Calibration Services

Mass, pressure, force, torque, flow, humidity and temperature

VTT MIKES

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VTT MIKES

Mass, pressure, force, torque, flow, humidity and temperature

Calibration of weights

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Masses less than 50 kg

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Masses of 50 kg or more

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Traceability

The weight standards of VTT MIKES mass laboratory are traceable via the Pt-Ir prototype number 23 of kilogram to the international prototype of kilogram kept at the BIPM. The comparability of measurement standards of mass laboratory is maintained by international comparisons (e.g. EURAMET key comparisons). We carry out research and development related to scales and weights and offer expert services on the usage of scales and weights. Our mass laboratories are of high quality and we have scales equipped with automatic weight handlers. Our laboratories are located in Espoo and Kajaani.

Measurement methods

The measurement range of mass at VTT MIKES is 1 mg ... 2000 kg. The calibrations of weights are performed by using generally accepted weighing methods: the direct comparison method and the subdivision method. In the first method, the weight is directly compared to a standard and in the latter, a set of weights is calibrated by using one or several weight standards.

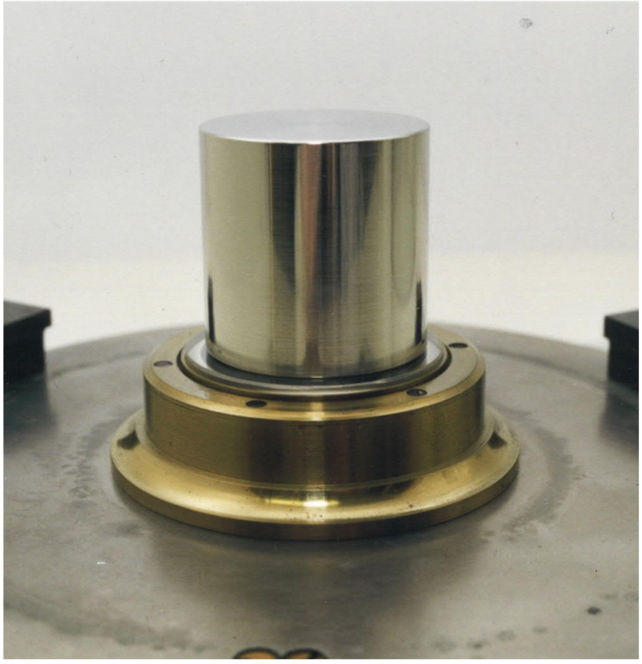

Figure 1. At left Finland's national prototype of the kilogram (no. 23), at right different weights at our Kajaani site.

Calibration services

VTT MIKES is capable to calibrate weights of OIML classes E1, E2, and F1, whose nominal masses are at most 20 kg (E1), 50 kg (E2) and 2000 kg (F1). In addition, VTT MIKES offers calibration services for weights of lower OIML classes, whose masses are between 10 kg and 2000 kg. VTT MIKES also calibrates other weights such as weights of pressure balances. In the calibration certificate, the masses are given as conventional masses or as true masses. The smallest achievable measurement uncertainties in mass calibrations are presented in table 1. Weights whose nominal mass is 50 kg or bigger are calibrated at VTT MIKES Kajaani.

Calibration of volume of weights

When calibrating a weight, a correction due to the air buoyancy has to be made to the weighing result. The magnitude of the correction depends on the volume of the weight and on the density of air. In order to be able to make the correction accurately enough, the volumes of the most accurate weights have to be known. Mass laboratory calibrates volumes and densities of solid artefacts. The density standard is either distilled water or silicon. The measurement methods is hydrostatic weighing. The measuring equipment is suitable for volume calibration of 2-kg weights or lighter. If needed, volumes of bigger weights can be determined by using e.g. dimensional measurements. The measurement uncertainties of volume calibrations of weights are presented in table 2.

Table 1. Measurement uncertainties of weight calibrations.

