CHAPTER «ENGINEERING SCIENCES»

INVESTIGATION OF THE PROCESS OF MEASUREMENT CONTROL OF THE CONCENTRATION OF CARBON DIOXIDE

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Abstract. The topic of monitoring the process of measurement control of carbon dioxide concentration is quite relevant, as there are currently many national and foreign carbon dioxide control means based on various measurement methods. But, in many cases, these measures are too expensive, that's why the payback period for such means is quite large, which makes their implementation at various company unprofitable. The purpose of the work is to increase the accuracy at the necessary speed of the process of controlling the concentration of carbon dioxide due to the assessment and compensation of the influence of influential factors on the optical-absorption method. *Methods of investigation.* The methods of the theory of measuring control, the theory of planning a scientific experiment during the experimental researches, computer modeling, the theory of measurements, measuring accuracies and technical control, methods of algorithmization and programming for the development of the software part of the measurement control tool were used to solve the problems in the work. *The subject of research* is the methods and means of increasing the control accuracy at a given speed of the optical-absorption method of controlling concentration of carbon dioxide.

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Introduction

Relevance of the topic. At the moment, there are many national and foreign means of controlling carbon dioxide, which are based on various measurement methods (optical, mechanical, physical, chemical). But, in many cases, these means are too expensive and, accordingly, the payback period of such measures is quite long (up to 15 years), which makes their implementation at various companies unprofitable. On the other hand, advanced measures cannot ensure the necessary accuracy and the reliability of the control, due to structural defects or low indicators of metrological characteristics – what is a necessary condition for the effective work of many systems [1].

Besides, they do not meet the modern requirements of adaptability [2]. Current methods of controlling the concentration of carbon dioxide take into account external disturbances, but for a complete solution of adaptation problems, it is necessary to take into account internal ones, such as: the setting of optical spectrum bands.

Also, requires solving the scientific-technical task of improvement a method of controlling the concentration of carbon dioxide, which could ensure high accuracy at the necessary speed of the gas control process, due to the implementation of innovative mathematical models for determining the concentration of gas components and engineering-technical solutions.

The following tasks were formulated and solved in the work, that to achieve the stated purpose, such as:

– analysis of current means and methods of controlling carbon dioxide concentration;

– development of a mathematical model of a tool for controlling carbon dioxide using the optical-absorption-infrared method;

– development of a structural scheme for controlling the concentration of carbon dioxide in the flue gas of boiler rooms;

– development of software tool for automatic control of carbon dioxide concentration;

– conducting experimental studies and confirming the adequacy of the developed measure for controlling the concentration of carbon dioxide.

Scientific significance of the outcomes:

1. Were received method's development for measuring and controlling the concentration of carbon dioxide in the flue gas of a boiler plant in the solar infrared region with open measuring and compensation channels,

specialty of which is the different working lengths of the photo-receiver waves. The values of the concentration of carbon dioxide are obtained on the basis of the ratio of the indices of the intensity of light fluxes, which passed through the open measuring and compensation channels, which allowed to reduce the measurement error to a value of less than 1% in the measurement range and to reduce the number of controlled parameters (humidity, dust).

2. The structural-algorithmic organization of the carbon dioxide concentration control system using the optical-absorption-infrared method was worked out.

3. Was improved the mathematical model of the photoelectric measuring transducer of the concentration of carbon dioxide in the flue gas of a boiler room, which takes into account the parasitic parameters of the structural elements of the photoreceptor and connects the output value – the value of the output voltage of the photoreceptor and the input – the value of the intensity of the light flux, and, as a result, the concentration of carbon dioxide, which is increased by 1.1-1.2 times.

Such practical results were obtained in the work:

1. The structural-algorithmic organization of the carbon dioxide concentration control system using the optical-absorption-infrared method was worked out, which, in its turn, takes into account the influence of influential factors and adaptation algorithms of its functioning in real conditions.

2. Software tool was worked out for automatic control of the concentration of carbon dioxide. The program for controlling the carbon dioxide concentration was written in the WinPLC7 software package in the STL programming language.

1. Overview of methods and measures for determining the concentration of carbon oxide

1.1 Objects of control characteristics

Carbon oxide (IV) is a persistent chemical compound common in natural gas, which contains it in amounts from several percent to practically pure carbon dioxide. It is colourless, has a sour taste and smell. It is the final product oxidation of carbon, does not burn, does not support burning and breathing. The toxic effect of carbon dioxide is manifested when its content in the air is 3-4% and consists in irritation of the respiratory tract, dizziness, headache, noise in the ears, mental excitement, unconsciousness.

Colorless and odorless gas, which is the natural structure of the atmosphere. Carbon dioxide is a product of burning fossil fuels. It has greenhouse properties, that is, itpromote to the retention of heat on the surface of the Earth and contributes to global warming.

In the national economy, carbon dioxide is widely used in the industrial industry for the production of soda, etc., as well as in the production of sugar, wine, beer, for the production of carbonated water, etc.

1.2 Choice of the carbon oxide concentration control method

The considered methods are compared in the table 1.1 and will be identify the most appropriate.

Table 1.1

Comparison of carbon oxide control methods

Method/ Parameter	Range measure-ments	Speed	Trouble-nothing	Multicom-ponent	Selecti-veness
Thermoconductive	0,5	0	1	1	0
Thermochemical	0,5	0	1	1	0
Magnetic	0,5	0	1	1	0,5
Pneumatic	0,5	0	1	1	0,5
Pneumoacoustic	0,5	0,5	0	0	0,5
Infrared	1	1	0	1	1
Semiluminescent	1	1	0	1	1
Fluorescent	1	1	0	1	1
Photocolorimetric	1	1	0	1	0,5
Ctrichkovy	0,5	0	1	1	0,5
Amperometric	0,5	0	1	1	0,5
Ionization	0	1	0	1	0
Semiconductor	0	0,5	1	1	0,5
Standard	1	1	1	1	1

For the selection of the method and measure for the determination of carbon oxide, the above methods were compared according to the following parameters: measurement range, speed, complexity, multicomponent, selectivity.

