LASER DENSITOMETER FOR MEASURING THE MASS CONCENTRATION OF DUST

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In this paper we present a description of a laser densitometer, its characteristics, and results of its metrological tests. This densitometer has been designed for measuring the mass concentration of dust. It uses photometric principle insrtumentally performed in a multipass cell. The range of mass concentration values detectable with the densitometer is from 3 *to* 18 mg/m^3, *the rms deviation of measurements being* 25 *per cent.*

The problem on express measuring the concentration of aerosol emissions and dust content in the atmospheric air becomes an urgent task nowadays. It is caused by some reasons, i.e., the rapid development of aerosol technologies (spreading drying, aerosol covers, powder metallurgy, spreading of poison chemicals and fertilizers, aerosol therapy), creation of systems of technological processes control where the raw materials or the final products are the dust, study of the processes of transfer and transformation of aerosol of natural or anthropogenic origin (fogs, clouds, dust), necessity of the control of air quality aimed at environmental protection (dust in production shops, testing of quality and reliability of industrial clearning of air, optimization of production process in pharmacology, optics, and microelectronics), the human environment protection (prevention of allergy and asthma, control of air in hospitals, and so on).

As the gas-dust medium is a complex unstable aerodynamic system that can not be satisfactorily described by one or two parameters, measurement of aerosol and dust concentration is quite a difficult metrological problem. Dust, being the polydisperse medium with a wide concentration range, different shapes and different physicochemical properties of particles,[1,2] makes a great problem for development of a universal method for measuring its mass concentration.

The available methods for measuring the concentration of aerosol and dust based on sedimentation can be used for high–precision measurements only in the small range of concentration[2]. Although the devices based on sedimentation of dust measure the mass concentration directly, they have low sensitivity. Measuring process with these devices is cyclic and laborious.

The need for devices capable of operating in the automated systems of control of air pollution appeared with the development of these systems and creation of the systems for the technological processes control. The devices based on the methods without sedimentation of dust satisfy these requirements better because they are capable of continuously measuring in automated regime.[1,2,4]

Recently, the meters of aerosol are widely used, which are based on use of the effects of extinction of laser radiation[3]. The phenomenon of scattering of laser radiation by aerosol in the local air volume is used in the laser densitometer. The wider range of measurable concentration is provided directly in the dust–air medium due to the combination of the well tested two–beam measurement pattern and a multipass cell.[5]

Extinction of a collimated optical beam is determined in the single scattering approximation described by the Bouger law[3] as follows:

$$J = J_0 \exp [- N \pi a^2 \kappa(z, z_0) L], \tag{1}$$

where J_0 and J are the intensity of the laser beam, incident and passed through the atmospheric aerosol layer, respectively; N is the number of particles in the scattering layer with the thickness of L; a is the particle radius; and, $\kappa(z, z_0)$ is the correction coefficient depending on the measurement conditions, it is found by calculations and varies from 0 to 2.

The relation between the intensity of the laser radiation transmitted and received after passing the optical thickness and the electrical signals taken from the transformation unit (of logarithmic amplifier) can be written as follows:

$$\ln(J / J_0) = (U_{\text{out}} - U_{\text{cal}}) \gamma, \tag{2}$$

where U_{out} is the signal value recorded in measurements; U_{cal} is the signal value obtained in the preliminary calibration, when there is no aerosol in the cell; and, γ is the correction coefficient that has the dimensions [1/V].

From Eqs. (1) and (2), we derive the equation for determining the number of particles in the volume bounded by the laser beam

$$N = \frac{(U_{\text{out}} - U_{\text{cal}}) \gamma}{\pi a^2 L \kappa(z, z_0)} . \tag{3}$$

Final expression for the mass concentration of spherical particles with the radius a and density ρ has the form

$$M = \frac{4}{3} a \rho \frac{(U_{\text{out}} - U_{\text{cal}}) \gamma}{L \kappa(z, z_0)} . \tag{4}$$

The formula derived is the initial expression for the laser densitometer for determining the mass concentration of aerosol (dust).

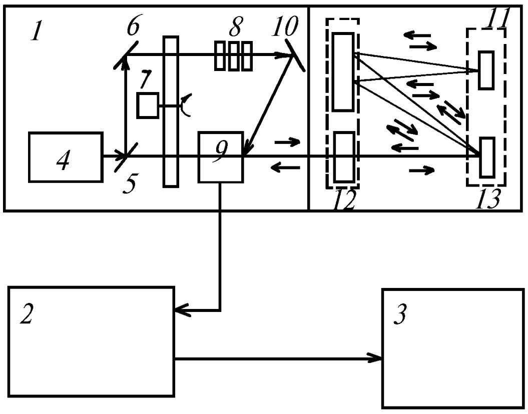

FIG. 1. Functional block diagram of the densitometer.

