CALIBRATION

Technical fundamentals

Calibration in the measuring technology industry

- General principles and definitions
- Calibration of flowmeters, level meters and temperature meters
- Influences in practical use
- References and measurement standards

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CT system solutions and calibration

CONTENT

Measuring devices are an integral part of our lives nowadays, whether in everyday life or on the job. They are often only recognised, however, when we take a much closer look. Take, for example, the scales at the supermarket check-out, the fuel volume measurement at the filling station pump, temperature measurement, velocity, flow volume and thermal energy, taxi meters etc. The wide variety of available quantities to be measured and measuring devices clearly illustrates the complex interplay between the quantity to be measured and the measuring device used. What does "accurate" actually mean in this context and how is this accuracy demonstrated? Why do we need accurate measuring devices? Using the example of flowmeters, the following sections will go into detail about these and other aspects.

Established in 1921, the family business of KROHNE employs 2564 people around the world and has representatives on all continents. The company has its headquarters in Duisburg, Germany where it develops, manufactures and sells products in the field of measuring technology. KROHNE stands for innovation and superior product quality. KROHNE is one of the market leaders in industrial process measuring technology.

Prior to leaving one of our factories in Germany, the United Kingdom, the Netherlands, France, Brazil, China, India or Russia, each KROHNE measuring device is thoroughly inspected in terms of its technical functions and device-specific features.

A number of tests which exceed statutory requirements ensure not only compliance with the specified technical data but also guarantee reliable use in extremely difficult application conditions.

"Is this device calibrated?", is a typical question heard relatively early on when using measuring devices. To answer this question in a satisfactory manner, different aspects of calibration are explained in what follows.

What is calibrated?

In principle, any physical trait of an object can be calibrated. This includes not only variables encountered in flow measurement technology like volume flow, mass flow, level and volume but also many other measurements found in day-to-day life such as temperature, length, mass, thermal energy, noise level velocity etc. When it comes to flowmeters it is usually the signal of one pulse output, where one pulse stands for one flowed through mass or volume, or a 4-20 mA output, which provides a signal in proportion to the volume, that is calibrated.

What is calibration?

Basically, calibration is a comparison of measurements followed by a written report of the results, the so-called systematic error of measurement. The resulting document is generally referred to as a calibration certificate or calibration protocol. Examples of calibration certificates can be found on page 26. The result of the comparison when calibrating is expressed as a difference, i.e. the deviation of the measurement of the device to be calibrated from the more accurate reference device. This difference can be expressed as a deviation in the unit of the quantity measured or as a percentage. The reference is then either the measured value or the measuring range end value.

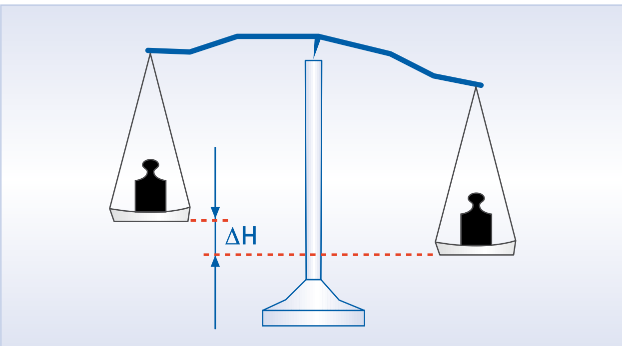

Figure 1.1: Beam balance

Typically, during calibration the measurement of the meter under test is compared to that of an identical or similar, more accurate measuring device. The example of the beam balance clearly demonstrates this: the left-hand side holds a 1 kg weight to be calibrated and the right-hand side holds a very accurate 1 kg weight. The difference in mass of the two weights results in a mass-scaled height difference between the two balance trays.

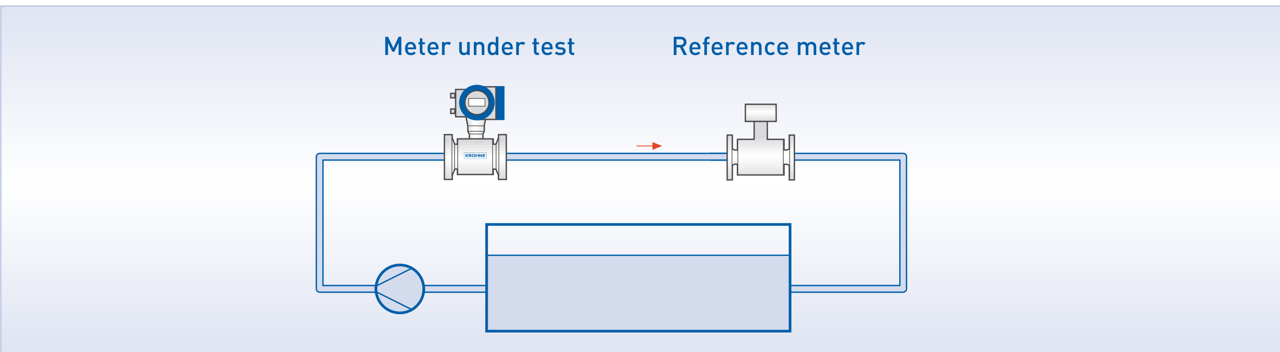

Figure 1.2: Flowmeter and reference

Flowmeter calibration generally takes place under fixed medium conditions like temperature, pressure, conductivity and volume flow as well as fixed ambient conditions such as pressure, temperature and humidity. What is calibrated is a pulse or frequency output, a 4-20 mA output, less frequently the display or bus signals. Depending on the accuracy required for the calibration, various processes including reference meters and gravimetric or volumetric liquid flow standard measurement calibration rigs may be used where the reference should have between three to five times less measurement uncertainty than the device to be calibrated. Reference meters are often used for calibration when similar measurement variables (e.g. variable area flowmeters) or measuring devices with defined error limits are calibrated, see Fig 1.2.

