

## REMOTE CORRELATION SPECTROSCOPY OF AEROSOL AND GAS EMISSIONS FROM INDUSTRIAL OBJECTS

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*A description of a correlation radiometer for measuring sulfur and nitrogen dioxides in the aerosol and gas emissions from industrial objects is presented. Investigation of metrological characteristics of the device is discussed and some results of field tests are presented.*

The method of correlation spectroscopy<sup>1</sup> is most promising for detection of gaseous pollution in the atmosphere. The method provides high noise protection of devices against foreign gases in the volume under study, insensitivity to the presence of aerosol and to variations in the radiation source brightness, as well as the feasibility of remote measurements. As a radiation source we can use both artificial emitters (active method) and scattered, reflected, or direct solar radiation (passive method).

The primary goal of our work was to create a simple while reliable nondispersing correlation gas analyzer for measuring the content of nitrogen and sulfur dioxides in aerosol and gas emissions from industrial objects. The general principle of operation is based on different attenuation of a light flux outgoing from the volume studied in two channels, namely, in reference channel containing a cell filled with the gas similar to a detected one and in a measuring channel containing neutral attenuators. This difference causes the relative change in a signal of one channel as compared to another one. The signal difference is proportional to the amount of gas measured along a sounding path.<sup>2</sup> The amount of a gas in a correlation cell is chosen optimal in order the spectral transmission of the cell at the absorption line centers of the gas investigated to be small. In this case, the system has high sensitivity, noise protection and a sufficiently wide dynamic range of measurements.<sup>2</sup>

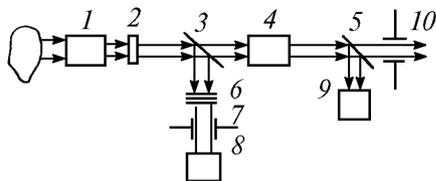


FIG. 1. Optical arrangement of the analyzer

We have produced a simple nondispersing gas analyzer. The gas analyzer contains two channels with separate detectors. The optical arrangement of the analyzer (Fig. 1) consists of a collimator 1 of quartz lenses 70 and 30 mm in diameter, converting a studied light flux with field-of-view angle of 30' to a parallel light beam 10 mm in diameter, an interference filter 2, a plane-parallel quartz plate 3, a quartz

cell with the gas studied 4, an interference mirror 5, a set of neutral attenuation filters 6, a smoothly tunable diaphragm 7, and photorecorders 8 and 9. Filter 2 and mirror 5 have spectral characteristics coinciding with the absorption band of NO<sub>2</sub> and SO<sub>2</sub> gases. The set of neutral filters 6 together with the smoothly varying diaphragm 7 makes it possible to equalize the light beams incident on the photodetectors. All optical parts were made of quartz glass transparent in the visible and near UV spectral ranges.

The optical elements are installed in a housing with the window 10 in the rear panel, which allows us to aim visually the analyzer at the region under study. The housing is mounted on a rotatable console, which measures in degrees the direction of the collimator both in horizontal and in vertical planes.

### TECHNICAL DESCRIPTION OF THE GAS ANALYZER

The gas analyzer is composed of separate units in a single housing. The functional block-diagram of the device is given in Fig. 2. The power supply (PS) converts the voltage of 220 V to stabilized voltage of  $\pm 12$  V. The light flux from the optical block arrives at the block of photomultipliers of reference channel (PM<sub>r.c.</sub>) and measuring channel (PM<sub>m.c.</sub>). PMs are supplied from PM conversion unit (CU), which converts +12 V voltage to 1–1.5 kV voltage. Preamplified with amplifiers A<sub>r.c.</sub> and A<sub>m.c.</sub> signals arrive at the unit of the functional converter (FC) and at digital display (DD) of the measurements results. The signals may also be inputted into a computer for subsequent processing. The device is calibrated using the set of reference cells with concentrations of NO<sub>2</sub> and SO<sub>2</sub> corresponding to the measurement range.

