Legions of Marshal Jozef Pilsudski monument, Radom, Poland

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METROLOGY SYMPOSIUM
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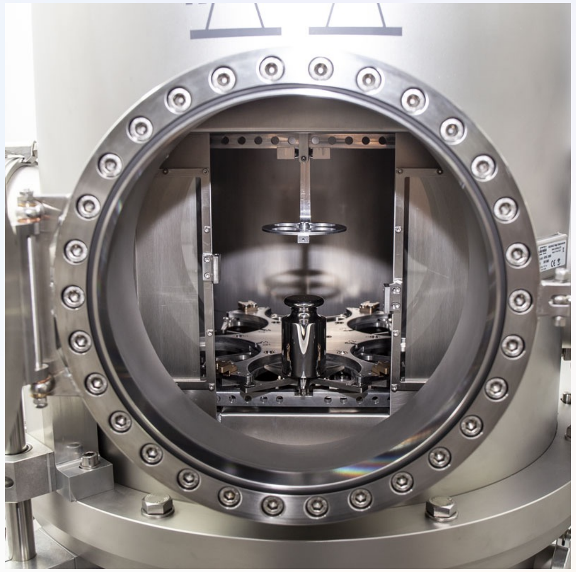
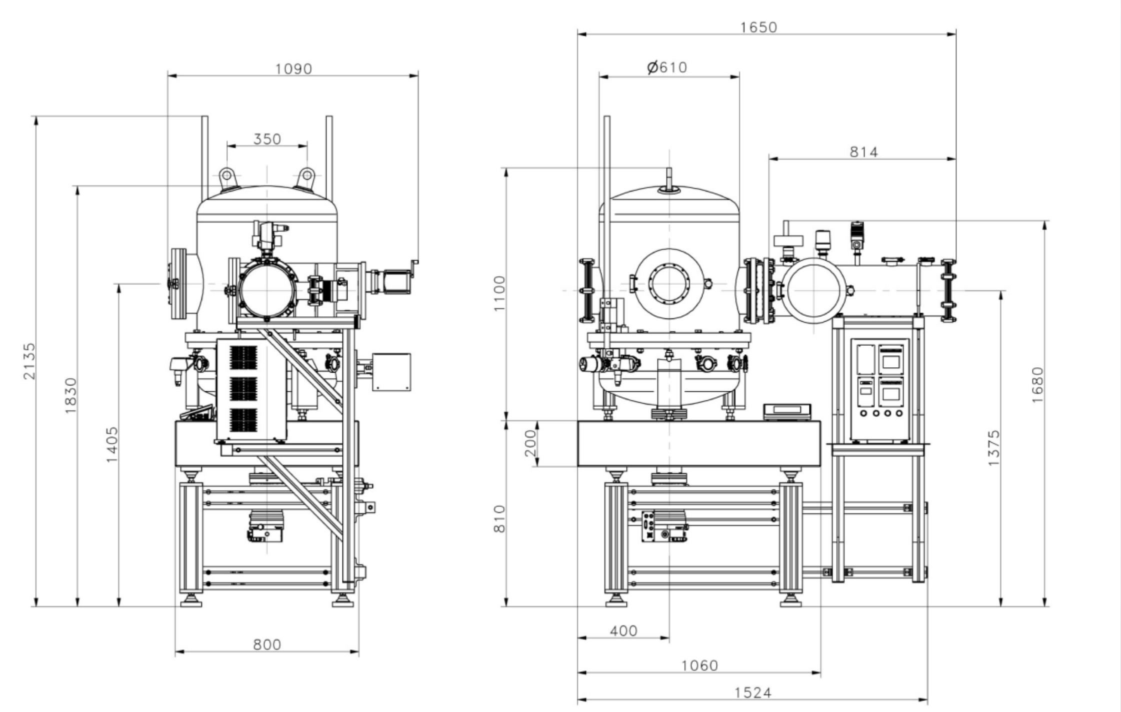
Application of RADWAG AVK 1000.5Y vacuum mass comparator for determining mass standards density

Motivation

An increasing number of metrology laboratories and institutes have recently decided to purchase **a vacuum mass comparator** to best ensure measurement traceability after the SI redefinition. This provides motivation to use this advanced equipment also for other purposes. One of them is the determination of density and volume of mass standards – usually realized by dedicated, costly hydrostatic comparators.