Therefore, for defining the concentration of carbon oxide, the infrared method based on an infrared gas analyzer turned out to be the most optimal.

2. Development of the transformation function. Physical and mathematical representation of the optical-absorpton infrared method

2.1 Physical and mathematical presentation of the optical-absorption infrared method

The physical representation of absorption consists in the fact that when optical radiation passes through a gas cuvette, gas molecules, absorbing radiation quanta corresponding to certain frequencies, are excited, that is, they increase their energy reserve.

If ultraviolet and visible radiation or radiation of the short-wave part of the infrared spectrum is absorbed, then the energy of electrons, energy corresponding to the oscillation of atomic nuclei, and the energy of rotation of the molecule around the center of gravity increases. If quanta are absorbed, which correspond to longer wavelengths of the spectrum of optical radiation, then oscillatory-orbital and, correspondingly, purely orbital degrees of freedom are excited. As a result, the absorption spectra of molecules consist of a number of bands with a complex structure. Figure 2.1 the part of the spectrum taken at a gas layer thickness of 100 mm, a pressure of 10,000 ppm and a temperature of 20°C is shown.

Infrared radiation is absorbed by all gases, with the exception of O_2, N_2, H_2O, Cl_2, and monatomic gases [3]. The absorption spectrum of monatomic gases or metal vapors differs from the infrared absorption spectra of molecules by its relative simplicity and is composed not of bands, but of

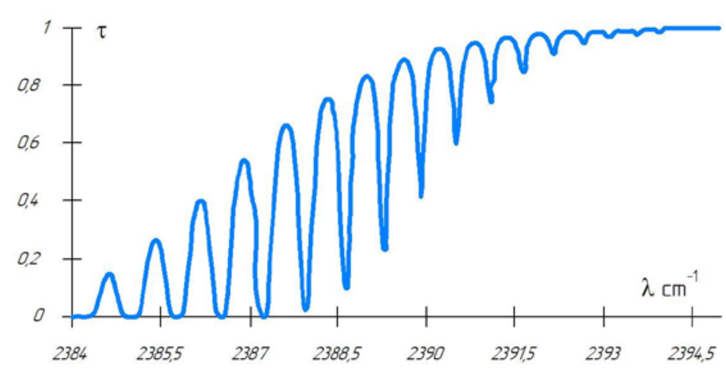

Figure 2.1. Vibrational-oscillation bands of carbon dioxide absorption

individual lines, in many cases, they are located only in the ultraviolet region in spectrum.

Both infrared and ultraviolet absorption spectra, depending on the nature of the given substance, have an individual character, which makes it possible to identify these substances.

3. Development of the sensor's structural scheme

3.1 Technical justification of the implementation of the structural scheme sensor control of the carbon oxide

Measuring transducer (VP). The measuring transducer must be responsible for the following metrological characteristics [4]:

– the conversion coefficient (sensitivity) of the VP is determined by the ratio

$$k = \frac{\Delta X}{\Delta Y}, \tag{3.1}$$

where ΔY is the change in the VP output signal;

ΔX is the change in the signal at the input of the VP.

The necessity of analyzing a gas mixture in the range from microconcentrations to macroconcentrations requires ensuring the maximum value of the coefficient k and its stability and independence from external factors.

– the transformation function (FP) represents the total dependence of the value of the output signal on the structure of the measuring component of the gas mixture at the input of the VP, which is used in a gas analyzer is characterized by a non-linear FP. Non-linearity of FP requires individual calibration of devices or the use of functional converters – linearizers. The grading characteristic (GX) of the VP is presented in Figure 3.1.

Without being nonlinearity, GX the sensitivity of the VP in the working range of the conversion is not constant. In this case, the sensitivity at any point of the characteristics is determined by the ratio

$$S = \frac{dY}{dX} = \lim \frac{\Delta Y}{\Delta X}. \tag{3.2}$$

The transitional process that takes place in the VP is shown in Figure 3.2.

Due to the development of industrial controllers, it is logical to carry out the task of processing measurement information with its help, ensuring the coupling of the output signal of the VP with the input of the controller.

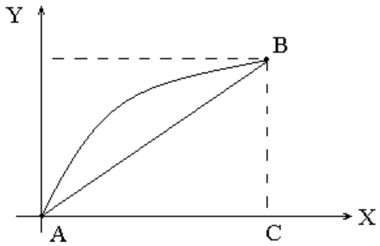

Figure 3.1. Grading characteristics of the VP

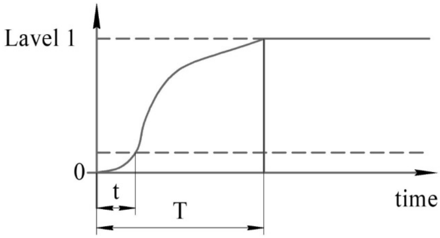

Figure 3.2. Transitional process in VP

To implement the system, we use the NXT 2.0 programmed robot. With the help of NXT 2.0, it is possible to create new highly productive management and control systems that meet the current requirements.

The measurement takes place in continuous mode. The functional scheme of the carbon oxide control system is presented in Figure 3.3 (the system is shown generalized in the form of a single channel [5], but the practical system is multi-channel for the multi-component analysis of a gas mixture.

The device that transforms the input value C into the measured value I is a measuring converter. In order to control carbon oxide, the function of the measuring transducer is performed by an optical sensor.

In recent years, optical sensors are built on optical photodiodes [6], which make it possible to make significant improvements in the design of the sensors: to avoid mechanical modulators, interference, and reduce the size of energy filters.

