Dynamic control system for mine ventilation

V V Semenov, A V Fisunov, I O Nikishin
Don State Technical University, Shakhty, Rostov Region, Russia

Abstract. An optoelectronic dust meter, based on the fluctuation method, was proposed as a dust sensor for the dynamic control system of mine ventilation. The scheme of the proposed sensor can significantly reduce the error of continuous measurement of dust concentration to 5%, as well as determine the average size of dust particles in the studied environment, on the basis of which to predict the occurrence of occupational diseases. Dust sensors are installed at a distance of 10-15 meters from sources of dust release (lavas, conveyor lines, etc.), in working faces of a coal mine on incoming and outgoing streams at a height corresponding to the breathing zone of miners.

1 Problem statement
In all existing domestic and foreign systems for automatic control of mine ventilation, the operational redistribution of air is carried out according to the data on the speed and temperature of air flows on outgoing streams and in working lavas, and the dust concentration is usually taken into account indirectly using static characteristics. This circumstance does not allow promptly and correctly to make decisions on the redistribution of air in mine workings. In this regard, the creation of a dust meter for a dynamic control system for ventilation of mines is an urgent task.

2 The purpose of this work
The purpose of this work is to provide dynamic control of the mine ventilation mode by using a sensor - dust meter with increased accuracy and continuity of operation as part of the ventilation control system.

At present, dust control is not carried out in most of the known automatic mine ventilation control systems [1-12]. However, dynamic control of mine ventilation is necessary to solve the problem of delivering a clean air stream to the working area and ejecting a dusty jet from the working area. Therefore, it is advisable to control the ventilation equipment of mines, taking into account the dustiness. The block diagram of such a system is shown in Fig. 1. At the same time, the most important elements of this system of dynamic control of mine ventilation are sensors for measuring the concentration of coal dust in a mine working. Dust sensors [13-19] are installed at a distance of 10-15 meters from sources of dust release (lavas, conveyor lines, etc.), in working faces of a coal mine on incoming and outgoing streams at a height corresponding to the breathing zone of miners.
Figure 1. Functional diagram of the mine ventilation control system: 1 – methane concentration control equipment; 2 – air velocity (flow) control equipment; D – dust meter; N – other sensors; 3 – control equipment of a local air flow regulator with an indicator of the position of the regulatory body; 4 – executive device of the local air flow regulator; 5 – control equipment for a group air flow regulator with an indicator of the position of the regulatory body; 6 – actuator for group air flow regulator; 7 – underground telemechanics; 8 – surface telemechanics; 9 – teleinformation reception devices with recording devices; 10 – air distribution control apparatus; 11 – apparatus for main ventilation fan controller; 12 – actuator for main ventilation fan controller; 13 – matching device; 14 – controlling computer

Figure 2. Block diagram of the optoelectronic sensor

3 Problem solution
Figure 2 shows a block diagram of the implemented dust meter. The dust meter works as follows. The microcontroller 23 supplies a pulse voltage to the light source 1, which is optically connected to the input of the device for dividing the light flux 2, the main purpose of which is to direct the separated light fluxes into the measuring channel 4 and the reference channel 13.
Pulsed light radiation, passing through the viewing windows 3, 5, is attenuated by dust in the measuring channel 4 and enters the light-separating mirror 6, the main task of which is to divide the light beam into two, one being much larger than the other. This separation is necessary for the simultaneous measurement of the dispersion and transparency of the medium: the transparency of the medium (the optical thickness of the system) is determined from the wide beam, and the dispersion of the optical signal is determined from the narrow one.

A wide beam falls on the photodetector 10, which converts the signal into an electrical one, which is fed to the amplifier 11 and then to the adder 21. In turn, the light flux remaining after separation with a high level of fluctuations enters the diaphragm 7, where the beam is narrowed, which is fed to photodetector 8, and then to amplifier 9, then the signal goes to adder 23.

The same happens with the reference channel 13. Pulsed light radiation, passing through the viewing windows 12, 14, is attenuated by the medium in the reference channel 13 and enters the light-separating mirror 15, the main task of which is, as in the previous case, the separation beam of light into two beams: wide and narrow. A wide beam hits the photodetector 19, which converts the light signal into an electrical one, which is fed to the amplifier 20 and then to the adder 21. In turn, the light flux remaining after separation with a high level of fluctuations enters the diaphragm 16, where the beam is narrowed, which enters the photodetector 17 and from there to amplifier 18 and adder 22. After equalizing and subtracting the signals, they are synchronously with the pulse voltage supplied to the emitter 1, are detected in the microcontroller 23 and then processed further according to a given algorithm in accordance with the formulas (1-5). Those. the microcontroller measures the concentration and average diameter of particles, and then the results obtained are sent to the LCD display 24.

