporozhets[1[0000-0002-0704-4116]]

[1] Institute of Engineering Thermophysics of NAS of Ukraine, Kyiv, Ukraine
a.o.zaporozhets@nas.gov.ua

Abstract. A system for monitoring and controlling the process of fuel combustion in boilers based on a stepwise change in the composition of the air-fuel mixture has been considered. Algorithms for the operation of the frequency controller in various modes have been developed. A software module has been created for monitoring the oxygen concentration in the exhaust gases based on the LM Programmer. The interaction of the developed software and hardware is shown.

Keywords: combustion control system, software, frequency regulator, algorithm, combustion regulation, oxy-fuel combustion boiler

1 Introduction

The problems of increasing the efficiency of fuel combustion and reducing emissions of harmful substances are particularly relevant nowadays, and in those industries where the combustion of large amounts of fuel occurs with insufficient completeness and with comparatively low efficiency. This group includes municipal boiler-houses and industrial enterprises with boiler power up to 3.5 MW [1, 2].

Nowadays conventional natural gas-fired boilers exhaust flue gases direct to the atmosphere at 150–200 °C. At such temperatures flue gases contain a large amount of energy and results in relatively low thermal efficiency ranging from 70% to 80%. Although condensing boilers for recovering the heat in the flue gases have been developed over the past 40 years, their present market share is still less than 25% [3]. This fact indicates the need to search for new methods and tools for optimizing the operation of boilers.

The efficiency of boiler installations depends on the availability of reliable information on the course of technological processes. The lack of control and measuring systems for the composition of the exhaust gases leads to a low efficiency of the boiler, in particular, due to poor-quality fuel combustion [4, 5, 6]. Therefore, in modern conditions of operation of boiler plants, the development of technological solutions aimed at finding and minimizing the causes and mechanisms of the formation of harmful substances in exhaust gases is relevant [7, 8]. One of such solutions is the development of a modern system of quality control of fuel combustion, which is based on modern computer technologies [9, 10].

2 Algorithm and Software

2.1 Algorithm of Control System

The algorithm of the automatic control system [11, 12] functioning for the fuel combustion in boilers by adjusting the air fuel ratio (AFR) by the signals from the oxygen sensor is shown in Fig. 1.

A special feature of the algorithm is the using of frequency control, by which the amount of air supplied to the combustion zone varies smoothly. The sensor measures the concentration of oxygen in the flue gases and the system processes the receiving information [13]. A control signal is generated depending on the received excess air ratio (EAR) value – the fan speed is reduced or increased by 0.1 Hz (for $\alpha > X$ or $\alpha < X$, respectively, where X is the measured EAR value). After the steady-state operation of the fan is established, the system is questioned again [14].

The dependence of the fan speed from EAR is determined by the following system of equations:

$$f(\alpha) = \begin{cases} f_0 - \Delta f & at\ X > \alpha_0, \\ f_0 & at\ X = \alpha_0, \\ f_0 + \Delta f & at\ X < \alpha_0, \end{cases} \tag{1}$$

where f_0 – the operating speed of the fan, Δf – the step of the speed changing, X – the current EAR value, and α_0 – the operating EAR value.

The system also provides the setting of eight operating ranges for the frequency controller. Within these limits, the fan speed remains constant. The limits of the frequency ranges for the controller are shown in Table 1.

Table 1. Frequency ranges of controller.

Point number	Symbols on the digital indicator	Frequency range, Hz
1	$0.f_0$	from 0 to 50
2	$1.f_1$	from f_0 to 50
3	$2.f_2$	from f_1 to 50
4	$3.f_3$	from f_2 to 50
5	$4.f_4$	from f_3 to 50
6	$5.f_5$	from f_4 to 50
7	$6.f_6$	from f_5 to 50
8	$7.f_7$	from f_6 to 50

2.2 System Software

The software for the formation of the stoichiometric ratio of the AFR of the burner with feedback from the oxygen sensor is made in the LM Programmer technical programming environment and works with Windows operating systems (XP, Vista, 7, 8, 10) and Bosch oxygen sensors through special controller [15, 16].

The developed software product is used to update the firmware, change the type of using fuel, and program the analog outputs (1V and 5 V).

