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DEVELOPMENT OF METHODS AND FACILITIES FOR INCREASING THE METROLOGICAL RELIABILITY OF OPTICAL-ABSORPTION GAS CONCENTRATION METER

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Abstract

The paper presents a method that increases the metrological reliability of optical-absorption gas concentration meter in dusty condition with required response speed and metrological performance during a long continuous running period.

Keywords: method, gas concentration measurement, dust, response speed, reliability

General statements. To solve problems connected with working conditions safety at industrial enterprises, in particular prevention of explosive situations, it is necessary to control the changes in atmosphere composition. Production processes result in the escape of the following gases: carbonic acid (CO_2) in the range from 1,73 to 2,40$^{vol.}$%; carbon monoxide (CO) – from 3,04 to 6,00$^{vol.}$%; carbohydrate (C_nH_m) – from 0,37 to 2,20$^{vol.}$%; methane (CH_4) – from 10,67 to 25,50$^{vol.}$%; oxygen (O_2) – from 0,40 to 1,04$^{vol.}$%; hydrogen (H_2) – from 59,50 to 78,17$^{vol.}$%; nitrogen (N_2) – from 4,00 to 4,98$^{vol.}$% [1]. These gas mixtures are very dangerous not only for production process, but also for people's health. Hostile environment and huge number of influencing factors do not allow creating a gas-analysis meter, which could provide continuous data about dangerous components concentration in the air with essential operating speed, accuracy and metrological reliability. As one of the best meters is the optical-absorption gas concentration meter, it is more rational to develop the methods for increasing its metrological reliability in complicated working conditions.

Research problems. Due to the well known optical-absorption method of gas concentration measurements [2] we have high operating speed with needed metrological reliability. It is possible due to open optic channels and compensation of dust influence on the result of gas concentration measurement. However, when the operation time in working conditions increases and the gas mixture dustiness grows dust particles settle on the optical components, and that leads to the decrease of information data. Thus, with decreasing of this signal up to 90% as it is shown in paper [3] the signal/noise ratio become critical for defining gas concentration. Real-time operation of such meters in coal mines, for example, makes up hundreds of hours, because in the process of measuring we should carry out constant graduation of the channel to achieve proper metrological reliability [4]. One more disadvantage of this method is the necessity of using two different sources of emission, and that complicates significantly engineering solutions and increases the cost of the device. So when analyzing several gas components we should use hardware redundancy, which leads to additional errors. All this requires additional algorithmic and hardware analysis of measurement results to achieve necessary metrological characteristics.

Consequently, there is a problem of increasing metrological reliability of optical-absorption gas concentration meter with high performance speed conditioned by the presence of an open optical channel. The problem also includes the necessity of correcting the sensitivity affected by dust particles that settle on the optical components of the meter. It will improve the time of continuous running in working conditions at industrial enterprises with high dustiness and provide necessary metrological performance and operation speed.

Problem solution. This method is based on the following ideas:

1. Main measuring channel, which is necessary for high speed performance, is left open.
2. We should create a reference channel with a cleaning filter, which will correct the results of the main channel. In the reference channel there must be no dust particles.
3. From time to time we should compare the main channel and reference channel data; in case of systematic increase in the data difference it is necessary to correct the main channel data in order to improve its reliability.
4. The main channel sensitivity is to be improved by means of controlling the main channel emission source.

To solve the problem we suggest the comparison of the main channel and reference channel data, in case of systematic increase of data difference we should correct the main channel data. Reference optical channel includes a cleaning filter, which keep almost all dust out of the measuring channel. That is why in the output signal of the reference channel there is no error component conditioned by the dust in the measured gas mixture. However, in the output signal of the main channel there is a systematic error component caused by dust particles in the outer environment and, consequently, in the measuring channel; which tends to grow in time. In the process of periodical comparison of the reference and main channels data we analyze the results and make a conclusion as for the gas concentration measurement. If the difference between output data increases and goes beyond permissible limits we should calculate the control action for the main channel.