RADWAG AVK 1000.5Y vacuum mass comparator

Application of RADWAG AVK 1000.5Y vacuum mass comparator for determining mass standards density

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Simultaneous determination of mass and volume of a standard by weighings in air

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Abstract
Volume is an input quantity in the measurement model for the mass of a body, say, a mass standard. The classical method to determine volume, hydrostatic weighing, is time-consuming, expensive and can introduce instability in the standard mass. Some years ago an alternative method was proposed, based on weighings in air at different densities. We generalize the method, showing that also the mass of the standard can be determined with it using a weighted-least-squares adjustment. To this purpose, we discuss a measurement model taking into account the covariances between the input estimates. The method, experimentally validated, yields uncertainties for the mass estimates that are smaller than those obtained with the traditional method, and gives the further advantage of directly providing the covariance between mass and volume.

The method requires multiple repetitions or a lot of artefacts, advanced maths with overdetermined system of equations.

Linear corelation between air density ρ_a (about 20% range) and comparator indications Δm_w:

$$\Delta m_w = -\Delta V \rho_a + \Delta m,$$

(parameters)

Table 1. Uncertainty budget for ρ_a calculated using the CIPM formula.

X_i	$u(X_i)$	$u_i(\rho_a)/(\text{kg m}^{-3})$
t	0.008 K	$2.8 \times 10^{-5}\ \rho_a/\text{kg m}^{-3}$
p	$1.5\ \text{Pa} + (p/\text{Pa} - 75\,000) \times 2.1 \times 10^{-5}\ \text{Pa}$	$2.1 \times 10^{-5}\rho_a/\text{kg m}^{-3}$
t_d	0.10 K	3.3×10^{-5}
χ_{CO_2}	$10\ \mu\text{mol mol}^{-1}$	$4.2 \times 10^{-6}\rho_a/\text{kg m}^{-3}$
Others		2.2×10^{-5}
ρ_a		$3.3 \times 10^{-5} + 2.1 \times 10^{-5}\rho_a/\text{kg m}^{-3}$

Table 2. Uncertainty budget for ρ_a calculated using the buoyancy artefacts.

X_i	Value	$u(X_i)$	$u_i(\rho_a)/(\text{kg m}^{-3})$
ΔV_{BA_0}	283.891 cm^3	0.0042 cm^3	$1.48 \times 10^{-5}\rho_a/\text{kg m}^{-3}$
Δm_{BA}	340.944 mg	0.0020 mg	7.0×10^{-6}
Δm_{BAw}	0 mg to 80 mg	0.0020 mg	7.0×10^{-6}
$\rho_a/\text{kg m}^{-3}$	0.9 to 1.2		1.67×10^{-5} to 2.04×10^{-5}

In the paper there is no final data concerning the determining of mass standard density (only ΔV and Δm as measurands).

Table 4. Results.

	New method			Traditional method	
Comparison	$\Delta V_0/\text{cm}^3$	$\Delta m/\text{mg}$	χ^2	$\Delta V_{0_h}/\text{cm}^3$	$\Delta m/\text{mg}$
1 kg SS (HK1000)	0.6149(13)	1.7069(12)	7	0.6136(11)	1.7052(13)
100 g SS (HK1000)	0.1975(12)	0.0725(12)	4	0.1970(4)	0.0719(7)
Pt–Ir vs Nim (M_one)	−78.6762(12)	−1.7393(8)	9	−78.6760(9)	−1.7391(19)
1 kg Pt–Ir (M_one)	0.0224(4)	−1.0656(5)	16	0.0228(4)	−1.0651(5)

Idea

The basic idea is to utilize the difference in buoyancy force when comparing mass standards in a vacuum as well as in the air of constant pressure. In the proposed method only one value of air pressure (air density) is chosen. Since the density of air under normal pressure is three orders of magnitude smaller than the densities of liquids and solids the expected difference is relatively small, however sufficient to be effectively measured by an exceptionally sensitive and repeatable vacuum mass comparator.