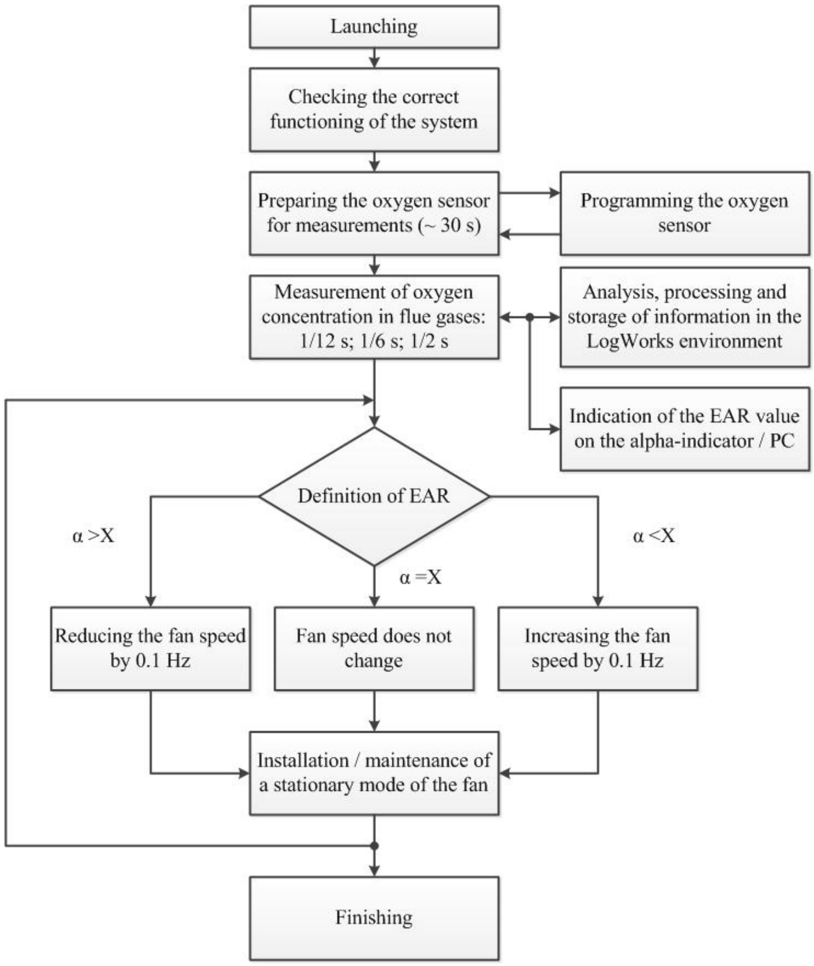


Fig. 1. The algorithm of functioning of the control system on the basis of the frequency regulation.

To start the software environment, it is necessary to connect the oxygen sensor through a connecting cable using the COM port to a PC (if the COM port is missing, the connecting cable can be used a special COM-to-USB adapter) and plug it into an electrical network. The shortcut for launching the program after installation will be located in the "Programs" section of the "Start" panel.

The working environment of the software product shown in Fig. 1.

In the main window of the software environment, the user has the opportunity to change the name of the connected sensor and the type of fuel, according to which he wants to monitor. Standard settings include the following types of fuel:

- propane;
- methanol;
- ethanol;
- compressed natural gas;
- diesel;
- manual setting.

Manual tuning involves the independent introduction of the required stoichiometric value of "air-fuel". Some aspects about this quantity are given in [17].

The software product can connect up to two analog outputs: 1) 5V (for a wideband oxygen sensor) 2) 1V (for a typical planar oxygen sensor).

Fig. 2. LM Programmer Workbench.

The operating environment of the software for connection via the 5 V analog output shown in Figure 2.