For realization of this method we made a model of influence factors. This factors lead to the variation of optical radiation in the main channel (figure 1, a) and the reference channel (figure 1, b) of the gas concentration meter. In this model the influence of information factor (C – measured gas concentration, $^{vol.}$%) and destabilizing factor (C_D – dust concentration, mg/m^3) on the optical radiant flux of the main and reference channels ($F_{IN1}(I_1)$ and $F_{IN2}(I_2)$) is shown as segments with such characteristics:

– absorption coefficient $T_C(C,\lambda)$ of the measured gas (C);

– transmission coefficient $T_D(C_D)$ of dust and open optical channel lens dustiness C_D, which is conditioned by absorption and spreading of infrared radiation (IR) in a certain wavelength range (λ).

$S_{IN1}(I_1,\lambda)$, $F_{IN1}(I_1)$ and $S_{IN2}(I_2,\lambda)$, $F_{IN2}(I_2)$ are spectral power densities and powers of the main and reference channels input IR radiation during power supply from currents I_1 and I_2; $S_{OUT1}(C, C_D, I_1, \lambda)$, $F_{OUT1}(C, C_D, I_1)$ and $S_{OUT2}(C, I_2, \lambda)$, $F_{OUT2}(C, I_2)$ are spectral power densities and powers of the main and reference channels output IR radiation respectively.

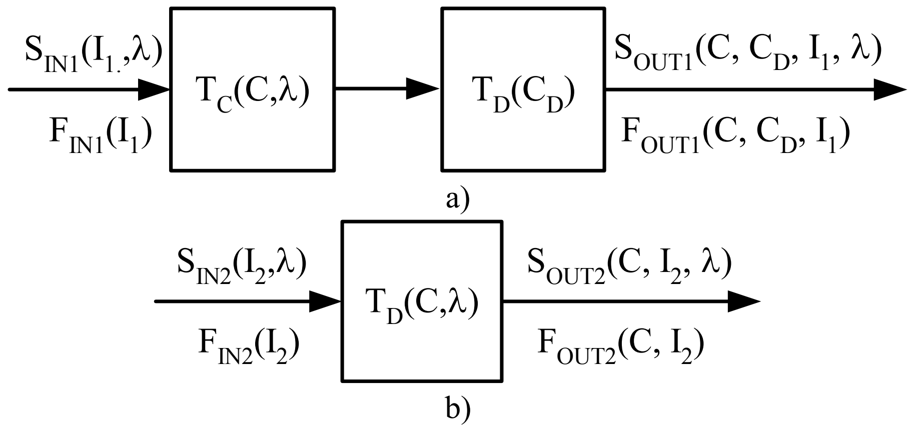

Figure 1 – Factors, which lead to power change in open main channel (a) and reference channel (b)

Implementation of the metrological reliability increasing method employs an optoelectronic unit in the meter structure, which consists of two spatial optical channels: an open main channel (OC_1) and a reference channel (OC_2), which has a cleaning filter. Block diagram of this gas meter is shown on figure 2, where RS_1 and RS_2. RS_1 and RS_2 are IR sources of main OC_1 and reference OC_2 optical channels; FD_1 and FD_2 are photo detectors of IR radiation; $SCMV_1$ and $SCMV_2$ are current sources controlled by voltage; UMV_1 and UMV_2 are photo detector output signal converting and normalization units; UC is a calculation unit; DP is a digital potentiometer.