However, instead of flowmeters, flow calibration rigs are now used as the reference for precision calibration. In this case the flowing mass or volume is displayed via a mass and density measurement or volume measurement. This ultimately enables the most accurate measurement of the volume or mass of flowing products. Here, we distinguish between calibration rigs based on either the volumetric or gravimetric principle, see Fig 1.3 and Fig 1.4:

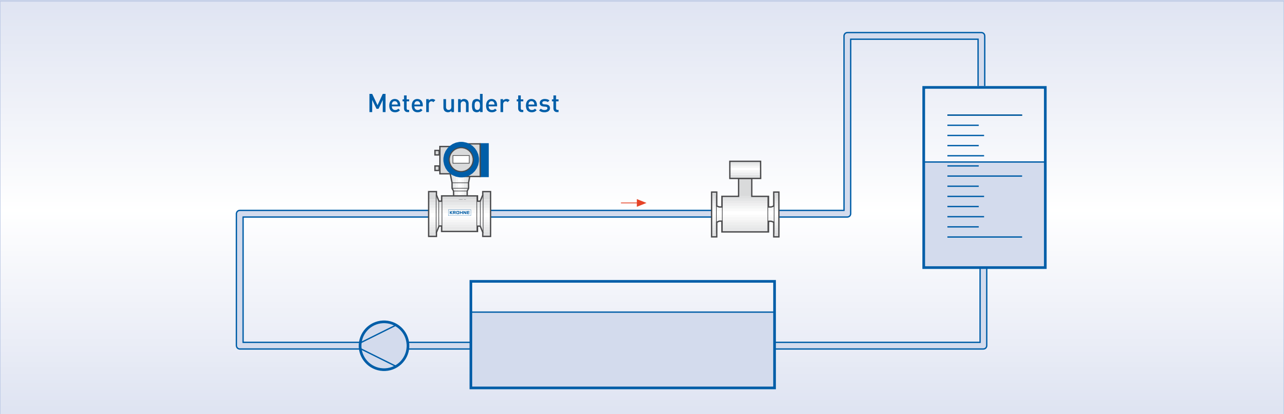

Figure 1.3: Volumetric calibration rig

In the case of volumetric calibration rigs the volume flowing through a meter under test is compared to the reference volume of a cylinder, tower or tank with an interior volume that is precisely known. The reference volume can be determined geometrically or by volumetric measurement in intervals using reference volumes. So-called piston prover systems are also based on the volumetric principle. With these systems, a known volume of a test product is pressed out by a propelled piston, passing through the meter under test into a storage tank. When the piston is pulled back, further measurements are made possible.

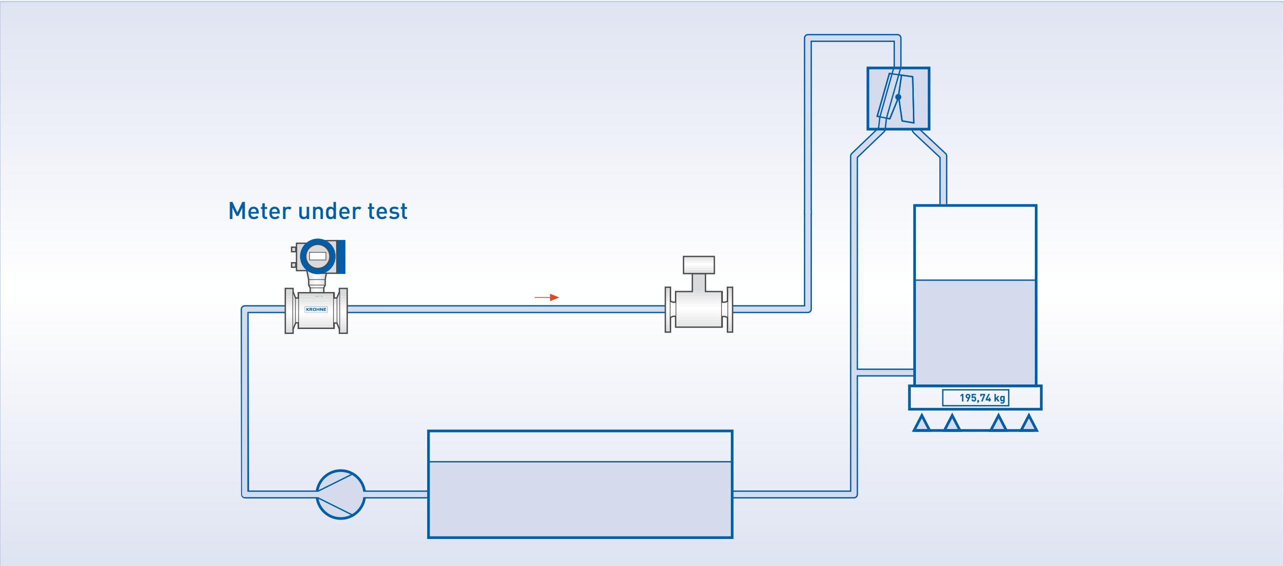

Figure 1.4: Gravimetric calibration rig

When it comes to gravimetric calibration rigs, the volume (or mass) flowing through the meter under test is compared to the indicator on a scale. The reference volume is then determined using the density of the product and by taking into account the various influencing variables on the measuring process. In most cases, testing is done in flying start-stop mode, whereby a diverter routes the product into the scale, or in standing start-stop mode. The calibration of the scales is typically done using stainless steel standard weights in accuracy class F2.

