Movable mirror of Michelson interferometer in Fourier’s spectrometer steadiness assessment

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Abstract. A method to assess steadiness of movable mirror of Michelson interferometer in Fourier’s spectrometer has been developed. Steadiness of movable mirror motion has been analyzed experimentally using three devices with different control systems of the movable mirror. A comparative analysis of the speed steadiness of the frame motion has been made, using analog and digital control types, with and without feedback. We have found that the developed method helps to analyze the above mentioned process faster if there is an interference pattern. We have shown that the control system without feedback has more deviation of speed motion than one with feedback.

1. Introduction
Learning about the atmospheric composition is a relevant problem of modern science. To solve this problem we often use IR spectroscopy methods, and to get spectral information we use the Fourier-transform infrared spectroscopy technique [1].

Spectrometer reference channel determines the mirror movement. In order to get the correct spectrum in fast scanning Fourier Transform Infrared Spectrometers, based on Michelson interferometer, it is necessary to make movable mirror motion steady [1]. Steadiness of movable mirror motion is determined by introducing feedback into the system. In this paper we consider the method to assess steadiness of movable mirror motion. Judging by the interference pattern changes of the laser channel on photodiode we find instantaneous speed and then from that we find movable mirror motion steadiness. We also have compared the steadiness of movable mirror motion using analog and digital feedback systems and systems without feedback.

2. Experimental research method
On figure 1 you can see a mechanical schematic of IR-channel and Michelson interferometer’s laser channel within the Fourier Transform Infrared Spectrometer. By means of the laser (10), beam splitter (5) and movable (4) and non-movable mirrors (3) reference channel photodiode displays an interference pattern. Judging by interference fringes’ changes over time we find instantaneous speed of a movable mirror [4]. By means of the oscilloscope, AKIP-4125/2A, we receive data from the photodiode (6).

To compare motion steadiness we use three Fourier Transform Infrared Spectrometers. Two of them have feedback of different types: analog and digital. The third one was assembled specially to make sure that the system without feedback works properly [9].

Circuit diagrams of movable mirror control systems are shown on the figure 2. Movable mirror motion speed changes through the changes in the magnetic field in the linear actuator. Magnetic field, in its turn, is controlled with pulse-width modulation signal (PWM). When the movable mirror reaches one of the end probes (pic.2), the direction of motion is changed and the duty cycle starts to go down to zero, and then increases until it reaches the other probe. While the movable mirror is...
moving, we see readings of the interference pattern in the reference channel. In the system with feedback mirror stabilization after the turn happens in accordance with the reference channel data.

**Figure 1.** Circuit diagram of IR-channel and Michelson interferometer’s laser channel within the Fourier Transform Infrared Spectrometer: 1 — movable frame; 2 — linear actuator; 3 — non-movable mirror; 4 — movable mirror; 5 — beam splitter; 6 — reference channel photodiode; 7 — magnets; 8 — Hall effect sensors; 9 — leaf spring; 10 — laser; 11 — light beam.

**Figure 2.** Circuit diagrams movable mirror control systems; a) open loop, b) closed loop: 1 — basic controlling unit; 2 — PWM (pulse-width modulation) signal amplifier card; 3 — frame with the linear actuator; 4 — Hall effect sensors; 5 — magnet; 6 — frame motion steadiness measuring device; 7 — feedback.

3. **Fourier Transform Infrared Spectrometer’s reference channel data processing algorithm**
Michelson interferometer’s movable mirror motion speed steadiness is determined through assessment of instantaneous speed deviation from the average value. You can see the algorithm of instantaneous speed recovery basing on the reference channel data on figure 3.
To receive data from the photodiode we chose voltage of 200 mV and sample rate of 2.5 kHz. This way, interference pattern is a set of points \( Y_i \).

First, we multiply the set of points \( Y_i \) of the interference pattern from the reference channel by Gauss function and as a result we get two-dimensional square matrix \( B_{ij} \):

\[
B_{ij} = Y_i \exp\left(\frac{-(i-j)^2}{2\sigma^2}\right)
\]

where \( j \) — is the frequency index, changes \((0; w - 1)\), \( \sigma \) — Gaussian’s width [8].

Then we applied two-dimensional Fourier Transform to the values obtained \( B_{ij} \) [6, 7]:

\[
C_{jk} = B_{ij} \exp\left(\frac{I}{W} ik\right)
\]

where \( I \) — is a complex unit, \( B_{ij} \) — is the two-dimensional square matrix, \( W \) — is the interferogram length.

\( Y_i \) signal intensity changes with time. Movable mirror speed change was recovered from \( Y_i \) intensity change frequency and the reference channel wave length. To obtain intensity change at peak heights of Fourier Transform we taking into account the interferogram length in general [2]:

\[
v_j = \frac{2r}{W} \arg \max_{k, \frac{y}{2}} |C_{ik}|
\]

Thus we obviously recover the movable mirror instantaneous speed:

\[
V_j = v_j \lambda_0
\]
where $\lambda_o$ — is laser’s light beam wave length numerically equal to 0.6328μm and $r = 1/c$ — is the value used for dimensionality recovery (we need it because manipulations (1-3) are non-dimensional, but equivalently equal to the frequency [1]).

Next, let us find out the movable mirror motion steadiness. We will take into account the time interval before the turn and after the motion is stabilized, because these moments of the mirror motion are suitable for obtaining different things’ spectrums.