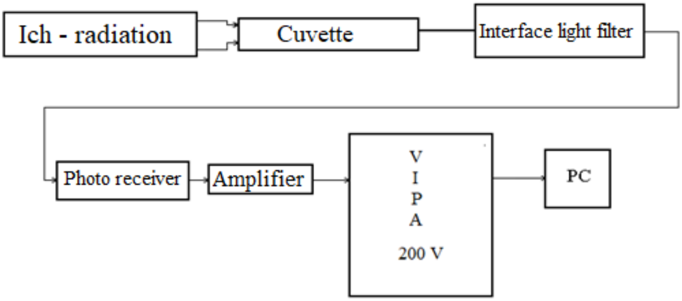

Figure 3.3. Functional scheme of the carbon oxide control system

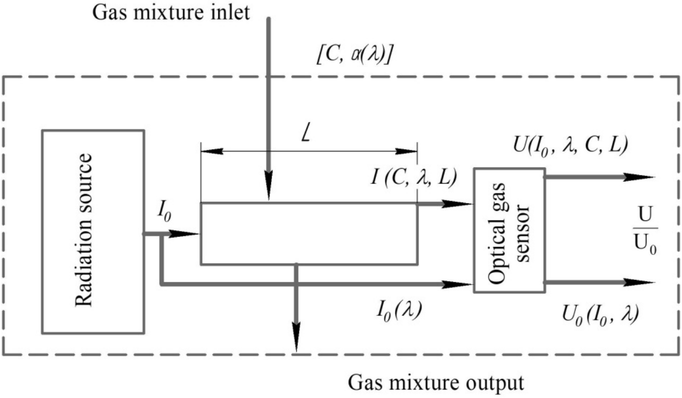

Figure 3.4. Structural diagram of the developed optical gas sensor

4. Development of a mathematical model for measuring the concentration of carbon dioxide in the flue gas of a boiler station

4.1 Analysis of absorption spectra of control sensors

To determine the tuning lengths of the photoreceptors to control the concentration of carbon oxide, we will analyze the absorption spectra of gases [7], atmospheric gases.

The analysis of absorption spectra of solar components of atmospheric gases of boiler stations in the full infrared range of 0.75-15 μm (13330-667 cm^{-1}) is presented in Figure 4.1-4.5.

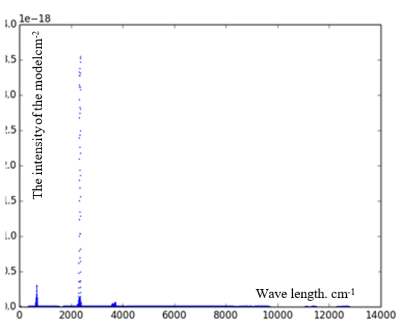

Figure 4.1. CO_2 absorption spectrum in the range of 0.75-15 μm

From the analysis of the spectra, it was concluded that the most active region is found in the range of 2200-2500 cm^{-1}.

It can be seen from the analysis of the absorption spectra of solar atmospheric gases that practically all absorption bands are found next to each other. In addition, water vapor, which is present in the gas,

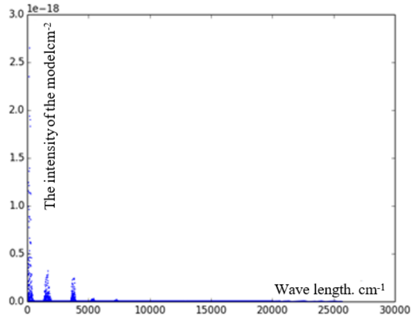

Figure 4.2. H_2O absorption spectrum in the range of 0.75-15 µm

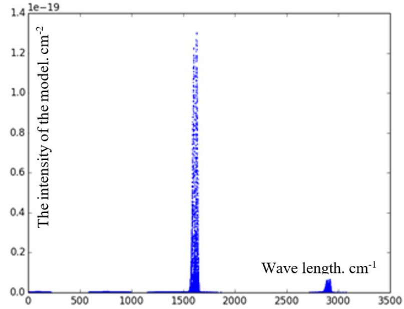

Figure 4.3. N_2O absorption spectrum in the range of 0.75-15 µm

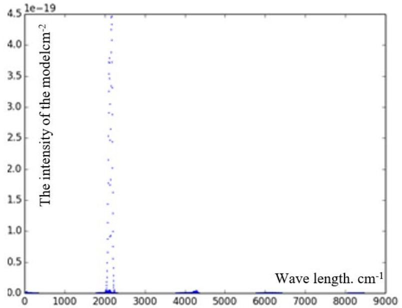

Figure 4.4. CO absorption spectrum in the range of 0.75-15 µm

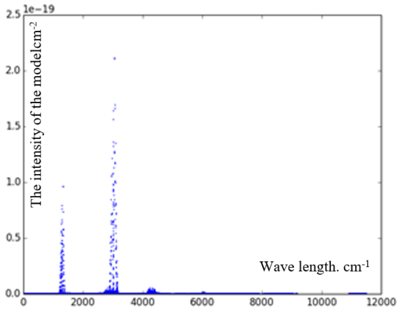

Figure 4.5. CH_4 absorption spectrum in the range of 0.75-15 µm

occupies a wide spectrum of absorption band lengths. Having analyzied the absorption lengths of gases, it is necessary to select infrared emitters and receivers based on already known input data.

In this way, it is possible to determine the parameters of photodiodes and photoreceivers, taking into account the intersection of absorption lines. That is, the control points for each gas appear in such a way that there is no slow absorption of other gases nearby, which could affect the measurement results.

