Tests of modern vacuum gauges for type approval for the last 10 years

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Abstract. The article presents data on modern vacuum gauges designed to measure absolute pressure. The gauges have been tested for type approval after 2008. The principle of operation and the main metrological characteristics of the following types of vacuum meters are analyzed: membrane-capacitive, capacitive, wide-range, inverse-magnetron, deformation, electronic with integrated display, thermal, ionization and magnetic discharge. Information on these gauges is included in the Federal Information Fund for ensuring the uniformity of measurements and possibility to be applied for state regulation of measurements.

1. Introduction
According to the Federal Law No. 102-FZ "On ensuring the uniformity of measurements" (Chapter 3, Article 11) the approval of the type of Measuring Instruments (MI) is one of the forms of state regulation for ensuring the measurements uniformity.

The decision about approval the MI type is made by the Federal Authorization organization (Rosstandart) on the basis of the positive results of the MI tests for the purpose of the type approval (Chapter 3, Article 12, paragraph 2.). The information about approved MI is entered in the Federal Information Fund for Ensuring Measurement Uniform.

The approval of the type of MI is certified by a certificate of type approval issued by the Federal Executive Authority. The validity of the certificate is usually 5 years.

The data on modern vacuum gauges from 2008 are shown below. The gauges have been tested for approving the type. The information about these gauges is included in Federal Information Fund and can be applied for state regulation of measurements.

2. Thermal vacuum gauges
The principle of operation of such vacuum gauges is based on the dependence of the thermal conductivity of the discharged gas on pressure [1].

During the pumping the gas in working volume of the measuring sensor of the vacuum gauge is discharged, which leads to the change of thermal conductivity of the gas and, as a consequence, to the change in the temperature of the thin heated wire (the filament of the sensor). The wire is the shoulder of the measuring bridge circuit. The change in the resistance of this arm, caused by the change in its temperature, leads to unbalance of the bridge. An electrical voltage signal which is proportional to the pressure arises. The metrological characteristics of thermal vacuum gauges are given in table 1.

3. Ionization vacuum gauges
The principle of operation of vacuum gauges is based on the dependence of the current of positive
ions, formed as a result of ionization of rarefied gas molecules on the measured pressure. Metrological characteristics of ionization vacuum gauges are indicated in table 2.

Table 1. Metrological characteristics of thermal vacuum gauges.

| Type of gauges | Range of reading, \( \text{Pa} \) | Measurement range, \( \text{Pa} \) | Relative error, \% | Manufacturer | Registration number № |
|----------------|----------------------------------|-------------------------------|------------------|--------------|----------------------|
| VTT-18-2       | \( 1,33 \times 10^{-2} \ldots 66 \) | \( 1 \times 10^{-1} \ldots 66 \) | \( \pm 25 \)     | “S.A. Vekshinskii Institute of vacuum technique”, Russia | 37033-08 |
| VTS-18-2 (resistance) | \( 6,6 \times 10^{-2} \ldots 1 \times 10^{2} \) | \( 1,3 \ldots 3,9 \times 10^{3} \) | \( \pm (60..40) \) | “S.A. Vekshinskii Institute of vacuum technique”, Russia | 41803-09 |
| VD             | \( 5 \times 10^{-2} \ldots 10^{4} \) | \( \pm (100..15) \) | 43629-10 |
| VSP            | \( 10^{-2} \ldots 10^{5} \) | \( 10^{2} \ldots 10^{6} \) | \( \pm (100..15) \) | “Thyracont Vacuum Instruments GmbH”, Germany | 44060-10 |
| APG (resistance) | \( 10^{-2} \ldots 10^{5} \) | \( 10^{2} \ldots 10^{4} \) | \( \pm 20 \) | “Edwards Limited”, UK | 44391-10 |
| CVG101, CVM201, CVM211 | \( 10^{-2} \ldots 1,3 \times 10^{5} \) | \( 10^{2} \ldots 10^{3} \) | \( \pm (35..15) \) | “InstruTech, Inc.”, USA | 51328-12 |
| CVC 3000, VSP 3000, DCP 3000, VSP 3000 Televac 2A, 4A | - | \( 10^{-1} \ldots 10^{5} \) | \( \pm (30..15) \) | “VACUUBRAND+ CO KG”, Germany | 51918-12 |
| TPR, TPG 201, PPT 200, ERSTEVAK | \( 1,3 \times 10^{-1} \ldots 1,3 \times 10^{5} \) | \( 5 \times 10^{-1} \ldots 10^{3} \) | \( \pm 30 \) | “The Fredericks Company”, USA | 56243-14 |
|                  | \( 10^{-2} \ldots 10^{3} \) | \( 10^{2} \ldots 10^{3} \) | \( \pm (50..30) \) | “Pfeiffer Vacuum GmbH”, Germany | 63031-16 |
|                  | - | \( 5 \times 10^{-8} \ldots 10^{3} \) | \( \pm (40..10) \) | “Thyracont Vacuum Instruments GmbH”, Germany | 64910-16 |
|                  | \( 5 \times 10^{3} \ldots 1,5 \times 10^{3} \) | \( 5 \times 10^{2} \ldots 1,5 \times 10^{3} \) | \( \pm (50..10) \) | “Leybold GmbH”, Germany | 68784-17 |

