Modernization of the hardware and software complex of the national standards service in the area of pressure measurement technology for the calibration of vacuum gauges and development of a calibration simulator

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Abstract. The article provides information about the functions and the algorithm of modernization of the software and hardware complex for automating the calibration process of vacuum gauges, offers software as a simulator for learning the procedure for calibrating vacuum gauges and effective training of testers. It is shown that in the department for national standards in the field of pressure measurement of D. I. Mendeleyev Institute for Metrology VNIIM. The modernization makes it possible to reduce the work intensity of the test procedure, to reduce the influence of the "human factor", to increase the work productivity of the inspector and to reduce the training time for inspectors in the field of vacuum measurements.

1. Introduction
In order to increase labor productivity and improve the quality of the work carried out, it is necessary to modernize the calibration procedure for vacuum gauges by introducing a software and hardware complex to automate some steps of this procedure. The quality of the calibrations carried out can also be positively influenced by the software for training inspectors.

2. Hardware and software complex for calibrating measuring devices
When calibrating vacuum gauges, the tester is confronted with a number of routine steps that require special care and skill [1]. These phases include:

- Pumping the vacuum chamber with the vacuum gauges down to the final residual pressure;
- Discreet serial setting of pressure points within measurement range through gas dosing valve;
- Recording the information from the vacuum gauges;
- Transfering of the recorded measured values to the PC program for correction and calculation of the metrological properties of vacuum gauges.

These stages are very labour consuming because the number pressure points per decade is 3-5, and the total number of points can reach 20-30 for just one calibrated vacuum gauge. In this context, it was decided to automate the vacuum gauge calibration steps above.

The automation of the calibration process of the vacuum gauge requires the creation of a hardware and software complex (HSC) to control the reference vacuum gauge (switching the supply
line and turbo molecular pump on and off, controlling the electromagnetic variable valve for the gas supply, recording the measured values of the reference vacuum gauges) and that record the readings from the calibrated vacuum gauges. The HSC contains software for a personal computer (PC) that is used in the application "Calibration of vacuum gauges. 2310-1-2020", the main application window is shown in figure 1.

The main window of the software contains:
- Data exchange panel with calibrated vacuum gauge;
- Panel for data exchange with the control unit;
- Panel for recording the calibration results.

To protect the software, identification via the version number is provided. Control of software integrity and authenticity is provided. Error messages are issued.

![Vacuummeter calibration.2310-1-2020 v.1.0](image)

**Figure 1.** The main software window.

Tamper protection access to program settings with a password is provided. Protection level of the software "calibration of vacuum gauges. 2310-1-2020" "from unintentional and intentional changes" average according to R 50.2.077-2014.
Thus the HSC consists of:
- PC with preinstalled software based on the Windows 2000 operating system, HP, 7,8,10. The frequency of the central processor is not less than 500 MHz, the CPU is not less than 512 MB. (or a programmable logic controller (PLC));
- control unit (CU);
- an electromagnetically controlled gas supply valve installed on a vacuum gauge;
- solenoid valves to the pumping system (option).

In order to automate the process of calibration of vacuum gauges, a vacuum gauge can be used, the structure diagram of which is shown in figure 2 (conventional graphic representations are created according to [2]).

![Figure 2. Block diagram of a vacuum gauge installation.](image)
The structure diagram of the HSC is shown in figure 3.

![Figure 3. Block diagram of the HSC.](image)

The control unit consists of a microcontroller, PC communication ports, control vacuum gauges, calibrated vacuum gauges, a control circuit for an adjustable solenoid valve, control circuits for additional valves (optional), a WiFi module for transferring measurement data to the Internet storage cloud Module for recording environmental parameters (temperature, humidity, air pressure - optional).

Before calibrating the P1 vacuum gauge using the experimental comparison method with the P2 control vacuum gauge, the VA1 valve is opened and the valves VA2, VA3 are set to closed. The mechanical vacuum pump N is switched on. When the pressure in the measuring chamber CV1 drops to a pressure at which the turbo molecular pump NR can be switched on, the valves VA2, VA3 are opened and the turbo molecular pump NR switched on. According to paragraph 6.5.6 of [1], a controlled gas supply to the measuring chamber takes place through the VF1 valve, controlled by the HSC. In the pressure measuring range (P_min-P_max), pressure points are set discretely, sequentially in ascending order with an intensity of at least 5 points per decade. According to paragraph 6.5.7 of [1], the calibration is performed in static mode (allowed when calibrating vacuum gauges that do not affect the gas composition).