Goal

The main goal of our work is to make density measurements with **RADWAG AVK 1000.5Y vacuum mass comparator**, compare the results with those from other methods and predict theoretically the measurement uncertainties for the proposed method.

Procedure

- The crucial point is to determine as precise as possible the density of air. The approximate formula (E.3-1) for air density specified OIML R 111-1 2004 (as well as formula recommended by CIPM) could be not good enough for this purpose without very precise measurement of pressure, temperature, humidity and air composition variations.

  M. Gläser *et al* 1991 *Metrologia* **28** 45

- Thus, we decided to utilize the direct method of buoyancy by weighing (in vacuum and air) two mass standards of considerably different and metrologically validated densities. The preferred pairs of mass standards are steel cylinder – aluminum cylinder or steel cylinder – silicon sphere.

- After the determining of the air density, the main step is a measurement of the buoyancy force difference between tested mass standard and the reference mass standard. The comparison of the calculated density results with those obtained with liquid-based density comparator has been performed.

AIR DENSITY MEASUREMENT

$t = 23.7\ °C$ $k = 2$

Steel:

$\rho_{1\_20°C} = 8010.6\ kg/m^3$ $\rho_1 = \rho_{1\_20°C} \cdot [1 - \alpha_{steel} \cdot (t - t_{20°C})] = 8009.7\ kg/m^3$ $u_{\rho_1} = 1.5\ kg/m^3$

$m_1 = 0.499\,999\,956\ kg$ $u_{m_1} = 1 \cdot 10^{-9}\ kg$ $\alpha_{steel} = 0.00005\ 1/°C$

Al:

$\rho_{2\_20°C} = 2817.8\ kg/m^3$ $\rho_2 = \rho_{2\_20°C} \cdot [1 - \alpha_{Al} \cdot (t - t_{20°C})] = 2817.3\ kg/m^3$ $u_{\rho_2} = 2.6\ kg/m^3$

$m_2 = 0.500\,136\,341\ kg$ $u_{m_2} = 2 \cdot 10^{-9}\ kg$ $\alpha_{Al} = 0.00007\ 1/°C$

VACUUM (or from certificate):

$$\mathbf{dm_{21} = m_2 - m_1 = 1.36385 \cdot 10^{-4}\ kg}$$

$$V_1 = \frac{m_1}{\rho_1} = 6.2429 \cdot 10^{-5}\ m^3$$

$$V_2 = \frac{m_2}{\rho_2} = 1.7754 \cdot 10^{-4}\ m^3$$

$$u_{V_1} = V_1\sqrt{\left(\frac{u_{m_1}}{m_1}\right)^2 + \left(\frac{u_{\rho_1}}{\rho_1}\right)^2} = 1.2 \cdot 10^{-8}\ m^3$$

$$u_{V_2} = V_2\sqrt{\left(\frac{u_{m_2}}{m_2}\right)^2 + \left(\frac{u_{\rho_2}}{\rho_2}\right)^2} = 1.6 \cdot 10^{-7}\ m^3$$

AIR:

$$\mathbf{I_{21_{air}} = 485.2 \cdot 10^{-9}\ kg} \qquad \mathbf{u_{I_{21_{air}}} = 9.8 \cdot 10^{-9}\ kg}$$