The functional block diagram of the densitometer is shown in Fig. 1. The device design has three parts: photometric unit *1;* transformation unit *2*, and microprocessor *3*. Photometric unit is divided into two parts: an optical–mechanical unit and a multipass cell *11*. Radiation of the He–Ne laser *4* is divided in the optical–mechanical unit by a semitransparent mirror *5* into the sounding and reference beams. The sounding beam passes to the multipass cell after modulation with a chopper *7* through the input window. More than 200 passes in the cell can be provided using transformation of the mirror unit *13,* that corresponds to the path length of 100 m when the cell is 0.5 m long.

After passing through the cell, the laser beam returns to the optical–mechanical unit and passes to the photodetector *9*. In order to extend the dynamic measurement range, the intensity of the reference and the sounding beams coming from the cell are made equal to each other by means of selection of the number of neutral light filters *8*. The turning mirrors *6* and *10* are used to reduce the device over–all dimensions. The spherical mirrors in the units *12* and *13* provide focussing of the laser beam for each pass into the cell. As a result, the beam diameter at the output of the cell differs slightly from the diameter at its input. Commutation and modulation of laser radiation in the reference and sounding channels are made by the electromechanical chopper *7*.

The shape of a signal from the photodetector is shown in Fig. 2. It is the subsequence of unipolar pulses of fixed frequency with the rectangular envelope. The signal with such a form makes it possible to apply the amplifier of the alternating current that has higher stability and feasibility of selecting the signal against the noise background, in comparison with the amplifier of direct current.

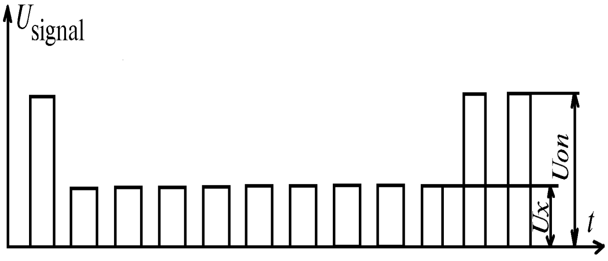

FIG. 2. Shape of the signal from the photodetector.

The values of logarithm of the ratio of the sounding and reference signals are determined according to the Eq. (2) in the transformation unit (see Ref. 6). Current value of this logarithm is shown on the built–in digital indicator and enters the processor unit. The built–in calibrator is in the transformation block for control of the capacity for work and testing the reliability of transformations.

The signal coming from the transformation unit is used for calculation of the mass concentration of aerosol by Eq. (4), embedded to the processor unit. In addition to the current value (2), it is necessary to input to the processor from the keyboard the values of particle size and density that are characteristic for the region unde study, the number of passes of optical radiation in the cell, and the value of U_{cal}. This value is determined at the initial calibration of the device after pumping the air cleaned by AFA filter through the closed cell. Determination of U_{cal} makes it possible to increase the accuracy of measuring the aerosol concentration.

The calculational results obtained in the processor are automatically indicated every 10 s on the digital indicators on the front panel of the unit. The regime of averaging is possible over 60 values each 10 min. In addition, the data of each measurement can be transmitted by request of external computer for subsequent processing and storage.

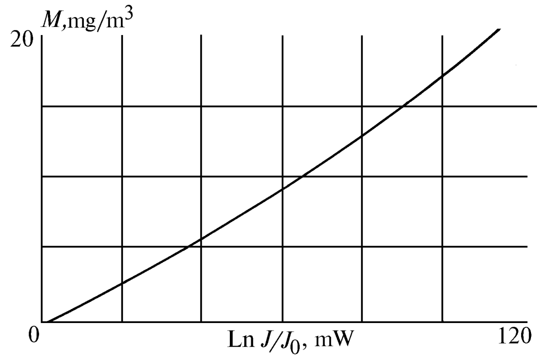

FIG. 3. Transfer function of the densitometer.

The prototype of the densitometer designed and created in Design and Technology Institute "Optika" has got the state metrological certification performed in Scientific–Production Union "D.I. Mendeleev All–Union Scientific–Research Institute of Metrology". It was carried out in special chambers using the devices based on weight and electroinductive methods as a standard. The transfer function of the densitometer (Fig. 3) was determined during testing. The empirical correlation coefficient between readings of the device based on the grammeter method and the laser densitometer is equal to 0.993, and the correlation coefficient between readings of the electroinductive device and the densitometer is close to 0.985.

By the results of metrological certification, the laser densitometer is adopted for pilot operation with the following characteristics.

Parameters of dust to be analyzed: mean radius of 1.2±0.1 μm and density of 2.16 g/cm^3. If the number of passes in the cell equals 64, the range of measurable dust concentration is 3–18 mg/m^3 with the relative measuring error of 25%.

The device is energized from 220 V, 50 Hz and its power is 310 W. The over–all dimensions of the transformation unit and processor are 270×300×200 mm, and their weights are 12 kg. The over–all dimensions of photometric unit are 820×290×100 mm, and its weight is 10 kg.

Further development of the device in the mechanism of the change of the number of passes in the multipass cell will allow us to change discretely the length of optical path in the cell and significantly extend the range of measurable values of the aerosol (dust) mass concentration. The designed small–size multipass cell can also be used in the correlation radiometers.

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