Why calibrate?

In principle, measuring devices are calibrated to gather information about the current behaviour or condition of the measuring device at the time of calibration. Any calibration is always tied to the existing temporal and local conditions. Prognoses about the behaviour of the measuring device in the application can be made, for example, based on experience or farther-reaching tests.

In regards to the information gathered about the measuring device during calibration, a distinction is generally made between industrial and legal metrology. In the field of industrial metrology, i. e. for use in the food and beverage industry, pharmaceuticals, the oil and gas industry for mixing and dosing processes, feeding plants etc., requires measuring devices that measure the mass flow as stable as possible and without fluctuations. On top of that, the devices must be able to display the same values over longer periods of time, i.e. they must have good long-term stability. This ensures high process stability.

In the field of legal metrology, i. e. anywhere goods must be billed, the measuring devices must measure within the maximum permissible errors and be regularly recalibrated, which is called verification (see also calibration law and calibration ordinance).

With the introduction of the Measuring instruments directive 2004/22/EC in 2004, custody transfer was standardised on a European level and it became legal in Germany on 30 October 2006. In addition to the general, fundamental requirements such as error limits, suitability, resistance etc., the device-specific part defines the requirements using 10 different types of measuring devices. These are:

MI-001 Water meters

MI-002 Gas meters and volume conversion devices

MI-003 Active electrical energy meters

MI-004 Heat meters

MI-005 Measuring systems for the continuous and dynamic measurement of quantities of liquid other than water

MI-006 Automatic weighing instruments

MI-007 Taximeters

MI-008 Material measures

MI-009 Dimensional measuring instruments

MI-010 Exhaust gas analysers

In addition to standardised European technical requirements on the respective measuring devices and unlike domestic law, the conformity assessment (formerly initial calibration) can now also be performed by the manufacturer (module D). The conformity of a measuring device can also be evaluated by an independent, third party which becomes an authorised body through accreditation (module F). The conformity assessment according to module D or F takes place in combination with a European type examination certificate (module B). A measuring device that has been evaluated for conformity obtains a declaration of conformity from the manufacturer and can now be made available to an end user (released).

Although these measuring devices have been governed in accordance with national law by way of domestic type approvals and calibration, measuring devices putted into use after the Measuring Instruments Directive are subject to a conformity assessment. Calibration is carried out by the calibration office or a nationally recognised test body. Each country has jurisdiction over this task and it is valid for all measuring devices that are recalibrated once the reverification period has expired as well as for "first calibrations" of measuring devices not subject to European law such as cooling measurements. All measuring devices not mentioned in the European measuring instruments directive as well as features specific to each country, such as the length of the calibration period and exceptions to mandatory verification, are subject to national law.

Any error of measurement detected during calibration as a result of repeat measurements is the so-called **systematic measurement error**. This remains constant as regards the value and the sign, provided the conditions during measurement do not change and it can always be reproduced under the same conditions. In addition to systematic measurement errors there are also random measurement errors. As the word implies, there is nothing "systematic" about this kind of error, it occurs randomly. Fig 2.1 illustrates the difference between systematic and random measurement error.

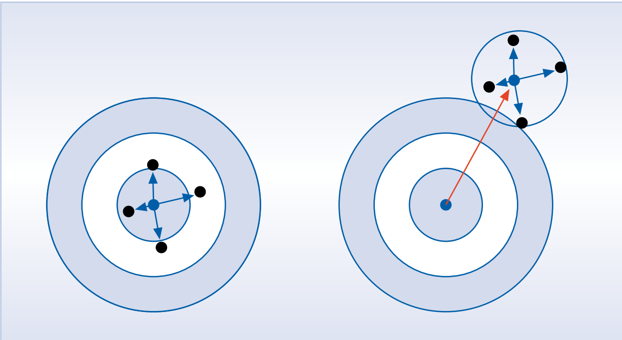

Figure 2.1: Systematic and random errors

If you look at the target on the left, the points (individual values) are evenly distributed around the blue centre, which in this case is defined as the correct value as agreed and the mean is exactly the centre of the target. The blue arrows indicate the random error of the individual values from the mean value. This can also be referred to as a scattering of the points around the mean. In the picture on the right, the same points are all farther from the centre of the target. The resulting systematic error is represented by the orange arrow.

Random measurement errors are caused by such things as reading errors, fluctuations in ambient conditions, unstable process conditions, device characteristics and so on.

Unlike calibration, when **adjusting** a device the systematic measurement error is not only determined and documented but also corrected by way of a manual intervention in the device. A familiar example of this is "setting" a watch according to the news. When comparing the display on the watch to the reference clock on the television (calibration process), you notice an error. The watch is, for example, five minutes slow (systematic measurement error). Now, although no calibration certificate is issued, you could make a mental note of the error and take that into account each time you look at the watch. However, as a rule this is too much of a hassle for us, and we make the error smaller by resetting the hands on the watch. We have thus adjusted the watch, in other words we have performed a lasting intervention.

Flowmeters are usually calibrated at different flow rates, which can be measured again if necessary. Examples of flowmeter calibration certificates can be found at the end.