Due to the air buoyancy effect, one gets from the Archimedes law:

$$\mathbf{I_{21_{air}} = m_2 - m_1 - \rho_{air} \cdot (V_2 - V_1)}$$

Thus:

$$\boldsymbol{\rho_{air} = \frac{(m_2 - m_1) - I_{21_{air}}}{V_2 - V_1} = \frac{(m_2 - m_1) - I_{21_{air}}}{\frac{m_2}{\rho_2} - \frac{m_1}{\rho_1}} = 1.1806127\ \frac{kg}{m^3}}$$

AIR DENSITY UNCERTAINTY (1)

Sensitivity coefficients:

$$\frac{\partial\rho_{\mathrm{air}}}{\partial I_{21_{\mathrm{air}}}}=\frac{1}{\frac{m_1}{\rho_1}-\frac{m_2}{\rho_2}}=-8686.1\,\frac{1}{\mathrm{m}^3}$$

$$\frac{\partial\rho_{\mathrm{air}}}{\partial m_1}=\frac{1}{\frac{m_1}{\rho_1}-\frac{m_2}{\rho_2}}-\frac{I_{21_{\mathrm{air}}}+m_1-m_2}{\rho_1\cdot\left(-\frac{m_1}{\rho_1}-\frac{m_2}{\rho_2}\right)^2}=-8686.1\,\frac{1}{\mathrm{m}^3}$$

$$\frac{\partial\rho_{\mathrm{air}}}{\partial m_2}=-\frac{1}{\frac{m_1}{\rho_1}-\frac{m_2}{\rho_2}}+\frac{I_{21_{\mathrm{air}}}+m_1-m_2}{\rho_2\cdot\left(\frac{m_1}{\rho_1}-\frac{m_2}{\rho_2}\right)^2}=8683.7\,\frac{1}{\mathrm{m}^3}$$

$$\frac{\partial\rho_{\mathrm{air}}}{\partial\rho_1}=m_1\cdot\frac{I_{21_{\mathrm{air}}}+m_1-m_2}{\rho_1^2\cdot\left(\frac{m_1}{\rho_1}-\frac{m_2}{\rho_2}\right)^2}=-7.9946\cdot10^{-5}$$

$$\frac{\partial\rho_{\mathrm{air}}}{\partial\rho_2}=-m_2\cdot\frac{I_{21_{\mathrm{air}}}+m_1-m_2}{\rho_2^2\cdot\left(\frac{m_1}{\rho_1}-\frac{m_2}{\rho_2}\right)^2}=6.4638\cdot10^{-4}$$

AIR DENSITY UNCERTAINTY (2)

Budget of uncertainties:

$$u_{\rho_{air}}\left(u_{I_{21_{air}}}\right) = \left|\frac{\partial \rho_{air}}{\partial I_{21_{air}}}\right| \cdot u_{I_{21_{air}}} = 8.5136 \cdot 10^{-5}\ \frac{\mathrm{kg}}{\mathrm{m}^3}$$

$$u_{\rho_{air}}(u_{m_1}) = \left|\frac{\partial \rho_{air}}{\partial m_1}\right| \cdot u_{m_1} = 8.6861 \cdot 10^{-6}\ \frac{\mathrm{kg}}{\mathrm{m}^3}$$

$$u_{\rho_{air}}(u_{m_2}) = \left|\frac{\partial \rho_{air}}{\partial m_2}\right| \cdot u_{m_2} = 8.6837 \cdot 10^{-6}\ \frac{\mathrm{kg}}{\mathrm{m}^3}$$

$$u_{\rho_{air}}(u_{\rho_1}) = \left|\frac{\partial \rho_{air}}{\partial \rho_1}\right| \cdot u_{\rho_1} = 1.1992 \cdot 10^{-4}\ \frac{\mathrm{kg}}{\mathrm{m}^3}$$

$$u_{\rho_{air}}(u_{\rho_2}) = \left|\frac{\partial \rho_{air}}{\partial \rho_2}\right| \cdot u_{\rho_2} = 1.6806 \cdot 10^{-3}\ \frac{\mathrm{kg}}{\mathrm{m}^3}$$