To do this let us find the root-mean-square deviation $\Delta V_{cp}$ of these sections [3]:

$$V_{cp} = \frac{1}{n} \sum_{i=1}^{n} \frac{V_i}{n};$$

$$\Delta V_{cp} = K \sqrt{\frac{\sum_{i=1}^{n} (V_i - V_{cp})^2}{n(n-1)}}.$$

### 4. Results and discussion

On figure 4a you can see the plot of the Fourier Transform IR spectrometer with analog control and feedback frame instantaneous speed change before the turn in recovery mode.

![Mirror speed graph](image)

**Figure 4.** Fourier Transform IR spectrometer with analog control and feedback mirror speed plot (a). Instantaneous speed change plot of the sector being processed (b)

On the figure 4b you can see instantaneous speed change plot of the sector being processed, before the frame turns, since the correct spectrum of the substance being studied can be obtained only in the sectors, where the frame’s motion speed is steady.

From the plot (figure 4b) and the formulas (2), (3) we have the average instantaneous speed $V_{cp} = 3.65 \cdot 10^{-3} m/s$ and the root-mean-square deviation $\Delta V_{cp} = 1.16 \cdot 10^{-5} m/s$.

Similarly to these we got the results for Fourier Transform IR Spectrometer with digital control and feedback (figure 5) and for spectrometer developed model without feedback (figure 6). We got the results for Fourier Transform IR Spectrometer with digital control and feedback: $V_{cp} = 3.27 \cdot 10^{-3} m/s$; $\Delta V_{cp} = 1.53 \cdot 10^{-5} m/s$. 
Figure 5. Fourier Transform IR spectrometer with digital control and feedback mirror speed plot. Instantaneous speed change plot (a). Instantaneous speed change plot of the sector being processed (b).

Next, we got the results for spectrometer developed model without feedback (figure 6):

$$V_{cp} = 3.32 \cdot 10^{-3} \text{ m/s} ; \Delta V_{cp} = 0.83 \cdot 10^{-4} \text{ m/s}.$$  

Figure 6. Mirror speed plot developed model of Fourier Transform IR spectrometer without feedback. Instantaneous speed change plot (a). Instantaneous speed change plot of the sector being processed (b).

The data obtained shows that the differences in frame motion steadiness between analog and digital circuits are insignificant. The root-mean-square deviations equal $\Delta V_{cp} = 1.16 \cdot 10^{-5} \text{ m/s}$ and $\Delta V_{cp} = 1.53 \cdot 10^{-5} \text{ m/s}$ respectively are within the margin of error sufficient for detecting spectrums of the substances being studied. In the open loop system the obtained deviation $\Delta V_{cp} = 1.185 \cdot 10^{-4} \text{ m/s}$ is too big for normal data processing. The average instantaneous speed value obtained earlier [1] agrees with the data obtained in this paper.

|                       | Fourier Transform Infrared Spectrometer with analog control | Fourier Transform Infrared Spectrometer with digital control | Fourier Transform Infrared Spectrometer open loop |
|-----------------------|-------------------------------------------------------------|------------------------------------------------------------|--------------------------------------------------|
| $V_{cp}$; $\text{m/s}$| $3.65 \cdot 10^{-3}$                                       | $3.27 \cdot 10^{-3}$                                       | $2.73 \cdot 10^{-3}$                             |
| $\Delta V_{cp}$; $\text{m/s}$ | $1.16 \cdot 10^{-5}$                                       | $1.53 \cdot 10^{-5}$                                       | $1.19 \cdot 10^{-4}$                             |

5. Conclusion
In this paper we wanted to show Michelson interferometer in Fourier’s spectrometer’s movable mirror motion steadiness assessment method applicability. According to the obtained data, the instantaneous speed deviate the average value of the instantaneous speed. On this basis, it is possible to find the numerical result of the movable mirror motion steadiness. It is shown that the results coincide with other studies, which proves the applicability of the method for solving problems on the alignment of FTIR spectrometers based on the Michelson interferometer. Thus, we can conclude that the system without feedback is not applicable for this type of device and the simplification of the system by this method is not possible.

References
[1] Morozov A N, Svetlichny S I 2014 Fundamentals of Fourier spectroradiometry Moscow: Nauka. – 456 p.
[2] Simonchik K K, Tropchenko A Y, Khitrov M V 2012 Digital signal processing Textbook for Digital Signal Processing SPb SPbSU ITMO108 p.
[3] Shvedov A S 2005 Theory of Probability and Mathematical Statistics Ed. House HSE 254 p.
[4] Arkhipov V V 2010 Scanning systems for fast-scanning Freier spectrometers Optical journal 9 p.
[5] Besekersky V A, Popov E P 1975 Theory of automatic control systems Moscow Science 711 p.
[6] Afonsky A, Dyakonov V P 2009 Digital analyzers of spectrum, signals and logic Ed. prof. V.P. Dyakonov Moscow: SOLON-Press p. 248.
[7] Dyakonov V.P. MATLAB 6.5 SP1 / 7.0 + Simulink 5/6. Signal processing and filter design. - M : SOLON-Press, 2005. - p. 576.
[8] Wentzel E S 2005 Theory of Probability 10th ed., Sr ., Moscow: Academia 576 p.
[9] Adam Osborne 1980 An Introduction to Microcomputers 2nd Ed Berkeley (California): Osborne-McGraw Hill P. 1-1.
[10] Egorov A S 2012 Infrared Fourier spectroscopy -Electronic teaching aid, Nizhny Novgorod State University. N.I. Lobachevsky.