4. Magnetic electro-discharge vacuum gauges
The principle of operation of magnetic vacuum gauges is based on the dependence of the measured pressure on the ion current of the gas discharge arising in the discharge vacuum gap between cathode and anode of the pressure sensor as a result of the interaction of intersecting electric and magnetic fields. The voltage of several kilovolts is supplied to the sensor anode from the controller, while the cathode is at zero potential. The electrons appear between the electrodes under the action of electric and magnetic fields, whose voltage vectors are mutually perpendicular, begin to move. The ionization of gas molecules occurs during this motion as a result of collisions of electrons with gas molecules. Positively charged ions are directed to the cathode. The ionization current is proportional to the measured pressure. The metrological characteristics of magnetic electro-discharge vacuum gauges are given in table 3.

5. Diaphragm-capacitive vacuum gauges
The principle of operation of this vacuum gauge is based on the use of the relationship between the measured pressure and the elastic deformation of the sensor element. Flat practically gas-tight membrane is applied as the sensitive element. One side of the membrane is the evacuated volume
pumped to residual pressure which does not exceed $10^{-7}$ Pa. The pressure is maintained for a long time by a chemical getter (getter). The measured pressure is applied to the other side of the membrane causing deformation of the membrane, which leads to the change in the electrical capacitance between the membrane and the electrodes located in the vacuum volume. The capacity is included in one of the shoulders of the bridge circuit. This creates an imbalance of the bridge. The electrical signal appears proportional to the measured pressure. The metrological characteristics of membrane-capacitive vacuum gauges are given in table 4.

### Table 2. Metrological characteristics of ionization vacuum gauges

| Type of gauges | Range of reading, Pa | Measurement range, Pa | Relative error, % | Manufacturer | Registration number № |
|---------------|----------------------|-----------------------|-------------------|--------------|-----------------------|
| VI-18         | 1,3·$10^{-9}$ ... 8·$10^{-1}$ | ±35                    | "S.A. Vekshinskii Institute of vacuum technique", Russia | 37034-08 |
| AIGX –        | 6,6·$10^{-8}$ ... 6,6 | ± 15                  | «Edwards Limited», UK | 44388-10 |
| IGM400, IGM401 | 1,3·$10^{-7}$ ... 6,7 | ± 25                  | «InstruTech, Inc.», USA | 51327-12 |
| CCM           | 1,3·$10^{-7}$ ... 1,3 | ± 30                  | «InstruTech, Inc.», USA | 66042-16 |
| IONIVAC       | 5·$10^{-8}$ ... 1·$10^{6}$ | ± (25...15)           | «Leybold Germany» | 67723-17 |

### Table 3. Metrological characteristics of magnetic electro-discharge vacuum gauges.

| Type of gauges | Range of reading, Pa | Measurement range, Pa | Relative error, % | Manufacturer | Registration number № |
|---------------|----------------------|-----------------------|-------------------|--------------|-----------------------|
| Televac       | от 1,3 10–9 до 1,3 10–1 | ±60                  | «The Fredericks Company», USA | 56242-14 |
| 7B2,7E,7F, 7FC,7FCS | от 1,3 10–7 до 1,3 10–1 | ±60                  | «The Fredericks Company», USA | 56242-14 |

### Table 4. Metrological characteristics of membrane-capacitive vacuum gauges.

| Type of gauges | Range of reading, Pa | Measurement range, Pa | Relative error, % | Manufacturer | Registration number № |
|---------------|----------------------|-----------------------|-------------------|--------------|-----------------------|
| CMR, CCR      | 10$^{-7}$ ... 1,33·$10^7$ | ± (30...2)           | «Pfeiffer Vacuum GmbH», Germany | 63021-16 |

### 6. Capacitive vacuum gauges

The principle of operation of capacitance vacuum gauges is based on the relationship between the measured pressure and the change in the electrical capacitance caused by the elastic deformation of the sensitive element. The alumina ceramic diaphragm is used as sensitive element of capacitive vacuum gauges. The metrological characteristics of capacitive vacuum gauges are given in table 5.

### Table 5. Metrological characteristics of capacitive vacuum gauges.

| Type of gauges | Range of reading, Pa | Measurement range, Pa | Relative error, % | Manufacturer | Registration number № |
|---------------|----------------------|-----------------------|-------------------|--------------|-----------------------|
| DVR 2, DVR3, CVC 3000, DCP 3000, VSK 3000, CVC 3000, VSK 3000 | 0,1-1080 | ±1                  | «VACUUBRAND +CO KG», Germany | 51917-12 |
7. Wide-range vacuum gauges
Wide-range vacuum gauge is a combined device in which two sensors are combined in one canopy: Pirani thermal sensor and a magnetic electric discharge sensor (cold cathode) or Pirani thermal sensor and an ionization transducer (hot cathode). The metrological characteristics of the wide-range vacuum gauges are given in table 6.

