Development of the automated vacuum test bench for altimeters

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Abstract. The work is devoted to study characteristics of the compact vacuum test bench, a feature of which is the presence of a programmable control system. During the work, the stages of assembly of the stand and technical requirements are described. Studies are being conducted to assess the build quality of the stand and the operation of the control system.

1. Introduction
Pressure tests are not widespread and are rarely carried out with the exception of certain areas of industry. In this regard, miniature test benches for small-sized products are almost never found on the market. However, there are a number of devices, for testing which the optimal solution is precisely small-sized, easy to manage and inexpensive stands. Such devices include electronic altimeters – devices for determining altitude. The parameters of the designed stand were determined mainly by the requirements for the testing altimeters.

2. Description of the tested production
“VOG Altimeter” altimeters are intended for use in skydiving. During the flight in a plane, the device automatically turns on and at the time of the jump with the help of the built-in speaker begins to inform the skydiver about the current height above ground level.

The principle of operation of such an altimeter is as follows. The sensor generates a digital signal based on the current absolute pressure value. During the free fall air pressure gradually rises, and these changes are captured by the microcontroller. Based on the current pressure value and the pressure value at ground level, the current altitude is calculated. When passing through certain height values the device via the speaker tells to skydiver these values. This approach simplifies the control of the height.

To determine the correctness of the altimeter operation, the most appropriate solution is to use a miniature vacuum test bench, which allows changing the pressure inside the chamber according to a given algorithm.

3. Development of the test bench
The following are the requirements that the constructor stand had to meet:
- Ability to create absolute pressure in the chamber of less than 36 kPa (corresponds to an altitude of about 8000 m);
- Ability to create excess pressure of at least 5 kPa;
- Adjustment of the rate of increase and decrease of pressure;
The presence of a transparent chamber with the ability to quickly access inside;

Ability to work in automatic mode using the specified program;

Indication of key parameters;

Accuracy of pressure maintenance: not less than ± 100 Pa.

Since it was rather difficult to find an inexpensive ready-to-use stand with the described parameters, it was decided to make it independently. Constructed stand is shown in figure 1.

Figure 1. The test bench without control system board.

To create underpressure and overpressure, a membrane compressor with a DC motor was purchased. This choice made it possible to control the speed of the compressor through pulse width modulation (PWM) [1]. With changing the operating mode "vacuum" – "overpressure", it is also necessary to change the connections of the tying tubes to change the direction of airflow. For this purpose, two three-way solenoid valves were purchased. Three more such valves are added for multi-level discrete throttling during compressor operation in order to extend the control range. Each of the three valves is connected on one side with a vacuum chamber, and on the other with a tip having a hole of a certain diameter. The choice of the chamber was the most difficult stage, since specific requirements and some uncertainty of the structure and its initial purpose were presented to it. However, in the end, the choice was made in favor of a food container with a tight-fitting lid. On the one hand, this solution satisfied all the requirements, and on the other, it remained quite economical. The glass container, among other things, allows increasing the mechanical rigidity and durability of the chamber, and the plastic cover, in addition to the presence of convenient latches, allows simplifying the process of inserting the fittings for connecting the piping.

The selected absolute pressure sensor converts pressure to an analog voltage signal. Since the sensor is designed to measure pressure up to 400 kPa, and the stand is designed to work with a maximum pressure of about 110 kPa, the measuring range of the sensor was narrowed with the help of an operational amplifier. This made it possible to use more discrete values when digitizing the signal
and improve the accuracy of the conversion. As a microcontroller applied ATmega128A chip [2] having enough channels to control, display and get information. This microcontroller has PWM channels for controlling the speed of the compressor and an analog-to-digital converter (ADC) [3] for converting the measured pressure and implementing stand control in the manual mode. To display the current values of the main parameters display on the HD44780 controller is selected [4]. A power supply unit with output voltages of +12 V, +24 V and +5 V was purchased to power the stand. This allowed refusing additional power conversion.

The volume of the vacuum chamber is 1200 cm³, which allows, if necessary, to place several devices in it at once. On the one hand, such a volume contributes to maintaining a relatively high rigidity of the structure, and on the other, the possibility of a slow change in pressure and the absence of the influence of its oscillations when the compressor is running. Additionally, for clarity, a calibrated vacuum gauge was added to the system, which can also be used to calibrate and adjust the system.

4. Research the quality of work

In order to implement the automatic testing mode, special software for the microcontroller was written. It allows testing altimeter without the need for human participation in the control of the stand during the tests and improves the accuracy and repeatability of the tests. Since the pneumatic part of the stand is not completely sealed, one of the studies was to assess the accuracy of maintaining the pressure in the chamber. Based on the measured pressure fluctuations, the corresponding heights were obtained, which are presented in figure 2.

![Figure 2. Height fluctuations in the mode of maintaining the set pressure.](image)

An analysis of the chart shows that the height fluctuations do not exceed 3.45 m, which indicates a fairly high stabilization accuracy, despite the use of the relay control law and a ten-bit ADC.

In addition to the study of the accuracy of pressure maintenance, the assessment of the uniformity of pressure change with time was carried out. The chart of the height change obtained by recalculating the measured pressure values at a fixed compressor rotation speed and a constant position of throttling valves is shown in figure 3. The figure also shows the chart obtained by discretely changing the rotational speed of the compressor and switching the throttling valves in accordance with the current pressure value.
Figure 3. Height change with different control modes.

When analyzing the figure, it is clear that with the constancy of the control action, the height value changes nonlinearly, which can affect the quality of the tests, especially at small values when the pressure change occurs too quickly. Despite the discreteness of the control, when implementing a more linear pressure change, the quality of the process is significantly better and much of the nonlinearity is eliminated. However, in the general case, the dependence of pressure on height is not linear [5]. In this regard, the program is planned to make changes and implement height control, calculated on the basis of pressure. It is also planned to improve the quality of management and simplify the program by replacing the discrete control law to another, that using the rate of height change as feedback, that is, to build a control system with a proportional-derivative (PD) controller [6].

Additionally, it should be noted, that the designed stand is more versatile, and when testing other products, a new program can be written into the microcontroller.

5. Conclusions

The following parameters were determined during the test bench study:

- Absolute pressure in the chamber: less than 16 kPa;
- Maximum overpressure in the chamber: 5 kPa (can be increased up to 150 kPa or more when changing the design of the chamber);
- Accuracy of pressure maintenance: ± 13.35 Pa;
- Maximum rate of change of pressure: more than 615 Pa/s in case of decrease, more than 3750 Pa/s in case of increase;
- Average rate of pressure increase due to leaks: 23 Pa/s.

Since the control circuit, in addition to the microcontroller, contains a large number of other components, then it is planned to make a separate printed circuit board (PCB) for them. Drawing scheme and layout of the board will be made in Altium Designer [7]. It is planned to manufacture PCB using a computer numerical control (CNC) machine. There will also be considered the issue of additional implementation of manual control, improving the impermeability of the pneumatic part of the system and replacing the analog sensor with a digital one in order to simplify the electrical circuit and improve measurement accuracy.
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