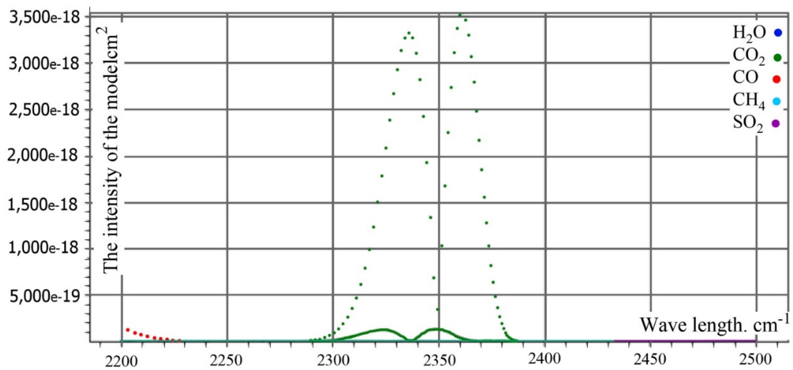

Figure 4.6. Absorption spectrum of organic components of atmospheric gases in the range of 4-4.5 μm (2200-2500 cm-1)

4.2 Coefficient of CO_2 absorption in the atmosphere

There are table values of the spectral absorption $k_n(\lambda)$ index for natural gases are used, but they are brought to normal or standard conditions, which is not suitable for the object of control, because [8] the spectral absorption index depends on the type and temperature, and if spectral lines.

From the analysis of absorption spectra, CO_2 has the most intense absorption band with a central length of 4.264 μm. The contour of this band is described by the Lorentz function [9] (we write this function in terms of the length λ)

$$k_i(\lambda) = \frac{S(\lambda_i)}{\pi} \cdot \frac{\sigma}{\sigma^2 + (\frac{1}{\lambda} - \frac{1}{\lambda_i})^2}, \tag{4.1}$$

where S is the intensity of the absorption band, λ and λ_0 are the length and center of the absorption band, σ is the width of the absorption band.

In turn

$$S(\lambda_s) = \int_0^\infty k_s(\lambda)\, d\lambda. \tag{4.2}$$

At the same time, Brechler P.I. [10] proposed to consider the absorption bands of an infinite succession of equidistant lines λ_i of equal intensity and width.

Necessary information about the gas (intensity and spectral half-width of the lines) can be found in the HITRAN database [11]. Gas data are stored in a current file and present a table where the name of the gas, the x-wave number, the intensity of the gas line, and the spectral half-width of the line are presented in columns.

Table 4.1

Physical properties of absorption bands of atmospheric gases

Gas mixture serial number	**Xwave number (υ)**	**The intensity of the gas line (S)**	**Spectral half-width of lines (σ)**
23	2373.455087	2.058E-30	.06800
63	2373.470292	1.330E-28	.06440
23	2373.473365	1.213E-25	.06010
21	2373.477165	7.860E-28	.07730
21	2373.484763	5.652E-27	.05860
24	2373.507231	2.038E-30	.05680
21	2373.524463	2.052E-29	.05610
23	2373.529430	1.972E-29	.07280
24	2373.556092	1.370E-30	.05660
11	2373.572984	9.372E-28	.01980
21	2373.576440	5.582E-28	.07940
61	2373.587840	1.521E-29	.04700
24	2373.629919	1.621E-23	.06580
61	2373.630875	6.218E-29	.04500
24	2373.636738	1.411E-30	.05660
21	2373.661105	3.602E-28	.08150
21	2373.665624	1.034E-18	.06810
61	2373.671538	3.617E-29	.04500
63	2373.681517	2.192E-28	.02240

5. Assessment of the key metrological characteristics

5.1 Static metrological characteristics

Figure 5.1 presents the generalized structural model of the measuring channel for the concentration of gas mixture components.

Figure 5.1. the following definitions are decided: φ/I_x – concentration-current converter; I_x/U_x – current-voltage converter; ADC – analog-to-digital converter; U_0 – resistance voltage; N_x is the value of the code for analog-to-digital conversion; MP, IND – microprocessor and indication.

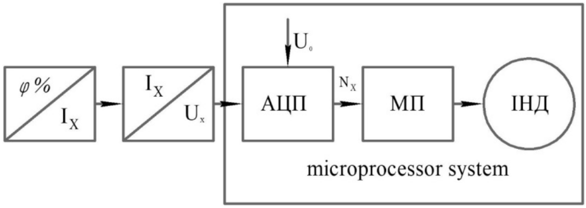

Figure 5.1. Model of the measured channel

The magnitude of the radiation flow that passed through the measuring cuvette with the gas being analyzed can be determined by the Lambert-Behr law

$$I_x = a \cdot [1 - \exp(-b \cdot \phi_x)], \tag{5.1}$$

where Ix is the output electrical signal (current);

a – constant;

b – constant;

φ is the mass concentration of the component of the gas mixture.

The type of dependence that represents the function (for the constant length of the optical path (l = const)) is presented in Figure 5.2.

The graphical dependence of the output code Nx on the concentration φ_x is presented in Figure 5.3.

A rather important metrological characteristic is the range of measurements. In DCTU 2681-94, the range of readings and the range of measurements are distinguished.

The scale range is the interval of quantities of the measured value, which is limited by its initial and final values.

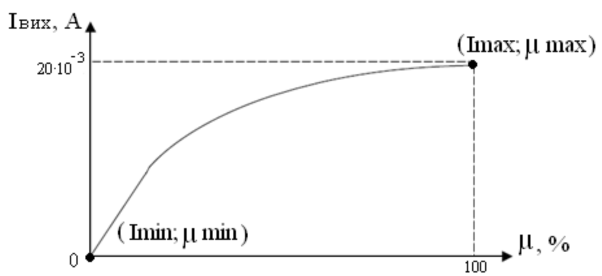

Figure 5.2. Graphic representation of the convert equation

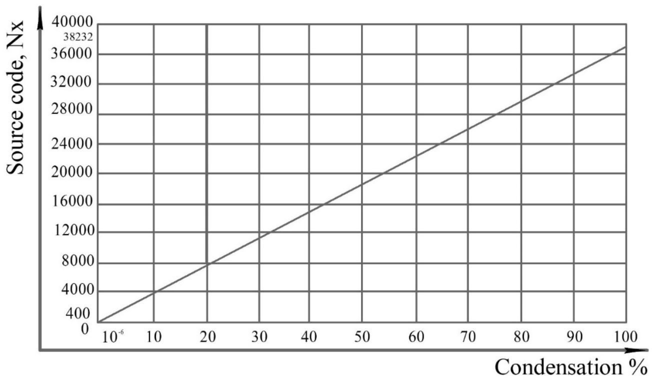

Figure 5.3. Graphic representation of the measurement channel equation concentrations of gas mixture components

$$D_{показів} = 0 - 100\% , \tag{5.2}$$

The range of measurements is the interval of quantities of the measured value, within which the measurement procedure is normalized.