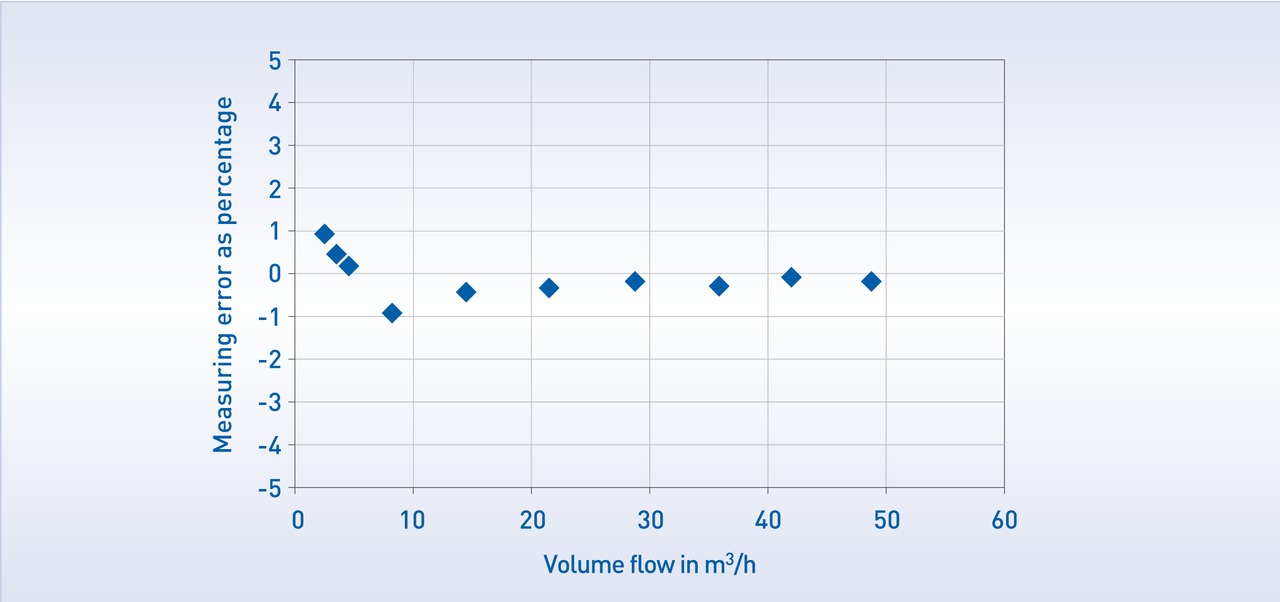

Figure 2.2: Calibration curve of a flowmeter

The measurement errors at the different flow rates result in the calibration curve plotted in a table or graph on the calibration certificate, see also pg. 26 ff. In everyday language the calibration curve is also called an error curve. Of course the term calibration curve is not quite right as no intermediate values were measured between the individual points. Using the calibration curve makes it possible to detect to what degree the calibration values fluctuate at the different flow rates; in other words, you can assess the linearity of the flowmeter. The less the individual calibration values deviate from one another overall, the greater the **linearity** of the measuring device. Calibration values for flowmeters with great linearity across the entire measuring range do not have to be compensated for through corrections within the control centre software of the corresponding application, provided the mean value of the deviations is close enough to zero.

In 1977, calibration laboratories in industrial enterprises, research institutions and technical authorities joined forces to form the Deutschen Kalibrierdienst (DKD) [German calibration service]. The goal was to formally approve the actions of the National Metrology Institute (Physikalisch-Technische Bundesanstalt or PTB), privatise parts of the state duties and responsibilities and thus reduce trade barriers. Accredited DKD laboratories can perform calibrations of measuring devices within the scope of the measurands and measuring ranges determined by the accreditation. The advantage of this is that the measurements can be traced back to the respective measurement standard of a specialist PTB laboratory. The calibration results are documented on a DKD calibration certificate. Today, many DKD laboratories are accredited for a variety of measurement categories including optical, electrical, acoustic, magnetic and dimensional indicators, flow measurements as well as temperature and humidity. Technical committees develop and provide guidelines and manuals for the calibration of the different measurement variables. With the law regarding the accreditation body from 31.07.2009, the DKD accreditation body was transformed with effect from 17.12.2009 into the Deutsche Akkreditierungsstelle GmbH (DAkks) [German Accreditation Body], s. a. www.dakks.de

Variable area flowmeters are one of the things manufactured at the KROHNE site in Duisburg, Germany. This is a tradition which started in 1921 and has stood its ground to date with a wide range of devices. Whether the DK devices are made of glass or metal, H250 or VA 40, the variety of different devices is reflected among other things in the requirements placed on the calibration rigs. The calibration of the scales of variable area flowmeters is done by comparison with a highly accurate flowmeter. Instruments used include. Coriolis flowmeters, electromagnetic flowmeters and even reference glasses. Fig 3.1 illustrates calibration using electromagnetic flowmeters at the elevated tank calibration facility.

Figure 3.1: Elevated tank calibration facility

The 9 m high elevated tank is operated with water and is used to calibrate H250 devices. Flow rates up to 120 m3/h are possible. Fully automatic calibration can take place simultaneously at five measuring stations. A camera system accurately measures the indicator position with a resolution of ± 0.1 % of the calibration scale. The respective flow points at which calibration takes place are automatically started and the results for each device are stored in the database. The installation site can also be varied so that devices normally receiving the flow from below as well as the devices like the KROHNE variants that receive flow from above or horizontally can be calibrated.

In the glass segment or with DK metal devices, the devices to be calibrated are compared to high resolution variable area flowmeters.