Mass	Measurement uncertainty (k=2)
2000 kg *)	3000 mg
1000 kg *)	1500 mg
500 kg *)	750 mg
200 kg *)	300 mg
100 kg *)	200 mg
50 kg *)	30 mg
20 kg	3.0 mg
10 kg	1.5 mg
5 kg	1.0 mg
2 kg	0.3 mg
1 kg	0.05 mg
500 g	0.03 mg
200 g	0.02 mg
100 g	0.015 mg
50 g	0.010 mg
20 g	0.008 mg
10 g	0.007 mg
5 g	0.005 mg
2 g	0.004 mg
1 g	0.003 mg
500 mg	0.003 mg
200 mg	0.002 mg
100 mg	0.0015 mg
50 mg	0.0015 mg
20 mg	0.0010 mg
10 mg	0.0008 mg
5 mg	0.0008 mg
2 mg	0.0008 mg
1 mg	0.0008 mg

*) Calibration in VTT MIKES Kajaani.

Table 2. Measurement uncertainties of calibrations of weight volumes.

Mass	Volume	Uncertainty (k=2)
1 g – 2 kg	0.1 – 255 cm^3	0.000 3 – 0.008 cm^3

Calibration of pressure measuring devices

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Figure 1. Pressure balance.

VTT MIKES has good capabilities to calibrate different measuring devices of pressure. The measuring range for gauge pressure is 0 ... 500 MPa and for absolute pressure 0.0005 Pa ... 1.75 MPa. The best measurement standards at VTT MIKES are pressure balances, which are used to realise pressure according to its definition p = F / A, i.e. pressure is force divided by area. The force is produced by the mass of the piston of the pressure balance and by the masses of weights loaded over the piston. The local value for the acceleration of free fall must be known. The area A is the effective area of the piston cylinder assembly of the pressure balance.

Pressure balances are used for gauge and negative gauge pressure measurements and for absolute pressure measurements. To cover a wide range of pressures, several piston cylinder assemblies of different sizes are needed in order to be able to realise different pressures and to keep the number of weights still easy to handle.

In pressure ranges below the range of pressure balances, capacitive sensors and spinning rotor gauges are used as measurement standards. The lowest pressures (absolute pressures 0.0005 Pa ... 2 Pa) are calibrated by using spinning rotor gauges. These measurements are demanding, as they require long stabilisation and measurement times.

Measurement methods and devices used for pressure depend on the pressure range.

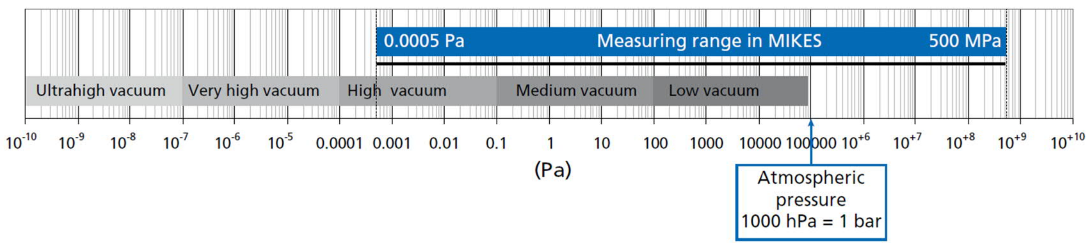

Figure 2. Pressure measurements are made in a very broad pressure range, for instance from 10^{-9} Pascals required in particle accelerators to over 10^{9} Pascals, i.e. 1 GPa, pressures used in powder metallurgy. Measuring devices and their operational principles are very different in different pressure ranges. The measurement range in VTT MIKES is from 0.5 mPa to 500 MPa and is marked with blue bar in the figure.

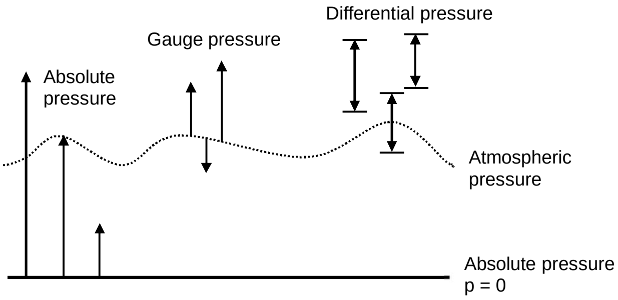

Figure 3. In practice, measurement of pressure is always measuring differential pressure. Depending on the reference point various names are used for pressure and diverse devices used.

Absolute pressure

The ideal vacuum as reference point (vacuum gauges).

Atmospheric pressure

Atmospheric pressure is the absolute pressure caused by the atmosphere so the reference is the ideal vacuum (barometers).