$$D_{вимірювань} = 10^{-6} - 100\% , \tag{5.3}$$

In measurement practice, the term «full range» is also widely used, which means the ratio of the upper measurement limit xmax to the sensitivity threshold.

$$D = \frac{x_{\max}}{x_П} = \frac{100}{10^{-6}} = 10^8 . \tag{5.4}$$

5.2 Assessment of dynamic metrological characteristics

When carrying out measurements of physical quantities, always arises a transient mode of operation for the purpose of measurements, in which the signal at its output changes significantly in time. This fact is explained by the inertial properties of the measurement system. Therefore, the concept of dynamic error is used to assess the accuracy of measurements in dynamic mode.

Dynamic accuracy is represented by dynamic characteristics and is determined by the instantaneous difference in the value of the input signal, calculated by the input signal and the value of the nominal static characteristic, and the instantaneous value of the signal at this moment in time.

Dynamic characteristics are divided into complete and partial characteristics based on the completeness of the characteristic features of the measurement method [12; 13].

Full dynamic characteristics unambiguously determine the change in the output signal for the measurement process with any change in the input signal or influential values.

Frequency dynamic characteristics are all functions or parameters of the full dynamic characteristics of measurement tools, for example, constant of time, time of setting the output signal delay.

6. Hardware and software implementation of the carbon oxide sensor

6.1 Software implementation of control measures

Hardware. To implement the given task, we use the VIPA PLC of the System 200V series [14]. System 200V modules can be used to expand

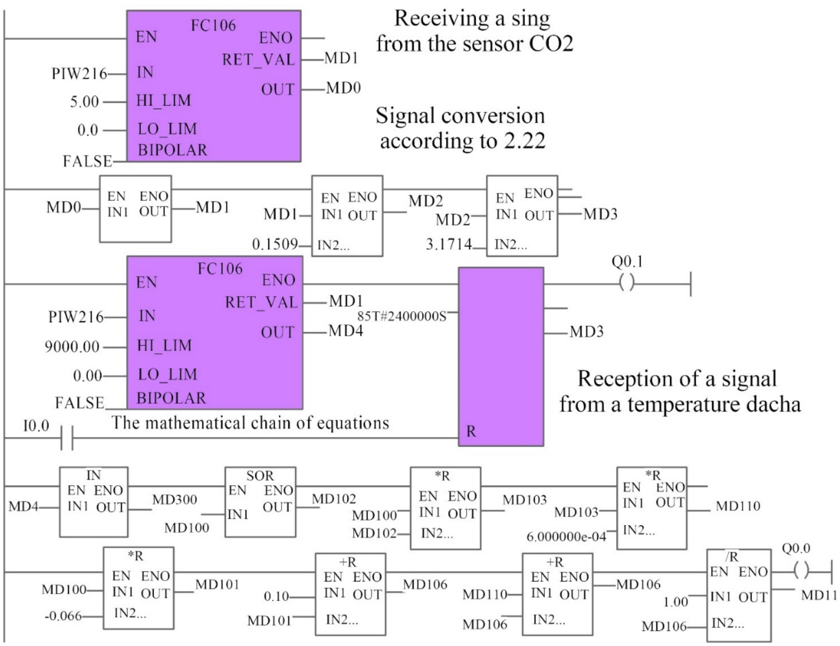

Figure 6.1. Software package

automation systems based on the data base of Siemens controllers and the PROFIBUS industrial bus, using a single development tool. The System 200V series is built on the modular principle.

Software. To implement the task, we use the WINPLC7 software package for configuration, programming, program adjustment and diagnostics of VIPA controllers of all series. WINPLC7 contains all necessary tools for project creation: hardware configurator, character editor, PROFIBUS network configurator, program editor, controller emulator.

This software can be used to solve a wide range of automation tasks [15]. The package includes built-in Hardware configuration – an add-on for communication between a microcontroller and a computer.

Algorithm and program development. The program will be written in the WINPLC7 software package in the Statement List (STL) programming language. The algorithm of the program is as follows: in order to control

STL FBD LAD

			RLO/IN	STA/OUT	Ñòàíäàðòíûé	Ñëîâî ñîñòîÿíèÿ
0:		CALL FC105	–	–		
1:		IN:=PIW768	0	0		
2:		HI_LIM:=20.00	–	–		
3:		LO_LIM:=0.00	–	–		
4:		BIPOLAR:=FALSE	–	–		
5:		RET_VAL:=MW0	0	0		
6:		OUT:=MD0	0000 0000	0000 0000		
7:		A BR	1	1	0	1 0000 0111
8:		JNB _001	1	1	0	1 0000 0110
9:		L MD 0	1	1	0	1 0000 0110
10:		L MD 1	1	1	0	1 0000 0110
11:		+R	1	1	0	1 0000 0110
12:		T MD 2	1	1	0	1 0000 0110
13:		AN OV	1	0	0	1 0000 0011
14:		SAVE	1	0	0	1 0000 0011
15:		CLR	0	0	0	1 0000 0000
16:	_001	:A BR	1	1	0	1 0000 0111
17:		JNB _002	1	1	0	1 0000 0110
18:		L MD 1	1	1	0	1 0000 0110
19:		L 2.718	1	1	1076753334	1 0000 0110
20:		*R	1	1	0	1 0000 0110
21:		T MD 3	1	1	0	1 0000 0110
22:		AN OV	1	0	0	1 0000 0011
23:		SAVE	1	0	0	1 0000 0011
24:		CLR	0	0	0	1 0000 0000
25:	_002	:A BR	1	1	0	1 0000 0111
26:		JNB _003	1	1	0	1 0000 0110
27:		L MD 3	1	1	0	1 0000 0110
28:		L MD 4	1	1	0	1 0000 0110
29:		*R	1	1	0	1 0000 0110
30:		T MD 5	1	1	0	1 0000 0110
31:		AN OV	1	0	0	1 0000 0011
32:		SAVE	1	0	0	1 0000 0011
33:		CLR	0	0	0	1 0000 0000
34:	_003	:A BR	1	1	0	1 0000 0111
35:		JNB _004	1	1	0	1 0000 0110
36:		L MD 5	1	1	0	1 0000 0110
37:		L MD 2	1	1	0	1 0000 0110
38:		/R	1	1	2139095040	1 1111 0110
39:		T MD 6	+INF	+INF	2139095040	1 1111 0110
40:	_004	:NOP 0	1	1	2139095040	1 1111 0110
41:						