| Type of gauges | Range of reading, Pa | Measurement range, Pa | Relative error, % | Manufacturer | Registration number № |
|----------------|----------------------|-----------------------|------------------|--------------|------------------------|
| Meradat-VIT    | 1,33·10^{-3}…1·10^{-5} | 1,33·10^{-3}…1·10^{-6} | ± (50…30)       | JSC «Meradat», Russia | 41616-09               |
| IGM402         | 1,3·10^{-7}…1·10^{-5} | 1,3·10^{-7}…10^{-3}  | ± (25...15)      | «InstruTech, Inc.», USA | 51329-12               |
| PKR, PBR, IMR, HPT MPT | 5·10^{-8}…10^{6} | 10^{-7}…10^{3} | ± (100...30)     | «Pfeiffer Vacuum GmbH», Germany | 62158-15               |

8. Deformation vacuum gauges
The principle of operation of these vacuum gauges is based on the use of the relationship between the measured pressure and elastic deformation of the piezoresistive sensing element. The metrological characteristics of deformation vacuum gauges are given in table 7.

| Type of gauges | Range of reading, Pa | Measurement range, Pa | Relative error, % | Manufacturer | Registration number № |
|----------------|----------------------|-----------------------|------------------|--------------|------------------------|
| VDTO-3         | 1,33·10^{-3}…1·10^{-5} | 1,33·10^{-3}…1·10^{-6} | ± 10 (relative)  | "Alex S&E” SRL, Moldova | 40410-09               |
| APR, CPT 200   | 10…5,5·10^{6}       | 10…5·10^{6}          | ± 2 (given)      | «Pfeiffer Vacuum GmbH», Germany | 63314-16               |

9. Electronic vacuum gauges with integrated display
Electronic vacuum gauges with integrated display are made in one housing, where are located two measuring sensors: the crystal quartz sensor and the double inverse magnetron sensor with cold cathode. Metrological characteristics of electronic gauges with an integrated display are given in table 8.

| Type of gauges | Range of reading, Pa | Measurement range, Pa | Relative error, % | Manufacturer | Registration number № |
|----------------|----------------------|-----------------------|------------------|--------------|------------------------|
| ERSTEVAK       | 5·10^{-8}…1·10^{-5} | ± (40...10)           | "Thyracont Vacuum Instruments GmbH", Germany | 64910-16     |
| CC-10          | 1,33·10^{-7}…10^{-3} | ± (70...35)           | «The Fredericks Company», USA | 65023-16     |
| MP2AR          | 1,33·10^{-4}…2,67·10^{-3} | ± (100...20) | «The Fredericks Company», USA | 65198-16     |
| MP4AR,MX4A     | 1,33·10^{-4}…10^{-3} | ± (100...15)         | «The Fredericks Company», USA | 66274-16     |
| MP7ER          | 1,33·10^{-4}…10^{-3} | ± (50...35)          | "Televac A Division of The Fredericks Company", USA | 66674-16     |
| MP7FR          | 1,33·10^{-4}…10^{-3} | ± (70...35)          | "Televac A Division of The Fredericks Company", USA | 66674-16     |

10. Inverse-magnetron vacuum gauges
The inverse-magnetron vacuum gauges are made in a single canopy, in which there are two sensors: the inverse magnetron and the Pirani sensor. The inverse-magnetron sensor is a discharge tube, inside
of which the cathode plate on the grounded potential and the anode with high positive charge are placed parallel to each other. Two permanent magnets are outside of the discharge tube. The metrological characteristics of the inverse magnetron vacuum gauge are given in table 9.

| Type of gauges | Range of reading, Pa | Measurement range, Pa | Relative error, % | Manufacturer | Registration number № |
|----------------|----------------------|-----------------------|-------------------|--------------|----------------------|
| MPG400         | $5 \times 10^{-9}$ ... $1 \times 10^{7}$ | ± 30                  | «Inficon», Lichtenstein | 63642-16     |

11. Viscous vacuum gauges

The principle of operation of vacuum gauges is based on the dependence of the viscosity (internal friction) of the rarefied gas on the measured pressure. The metrological characteristics of viscous vacuum gauges are given in table 10.

| Type of gauges | Range of reading, Pa | Measurement range, Pa | Relative error, % | Manufacturer | Registration number № |
|----------------|----------------------|-----------------------|-------------------|--------------|----------------------|
| SRG            | $5 \times 10^{-5}$ ... $1 \times 10^{7}$ | ± (10...1,3)          | "MKS Instruments", Germany | 40361-09     |

12. Conclusion

The mentioned vacuum gauges can be used for state regulation of measurements along with gauges that were manufactured before 2008 and had valid certificates of the type approval for that period. It should also be noted that in general since 2008 imported vacuum gauges have been tested unfortunately.

Now D. I. Mendeleev Institute of Metrology develops domestic modern vacuum gauges with a sensor based on MEMS technology.

References

[1] Rozanov L N 1990 Vacuum Technique (Moscow: Higher School) 320