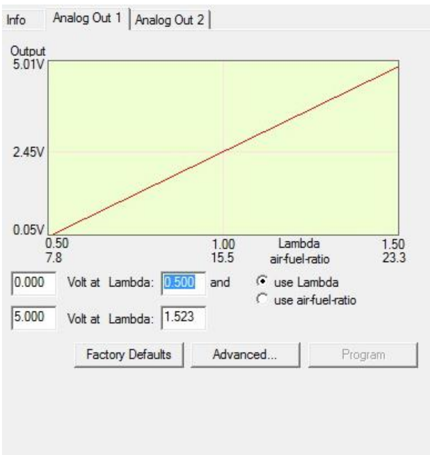


Fig. 2. The working environment of the program with connecting to the 5 V analog output

In this window, the user has the ability to calibrate the software product according to their own needs using the appropriate voltage values (ranging from 0 to 5 V) and coefficient α or the required amount of air (in a volume ratio) per unit of fuel. The dependence of the output voltage from the coefficient α is linear.

During pressing the Advanced key, it can be set the response speeds of the sensor according to the set of values: 1/12 sec, 1/6 sec, 1/3 sec. Also, if desired, it can be set the output voltage for warming up the sensor and generating information about false operation (in the range from 0 to 5 V) (Fig. 3).

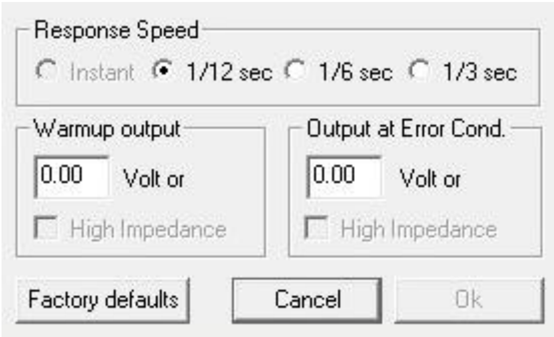


Fig. 3. Setting up the program in Advanced mode

The operating environment of the software during connecting via an analogue output of 1 V shown in Fig. 4.

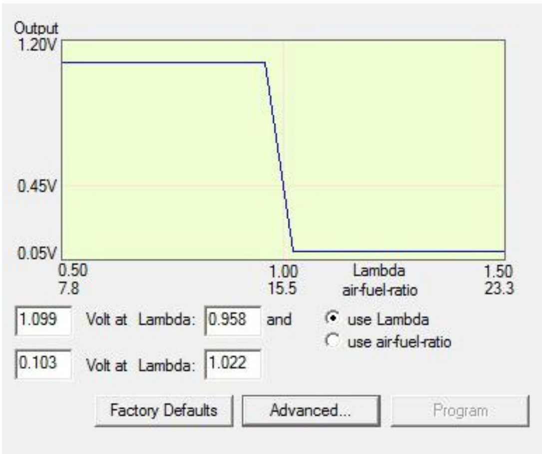


Fig. 4. The working environment of the program during connecting to the 1 V analog output

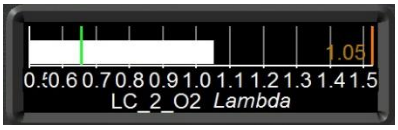
In this window, the user also has the ability to calibrate the software product according to 2 parameters: the voltage value (ranging from 0 to 1 V) and the coefficient α or the required value of the amount of air (in volume ratio) per unit of fuel. The type of dependence of the output voltage on the coefficient α is stepwise.

Pressing the Factory Defaults key resets the operating parameters to the factory settings.

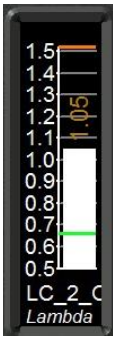
The mode of displaying current information on the content of residual oxygen in the exhaust gases is possible in 3 display modes: 1) arrow; 2) linear; 3) bar (Fig. 5) with the display of both the information on the AFR and the coefficient α.

The user of the software can choose the type of the required indication of the monitoring parameter, and he can use from 1 to 3 types at the same time.

(a)



(b)



(c)

Fig. 5. The modes of indication of the coefficient α in the exhaust gases (oxygen sensor in the working environment): (a) arrow; (b) linear; (c) bar

As part of the software product, the user can not only control the amount of residual oxygen in the exhaust gases, but also record the changes in this parameter using the internal Real-Time Log environment. The Real-Time Log runtime shown in Fig. 6.