Figure 6.2. An example of program work on the first channel

the concentration of carbon dioxide in the flue gas of the boiler stations, a variable electric information signal about the flue gas system is transmitted. This signal will receive the FC105 function block (Scaling analog value) and convert it into a 'real' variable (MDx). MDx – corresponds to the value of the electrical signal (voltage), which is in the range of 0-5 V.

The developed software package for controlling the concentration of carbon dioxide in the flue gas of a boiler stations [16] with basic subprograms is presented in Figure 6.1.

An example of the operation of the program on the first channel when a zero electric signal is applied to the PLC to check the operation of the algorithm and the program is shown in Figure 6.2.

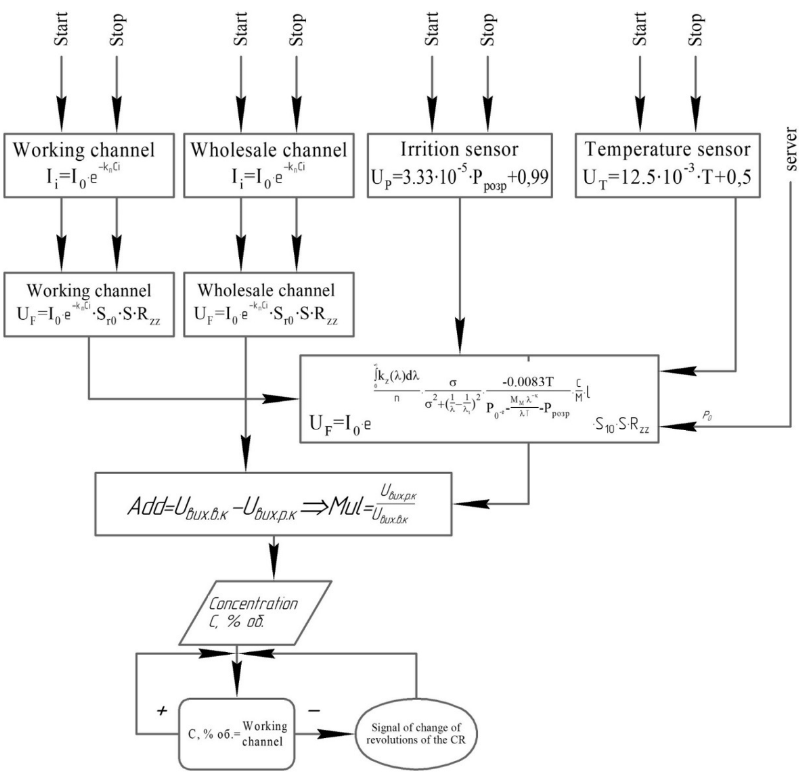

Figure 6.3. Algorithm for carbon oxide concentration monitoring

Also, due to the introduction of an additional channel for measuring the density of flue gas, a method of emergency control of the burning of boiler burners was established, which, unlike existing methods, analyzes the test not only for methane concentration, but also for flue gas density, which made it possible to increase the probability of establishing the correct diagnosis and reduce mistaken activation during emergency control. The working example of the program is demonstrated on the working example of the temperature measurement channel. The measuring channel is implemented in the WINPLC7 software package [15] in the Ladder Diagram (LAD) programming language [17]. In the program, the functional block FC 105 (Scaling analog value) accepts values from TRD in the specified range (0–9000 Ωm) and displays its effective value (variable MD 4). At the start of signal transmission from the sensor, the programmed timer (T1) starts. At the next stage, variable MD 4 is transferred to the mathematical chain, which describes the functional dependence (2.24) and at the output of the chain (variable MD1) displays the value of the temperature of the gas mixture in 0C. In the working mode, the Q0.0 and Q0.1 indicators are located in the state of the logical unit. An example of the operation of the program [18] with a resistance

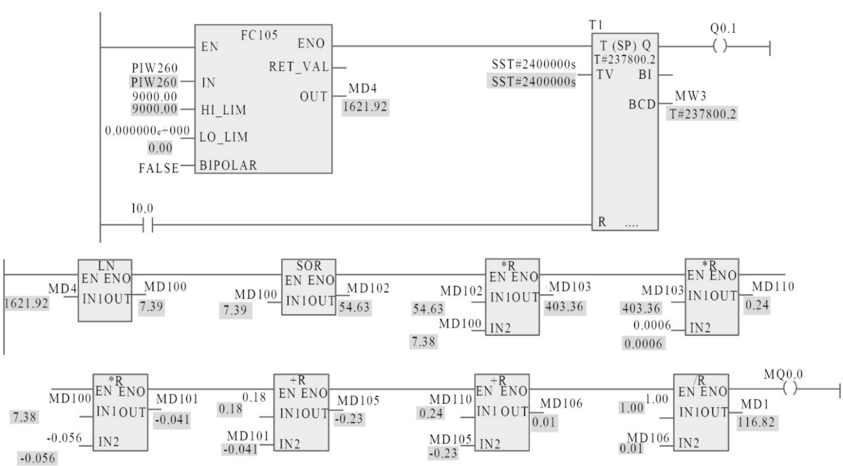

Figure 6.4. Software implementation of the temperature measurement channel

value of 1621.92 Ω taken from the TRD and a corresponding temperature of 116.82 0C per second after the start of the measurement is shown in Figure 6.4.