Gauge pressure

The reference point is the atmospheric pressure. E.g., the tyre pressure of a car is gauge pressure. Any gauge pressure can be converted to an absolute pressure by adding the momentary atmospheric pressure.

Negative gauge pressure

The reference point is the atmospheric pressure. When converted to absolute pressures, negative gauge pressure is thereby lower than the atmospheric pressure. Thus, negative gauge pressure means that the objects pressure is lower than the pressure in its environment.

Differential pressure

Pressure is called as differential pressure especially when the reference pressure is other than the vacuum or the atmospheric pressure. The reference pressure is then usually called as a line pressure.

Absolute pressure gaseous medium Pressure range (Pa)	Relative measurement uncertainty k = 2 (%)	Gauge pressure gaseous medium Pressure range (Pa)	Relative measurement uncertainty k = 2 (%)
0.0005	9	100	0.03
0.001	6	1000	0.01
0.01	3	10 000	0.004
0.1	3	100 000 (0,1 MPa)	0.003
1	2	1 000 000 (1 MPa)	0.002
10	0.5	10 000 000 (10 MPa)	0.004
100	0.1	16 000 000 (16 MPa)	0.004
1000	0.01		
10 000	0.005		
100 000 (0.1 MPa)	0.004		
1 000 000 (1 MPa)	0.004		
1 750 000 (1.75 MPa)	0.003		

Figure 4. Piston cylinder assemblies of different size for pressure balances.

Negative gauge pressure gaseous medium Pressure range (Pa)	Relative measurement uncertainty k = 2 (%)	Gauge pressure, in oil medium Pressure range (Pa)	Relative measurement uncertainty k = 2 (%)
–100	0.03	500 000 (0.5 MPa)	0.005
–1000	0.01	1 000 000 (1 MPa)	0.004
–10 000	0.005	10 000 000 (10 MPa)	0.003
–100 000 (–0.1 MPa)	0.004	100 000 000 (100 MPa)	0.003
		500 000 000 (500 MPa)	0.01

Calibration of force and torque

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Traceability and calibration of force

VTT MIKES Kajaani performs force calibrations from 10 N to 1 MN. The smallest measurement uncertainty is 2×10^{-5}.

Calibrated measurement devices are usually force transducers, force measurement devices, balances (e.g. hook, wheel weight and airplane) and pull force testers.

The calibration of force is based on the ISO 376 standard. The force calibrations from 10 N to 100 kN are carried out in a deadweight force standard machines. Deadweight force standard machine is a mechanical structure that generates force by subjecting deadweights to the local gravitational field. Hydraulic amplification force standard machine can be used in the calibrations from 20kN to 1MN.

Force calibration results are traceable to the International System of Units (SI) and the calibrations meets the requirements of the ISO/IEC 17025 standard for the traceability and measurement uncertainty.

Figure 1. The 1-MN hydraulic amplification force standard machine and the 100-kN deadweight force standard machine. The total equipment height is eight meters, including the deadweights below floor level.

Table 1. Measurement ranges and uncertainties for force.

Method	Measurement range	Measurement uncertainty (*k*=2)
Deadweight	Compression / tension: 10 N ... 10 kN	$2 \cdot 10^{-5}$
Deadweight	Compression / tension: 10 kN ... 100 kN	$5 \cdot 10^{-5}$
Hydraulic amplification	Compression / tension: 20 kN ... 1 MN	$1 \cdot 10^{-4}$

Calibration of torque and traceability

VTT MIKES Kajaani performs calibrations of torque in the range 4 Nm ... 20 kNm, the smallest uncertainty being 5×10^{-4}.

Calibrated torque measurement devices are usually torque transducers, torque calibration or testing devices and hand torque tools. Torque transducers are used for example in the research of rotating machines such as pumps and motors. Torque calibration or testing devices can be used for the calibration of hand torque tools or testing torque from different type of products, for example the opening torque of a bottle cap. Hand torque tools are used mainly for assembling of screws and nuts.

The calibration of torque is based on the Euramet cg-14 calibration guide or ISO 6789 standard. Torque transducers and torque calibration devices for hand torque tools are calibrated according to the Euramet cg-14 calibration guide. The calibration of hand torque tools is based on ISO 6789 standard.