compounded uncertainty

$$\boldsymbol{u_{\rho_{air}} = \sqrt{\left[u_{\rho_{air}}\left(u_{I_{21_{air}}}\right)\right]^2 + \left[u_{\rho_{air}}(u_{m_1})\right]^2 + \left[u_{\rho_{air}}(u_{m_2})\right]^2 + \left[u_{\rho_{air}}(u_{\rho_1})\right]^2 + \left[u_{\rho_{air}}(u_{\rho_2})\right]^2} = 1.7 \cdot 10^{-3}\ \frac{\mathrm{kg}}{\mathrm{m}^3}}$$

$$\boldsymbol{\rho_{air} = (1.1806 \pm 0.0017)\ \frac{\mathrm{kg}}{\mathrm{m}^3}}$$

$$\boldsymbol{\frac{u_{\rho_{air}}}{\rho_{air}} \cdot 100\% = 0.14\ \%}$$

DETERMINATION OF TESTED WEIGHT VOLUME BY COMPARISON WITH STANDARD 1

$I_{\mathrm{t1_{vac}}} = -6.0 \cdot 10^{-9}\ \mathrm{kg}$ $\quad u_{I_{\mathrm{t1_{vac}}}} = 1.0 \cdot 10^{-9}\ \mathrm{kg}$

$I_{\mathrm{t1_{air}}} = 4.2 \cdot 10^{-9}\ \mathrm{kg}$ $\quad u_{I_{\mathrm{t1_{air}}}} = 1.8 \cdot 10^{-9}\ \mathrm{kg}$

$k = 2$

$t = 23.7\ ^\circ\mathrm{C}$

In vacuum: $I_{\mathrm{t1_{vac}}} = m_{\mathrm{t}} - m_1$

Due to the air buoyancy effect from the Archimedes law:

$$I_{\mathrm{t1_{air}}} = m_{\mathrm{t}} - m_1 - \rho_{\mathrm{air}} \cdot (V_{\mathrm{t}} - V_1) \quad \text{where} \quad V_1 = \frac{m_1}{\rho_1}$$

Thus, tested weight volume is given by:

$$V_{\mathrm{t}} = \frac{m_1}{\rho_1} - \frac{I_{\mathrm{t1_{air}}} - I_{\mathrm{t1_{vac}}}}{\rho_{\mathrm{air}}} = 6.2420201 \cdot 10^{-5}\ \mathrm{m}^3$$

TESTED WEIGHT VOLUME UNCERTAINTY (1)

Sensitivity coefficients:

$$\frac{\partial V_{\mathrm{t}}}{\partial I_{\mathrm{t1_{air}}}} = -\frac{1}{\rho_{\mathrm{air}}} = -0.8470178219\,\frac{\mathrm{m}^3}{\mathrm{kg}}$$

$$\frac{\partial V_{\mathrm{t}}}{\partial I_{\mathrm{t1_{vac}}}} = \frac{1}{\rho_{\mathrm{air}}} = 0.8470178219\,\frac{\mathrm{m}^3}{\mathrm{kg}}$$

$$\frac{\partial V_{\mathrm{t}}}{\partial m_1} = \frac{1}{\rho_1} = 1.24857692835 \cdot 10^{-4}\,\frac{\mathrm{m}^3}{\mathrm{kg}}$$

$$\frac{\partial V_{\mathrm{t}}}{\partial \rho_{\mathrm{air}}} = \frac{I_{\mathrm{t1_{air}}} - I_{\mathrm{t1_{vac}}}}{\rho_{\mathrm{air}}^2} = 7.317879744 \cdot 10^{-9}\,\frac{\mathrm{m}^6}{\mathrm{kg}}$$

$$\frac{\partial V_{\mathrm{t}}}{\partial \rho_1} = -\frac{m_1}{\rho_1^2} = -7.7947210442 \cdot 10^{-9}\,\frac{\mathrm{m}^6}{\mathrm{kg}}$$