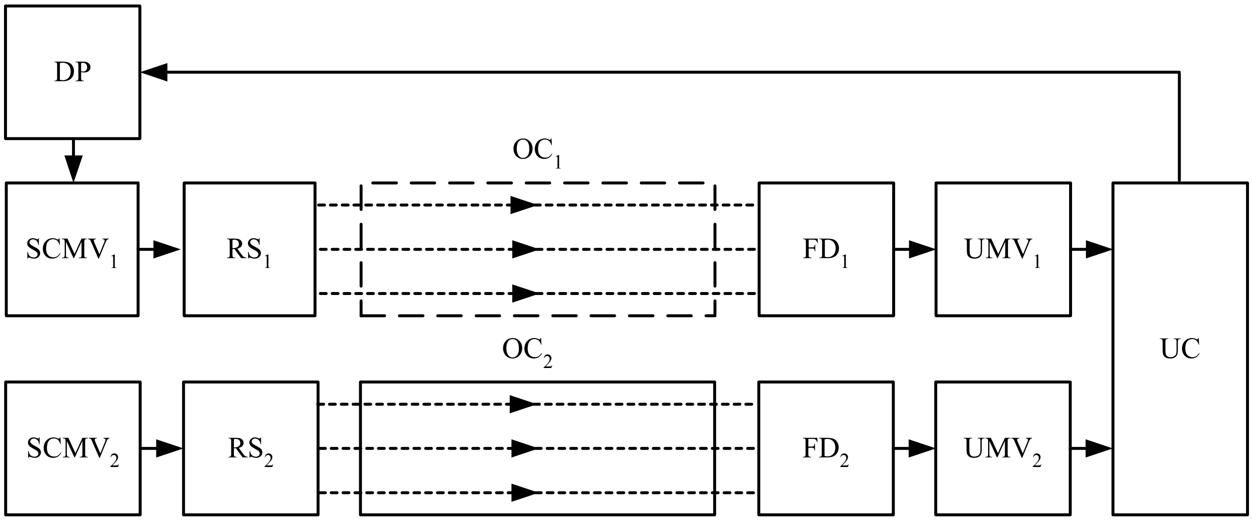

Figure 2 – Block diagram of the optoelectronic unit of a gas concentration meter

As IR sources of measuring channels we used light-emitting diodes with central wavelength equal to maximal intensity of measured gas absorption spectral lines. IR fluxes from RS of measuring channels come to open main OC_1 and reference OC_2 optical channels. After having come through optical channels IR fluxes enter photo detectors FD_1 and FD_2 respectively. Output signals from FD_1 and FD_2 are current signals, their values being proportional to output data from OC of the main and reference measuring channels:

$$I_{OUT1}(C, C_D, I_1) \sim F_{OUT1}(C, C_D, I_1);$$

$$I_{OUT2}(C, I_2) \sim F_{OUT2}(C, I_2).$$

For mathematical description of this method we considered the paths of IR radiation from RS $F_{IN1}(I_1)$ and $F_{IN2}(I_2)$ through main OC_1 and reference OC_2 optical channels. Dependencies $F_{IN1}(I_1)$ and $F_{IN2}(I_2)$ are watt-ampere characteristic of RS, which may be shown as:

$$F_{IN}(I) = S_{I\to F} \cdot I, \qquad (1)$$

where $S_{I\to F}$ is RS optical flow sensitivity to the value of the current (I), which runs through it.

After main channel OC_1 IR flow changed because of the following factors:

– $\Delta F_{C\,OUT1}(C)$ radiation absorption of controlled gas;

– $\Delta F_{D\,OUT1}(C_D)$ radiation absorption of dust suspended particles and dust on the lenses of main channel.

