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Modification of the Experimental Setup of the FTIR Spectrometer and Thirty-meter Optical Cell for Measurements of Weak Selective and Nonselective Absorptions

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Abstract—The improvement of the experimental setup based on a Fourier spectrometer Bruker IFS-125 and a 30-meter multipass optical cell is described. The improvement includes the cell equipment with a system of automated adjustment of the number of beam passes without cell depressurization and ensures the cell work at high temperatures.

Keywords: Fourier spectrometer, multipass cell, absorption spectrum

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INTRODUCTION

Absorption spectra of atmospheric gases include both strong absorption bands, consisting of many individual spectral lines, and "transparency windows" between them with much weaker absorption. The radiation absorption in these windows is mainly conditioned not by spectral lines, but the so-called "continuum absorption", i.e., the absorption component which weakly depends on the frequency. The water vapor continuum absorption, which strongly affects the atmospheric radiation balance and remote sensing, has been most actively studied in recent years [1–3]. Weak spectra of selective and continuum absorptions are measured using calorimetric interferometry [4], Fourier-transform spectroscopy with multipass cells, and cavity ring-down spectroscopy [7, 8]. Each of these techniques has a specific uncertainty type, and the continuum absorption values measured by these techniques strongly differ [3, 9].

The analysis of our Fourier-transform spectroscopy measurements has shown that the error in determination of the baseline (i.e., zero level of "absorption/attenuation") gives an essential contribution to the total budget of measurement errors of weak selective absorption [1, 5]. By virtue of a series of causes, the baseline measured in the cell with a gas under study differs from that measured in the empty cell. This may be due, among other things, to changes in the radiation source intensity and the receiver sensitivity during the time the cell is filled with water vapor.

To decrease the baseline uncertainty when measuring the continuum absorption by the Fourier-transform spectrometry with multipass cells, it is possible to use the approach suggested earlier in [10], where the effective optical depth of water vapor in the cell was determined from the ratio

$$\tau(\nu) = -\ln\left\{\frac{I_{\max}(\nu)\, I^{*}_{\min}(\nu)}{I_{\min}(\nu)\, I^{*}_{\max}(\nu)}\right\}, \qquad (1)$$

of signals measured at the minimal $I_{\min}(\nu)$ and maximal $I_{\max}(\nu)$ numbers of beam passages in a multipass cell filled with water vapor and in the empty cell (denoted by asterisk). If the adjustment of the number of beam passages is sufficiently fast and proceeds without the cell depressurization, then Eq. (1) allows us to find the magnitude of absorption conditioned only by gas in the cell. In this case, the baseline uncertainties caused by variations in the radiation source intensity, receiver sensitivity, and spectral dependence of the mirror reflective coefficient, if any, become minimal.

For engineering implementation of this method and measurements at high temperatures, we significantly improved the 30-m cell (the description is given below).