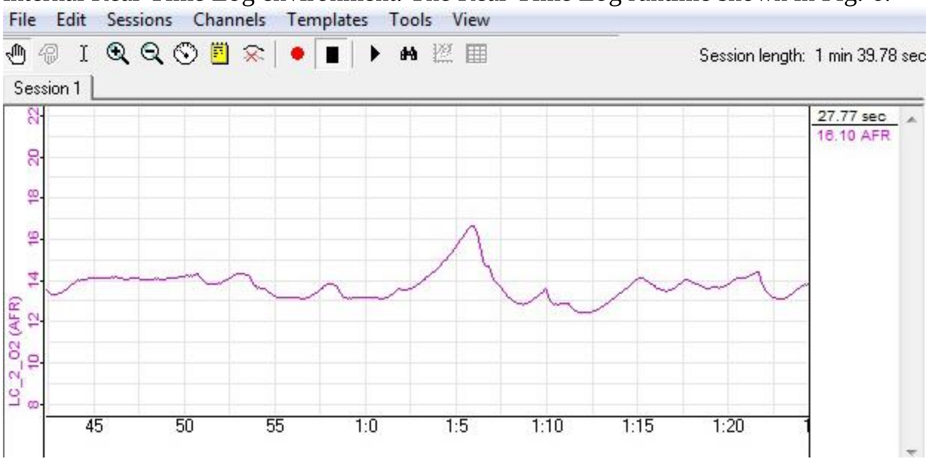
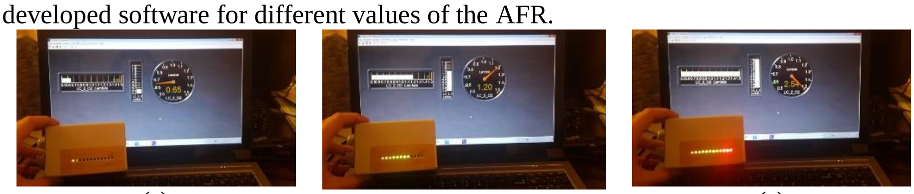


Fig. 6. Real-Time Log environment

The program monitors the AFR depending on the duration of the analysis of the composition of the exhaust gases. The resulting graph can be obtained during the entire monitoring time and saved to a file with the .log extension for further analysis and processing of information.

This software has a direct connection with the developed digital α-indicator that allows to control the excess air ratio using a frequency controller, that is, to realize the possibility of correcting the operating modes of the boiler unit by introducing feedback on the oxygen sensor signals. Fig. 7 shows the interaction of the α-indicator with the developed software for different values of the AFR.



(a) (b) (c)

Fig. 7. The interaction of the α-indicator and the developed software product in various modes of operation of the boiler: (a) enriched mixture; (b) a mixture close to stoichiometric; (c) lean mixture

The adaptation of these software tools allows them to be used both directly in the system of automatic control of the process of fuel combustion and in the monitoring system (gas analysis device) of the composition of the exhaust gases of the boiler units.

3 Conclusions

An algorithm for the functioning of the control and monitoring system for the process of fuel combustion is proposed, which based on the using of a wide-band oxygen sensor and a variable-frequency electric drive of a blower fan. This system will ensure efficient combustion of fuel resources in the boiler by maintaining stoichiometric of AFR.

Based on the oxygen sensor, a portable system for monitoring the process of fuel combustion in boilers has been created. A feature of the system is a wide range of measurement of EAR, rapid measurement of oxygen concentration, the absence of a system for sampling and sample preparation, a relatively low cost.

For the control system of the fuel combustion process, software modules have been developed that control the formation of the stoichiometric AFR for various types of gaseous and liquid fuels.

The software for the control and management system of the fuel combustion process has been adapted, it will allow quickly and accurately determine the current operating modes of the boiler unit.