TESTED WEIGHT VOLUME UNCERTAINTY (2)

$$t = 23.7\ °\mathrm{C}$$

Budget of uncertainties:

$$u_{V_\mathrm{t}}(I_{\mathrm{t1}_\mathrm{air}}) = \left|\frac{\partial V_\mathrm{t}}{\partial I_{\mathrm{t1}_\mathrm{air}}}\right| \cdot u_{I_{\mathrm{t1}_\mathrm{air}}} = 1.52463207 \cdot 10^{-9}\ \mathrm{m}^3$$

$$u_{V_\mathrm{t}}(I_{\mathrm{t1}_\mathrm{vac}}) = \left|\frac{\partial V_\mathrm{t}}{\partial I_{\mathrm{t1}_\mathrm{vac}}}\right| \cdot u_{I_{\mathrm{t1}_\mathrm{vac}}} = 8.4701782 \cdot 10^{-10}\ \mathrm{m}^3$$

$$u_{V_\mathrm{t}}(m_1) = \left|\frac{\partial V_\mathrm{t}}{\partial m_1}\right| \cdot u_{m_1} = 1.248576928 \cdot 10^{-13}\ \mathrm{m}^3$$

$$k = 2$$

$$u_{V_\mathrm{t}}(\rho_\mathrm{air}) = \left|\frac{\partial V_\mathrm{t}}{\partial \rho_\mathrm{air}}\right| \cdot u_{\rho_\mathrm{air}} = 1.234579018 \cdot 10^{-11}\ \mathrm{m}^3$$

$$\boldsymbol{V_\mathrm{t} = (6.2420 \pm 0.0012) \cdot 10^{-5}\ \mathrm{m}^3}$$

$$u_{V_\mathrm{t}}(\rho_1) = \left|\frac{\partial V_\mathrm{t}}{\partial \rho_1}\right| \cdot u_{\rho_1} = 1.1692081566 \cdot 10^{-8}\ \mathrm{m}^3$$

$$\boldsymbol{\frac{u_{V_\mathrm{t}}}{V_\mathrm{t}} \cdot 100\% = 0.019\ \%}$$

$$\boldsymbol{u_{V_\mathrm{t}} = \sqrt{\left[u_{V_\mathrm{t}}(I_{\mathrm{t1}_\mathrm{air}})\right]^2 + \left[u_{V_\mathrm{t}}(I_{\mathrm{t1}_\mathrm{vac}})\right]^2 + \left[u_{V_\mathrm{t}}(m_1)\right]^2 + \left[u_{V_\mathrm{t}}(\rho_\mathrm{air})\right]^2 + \left[u_{V_\mathrm{t}}(\rho_1)\right]^2} = 1.2 \cdot 10^{-8}\ \mathrm{m}^3}$$

FINAL DETERMINATION OF TESTED WEIGHT DENSITY AND ESTIMATION OF ITS UNCERTAINTY

$$\boldsymbol{\rho_\mathrm{t} = \frac{m_\mathrm{t}}{V_\mathrm{t}} = 8010.226\ \frac{kg}{m^3}}$$

where $\boldsymbol{m_\mathrm{t} = m_1 + I_{\mathrm{t1vac}} = 0.499\,999\,950\ kg}$

$$\boldsymbol{\rho_\mathrm{t} = \frac{m_1 + I_{\mathrm{t1vac}}}{V_\mathrm{t}}}$$

$$\frac{\partial \rho_\mathrm{t}}{\partial I_{\mathrm{t1vac}}} = \frac{1}{V_\mathrm{t}} = 16020.454\ \frac{1}{\mathrm{m}^3} \qquad \frac{\partial \rho_\mathrm{t}}{\partial m_1} = \frac{1}{V_\mathrm{t}} = 16020.45457\ \frac{1}{\mathrm{m}^3} \qquad \frac{\partial \rho_\mathrm{t}}{\partial V_\mathrm{t}} = -\frac{I_{\mathrm{t1vac}} + m_1}{V_\mathrm{t}^2} = -128327469.5\ \frac{\mathrm{kg}}{\mathrm{m}^6}$$