The development calibration rig put into operation in 2009 is available for measurements of air-volume flows up to 2500 m3/h. Calibration is performed using two turbines that are regularly traced back to the measurement standard of a national body to ensure measuring accuracy. Figure 3.2 shows the measuring section and references of the large air calibration rig.

Figure 3.2: Large air calibration rig

The production of the OPTISWIRL vortex flowmeter series represents the second large product line at the Duisburg site. For the calibration of the vortex flowmeters alone, two revolver calibration rigs were built. Through the rotation of the revolver, the measuring sections necessary to calibrate different nominal sizes can be rotated to the level of the measuring section without long conversion times. Calibration takes place with water at flow rates up to 575 m^3/h using electromagnetic flowmeters. Long inlet runs in front of the meter under test and specially fabricated inlet runs for the references guarantee precise measuring conditions with long-term stability. The flow points are started and measurement data is recorded automatically. The measurement data are stored in a database. Figure 3.3 depicts the large revolver calibration rig used to calibrate vortex flowmeters.

Figure 3.3: Revolver calibration rig

Figure 3.4: Small air calibration rig

Flowmeters in the lower flow range can be calibrated with the help of the small air calibration rig up to 500 m^3/h under normal conditions and 8 barg at temperatures up to 90 °C. Critical nozzles are used as reference. They are regularly traced back to national and international standards. In addition to being able to calibrate the flowmeters in a vertical or horizontal position, meters of varying physical measuring principles can be calibrated.

Electromagnetic flowmeters were added to the product range in 1961 with the foundation of the Dutch branch in Dordrecht. Today, electromagnetic flowmeters and ultrasonic flowmeters from DN 2.5 to DN 3000 are manufactured at KROHNE Altometer, placing huge demands on the calibration rigs. The largest flowmeters are calibrated with the help of the tower seen from a distance. The 44 m high calibration tower, which can create volume flow rates up to 30,000 m3/h, contains about half a million litres of water. Highly precise position encoders mounted along the entire height of the inside of the tower enable maximum precision when calibrating extremely large measuring devices. This huge engineering feat is put into perspective with the size comparison of the flowmeters shown in figure 4.2.

Figure 4.1: 44 meter high calibration tower at KROHNE Altometer

Figure 4.2: Ultrasonic flowmeters nominal size DN 3000

Smaller nominal sizes are calibrated preferably using piston provers at KROHNE Altometer. The precisely known interior volume of a cylinder is displaced during calibration and compared to the volume measured by the meter under test. A direct comparison of volumes reduces the number of influencing variables, enabling calibrations with extremely small measuring uncertainty. Electromagnetic flowmeters and ultrasonic flowmeters are usually calibrated with water. Special calibrations using other liquids can be carried out with calibration rigs specially equipped for this purpose. Regular comparisons with the Netherlands Metrological Institute (NMI) and comprehensive quality management in combination with long years of experience logged by employees make cutting edge, superior calibrations possible.

Figure 4.3: Piston prover calibration rig

The technical development made in leaps and bounds by Coriolis measuring devices has become extremely evident over the past years. Straight tube Coriolis devices open up new dimensions in precision measurement technology. Measuring the mass flow using the Coriolis effect eliminates a whole series of influencing variables present with other calibration methods. During the calibration of Coriolis measuring devices, the indicator of the meter under test is directly compared to the water mass that flowed into the weighing container. All devices are calibrated at different process temperatures. For example, the straight tube devices are calibrated at 20 °C, 40 °C and 60 °C so that through this process the process influences for each device can be individually measured and corrected. As the density measurement is also calibrated during calibration, the customer can choose to calibrate to mass or volume measurement. The entire calibration process is computer controlled and therefore completely automated. Upon completion of the process a separate calibration certificate is issued for each measuring device.

Figure 5.1: Calibration for large-size Coriolis measuring devices

When mass flowmeters with nominal sizes up to DN 250 were added to the product range, existing calibration facilities had to be expanded. The "mega rig" put into operation in 2008 can handle mass flows up to 860 t/h with minimal measuring uncertainty. In order to maintain the consistently high standard of accuracy of calibration, the calibration rigs DN 15 to DN 250 are accredited by the British calibration service provider UKAS[1]. A separate calibration rig is available for the calibration of mass flowmeters with small nominal sizes starting at DN 1. Here, too, with the so-called "stationary start-stop" measuring principle, the mass of water that flows through the meter under test is directly compared to the indicator on the scales. To reduce calibration times, up to three devices can be simultaneously calibrated. A sophisticated signal processing system prevents the devices from interfering with one another. Calibrations are possible at water temperatures of 20 °C, 40 °C and 60 °C.

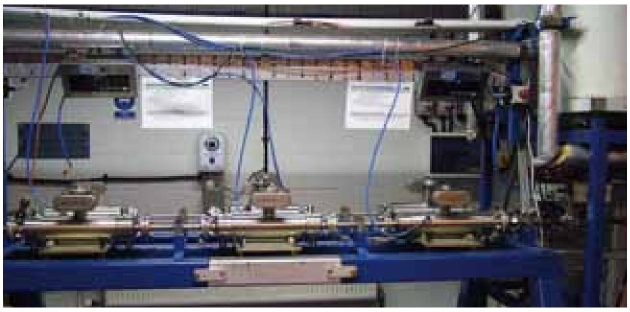

Figure 5.2: Calibration rig for mass flowmeters

1 United Kingdom Accreditation Service

At the KROHNE site in Romans, France, level meters are manufactured and calibrated. TDR level meters (Time Domain Reflectory/guided microwaves) in the OPTIFLEX series are calibrated on 30 m tracks. In the process, the reflector plate can be automatically positioned on the required calibration point. High demands are placed on the measurement process, both in terms of measurement uncertainty as well as the repeatability of the results. With the help of a tensioning device, the cable is stretched to its optimal length. Due to the parallel setup of two tracks, installation times for the Optiflex devices are minimised. Another, manually-operated calibration rig makes calibration possible at distances up to 40 m.