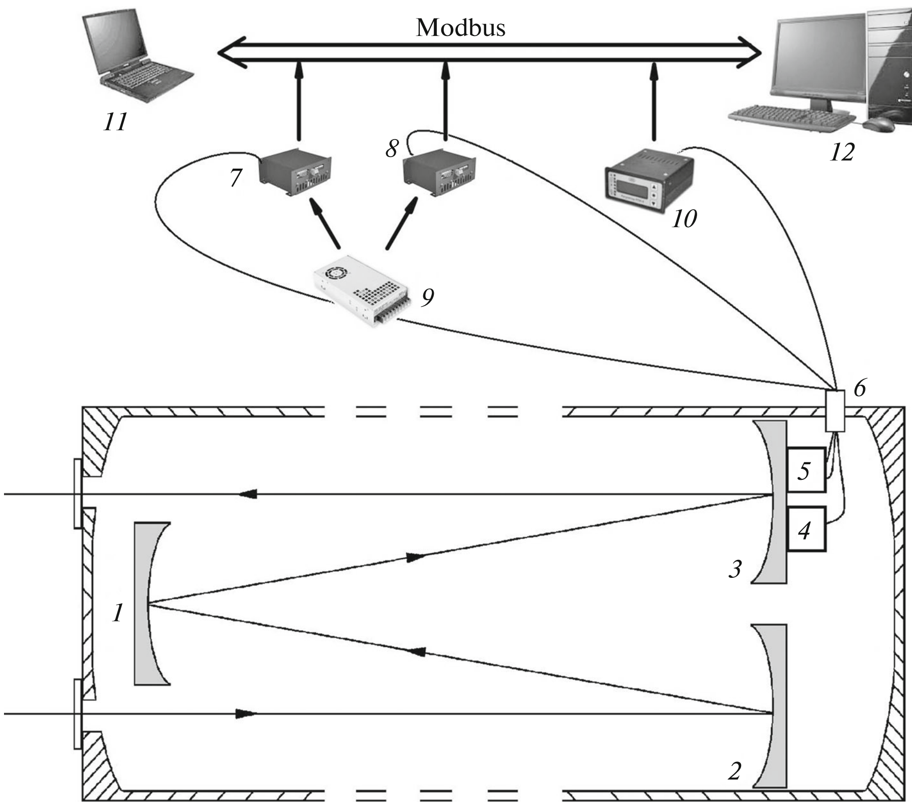

Fig. 1. Block-diagram of a 30-m cell, equipped with the mirror rotation control system; spherical mirrors of the cell (*1–3*); two stepwise motors for horizontal and vertical rotation of the mirror (*4*); two-channel displacement sensor (*5*); electric vacuum input of signals controlling the stepwise motors and output of signals from the two-channel movement sensor (*6*); stepwise motor controllers (*7* and *8*); power supply unit of controllers (*9*); displacement sensor controller (*10*); notebook (*11*), and personal computer (*12*).

The cell is a part of the spectroscopic complex based on the Bruker IFS-125 Fourier spectrometer [11, 12]; it is a stainless cylinder tube with inner diameter of 0.9 m and has a length of 30 m. To measure absorption spectra at high temperatures, we fixed tubes on the external surface of the cell, inside which the hot water circulates at a temperature of about 350 K. A large number of working holes of different diameters (from 5 to 50 cm) were made along the cell perimeter, covered by flanges, and vacuum conductors of large diameter for connecting the cell to pumps. In addition, a mechanical decoupler, which separates the mirror holder from the steel tube, is incorporated in the cell construction. All these places on the cell are potential points of water vapor condensation during measurements at high temperatures. In order to exclude the condensation in these places, additional heating was provided with a possibility of controlling the temperature.

The improved White optical system, consisting of three spherical mirrors with equal curvature radii, was installed inside the cell (Fig. 1). Diameters of two back mirrors (*2* and *3*) are equal to 30 cm; input front mirror (*1*) is 50 × 30 cm in size. The curvature center of the mirrors lies on the surface of the front mirror, with the center curvature located between the mirrors. The mirrors in heavy rims are installed on pads mechanically separated from the cell body via bellows.

The long length of the beam path in the cell is gained due to multiple light reflection from the mirrors located inside the cell at its end points. Before measuring spectra, the optical system was adjusted to a definite number of beam passes and evacuated to the ultimate pressure. During pumping and heating, the cell is deformed, which violates adjustment of the mirrors despite the presence of mechanical decoupler between the cell and the mirrors' pads. We have developed and made an optomechanical block, which allowed us to decline mirror (*3*) in two mutually perpendicular planes. That gave a possibility of adjusting the mirrors of the optical system and varying the number of beam passes in the cell without its depressurization.

The electrical part of the system of controlling the mirror rotation consists of the following components:

– two stepwise motors (*4*) with controllers and power supply unit (*7–9*);

– a two-channel movement controller (*5*);

– an electric vacuum input of signals controlling the stepwise motors and output of signals from the two-channel displacement sensor (*6*).