$$u_{\rho_\mathrm{t}}(I_{\mathrm{t1vac}}) = \left|\frac{\partial \rho_\mathrm{t}}{\partial I_{\mathrm{t1vac}}}\right| \cdot u_{I_{\mathrm{t1vac}}} = 1.6020 \cdot 10^{-5}\ \frac{\mathrm{kg}}{\mathrm{m}^3} \qquad u_{\rho_\mathrm{t}}(m_1) = \left|\frac{\partial \rho_\mathrm{t}}{\partial m_1}\right| \cdot u_{m_1} = 1.6020 \cdot 10^{-5}\ \frac{\mathrm{kg}}{\mathrm{m}^3}$$

$$\boldsymbol{u_{\rho_\mathrm{t}}(V_\mathrm{t}) = \left|\frac{\partial \rho_\mathrm{t}}{\partial V_\mathrm{t}}\right| \cdot u_{V_\mathrm{t}} = 1.5170\ \frac{kg}{m^3}}$$

$$\boldsymbol{\frac{u_{\rho_\mathrm{t}}}{\rho_\mathrm{t}} \cdot 100\% = 0.019\ \%}$$

$t = 23.7\ ^\circ\mathrm{C}$

$k = 2$

$$\boldsymbol{u_{\rho_\mathrm{t}} = \sqrt{[u_{\rho_\mathrm{t}}(I_{\mathrm{t1vac}})]^2 + [u_{\rho_\mathrm{t}}(m_1)]^2 + [u_{\rho_\mathrm{t}}(V_\mathrm{t})]^2} = 1.5\ \frac{kg}{m^3}}$$

$$\boldsymbol{\rho_\mathrm{t} = (8010.2 \pm 1.5)\ \frac{kg}{m^3}}$$

Application of RADWAG AVK 1000.5Y vacuum mass comparator for determining mass standards density

COMPARISON OF THE FINAL RESULT (density of tested weight standard):

$k = 2$

Vacuum mass comparator method, RADWAG:

$t = 23.7\ °\mathrm{C}$ $\quad t_{20°\mathrm{C}} = 20.0\ °\mathrm{C}$ $\quad \alpha_{\mathrm{steel}} = 0.00005\ 1/°\mathrm{C}$

$\rho_{\mathrm{t}} = (8010.2 \pm 1.5)\ \frac{\mathrm{kg}}{\mathrm{m}^3}$ $\quad \rho_{\mathrm{t\_20°C}} = \rho_{\mathrm{t}} \cdot [1 + \alpha_{\mathrm{steel}} \cdot (t - t_{20°\mathrm{C}})] = 8011.7\ \mathrm{kg/m^3}$

$$\boldsymbol{\rho_{\mathrm{t\_20°C}} = (8011.7 \pm 1.5)\ \frac{\mathrm{kg}}{\mathrm{m}^3}} \qquad \frac{u_{\rho_{\mathrm{t\_20°C}}}}{\rho_{\mathrm{t\_20°C}}} \cdot 100\% = 0.019\ \%$$

Hydrostatic density comparator method, RADWAG:

$$\boldsymbol{\rho_{\mathrm{t\_20°C}} = (8011.5 \pm 2.8)\ \frac{\mathrm{kg}}{\mathrm{m}^3}}$$

almost the same values, and

$$u^{\mathrm{vac}}_{\rho_{\mathrm{t}_{20°C}}} \approx \frac{1}{2} u^{\mathrm{hydr}}_{\rho_{\mathrm{t}_{20°C}}}$$