Figure 6.1: Optiflex calibration rig

The calibration of FMCW level meters (Frequency Modulated Continous Wave/non-contact radar waves) in the OPTIWAVE series takes place in a calibration tunnel lined with high-quality absorbent material. As many measuring points as necessary for the calibration can be set using automatic traversing. For calibrations of up to 5 m, a multi-position calibration rig is available. Device calibration takes place vertically with the help of two moving targets.

Figure 6.2: Optiwave calibration rig

The calibration rigs are checked regularly using a laser interferometer which is traceable to the standard of the National Physical Laboratory (NPL) or a comparable calibration service. This guarantees consistently high calibration quality.

Vortex and ultrasonic flowmeters are produced at the site in Samara, Russia. Meters up to a nominal size of DN 50 can be calibrated with the help of a water calibration rig. The revolver-type tilting inlet sections enable a time-optimised retrofitting of the measuring section. Ceramic electromagnetic flowmeters are used as reference. They can be traced back to international standards at pred-determined intervals. They also enable measurement with a repeat precision (repeatability) of less than 0.03 %.

Figure 7.1: Revolver calibration rig

At the KROHNE location in Chengde, China, variable area and vortex flowmeters are manufactured. Like calibration in Germany, flowmeters here are also calibrated using reference flowmeters. Depending on the required measuring accuracy, more precise glasses or even electromagnetic flowmeters can be used. The elevated tank shown in Figure 8.1 enables the calibration of H250 variable area flowmeters at any installation site.

Figure 8.1: Elevated tank

Small flows can be measured using a gravimetric measuring system. In this case, the flowing volume is traced back to a mass and density of the product.

Electromagnetic flowmeters and mass flowmeters are both manufactured at the KROHNE site in Shanghai. Here too, devices with nominal sizes up to DN 3000 and flow rates up to 18,000 m/h can be calibrated. The close technical dependence on the calibration rig technology of KROHNE Altometer makes the high standard of calibration of KROHNE flowmeters possible.

In Poona, India, electromagnetic flowmeters and variable area flowmeters are calibrated. The calibration of electromagnetic flowmeters is done using a volumetric reference. When calibrating variable area flowmeters, reference devices of superior accuracy are incorporated.

When you consider the calibration values of a flowmeter, ideally they should not deviate from the measuring values in the application. In fact, there are a number of influencing variables which require great care when installing in the application given the wide variety of flowmeters and measuring principles. Only by closely analysing the application can undetected systematic measurement errors be reduced from the outset. The inlet conditions of the flowmeter represents one of the main influencing variables on the measurement result:

Inlet and outlet sections

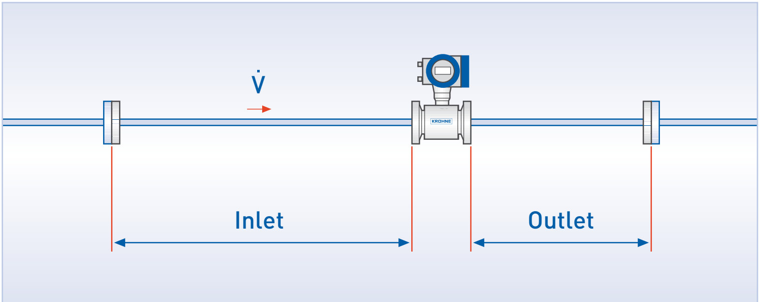

Figure 9.1: Inlet and outlet sections

Inlet and outlet sections refer to the section of a straight tube before and after the measuring device, not including built-ins (interferences) such as elbows, valves, ball valves etc. It can also be referred to as an unimpeded or free inlet section. This is usually expressed in a whole number multiple of the pipe diameter, e. g. a 10D inlet section on a DN 200 pipe corresponds to a length of 2 m. Observing the inlet and outlet sections of different lengths is sometimes necessary to reduce influences on the measuring result that originates in the system itself. These upstream/downstream influences on the measuring device are mainly reflected in the "quality" of the flow profile. Information regarding the minimum lengths of the inlet and outlet sections is generally contained in the technical documentation of the flowmeters.

Flow profile

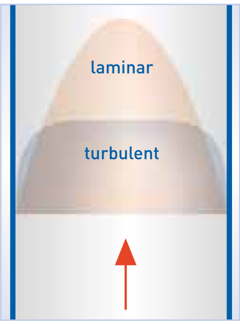

Figure 9.2:
2D flow profiles

The velocity distribution of the flow of liquids in closed pipelines is not constant across the pipe. Under ideal conditions, the closer you get to the "middle" of the pipe, the greater the flow velocity. The closer you get to the wall of the pipe, the slower the flow. The velocity distribution can be illustrated two-dimensionally or three-dimensionally across the pipe. This is called a velocity or flow profile. Figure 9.2 shows a two-dimensional, Figure 9.3 a three-dimensional laminar and turbulent flow. If you have an extremely long, straight pipeline, two different flow profiles are formed, depending on the diameter of the pipe, flow velocity and viscosity: either a laminar or a turbulent flow profile. The turbulent flow profile is "flatter" than the laminar one. These flow profiles are called swirl-free and rotationally symmetric. To achieve the desired measuring accuracy, the unimpeded inlet run required in front of a flowmeter depends on the measuring principle used (EMF, Vortex, ultrasonic, Coriolis etc.).

