Current state and prospects of development of the reference base in the field of measurements of low absolute pressures and vacuum

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Abstract. The article provides information on the composition and operation principles of the complex of state primary standards in the field of absolute pressures and vacuum of D. I. Mendeleyev Institute for Metrology (VNIIM). Measures for further improvement of the complex of primary standards of the Russian Federation in the field of absolute pressures and vacuum are proposed.

1. Introduction
At the moment, vacuum measurements and absolute pressure measurements in general are becoming more widespread and developed in the Russian Federation. This is due to the following factors:

• Concentration of the Russian Federation on the development of primarily high-tech industries, such as aerospace, nuclear power, electronics, micro- and nano-technology and others;
• More and more widespread introduction of vacuum equipment and technologies in all branches and spheres of human activity;
• The requirements of science and industry for the measurement range and accuracy of modern absolute pressure and vacuum measuring instruments are steadily increasing.

In this regard, D. I. Mendeleyev Institute for Metrology (VNIIM) conducted research aimed at assessing the current state of the system of metrological support in the field of absolute pressure and vacuum measurements.

2. Assessment of the current state of the complex of primary standards in the field of absolute pressure and vacuum measurements
To assess the current state of the reference base of the Russian Federation in the field of absolute pressure and vacuum measurements, the following studies were carried out:

1. Analysis of existing primary standards of the world's leading countries in the field of absolute pressure and vacuum measurements on the basis of publications and practical acquaintance with the set of primary standards in the field of vacuum measurements of the national metrology institutes of Germany (PTB) and Turkey (UME);
2. Analysis of the existing primary standards of the Russian Federation in the field of vacuum measurements and measurements of absolute pressures on the basis of the results of a number of research works to improve the state primary standards in the field of absolute pressures carried out in D. I. Mendeleyev Institute for Metrology (VNIIM) in the period from 2010 to 2018.
As a result of the review-analysis of the existing primary standards of the leading countries of the World the following results were obtained:

– principles of action and the composition of the existing set of primary standards of the leading countries of the World, as well as their hierarchy and relationship between themselves;

– advanced development of new primary standards in the field of pressure and vacuum measurements, due primarily to the redefinition of the basic SI units and based on optical methods of pressure reproduction [1–3].

Figure 1. Block diagram of the complex of primary standards of pressure of advanced countries.

Figure 2. Block diagram of the complex of primary pressure standards of the Russian Federation.

Based on the results obtained, a structural scheme of the complex of primary pressure standards of advanced countries was developed, which reflects the relationship and hierarchy of primary standards
in the field of pressure measurements of advanced countries, such as the United States, Germany and others. The developed scheme is shown in figure 1.

This block diagram made it possible to analyze the existing primary standards of the Russian Federation in the field of vacuum measurements and absolute pressure measurements. At the moment, the Russian Federation is armed with two primary standards in the field of absolute pressure and vacuum, which have overlapping measurement ranges in the region from 1 to 1000 Pa, as well as a secondary standard in the field of gas flow measurements in vacuum. These standards are the state primary special standard of the pressure unit for the absolute pressure region \(1 \cdot 10^{-6} \text{--} 1 \cdot 10^{3} \text{ Pa}\) GET 49-2016, the state primary standard of the pressure unit for the absolute pressure region in the range \(1 \cdot 10^{-1} \text{--} 7 \cdot 10^{3} \text{ Pa}\) GET 101-2011 and the state secondary (working) standard of the gas flow unit in vacuum in the range \(1 \cdot 10^{-12} \text{--} 1 \cdot 10 \text{ Pa} \cdot \text{m}^3/\text{s}\) GVET 49-2-2006. These standards are in D. I. Mendeleyev Institute for Metrology (VNIIM). As a result of the analysis of their composition, metrological characteristics, the results of research to improve them, the results of interlaboratory and international comparisons with their participation, a similar block diagram of the complex of primary pressure standards located in the D. I. Mendeleyev Institute for Metrology (VNIIM) is presented in figure 2.