An experimental model for controlling the concentration of carbon dioxide in the flue gas of boiler stations was developed.

7. Determination of control probability and validity of experimental results

7.1 Laboratory sample creation and experimental studies

The scheme for conducting laboratory examination of ZVK is presented in Figure 7.1.

7.2 Checking the adequacy of the developed mathematical model

In order to check the mathematical model developed in Chapter 4, experimental studies were carried out on a mock-up to determine the concentration of carbon dioxide in flue gas with a known C2 content at a length of 4.267 m A 1.5 mW InAsSbR optical laser diode was used as a radiation source, and a thin-film thermoelectric receiver was used as a radiation receiver. At the same time, the experimental measurements were divided into 10 cycles.

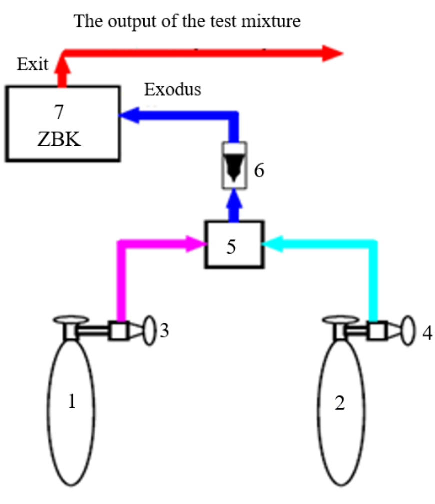

Figure 7.1. The procedure for conducting laboratory research of the ZVK: 1, 2 – cylinders with a test gas mixture; 3, 4 – taps; 5 – mixer; 6 – rotometer; 7 – ZVK

Calculate the CO_2 concentration according to the mathematical model developed in Chapter 4, which takes into account the influence of influential factors. In summary, a number of diatomic carbon concentration values were obtained (Table 7.3).

The structure of the model for evaluating control measures is presented in Figure 7.2.

Table 7.2

Microclimate parameters during the experiment

Parameter № cycle no.	Temperature, 0C	humidity, %	That's it мм. pt. st.	Fallout (rain, snow)
1	15.7	75	741	-
2	14.1	76	744	-
3	20.0	55	748	-
4	22.2	39	736	-
5	21.8	57	738	-
6	23.2	40	743	-
7	18.2	97	732	+
8	17.1	98	735	+
9	20.9	44	741	-
10	20.7	57	742	-

Table 7.3

The concentration of CO_2 is in accordance with the mathematical model

Number of measurement cycle\ actual value	1	2	3	4	5	6	7	8	9	10
0	0.004	0.001	0.002	0.001	0.003	0.002	0.001	0.001	0.001	0.002
10	10.035	10.035	10.044	10.092	10.092	10.092	10.092	10.092	10.035	10.035
12	12.017	12.018	12.007	12.034	12.055	12.043	12.023	12.011	12.015	12.017
14	14.029	14.027	14.021	14.022	14.029	14.021	14.023	14.028	14.021	14.022
16	16.017	16.019	16.007	16.009	16.003	16.011	16.015	16.016	16.017	16.015

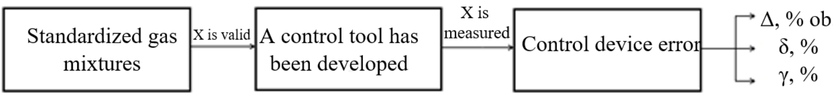

Figure 7.2. Error of a measuring of the control

According to the calculations, the value that differs the most from the actual value is 10.092%. As a result, the maximum absolute, single and aggregate concentration determination by the auxiliary control means is

$$\Delta = X_{В} - X_{Д} = 0.092\%об. \tag{7.1}$$

$$\delta = \frac{\Delta}{X_{Д}} = \frac{10.092 - 10.000}{10.000} \cdot 100\% = 0.92\%. \tag{7.2}$$

$$\gamma = \frac{\Delta}{X_N} \cdot 100\% = \frac{0.092}{20} \cdot 100\% = 0.46\%. \tag{7.3}$$

Then the limiting value of the reduced error

$$-\gamma_{гр} < \gamma < +\gamma_{гр} \Rightarrow -0.1\% < \gamma < 0.1\% \tag{7.4}$$

From here, you can determine the permissible limits of absolute and relative error

$$\Delta_{гр} = \pm \frac{\gamma_{гр}}{100\%} \cdot X_N = \pm 0.1\%об. \tag{7.5}$$

$$\delta_{гр} = \pm \gamma_{гр} \cdot \frac{X_N}{X_В} = \pm 0.99\% \tag{7.6}$$

Therefore, the limit value of the absolute error is constant, and the value of the error increases with the decrease of the measured value, that is, the accuracy of the control will decrease, if the readings of the device will be significantly less than the limit of measurement.