The calibration of torque is carried out in a deadweight torque standard machine or a reference torque standard machine. The measurement range for deadweight torque standard machines is from 4 Nm to 2 kNm. Reference torque standard machine can be used for calibrations up to 20 kNm.

Torque calibration results are traceable to the International System of Units (SI) and the calibrations meets the requirements of the ISO/IEC 17025 standard for the traceability and measurement uncertainty.

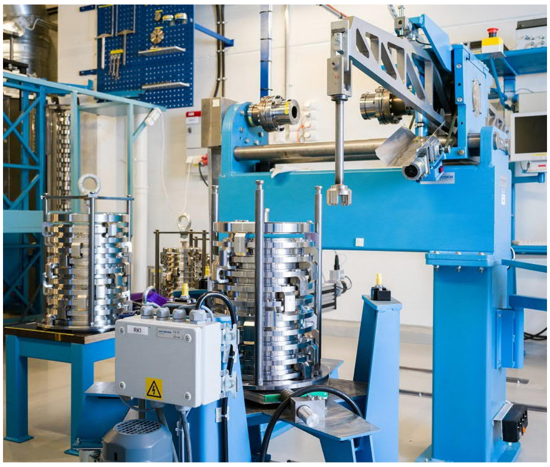

Figure 2. The 2-kNm deadweigth torque standard machine.

Figure 3. A 20-kNm torque standard based on a reference sensor.

Table 2. Measurement ranges and uncertainties for torque.

Method	Measurement range	Measurement uncertainty (*k*=2)
Deadweight	4 ... 200 Nm clockwise/anticlockwise	$8 \cdot 10^{-4}$
Deadweight	20 ... 2000 Nm clockwise/anticlockwise	$5 \cdot 10^{-4}$
Reference tarnsducer	0.2 ... 20 kNm clockwise/anticlockwise	$5 \cdot 10^{-4}$

Water flow meter calibrations

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Calibration provides reliability

Accurate liquid flow measurements are needed in many areas of industry, such as process, mining and energy industry. To maintain global competitiveness and high quality of the end products, accurate liquid flow measurements make it possible to optimise different industrial processes and in this way reduce raw material consumption and emissions to environment. Regular calibration and stability tracking of liquid flow meters are essential part of measurement reliability, regardless of the application.

Figure 1. Graphical user interface of the D200 liquid flow calibration rig.

Traceability

The most important activities of VTT MIKES Kajaani are to implement the traceability of the flow measurements in Finland, maintain liquid flow measurement standards, and provide calibration and expert services. These are achieved by participating in international and domestic research and intercomparison projects. The VTT MIKES's liquid flow calibration laboratory's quality management system is based on the ISO/IEC 17025 standard.

Calibration services

VTT MIKES Kajaani has three different calibration rigs for liquid flow calibrations. One of the rigs is the national measurement standard of flow. In this rig, the measuring principle is gravimetric and the measurements carried out are traceable to the national standards of mass, temperature and time.

The gravimetric reference standard of water flow is based on weighing the water. In the measurements, water is first continuously pumped up to a constant head tank located 20 m above ground level. The water level is held constant in the tank by sufficient overflow and by adjusting the water flow in a measuring pipe section, where the flow meters under test are placed. The calibration is done by comparing the results of the balance and the meter under test reading.

In the closed loop type calibration rigs, the reference meters are usually magnetic or Coriolis mass flow meters. In these rigs, the source of traceability up to DN200 is based on the national flow standard. For pipe sizes DN200 >, the source of traceability is a foreign NMI, typically PTB from Germany.

The measuring principles, ranges, and reachable measurement uncertainties are shown in Table 1.

Table 1. Measuring ranges of the liquid flow calibration rigs and the measurement uncertainty.

Equipment	Measuring principle	Pipe sizes	Volume flow	Pressure	Measurement uncertainty (*k*=2)
D100	reference meter	DN 15 – DN 50	0.3 l/s … 20 l/s	<0.7 MPa	0.3 %
D500	reference meter	DN 150 – DN 500	7 l/s … 750 l/s	<0.5 MPa	0.3 %
D200	gravimetric	DN 10 – DN 200	0.1 l/s … 200 l/s	0.4 MPa	0.05 %

For pulp and paper industry, VTT MIKES Kajaani has a mass circulating rig applied with a cooling system. Consistency area 0–7 % and flow speed 0.5–3 m/s.