Having come through reference channel OC_2 IR flow changes due to the losses caused by the only factor $\Delta F_{C\,OUT2}(C)$, which is IR radiation absorption by the controlled gas. If we take into account proportion (1), IR flows of the main and reference optical channels, which come to photo detectors FD_1 and FD_2, can be described as follows:

$$F_{OUT1}(C, C_D, I_1) = F_{IN1}(I_1) - \Delta F_{C\,OUT1}(C) - \Delta F_{D\,OUT1}(C_D) = \\ = S_{I_1 \to F_{IN1}} \cdot I_1 - \Delta F_{C\,OUT!}(C) - \Delta F_{D\,OUT1}(C_D); \quad (2)$$

$$F_{OUT2}(C, I_2) = F_{IN2}(I_2) - \Delta \Phi_{C\,OUT2}(C). \quad (3)$$

For the technical realization of this method it is necessary to provide the equality of output flows of the optical channels, which can be described by (2) and (3):

$$F_{OUT1}(C, C_D, I_1) = F_{OUT2}(C, I_2). \quad (4)$$

Equation (4) is equivalent to the equality of output electrical signals of current or voltage of measuring channels if the concentrations of measured gas are equal. Realization of the metrological reliability increasing method can be shown as the following mathematical formulation:

$$F_{OUT2}(C, I_2) - F_{OUT1}(C, C_D, I_1) = 0; \quad (5)$$

$$F_{IN2}(I_2) - \Delta F_{C\,OUT2}(C) - \left(S_{I_1 \to F_{IN1}} \cdot I_1 - \Delta F_{C\,OUT1}(C) - \Delta F_{D\,OUT1}(C_D)\right) = 0,$$

then

$$I_1 = \frac{F_{IN2}(I_2) + \Delta F_{D\,OUT1}(C_D)}{S_{I_1 \to F_{IN1}}}. \quad (6)$$

For the implementation of the method and facilities of metrological reliability increasing it is necessary to let IR flows simultaneously from two identical RS. Trough the measured gas volume of the open main channel we should transmit IR radiation with central wavelength, which corresponds to the maximum intensity of the measured gas IR absorption [2]. In the measured volume of the main channel there are suspended dust particles and the dust that has settled on the optoelectronic components. This leads to the decrease of measuring channel output signal. Suppose, gas concentration in the main optic channel is C_D=10 mg/m^3. Through the measured gas volume of the reference channel we transmit IR radiation with central wavelength, which also corresponds to the maximum intensity of measured gas IR radiation absorption. The reference channel includes a cleaning filter, which lets no dust particles into the measured volume. This leads to its higher persistence and thus decreases its operation speed. Time constant of such filters is not less than (3÷5) c, that is why the reference channel output signal remains practically the same even with the dust in the measured gas mixture. IR flows come simultaneously to the photo detectors of each channel. Photo detectors transform measuring channels IR radiation output signals into electric signals. Then we should perform transformation and normalization of photo detectors output signals. While simulating this method we obtained the following dependencies provided on figure 3, where 1 – voltage output signal U_{OUT2} of the reference channel; 2 – voltage output signal U_{OUT1} of the main channel with dust concentration C_D=10 mg/m^3 and current of RS $I_1 = 100$ mA; 3 – voltage output signal U_{OUT2} of the main channel with increased current of RS up to $I_1 = 100{,}8$ mA. These values depend on the concentration of measured gas, for example, methane in variation range from 0,0 to 4,0 $^{vol.}$%.