Table 1. Disadvantages of primary standards of the Russian Federation in the field of measurements of low absolute pressures and vacuum.

| Designation of the standard and/or the name of its component | Disadvantages |
|-------------------------------------------------------------|---------------|
| GET 101-2011:                                               |               |
| – deadweight absolute pressure gauge Ruska;                 |               |
| – laser interference mercury manometer LIRM.                |               |
| GET 49-2016:                                               |               |
| – reference system based on a membrane-capacitive transducers of compensatory type MEPK; |               |
| – reference complex based on vacuum reduction plant VREU.   |               |
| GET 49-2016:                                               |               |
| – reference system based on a membrane-capacitive transducers of compensatory type MEPK; |               |
| – reference complex based on vacuum reduction plant VREU.   |               |
| GVET 49-2-2006                                             |               |
| Static expansion system                                      |               |
| Development of primary standards based on advanced principles |               |

In the composition of GVET also there is no mechanical flowmeter. There is no status of the primary standard, although there is a large fleet of measuring instruments of the approved type.
Comparison of the two developed schemes, the results of international comparisons in the field of absolute pressure and vacuum measurements, as well as the metrological characteristics of the best standards in this field of measurements, allowed to identify the main shortcomings of the complex of primary standards of the Russian Federation in the field of absolute pressures and vacuum and to assess the degree of criticality. Thus, the state primary standards, which do not meet the generally accepted world practice and/or have a technical and metrological gap from the best world standards, are highlighted in gray in the scheme. The critical disadvantages of the primary absolute pressure and vacuum standards compared to the primary standards of the advanced countries are shown in table 1.

3. Results and discussion
The analysis allows formulating a number of topics for research and development. Since the issue of development of the latest primary standards on new (optical) measurement principles has a low theoretical and experimental study, it is advisable to formulate a number of theoretical research works aimed at assessing the possible metrological characteristics, development costs, criticality and feasibility of development, intended to create the latest standards in the field of absolute pressure measurements. In the course of these works, the search for alternative versions of the latest standards created in other countries and the preliminary design of the latest absolute pressure standards selected for development in the framework of research and development work on the creation of new standards, or in the framework of similar work on improving existing standards will be carried out. Such works are:

• research and development work "Study of the possibility of creating a primary standard of absolute pressure and vacuum, the principle of measurement of which is based on the phenomenon of refraction of light", the estimated duration of 1–2 years;
• research and development work "Study of the possibility of creating a primary standard of absolute pressure and vacuum, based on cold atoms", the estimated duration of 1–2 years.

In addition, in order to reduce the backlog of primary standards of the Russian Federation in the field of absolute pressure and vacuum from the advanced countries, it is necessary to perform a number of research and development work, which were formulated in the course of work to improve the state primary standards of absolute pressure, which were held in D. I. Mendeleyev Institute for Metrology (VNIIM) in the period from 2010 to 2018. These works are:

• research and development work "Development of a primary standard for a unit of gas flow in a vacuum based on a mechanical flowmeter", the estimated duration of work is 3 years;
• research and development work "Development of a mechanical flowmeter for the vacuum reduction reference installation from the GET 49-2016 complex", the estimated work duration 3 years;
• research and development work "Development of a new membrane-capacitive converter of compensation type in order to improve the state primary standards in the field of absolute pressure measurements GET 49-2016", the estimated duration of work 3 years;
• research and development work "Development of a static expansion/compression system to improve the state primary standards in the field of absolute pressure measurements GET 49-2016 and GET 101-2011", the estimated duration of work is 3 years.

It should be noted that the first two works can be combined into one, as well as the last two. It is possible to increase the duration of work.

4. Conclusions
As a result of the research the following results were obtained:

• "ideal" structure of the complex of primary pressure standards has been developed;
• critical shortcomings of the complex of primary standards of the Russian Federation in the field of absolute pressures and vacuum are formulated;
• set of research works aimed at reducing the gap in the measurement of low absolute pressures from the developed countries is proposed.
References

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