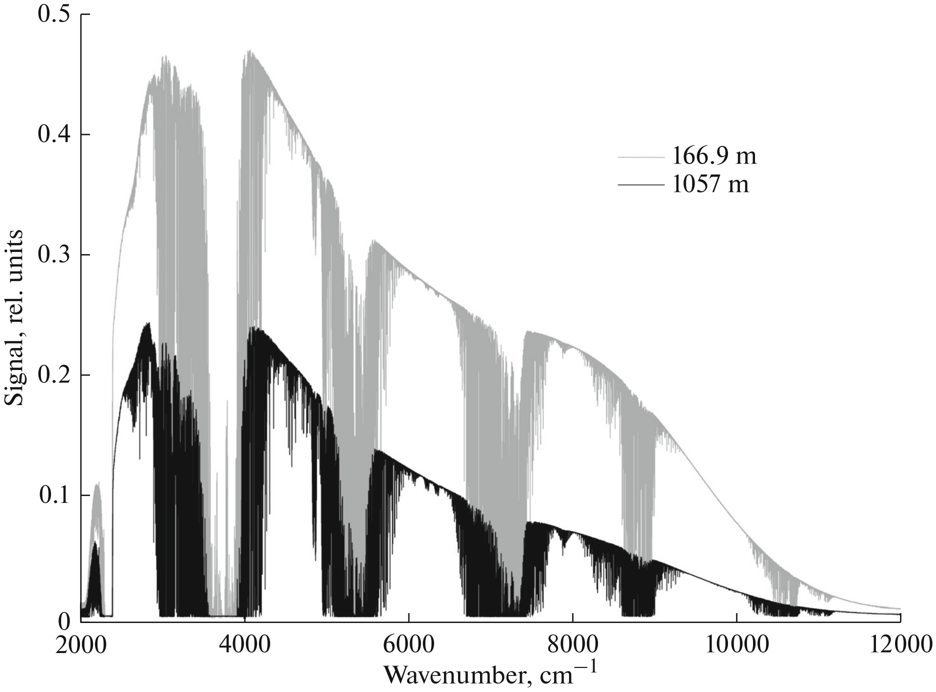

Fig. 2. Absorption spectrum of atmospheric air at different beam path lengths (166.9 and 1057 m).

The FL86STH80 stepwise motors with OSM-88RA controllers (Onitex company) were used in the control system. The controller allows the segmentation of the motor step with a coefficient of 1/16 and also to vary the motor current over wide limits, which is necessary in different modes of the system operation. The mirror rotation and its inclination at a preset angle is controlled by the IP-2K two-channel movement controller (ITM) with a resolution of 1 μm in each channel. The special LabView software was elaborated to control the rotating mirror and track its position. The advantage of the system suggested is the fact that all three controllers (two for stepwise motors and one for the displacement sensor) are located in one communication line and connected with a computer by one twisted pair of wires through the RS-485 interface. The data rate is 38400 Kbit/s. The Onitex controllers of stepwise motors are controlled by a set of simple Modbus commands (communication protocol based on the client-server architecture; allows a simple integration of devices supporting the protocol into a unitary network). Using the control system it is possible to change the angular position of a mirror in two planes, setting the step, speed, and magnitude of shift. Simultaneously with the mirror movement, its position is tracked by the displacement detector indicator .

The system allows the adjustment of the optical path from 166.9 to 1057 m. Note that, for gaining the maximal number of beam passes in the cell, the possibility of controlling the motor with 1/16 of the step was used. For further increase in the number of passes other types of stepwise motors and controllers are required. Earlier, a similar scheme of the remote control the mirror position with the help of stepwise motors was used in the laser spectrometer [3]; however, it provided for only an integer number of motor steps.

Figure 2 shows absorption spectra of atmospheric air in the range 2000–12000 cm^{-1}, recorded with a spectral resolution of 0.03 cm^{-1} at beam path lengths in the cell of 166.9 and 1057 m. The given spectra were obtained with the use of the developed system (the path length changed without cell depressurization).

The different signal levels in different ranges for an increase in the optical path length are conditioned by the spectral dependence of the mirrors' reflection coefficient, which can be taken into account in formula (1).

Thus, this improvement of the measurement complex based on a Fourier spectrometer and 30-m base cell enhances capabilities for the study of both the selective and nonselective absorption of gaseous media. The adjustment of the optical path length without the cell depressurization makes it possible to record many spectral lines during one measurment cycle, allowing recording both strong and weak spectra at identical magnitude of the signal-to-noise ratio. Further, it increases the continuum absorption measurement accuracy.

In addition, cold parts of the cell (mirrors, flanges, underwater elements of the vacuum system) are equipped with a heating cable. This provides for recording water vapor absorption spectra at high pressures, which is important for elucidation of the nature of the water vapor continuum.

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