![Figure 3. Block diagram of the microcontroller operation algorithm](image-url)
In fig. 3 shows a block diagram of the microcontroller operation algorithm for an electro-optical dust meter. After the initialization of the microcontroller, a pulse voltage is applied to the laser diode, then data is received from the photodetectors through both channels and both beams. Next, there is a synchronous digitization of the obtained voltages in narrow and wide beams and their processing according to expressions (1-5). After processing, the results are displayed on the display screen.

Let's consider the basic formulas used in the processing algorithm (Fig. 3) [20].

The average diameter of light attenuation by a particle is described by the following expression, m$^2$:

$$S_0 = (D/I_0^2)[S_\tau/\varphi(\tau)],$$  \hspace{1cm} (1)

where

- $D$ – optical dispersion;
- $S$ – beam cross-sectional area, m$^2$;
- $I_0$ – incident beam intensity;
- $\tau$ – system optical thickness;
- $\varphi(\tau)$ – a special function that relates the dispersion to the optical thickness of the system and the average number of particles in the transmitted volume, which is placed in the controller’s ROM.

The dispersion of the optical signal can be expressed by the following expression:

$$D = \frac{1}{N-1} \sum_{i=1}^{N} (I_i - \bar{I})^2,$$  \hspace{1cm} (2)

where $\bar{I}$ – the average intensity of a parallel light beam transmitted through the medium.

The average intensity of the parallel beam transmitted through the medium is:

$$\bar{I} = \frac{1}{N} \sum_{i=1}^{N} I_i,$$

where $I_i$ – the intensity of the transmitted light beam for the i-th measurement.

The dependence for determining the concentration of particles is expressed by the formula:

$$\bar{n} = \frac{\tau}{(l \times S_0)},$$  \hspace{1cm} (3)

where

- $\bar{n}$ – particles concentration, m$^{-3}$;
- $l$ – path length in the environment, m;
- $S_0$ – average particle attenuation diameter, m$^2$.

The optical thickness of the system is determined using the formula:

$$\tau = -\ln\left(\frac{\bar{I}}{I_0}\right),$$  \hspace{1cm} (4)

The average particle radius is determined by the expression, m:

$$r = \sqrt{\frac{S_0}{2\pi}},$$  \hspace{1cm} (5)

In fig. 4 shows an embodiment of the device in the form of an electrical schematic diagram. The scheme of the proposed sensor can significantly reduce the error of continuous measurement of dust concentration to 5%, as well as determine the average size of dust particles in the studied environment, on the basis of which to predict the occurrence of occupational diseases. The device works as follows: when power is supplied to the microcontroller D1 (ATmega 128), pulses are supplied from the microcontroller to the laser diode HL1 (HFE4091-341P) connected to port PB.0, then the light pulses pass through the system of optical lenses and mirrors, as well as measuring and reference channels, and fall on the photodiodes (BPW34) of the measuring VD1, VD3 and reference VD2, VD4 channels, with the help of which the optical signal is converted into electric current.
Figure 4. Electrical schematic diagram of the optoelectronic dust meter

Further, using the operational amplifiers AD820 measuring D2, D4 and reference D3, D5 channels, the signal is amplified to a level of 1 - 4.5V. Then the paired pulses go to the adders based on the TL062 D6, D7 operational amplifiers, where the signals are subtracted (U_{\text{BLX}} = U_2 - U_1). The measurement results go to the ports of the micro-controller D1 ADC0 and ADC1, where the signals are synchronously digitized and the optical thickness of the system, the dispersion of the optical signal D, the average diameter of light attenuation by a particle, the average radius of particles r, and the concentration of particles according to the formulas (1-5) using the values of the function \( \varphi (t) \) placed in the microcontroller’s memory. The calculation results are transferred to the LCD display LM016L.

Conclusions
Thus, due to the use of the proposed sensors, the dynamic control system makes decisions on the redistribution of air in mine workings. In addition to taking into account the total dust concentration by the dynamic control system, the system accumulates information about the dust load received by the body of workers with the respirable dust fraction, and also uses this information to optimize the control algorithms.