Value from certificate (Federal Office of Metrology and Surveying, BEV, Austria):

$$\boldsymbol{\rho_{\mathrm{t\_20°C}} = (8010.6 \pm 1.5)\ \frac{\mathrm{kg}}{\mathrm{m}^3}}$$

$$\Delta\rho_{\mathrm{t\_20°C}} = 1.1\ \frac{\mathrm{kg}}{\mathrm{m}^3}$$

$$\Delta\rho_{\mathrm{t\_20°C}} < u_{\rho_{\mathrm{t\_20°C}}}$$

DISCUSSION OF THE RESULTS AND UNCERTAINTIES FOR THE TESTED STANDARD OF MORE DIFFERENT DENSITY

$t = 23.7\ °\mathrm{C}$

$k = 2$

$I_{\mathrm{t1_{vac}}} = -6.0 \cdot 10^{-9}\ \mathrm{kg}$ $\quad u_{I_{\mathrm{t1_{vac}}}} = 1.0 \cdot 10^{-9}\ \mathrm{kg}$

Previous case:

$\boldsymbol{I_{\mathrm{t1_{air}}} = 4.2 \cdot 10^{-9}\ \mathrm{kg}}$

$u_{I_{\mathrm{t1_{air}}}} = 1.8 \cdot 10^{-9}\ \mathrm{kg}$

$$\boldsymbol{\rho_{\mathrm{t\_20°C}} = (8011.7 \pm 1.5)\ \frac{\mathrm{kg}}{\mathrm{m}^3}}$$

(typical range for stainless steel)

New case:

$\boldsymbol{I_{\mathrm{t1_{air}}} = -250.0 \cdot 10^{-9}\ \mathrm{kg}}$

$u_{I_{\mathrm{t1_{air}}}} = 1.8 \cdot 10^{-9}\ \mathrm{kg}$

$$\boldsymbol{\rho_{\mathrm{t\_20°C}} = (7982.7 \pm 1.5)\ \frac{\mathrm{kg}}{\mathrm{m}^3}}$$

GENERAL CONCLUSIONS

- A vacuum mass comparator (with a constant pressure option) is a valid device for mass standards density determining.
- Air density has been found with two certified mass standards of significantly different densities.
- Despite small buoyancy in air the density of the tested mass standard has been determined with less uncertainty than that with hydrostatic comparator due to better readability of the vacuum mass comparator.
- The proposed method stands out for its obvious advantage, which is the absence of contact between the test standard and the liquid (contrary to the case of liquid-based standard hydrostatic density comparators).
- The utilizing one device for two purposes is oriented towards economization and better management in metrological institutions.

RADWAG AVK 1000.5Y vacuum mass comparator

radwag.com

AVK 1000.5Y Automatic Vacuum Mass Comparator equipped with pumps, AVK 1000.5Y.LLS Automatic Vacuum Mass Comparator equipped with pumps and Load-Lock System, AVK 1000.5Y.CP Automatic Constant Pressure Mass Comparator

More information on the website

radwag.com/en/info,w1,D80

AVK 1000.5Y
Automatic Vacuum Mass Comparator equipped with pumps

AVK 1000.5Y.LLS
Automatic Vacuum Mass Comparator equipped with pumps
And Load-Lock System

AVK 1000.5Y.CP
Automatic Constant Pressure Mass Comparator

Application of RADWAG AVK 1000.5Y vacuum mass comparator for determining mass standards density

RADWAG AGV 1000.5Y density & volume comparator

RADWAG® radwag.com

AGV-8 1000.5Y Automatic Comparator for Determination of Mass standard's Density and Volume, AGV-2 20.5Y Automatic Comparator

More information on the website
radwag.com/en/info,w1,T4L

AGV-8 1000.5Y
Automatic Comparator for Determination of Mass Standard’s Density and Volume

AGV-2 20.5Y
Automatic Comparator

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