Figure 2. Part of the D500 liquid flow calibration rig.

Calibration of gas flows and density of liquids

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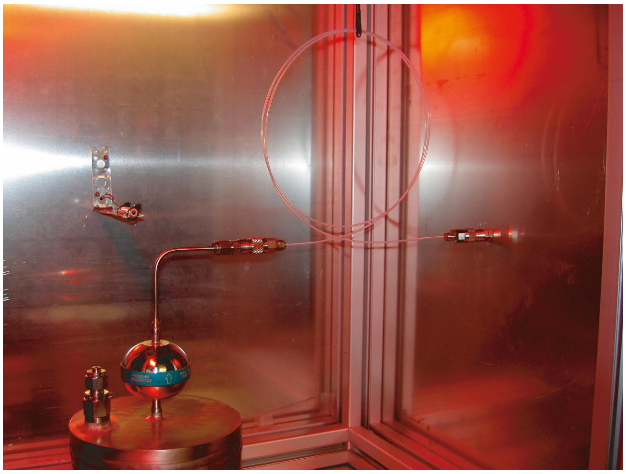
Calibration gives reliability

Measurement of small gas flows is needed in various applications. For instance, in health care and medical industry is very important to assure the safety of customers. In order to maintain international competiveness and to guarantee the high quality of products, the accuracy of gas flow measurements in process industry has to be reliably verified. No matter what the application is, the regular calibration and stability monitoring of gas flowmeters is an essential part of quality control. VTT MIKES calibrates gas flowmeters in the flow range 5 ml/min ... 110 l/min and offers research and expert services in the field of gas flow measurements and their reliability.



Traceability

VTT MIKES provides circumstances for traceable gas flow measurements in Finland by developing and maintaining standards for gas flows and offers calibration and expert services.

The traceability of gas flows at VTT MIKES is based on a dynamic weighing system, DWS developed at the flow laboratory of VTT MIKES. The measurements performed using this system are traceable to the national standards of mass and time. The DWS equipment is used to calibrate measurement standards based on laminar flow elements (LFE) and customers' devices whose relative accuracy level is better than 1 %.

The high level of our gas flow measurement activities is maintained by actively participating in international research projects and comparisons and by carrying out own research projects in this field.

Calibration services

If the relative accuracy level of a gas flowmeter is better than 1 %, the DWS equipment will be used in the calibration. Typical examples of such flowmeters are high-quality laminar flow elements and some piston-cylinder volume flowmeters.

Most of our customers' flowmeters are calibrated at VTT MIKES using the LFE calibration equipment. It is much more convenient to use than the DWS equipment and it does not have such a strict tolerances for environmental conditions. Performing of calibrations are thus more flexible and faster. The equipment has proven to be well suited for calibration of gas flowmeters having relative accuracy above 1 %. Such meters include thermal mass flowmeters and controllers.

Table 1. Measurement ranges and best achievable calibration uncertainties at VTT MIKES.

Quantity	Measurement range	Measurement uncertainty (*k*=2)
Mass flow (DWS)	0.1 mg/s ... 625 mg/s	0.3 % ... 0.8 %
Mass flow (LFE)	0.1 mg/s ... 625 mg/s	0.4 % ... 0.9 %
Volume flow (LFE)	5 ml/min ... 30 l/min	0.4 % ... 0.9 %

DWS = Dynamic weighing system,
LFE = Laminar flow element

Calibration of hygrometers

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Reliability from calibrations

Reliability of humidity measurements is important, e.g. in storage of wood, paper, food, etc. in aviation and environmental monitoring as well as in diverse fields of industry and research. Calibration of hygrometers at regular intervals and monitoring their stability is an essential part of verification of measurements.

VTT MIKES provides high-quality calibration services for instruments measuring humidity of gases and expert services on research and development related to humidity measurements and their reliability.

Traceability to humidity measurements

VTT MIKES creates conditions for traceable humidity measurements in Finland by developing and maintaining measurement standards for humidity and by offering calibration and expert services.

The high quality of the humidity laboratory is maintained by taking part in international research and comparison projects and by carrying out own research projects.

Traceability

Traceability of humidity measurements is based on a dew-point temperature scale. The scale is realised by using a humidity generator, which is the national measurement standard in Finland.