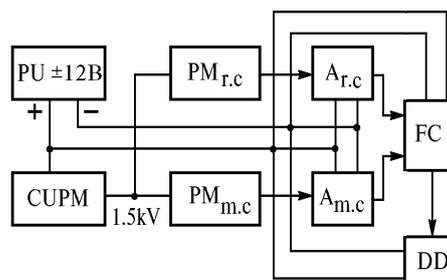


FIG. 2. Functional block-diagram of the analyzer

Figure 3 gives the calibration dependence of the difference to sum ratio for signals  $U_1$  and  $U_2$  of the two channels of gas analyzer on the mean concentration in the field of view of the device objective multiplied by the measurement path length ( $\text{g}/\text{m}^3 \cdot \text{m}$ ) in a measured volume, when the transmission coefficient of a reference cell of the device is equal to 0.0025 for  $\text{SO}_2$  (curve 1) and 0.004 for  $\text{NO}_2$  (2). From the figure it is clear that for the gas mass in a column of both  $\text{NO}_2$  and  $\text{SO}_2$  up to  $7 \text{ g}/\text{m}^3$  the dependence of relative disbalance of the analyzer channels increases linearly with the growth of mass of a gas measured. At large gas concentrations the signal of channel disbalance reaches saturation with subsequent decrease. The saturation level of calibration curves determines the upper level of operating dynamic range of the analyzer at about  $7 \text{ g}/\text{m}^3 \cdot \text{m}$ ; the lower level is determined by the ability of electronics is to distinguish the difference in the signals from channels against the noise and the instability of parameters of electronic units and radiation detectors. The range of detection with this analyzer is limited by the visibility range along the measurement path in the operating wavelengths range. Based on the results of the state metrological certification the gas analyzer under consideration is admitted to perform scientific research and creation of the gas-analytical means for sanitary-ecological monitoring of the atmosphere as well as to determine the variations in concentration of  $\text{SO}_2$  and  $\text{NO}_2$  against the background.

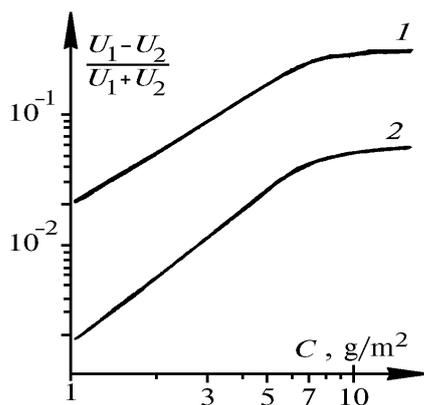


FIG. 3. Dependence of relative signal of the correlation gas analyzer on mass of absorbing gases.

Gas analyzer specifications

Range of $\text{NO}_2$ detection, $\text{g}/\text{m}^3 \cdot \text{m}$	0-7
Range of $\text{SO}_2$ detection, $\text{g}/\text{m}^3 \cdot \text{m}$	0-7
Principal relative error, %	30
Consumed power, W	16.5
Mass, kg	6

**TECHNIQUE FOR DETECTING THE  $\text{NO}_2$  AND  $\text{SO}_2$  CONTENT IN THE STACK SMOKE PLUME**

The device is located in the immediate vicinity of the gas plume propagation. Discrete scanning of the

device axis is made in the plume cross-section with a step  $\Delta\Theta_i$ . The data array of gas integral content in a sighting direction  $W(\Theta_i)$  is collected.  $\Theta_i$  is the sighting angle of the device optical axis counted from the vertical. The content of a gas in a volume element of normal cross-section is

$$S = H \sum_i W(\Theta_i) \cos^{-1}\Theta_i \Delta\Theta_i,$$

where  $H$  is the plume height above the ground surface determined by measurements of direction angles  $\alpha$  and  $\beta$  to the plume center from the two points shifted in a direction perpendicular to the plume propagation at the distance  $d$

$$H = d \tan\alpha \tan\beta / (\tan\beta - \tan\alpha).$$

The speed of the gas mass flow is  $F = S v$ , where  $v$  is the wind speed averaged over plume cross-section which can be measured according to the angular speed of the inhomogeneity displacement in the plume  $\omega$  by the formula  $v = H \tan \omega / \sin\alpha$ .