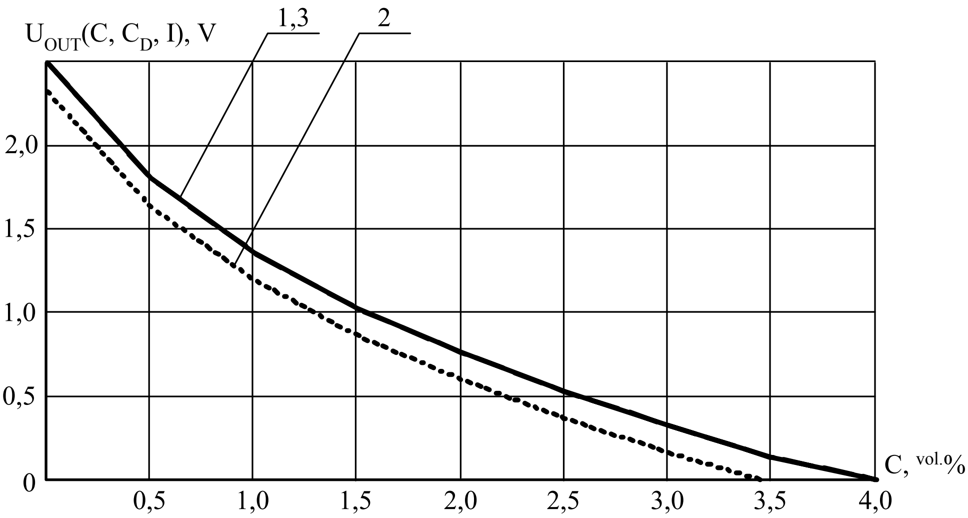

Figure 3 – Normalized transformation characteristics of output voltage signals

The measured gas concentration is defined by means of electric signals processing with compensation of the main channel output signal change, the value of which is conditioned by suspended dust particles and the dust that has settled on the optoelectronic components.

Processing of the electric signals is made in the following way: first we should define the difference of measuring channels signals using formula (5), if the result does not exceed the permissible error then it is possible to calculate gas concentration according to open main channel measurements results. In the other case, when the difference between measuring channels output signals grows systematically, we should calculate the control action on the RS of the main channel using formula (6). Figure 4 shows the dependence of current I_1, which flows through RS of the main channel, upon the value of voltage signals difference $\Delta U_{OUT} = U_{OUT2} - U_{OUT1}$. Using the residual voltage ΔU_{OUT}, we calculate current I_1 for RS supply of the main channel. The value of I_1 will grow up to that moment when output signal difference ΔU_{OUT} becomes less than permissible error, in the ideal way this value will be equal to 0. If the value of the current, which flows through the both channels of RS, is $I_1 = I_2 = 100$ mA then in order to make ΔU_{OUT} equal to 0 we need to increase RS current of the main channel up to $I_1 = 100{,}8$ mA, that is less than 1 % of the rating value when dust concentration in the main channel is C_D=10 mg/m^3.

Figure 4 – Dependence of the current, which flows through the RS of the main channel, on the measuring channels output voltage

Dependences1 and 3 provided on the figure almost coincide with one another during realization of this method. It confirms the effectiveness of the method and facilities in dusty working conditions. From the results which are shown on figure 3 we can draw a conclusion that this method allows compensating the multiplicative error component of the output signal, the value of which is conditioned by suspended dust and dust particles on the optoelectronic components in the main optical channel. It will allow making measurements in real time conditions and increase the period of continuous running and maintenance of such kind of meters.

If the obtained value of RS current exceeds the maximum permissible value for a particular kind of RS, the system formulates the signal about the necessity of maintenance. Information about gas concentration with maintenance signals is shown on the indicators and then transmitted through the digital link to the systems of gas control of industrial enterprises.

Implementation of this method increases metrological reliability of optical-absorption gas concentration meters in dusty condition with necessary response speed and metrological performance for a long time of continuous running. Gas concentration meters developed on the basis of this method allow controlling dangerous gases concentration in the working area of industrial enterprises in the conditions of high dustiness and explosive gas components.

Conclusion

1. The use of the main open optical channel provides necessary speed performance in the process of gas concentration measurement. The reference channel with a cleaning filter forms a correcting signal, which changes RS current of the main channel, increases its sensitivity and provides the independence of the results from the dustiness in the main channel. It allows increasing the metrological reliability with necessary response speed and metrological performance for a long time of continuous running.

2. The use of two identical RS simplifies engineering solutions for gas concentration meters. It simplifies the synthesis of gases concentration meters for multicomponent gas mixtures.

3. Implementation of this method provides necessary speed performance and accuracy in the process of gas concentration measurements and increases the period of continuous running in the conditions of high dustiness of the analyzed gas mixture. It allows measuring explosive gases concentration in real time conditions in working areas of industrial enterprises.

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