The core of a dew-point generator is a saturator in which total saturation of air with respect to water or ice is reached. The dew point temperature of the air coming out of the generator is calculated from the saturator temperature and from the pressure difference between the saturator and the device under calibration. When saturated air is led into the measurement chamber of the generator, the equipment is also suitable for calibration of relative humidity sensors.

Figure 1. Calibration of chilled mirror hygrometers.

The dew-point meter under calibration is directly connected to the dew-point generator. In calibration of a relative humidity sensor, the sensor is placed in the measurement chamber system. The reading of the sensor is compared to the value of relative humidity that is calculated from the dew-point temperature and the air temperature inside the chamber.

Calibration services

Most dew-point meters are calibrated using a dew-point generator. The measurement standards of humidity laboratory at VTT MIKES cover the dew-point temperature range –80 °C to +84 °C. Dew-point calibrations are also carried out as comparison calibrations in calibrators, for instance for capacitive dew-point meters.

Most relative humidity sensors are calibrated in a climatic chamber. The dew-point temperature and the air temperature in the chamber are measured by using a chilled mirror hygrometer and a digital thermometer, respectively. The relative humidity is calculated from measured temperature and dew-point temperature. If the achievable uncertainty is not sufficient or the temperature range extends to below +10 °C, the calibration is performed using a humidity generator. Relative humidity sensors are calibrated in the range 10 %rh to 95 %rh at temperatures between –20 °C and +85 °C.

In cases of other humidity quantities, calibrations are performed with the same equipment the relative humidity calibration systems. The values of these quantities are calculated from measured dew point temperature, temperature, and pressure.

Quantity	Measurement range	Measurement uncertainty (k=2)
Dew-point temperature	–80 °C ... –60 °C –60 °C ... +84 °C	0.2 °C ... 0.1 °C 0.05 °C ... 0.06 °C
Relative humidity	10 %rh ... 95 %rh (–20 °C ... +85 °C)	0.1 %rh ... 1.0 %rh (generator)
Relative humidity	10 %rh ... 95 %rh (+10 °C ... +85 °C)	0.4 %rh ... 2.0 %rh (climate chamber)

Calibration of radiation thermometers

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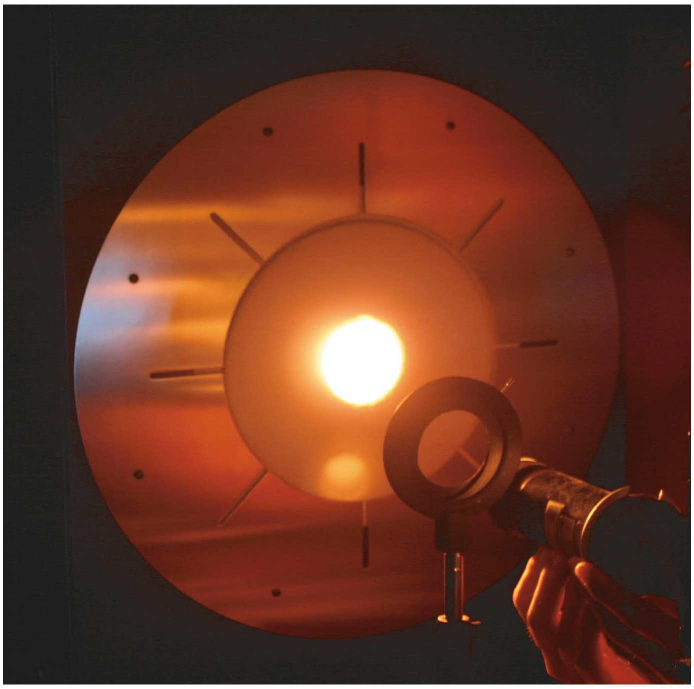
Measurement methods

Blackbody radiators are used in calibration of radiation thermometers. The operation range of VTT MIKES radiators is –40 °C ... 1500 °C.

The temperature of a blackbody radiator can be measured using e.g. a temperature sensor that is embedded in the radiator wall. When calculating the radiation temperature from the measured temperature, the emissivity of the wall and bottom materials of the radiating cavity and the geometry of the blackbody radiator as well as the temperature gradients are taken into account. The radiation temperature measured by a radiation thermometer is often lower than the surface temperature of the measured object, since the surface emissivity is usually lower than the emissivity of an ideal blackbody (the emissivity of a blackbody is 1 but the emissivity of a glossy copper surface is 0.1).