The aerosol content can be determined using the same technique. In this case the optical thickness  $\tau_i$  of the plume is measured at a radiation wavelength, which does not fall into the gas absorption bands, in discrete changing of the sighting angle of the device optical axis  $\Theta_i$  counted from the vertical with a step  $\Delta\Theta_i$ . Then the aerosol content in the volume element of the normal section  $S_a$  is

$$S_a = H \mu \sum_i \tau_i \cos^{-1}\Theta_i \Delta\Theta_i,$$

where  $\mu$  is the average value of the coefficient relating the values of the extinction coefficient of optical radiation with the mass concentration of aerosol.

Theoretical calculations of the coefficient  $\mu$  show<sup>3</sup> that for smokes of finely disperse aerosol this coefficient depends slightly on the variation of particle size spectrum and for woody smokes it is equal to  $0.4 \text{ mg} \cdot \text{km}/\text{m}^3$ .

The speed of aerosol mass flow equals  $F_a = S_a v$ .

The present technique is applicable to transparent smoke plumes when measuring the attenuation of direct solar rays by aerosol.

Under laboratory conditions the additional errors are estimated. These errors are caused by variations in the light flux at the input of the optical path due to the change of the radiation source brightness and the presence of neutral attenuator (haze, precipitation) along the measuring path as well as the errors caused by the presence of foreign gases at the path, which have close absorption lines.

The measurements have shown that variation of light flux due to the change in the source brightness by a factor of 20 results in the additional error not more than 4% in measuring  $\text{NO}_2$  and 6% in measuring  $\text{SO}_2$  content. As to foreign gases, the cells with  $\text{SO}_2$  have been used when measuring  $\text{NO}_2$  and vice versa. In this case the additional measurement error did not exceed 4%.

Thus, the total relative error of gas analyzer, caused by the above-mentioned factors, does not exceed 10%.

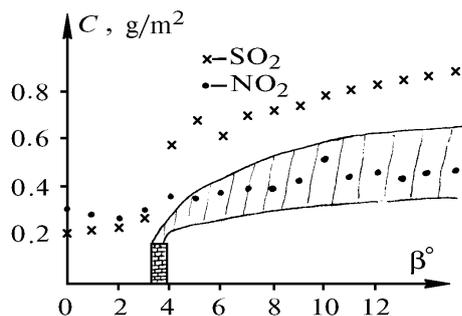


FIG. 4. Dependence of  $\text{NO}_2$  and  $\text{SO}_2$  content on the angle of scanning in a horizontal plane over Tomsk.

Following the laboratory tests of the analyzer a cycle of measurements of  $\text{NO}_2$  and  $\text{SO}_2$  content was carried out along a horizontal path over Tomsk near City Electric Power Station-1. Figure 4 shows the results of measurements. It is evident that in horizontal scanning the content of  $\text{NO}_2$  and  $\text{SO}_2$  increases in the direction of industrial emissions from the stack of the City Electric Power Station-1.

## CONCLUSION

The investigations of operation of the nondispersing correlation gas analyzer have shown that in the daytime it is possible by means of a given device to control the content of  $\text{NO}_2$  and  $\text{SO}_2$  in the air along horizontal and vertical paths, as well as in smoke plumes.

In this case the influence of aerosol and foreign gases in the volume under study results in the increase of relative error of measurements being not more than 10%.

Technical characteristics of the device allow such matters as formaldehyde  $\text{CH}_2\text{O}$ , carbon disulfide  $\text{CS}_2$ , toluene  $\text{C}_7\text{H}_8$ , benzene  $\text{C}_6\text{H}_6$ , iodine  $\text{I}_2$  vapors to be included into the list of measurable gases

## REFERENCES

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