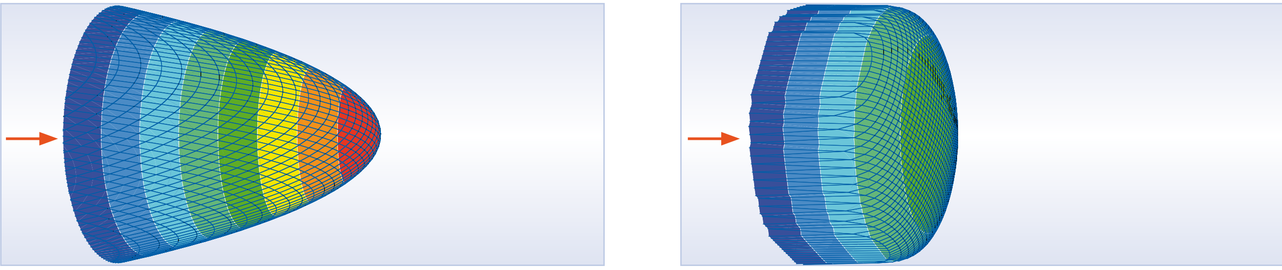

Figure 9.3: Three-dimensional flow profile

Installation situation

In terms of pipe direction the practical installation of a flowmeter in an application is always bound to on-site possibilities. Often, having system parts that change the flow profile located close to the measuring devices cannot be avoided. This includes built-ins like 90°elbows, 3D bends, shut-off devices, reducers and expansions, filters etc. Information regarding which combinations or built-ins and measuring devices are to be avoided can be found in the technical documentation of each measuring device.

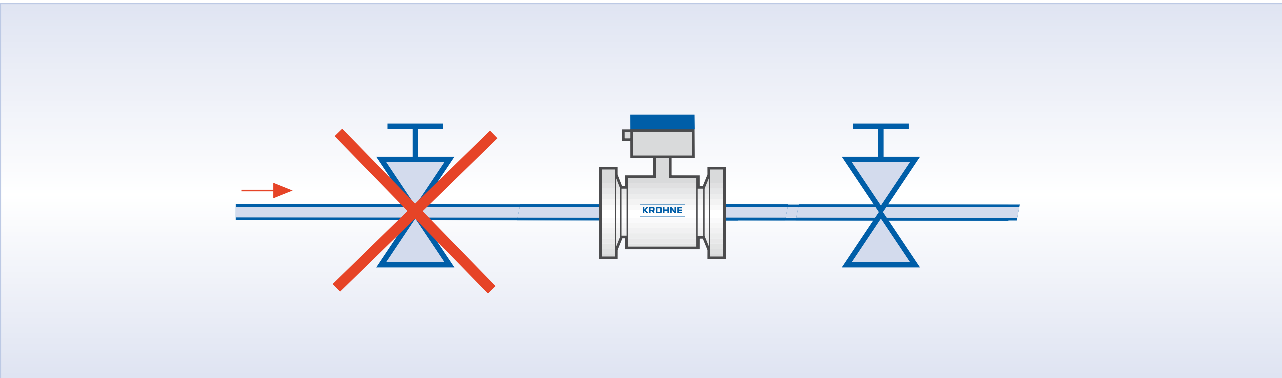

Figure 9.4: Installation notes for electromagnetic flowmeters

Figures 9.4 and 9.5 show examples from documentation with recommended flowmeter installation sites and those sites to avoid.