References

1. Babak., V., Mokiychuk, V., Zaporozhets, A., Redko, O. Improving the efficiency of fuel combustion with regard to the uncertainty of measuring oxygen concentration. *Eastern-European Journal of Enterprise Technologies*, 2016, Vol. 6, №8, pp. 54-59. doi: 10.15587/1729-4061.2016.85408

2. Toftegaard, M.B., Brix, J., Jensen, P.A., Glarborg, P., Jensen, A.D. Oxy-fuel combustion of solid fuels. Progress in Energy and Combustion Science, 2010, Vol. 36, Issue 5, pp. 581-625. doi: 10.1016/j.pecs.2010.02.001
3. Artemchuk, et al. Theoretical and applied bases of economic, ecological and technological functioning of energy objects (2017)
4. Haryanto, A., Hong, K.-S. Modeling and simulation of an oxy-fuel combustion boiler system with flue gas recirculation. Computers&Chemical Engineering, 2011, Vol. 35, Issue 1, pp. 25-40. doi: 10.1016/j.compchemeng.2010.05.001
5. Zaporozhets, A.A., Eremenko, V.S., Serhiienko, R.V., Ivanov, S.A. Development of an Intelligent System for Diagnosing the Technical Condition of the Heat Power Equipment. 2018 IEEE 13th International Scientific and Technical Conference on Computer Sciences and Information Technologies (CSIT), 11-14 September, 2018, Lviv, Ukraine. doi: 10.1109/STC-CSIT.2018.8526742
6. Zaporozhets, A., Eremenko, V., Serhiienko, R., Ivanov, S. Methods and Hardware for Dianosing Thermal Power Equipment Based on Smart Grid Technology, *Advances in Intelligent Systems and Computing III*, 2019, Vol. 871, pp. 476-492. doi: 10.1007/978-3-030-01069-0_34
7. Nikolopoulos, N., Nikolopoulos, A., Karampinis, E., Grammelis, P., Kakaras, E. Numerical investigation of the oxy-fuel combustion in large scale boilers adopting the ECO-Scrub technology. Fuel, 2011, Vol. 90, Issue 1, pp. 198-214. doi: 10.1016/j.fuel.2010.08.007
8. Zaporozhets, A.O., Redko, O.O., Babak, V.P., Eremenko, V.S., Mokiychuk, V.M. Method of indirect measurement of oxygen concentration in the air. *Scientific Bulletin of National Mining University*, 2018, №5, pp. 105-144. doi: 10.29202/nvngu/2018-5/14
9. Babak, V.P. et al. Hardware-software for monitoring the objects of generation, transportation and consumption of thermal energy (2016)
10. Babak, V.P. et al. Information Provision of Diagnostic Systems for Energy Facilities (2018)
11. Zaporozhets, A.A., Sverdlova, A.D. Peculiarities of application of Smart Grid technology in systems for monitoring and diagnostics of heat-and-power engineering objects. Technical Diagnostics and Non-Destructive Testing, 2017, №2, pp. 33-41. doi: 10.15407/tdnk2017.02.05
12. Merzlykin, P., Kharadzjan, N., Medvediev, D., Zakarliuka, I., Fadieieva, L. Scheduling Algorithms Exploring via Robotics Learning. CEUR Workshop Proceedings, vol. 2104, 2018. Online: http://ceur-ws.org/Vol-2104/paper_167.pdf
13. Babak, V., Kovtun, S. Calibration thermoelectric heat flux sensor in the diagnostic system of thermal state of electric machines. Tekhnichna elektrodynamika, 2019, №1, pp. 89-92. doi: 10.15407/techned2019.01.089
14. Kusiak, A., Song, Z. Combustion efficiency optimization and virtual testing: a data-mining approach. IEEE Transactions on Industrial Informatics, 2006, vol. 2, Issue 3, pp. 176-184. doi: 10.1109/TII.2006.873598
15. Kondratenko, Y., Kozlov, O., Topalov, A., Gerasin,, O. Computerized System for Remote Level Control with Discrete Self-Testing. CEUR Workshop Proceedings, vol. 1844, 2017. Online: http://ceur-ws.org/Vol-1844/10000608.pdf
16. Bykovyy, P., Sachenko, A., Kochan, V., Osolinskyi, O., Kochan, R. Reducing Power Consumption of Measurement and Control Modules Fed with Autonomous Power Supply. CEUR Workshop Proceedings, vol. 2104, 2018. Online: http://ceur-ws.org/Vol-2104/paper_255.pdf
17. Meyer, J., Yurkovich, S., Midlam-Mohler, S. Air-to-Fuel Ratio Switching Frequency Control for Gasoline Engines. IEEE Transactions on Control Systems Technology, 2013, Vol. 21, Issue 3, pp. 636-648. doi: 10.1109/TCST.2012.2188631