The PC software sets the order of the pressure points for installing the control unit. The CU, which controls the variable valve VF1 according to the measured values of the P2 control vacuum meter, sets the monitored pressure points one after the other and sends the measured values of the vacuum meters P1 and P2 to the PC software for logging.

During the calibration process, the software sets the required pressure points in sequence by sending a command via the control unit and reads the measured values from the control and the calibrated vacuum gauge without processing, notes the measured values in a table, the overall view of which is shown in table 1.

| Time     | P_{\text{control}}, \text{Pa} | P_{\text{calib}}, \text{Pa} |
|----------|-------------------------------|-----------------------------|
| 16:13:10 | 10.0                          | 11.0                        |
| 16:13:40 | 20.0                          | 22.0                        |
| 16:14:10 | 30.0                          | 34.0                        |
| 16:14:50 | 40.0                          | 42.0                        |
| 16:15:10 | 50.0                          | 52.0                        |

Since no mathematical operations are carried out with the measured values of the control and calibrated vacuum gauges (there are no metrologically significant functions and software parameters), the software does not introduce any additional errors when recording the measured values.
Devices can be used as control vacuum gauges:
- Baratron;
- MIDA.
- List of possible calibrated instruments:
  - Leybold CERAVAC CTR100 (Graphix controller);
  - Inficon;
  - and others.

The proposed modernization of the software and hardware complex for the calibration of vacuum gauges enables the labor intensity of the calibration process to be reduced, the influence of the "human factor" to be minimized, the labor productivity of the verification officer to be increased, and the time available for a qualitative analysis of the calibration data. It must be said that a verification officer’s productivity also depends on how quickly and efficiently he masters his profession. Effective software is gaining in importance as a simulator. In the second part of the article, we propose to consider a software option for teaching the procedure for calibrating vacuum gauges, developed in the Department of State Standards in the Field of Pressure Measurement in collaboration with the Department of Training of Highly Qualified Personnel and Educational Technologies of D.I. Mendeleev Institute for Metrology VNIIM.

3. The use of software in the training of verification officers
In the training of verification officers, practical skills in calibrating and testing vacuum gauges are required for the successful deepening of theoretical knowledge. Because of the complexity and high cost of the devices used to calibrate vacuum gauges, the approval of untrained professionals to use these devices and instruments is undesirable. In this regard, software has been developed that will enable future testers to acquire some of the skills required for calibration and testing with a vacuum gauge, as well as to test their theoretical knowledge. This virtual form of teaching is also important for distance learning if the student cannot be present during practical lessons.

The software is implemented as an application "Verification SVM-211 v.1.0" for a personal computer. The appearance of the main application window is shown in figure 4.
At the beginning of the work, the application invites the verification officer to familiarize himself with the description of the type of vacuum gauge SVM-211 [3] and the verification procedure [2].

Then the actions of the verification officer when checking the vacuum gauge are checked in the application, the verification officer offered:

- to establish the mechanical integrity of the measuring device;
- to determine the completeness of the measuring device (MD) received for inspection;
- to initiate pumping of the pressure in the measuring chamber of the virtual vacuum gauge up to the maximum residual pressure.

Upon determining that the measuring device is not mechanically damaged, the application happens to show either the device in transit or the whole (figure 5).

![Figure 5. Checking for mechanical damage to the MD.](image)

When examining the MD, the trainee may not have the MD further verified with mechanical damage, otherwise an error will be credited to him.

Upon determining that the MD is complete, the application will randomly display either a complete MD or an incomplete MD (figure 6).

![Figure 6. Checking the completeness of the measuring device.](image)

If the measuring device is incomplete, the trainee must stop the test process, otherwise an error will be credited to him.
After pumping out the measuring chamber of the vacuum gauge, the trainee is requested to alternately set the pressure points required for the calibration and to take the readings of the reference and calibrated vacuum gauge, to calculate the resulting error of the calibrated measuring device and to conclude whether he has passed the test.

4. Conclusions
In summary, we would like to emphasize once again that the algorithm for modernizing the software and hardware complex for automating the process of calibration of vacuum gauges carried out in the Department of State Standards in the Field of Pressure Measurement of D. I. Mendeleev Institute for Metrology VNIIM makes it possible to reduce the labor intensity of the verification process, to minimize the influence of the "human factor", to increase the labor productivity of the verification officer, to free up his time for a qualitative analysis of the calibration data. And the proposed software acts as a simulator for learning the procedure for checking vacuum gauges, which can greatly improve the quality of training of examiners at a lower cost.

References
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