References
[1] GOST R 55175-2012. The Atmosphere in Mine. Dust Control Techniques
[2] Liu T, & Liu S The impacts of coal dust on miners’ health: A review. Environmental Research, 2020, 190 doi:10.1016/j.envres.2020.109849
[3] Karpov E F, Basovskiy B I Coal Mines Ventilation and Degassing Control: Reference Guide – M.: Nedra, 1994. – 336 P.
[4] Hygienic Requirements for Coal Enterprises and Organization of Work. Sanitary rules and regulations (СанПиН 2.2.3.570–96). – М.: ИНТЭРСЭН, 1996. – 84 P.

[5] Vasilenko V I Automated Ventilation System for Non-Gas Coal Mines. Novocherkassk: NGTU, 1996 – 172 P.

[6] Pozdnyakov G A Scientific Basis, Methods and Technical Means of Normalizing the Atmosphere of the Preparatory Drifts of Coal Mines by Dust Factor: Abstract of PhD thesis. – Moscow, 1997. – 36 P.

[7] Wang H, & Sun Z Thermal dynamic system of the outcrop coal fire under the control of multi-ventilation power factors and its application. Journal of Chemical and Pharmaceutical Research, 2013, 5(9), 248-255.

[8] Kachurin N M, Vorobev S A, Levin A D, Botov F M Theoretical substantiation and practical results of underground workings ventilation simulation // Eurasian Mining. 2015. No. 2. P. 35–39. DOI: 10.17580/em.2015.02.09

[9] Grishin E L, Nakaryakov E V, Trushkova N A, & Sannikovich A N Experience in implementation of dynamic mine ventilation control. Gornyi Zhurnal, 2018 (8), 103-108. doi:10.17580/gzh.2018.08.15

[10] Kormshchikov D S, Zaitsev A V & Kiryakov A S, "Enhancement of energy efficiency in mine ventilation by introduction of main fan installations in underground mines", Gornyi Zhurnal, 2020, vol. 2020, no. 2. pp. 80-83.

[11] Guo L, Nie W, Yin S, Liu Q, Hua Y, Cheng, L, . . . Du T The dust diffusion modeling and determination of optimal airflow rate for removing the dust generated during mine tunneling. Building and Environment, 2020 , 178 doi:10.1016/j.buildenv.2020.106846

[12] Zhu Z, Wang H, & Zhou J Monitoring and control model for coal mine gas and coal dust. Chemistry and Technology of Fuels and Oils, 2020, 56(3), 504-515. doi:10.1007/s10553-020-01161-3

[13] Galaov R B, Balchugov V G, Kazakov B P, & Butakov S V Method of microclimate normalization in deep mines. Gornyi Zhurnal, 2015(6), 89-92. doi:10.17580/gzh.2015.06.18

[14] Chen L, Mao J, Zhao H, Zhou C & Gong X Size distribution and concentration of aerosol particles in yinchuan area, Physical Geography, 2019, 40(6), 538-553. doi:10.1080/02723646.2019.1613325

[15] Semenov V V, Danilenko I N Optical dust meter RF Patent № 2558278, IPC G01N21/59, G01N12/15, applicant and patent holder: «Don State Technical University» (DSTU) - № 2014106501/28; published. 27.07.2015

[16] Semenov V V, Popov E K Optical dust meter RF Patent № 2510497, IPC G01N21/94 applicant and patent holder South Russian State University of economics and service – № 2012132349/28; published 27.03.2014.

[17] Semenov V V, Popov E K The Method for Determining the Concentration and Average Particle Size of Dust RF Patent № 2510498, IPC G01N21/94, G01N 15/02 applicant and patent holder South Russian State University of economics and service – №2012132356/28; published 27.03.2014.

[18] Semenov V V, Asstaturov Yu G, Khanzhonkov Yu B Optico–Electronic Dust Meter Measurement Techniques, 2019. № 1 – pp 40–48.

[19] Semenov V V, Asstaturov Yu G, Khanzhonkov Yu B Optico-Electronic Dust Meter Measurement Techniques June 2019, vol. 62, Issue 3, pp 249–253 Cite as (https://doi.org/10.1007/s11018-019-01612-2)

[20] Shifrin K S Introduction to Ocean Optics – Saint-Petersburg: Hydrometeoizdat, 1983. – 278 P.