In VTT MIKES, radiation thermometers are calibrated by using either a calibrated reference pyrometer or reference radiators.



Traceability

The international temperature scale ITS-90 is realised above the temperature of 962 °C with a reference pyrometer and fixed-point radiators (962 °C, 1064 °C and 1085 °C). Of these fixed-points VTT MIKES has the first and the last one, which are the freezing points of silver (figure 1) and copper. Below the temperature of 962 °C, ITS-90 is realised by using resistance thermometers instead of a pyrometer. The reference equipment for radiation temperatures between –40 °C … 962 °C at VTT MIKES are based on resistance thermometers calibrated according to the ITS-90.

Size-of-source-effect

The size of the radiation source (size-of-source-effect, SSE) affects the calibration results of a radiation thermometer. A radiation thermometer detects thermal radiation also outside the blackbody radiator or the object to be measured. The significance of this additional thermal radiation depends on the construction of the optics (figure 2).

On demand, the size-of-source-effect is measured at VTT MIKES.

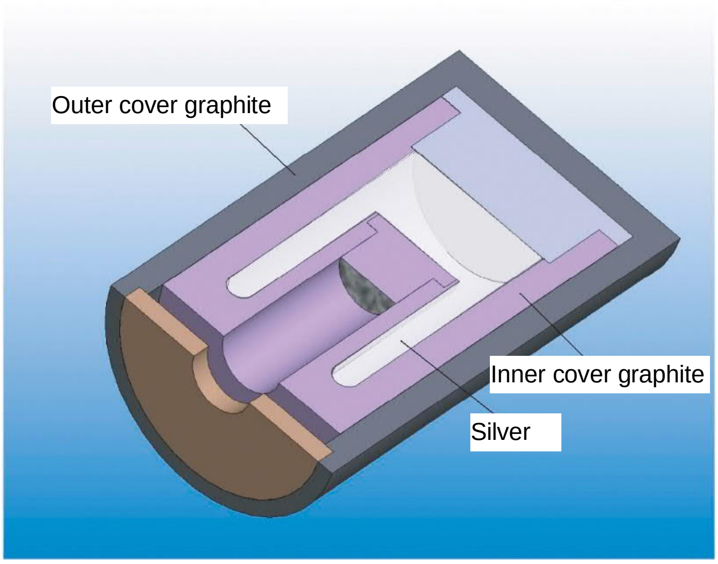


Figure 1. A silver cell that is used in the calibration of a reference pyrometer.

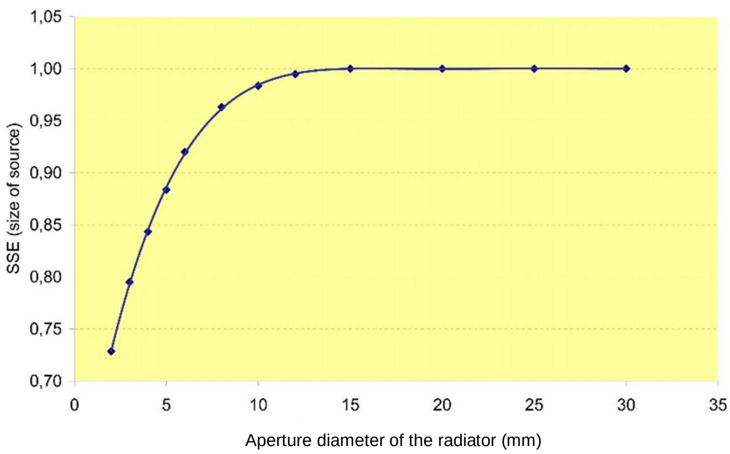


Figure 2. SSE: In this example, a pyrometer detects lower temperatures when the aperture of the radiator is less than 15 mm and the temperature of the radiator is higher than ambient temperature.

Vocabulary • reference meter: measurement standard • pyrometer: radiation thermometer (infrared thermometer) • a blackbody radiator does not reflect at all radiation coming from the outside. The temperature of an object depends only from the heat energy brought to the object and hence its radiation intensity is proportional to the temperature of the object.