Having conducted the measurement according to the indication of the device XP, we obtain the value of the measured value, the real value of which X is in the limits

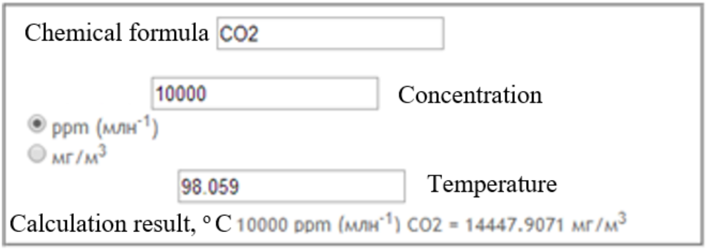

Figure 7.3. Table programs for converting ppm to mg/m³

$$\mathrm{X}_{П} - \Delta_{гр} < \mathrm{X} < \mathrm{X}_{П} + \Delta_{гр} \Rightarrow -9.9\%об. < X < 10.1\%об. \quad (7.7)$$

Estimation of measurement uncertainties. To estimate the uncertainty of measurements, we use the algorithm [19]. A series of measurements of the intensity of the radiation that passed through the gas under investigation, as well as of the influential variables – temperature and pressure, was conducted.

7.3 Assessment of reliability of control and accuracy of carbon oxide concentration measurements

It is known that the accuracy of the control reflects the degree of objectivity of the obtained results in comparison with the standard value of the measured value. Let's consider the initial instrumental control. It is defined as

$$Д_i = 1 - \alpha - \beta, \quad (7.8)$$

where α is a first-order error (production risk); β – error of the second kind (customer risk).

The controlled parameter in this work is the gas concentration C (4). Its definition is carried out with a certain error Δ. Accordingly, errors of the 1st and 2nd order are described by the equations [20]:

$$f(C) = \frac{1}{\sqrt{2\pi\delta}} \cdot e^{-\frac{(C-\bar{C})^2}{2\delta^2}}; \quad (7.9)$$

$$\phi(\Delta) = \frac{1}{\sqrt{2\pi\delta}} \cdot e^{-\frac{(\Delta-\bar{\Delta})^2}{2\delta^2}}, \quad (7.10)$$

The graphic representation of the functions f(C) and φ(Δ) is shown in Fig. 7.4–7.5.

The permissible limits are set within 3% of the deviation from the effective value of gas concentration: CA = 9.7 vol.%, CB = 10.3 vol.%. or CA = 14015 mg/m^3, CB = 14881 mg/m^3.

Substituting the given and experimental values into formula (7.8), we obtain the values α = 0.0312, β = 0.0010.

The methodological accuracy of gas concentration control using the developed tool is increased in comparison with existing control tools due to the consideration of a larger number of influential parameters.

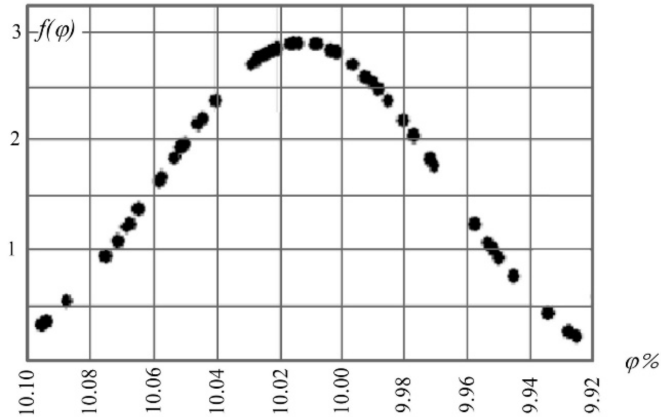

Figure 7.4. The function of the density distribution of probability gas concentration

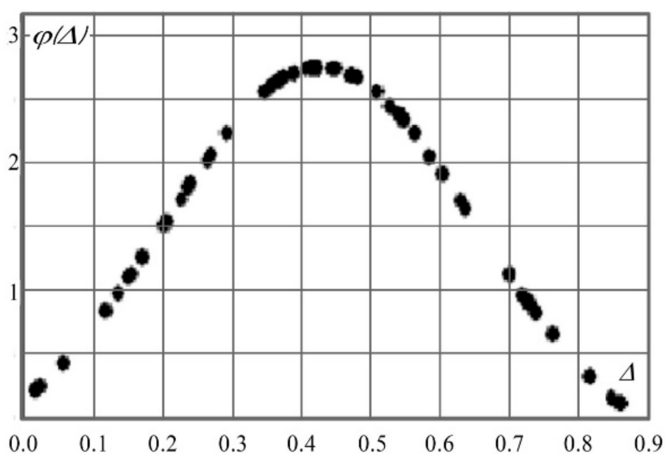

Figure 7.5. The density function of the distribution probability error of gas concentration measurements

The accuracy of the measurements is the inverse of the relative error, expressed in relative units. Considering that according to the results of experimental studies for a sample CO_2 concentration of 14448 mg/m^3

(10% vol. in the equalization ratio) the value of the cumulative standard uncertainty was obtained as 121 mg/m^3, then relative error of measurements is 0,92%, c. In this way, we get the accuracy T = 108.

8. Conclusions

The following tasks were completed and formulated in the work:

– current measures and methods of carbon dioxide concentration control were analyzed;

– developed a mathematical model of the tool for controlling carbon dioxide using the optical-absorption-infrared method;

– a structural method for controlling the concentration of carbon dioxide in the flue gas of boiler structures was developed;

– a software tool was developed for the automatic control of carbon dioxide concentration;

– experimental studies and confirmation of the adequacy of the developed carbon dioxide concentration control measure were carried out.

The research carried out in the work made it possible to obtain new, scientifically based theoretical and practical results, which are essential for increasing the accuracy at the necessary speed of the concentration control process.

The main results of the work are as follows:

1. An analysis of effective systems and methods of carbon oxide control was carried out. On a base of analysis of various methods and means of oxide control in the establishment of their main disadvantages then was chosen direction of research.

2. The developed mathematical model of the carbon measurer oxide using the optical-absorption-infrared method.

3. Technically justified implementation of the carbon oxide sensor structure. The static and dynamic characteristics of the sensor are calculated.

4. Developed software tool for automatic control of carbon oxide. A reasonable choice of hardware is a powerful VIPA 200V PLC and software for system implementation. The carbon oxide control program is implemented in the WinPLC 7 software package in the STL language.

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