Calibration of platinum resistance thermometers

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Calibration objects and methods

Standard platinum resistance thermometers (SPRT) of good quality (i.e. stable) are calibrated at the fixed points of the ITS-90 temperature scale. A fixed-point cell (Figure 1) usually contains pure metal, e.g. tin, zinc, aluminium or silver (Table 1) sealed in a crucible f purified graphite. The purity of the metal is typically ca. 99.99995 %. The graphite crucible is enclosed in a fused quartz tube.

The fixed-point cell is placed in a vertical tube furnace and the temperature is slowly raised until the melting is complete. At this stage, the furnace temperature is reduced to a value slightly below the melt temperature in order to start solidification. When the metal is in a supercooled state, the thermometer to be calibrated is carefully inserted into the cell. The thermometer is coupled to a resistance bridge using four-wire coupling. The solidification state can be maintained up to 10 hours (Figure 2) and the temperature of the fixed point cell stays within ±0.5 mK.

The resistance bridge is used to measure the electrical resistance of the thermometer during the solidification state. The thermometers are usually calibrated using three or five different fixed points.

Figure 1. Pt25-sensor (SPRT) in a fixed-point cell.

Calculation of calibration coefficients

The temperature T90 is determined according to the ITS-90 temperature scale. First a resistance ratio $W(T_{90}) = R(T_{90}) / R(T_{0.01°C})$ is calculated by dividing the sensor resistance at a given fixed point by the resistance value at the water triple point. A deviation function of the resistance ratio and calibration constants (*a*, *b*) are determined for each sensor under calibration. The deviation function can be e.g.

$$W(T_{90}) – W_r(T_{90}) = a[W(T_{90}) – 1] + b[W(T_{90}) – 1]^2$$

where $W_r(T_{90})$ is a reference function given in the ITS-90 scale. The deviation function to be used and the number of calibration constants depend on the temperature range and the used fixed points.

The deviation function can also be used to determine any temperature between the fixed points when the constants *a* and *b* are known. In this case, $W(T_{90})$ is first determined at the unknown temperature and the resulting W_r is used to calculate T_{90}.

Uncertainty in fixed point calibration

The uncertainties of the fixed points at VTT MIKES are between 0.0002 ... 0.010 °C. The lower limit is reached at the triple point of water and the upper limit at the fixed points of aluminium and silver. The uncertainty of the resistance thermometer calibrations is larger since it includes also uncertainties of the calibration equipment (resistance bridge, reference resistor) and the stability of the thermometer during the calibration.

Other fixed-point calibrations

Noble metal thermocouples of B-, R- and S-type are also calibrated at fixed points. The highest fixed-point temperature is the freezing point of copper at 1084.62 °C.

Traceability

The VTT MIKES fixed points are part of the realisation of the international ITS-90 temperature scale. The stability of the fixed-point cells are monitored and the temperatures they provide are compared to the temperatures from similar cells at our own and foreign laboratories.

VTT MIKES fixed points for resistance thermometers

Subtance	Temperature (°C)	State *
Argon (Ar)	–189.3442	t
Mercury (Hg)	–38.8344	t
Water (H_2O)	0.01	t
Gallium (Ga)	29.7646	m
Tin (Sn)	231.928	f
Zinc (Zn)	419.527	f
Aluminium (Al)	660.323	f
Silver (Ag)	961.78	f

* t = triple point, m = melting point, f = freezing point

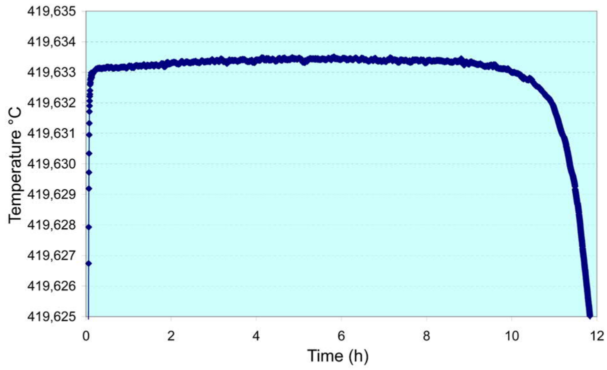

Figure 2. Freezing curve of zinc.

Abbreviations:
Pt25 = 25-ohm platinum resistance thermometer
HTPRT = high temperature platinum resistance thermometer

beyond
the obvious

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