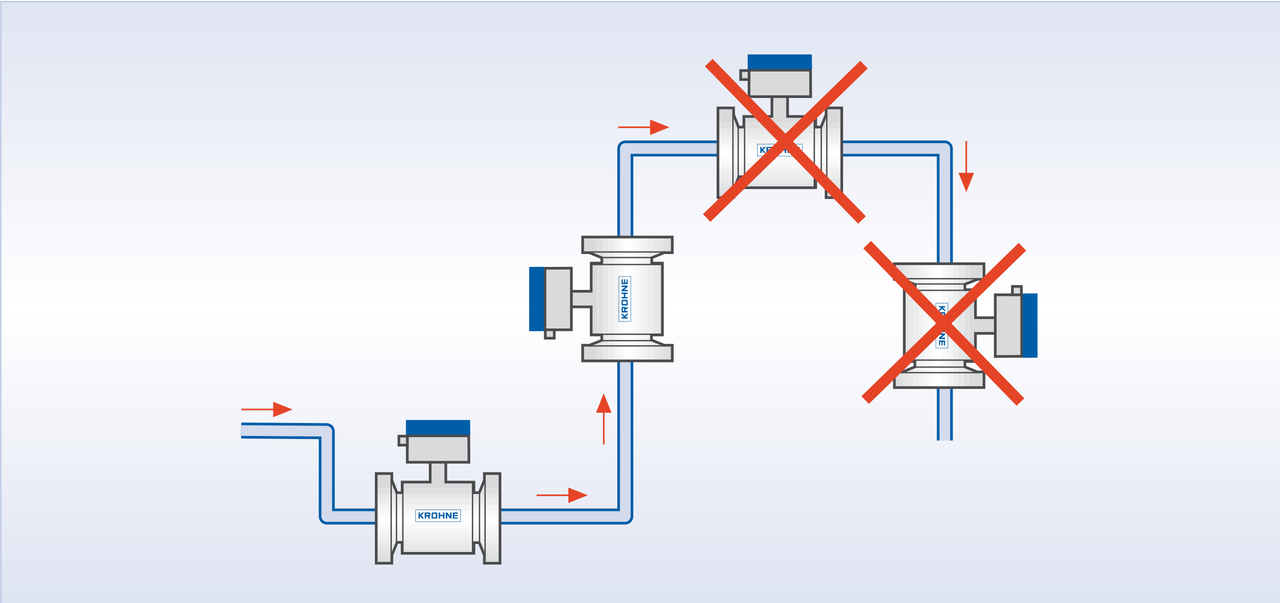

Figure 9.5: Installation notes for electromagnetic flowmeters

If there are built-ins in the pipeline, changes such as one-sided increases in velocity or swirling components in the local flow can be the consequence. These changes are slow to be diminished in the straight pipeline until finally a rotationally symmetric, distinct laminar or turbulent flow profile is restored. To counteract such interference with the measuring accuracy of the flowmeter, the data sheets for the respective flowmeters indicate minimum inlet sections based on the desired measuring accuracy.

In general, it can be said that longer inlet runs diminish the influence of flow interferences.

Calibration conditions

Flowmeter calibration generally occurs at defined pressure, temperature and ambient conditions. Changes in these conditions when using the measuring device in practice can result in more or less serious changes in the measured value. Nowadays, flowmeters such as variable area flowmeters, are sometimes designed for use in a specifically defined parameter range. Here, no corrections need be taken into account on site. If the influence of the parameter is significant, a correction may be made with the appropriate measurement of pressure and temperature (pressure and temperature compensation with vortex flowmeters). Significant meaning is thus attached to the"Quality" used for potential conversions of the material parameters used as data with significant measurement uncertainty have a direct impact on the result of the measurement.

As a general rule, flowmeters are calibrated using water or air. Operating points which in terms of density, temperature, viscosity etc. deviate from the calibration conditions, can be taken into account mathematically if necessary. In order to perform measurements with minimal uncertainty, some circumstances may require that calibration be done with the original liquid or original gas (true gas calibration).

Figure 9.6: Vortex flowmeter with integrated pressure and temperature compensation

Repeatability / reproducibility

To guarantee process conditions with a high degree of stability, flowmeters with high repeatability are required, i.e. the measuring device should also output the same measured values with minimal scattering, regardless of the absolute accuracy of the individual values under the same operating conditions in realtime. Data about the repeatability of a measuring device can only be collected under repeatability condition of measurement. This includes such things as constant temperatures, pressures, humidity, observers, measurements following one another at close intervals and the same reference. Multiple measurements on a test rig can be used as data for repeatability. In the absence of quantitatively useful calculation specifications in the area of liquid measurements, it is often the smallest and largest values that are used but these are not statistically meaningful and do not allow for a comparison of information. A recommendation for the quantitative determination of repeatability can be found in [7]. The terms generally used for this in the literature are "repeatability" or "reproducibility". In contrast to that there is advanced reproducibility which takes into account different observers, installation sites and changed process and ambient conditions. As for repeatability there is no known calculation specification for liquids for the specification of a quantitative value.

Long term stability

If a measuring device is observed in use over a longer period of time, the measurement should not drift at all under constant conditions. If the measurement errors caused by any aging, drift or environmental influences is negligible over a longer period of time, the measuring device is said to have high long-term stability.

Calibration usually takes place with the help of a "more accurate" measuring device. This device is referred to as the reference, the measurement standard or superior measurement standard. It is crucial here that the influence of the Reference on the result of the calibration of the meter under test is negligibly small. To guarantee this, there is something called the 1/5 rule. This rule states that the uncertainty of the reference may be a maximum of 1/5 of the targeted calibration uncertainty. In individual cases, the factor between the meter under test and the reference may be 1/3 but in general it can be said that higher values (1/10) are the goal.

So who has the "right" measuring device? To tackle this problem, 17 European states came together in 1875 with the goal of presenting and using specific units consistently.

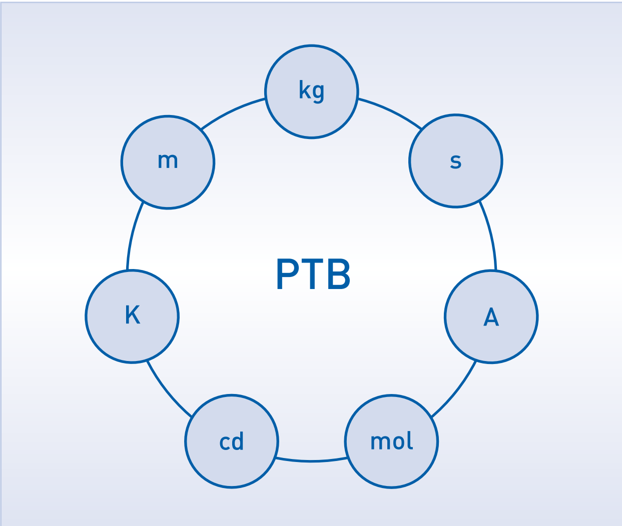

Figure 10.1: SI base units

Figure 10.2: International kilogram prototype

The meter and kilogram were adopted as the superior measurement standard and the production of prototypes, which should then be used as the material measure, was set. Today, the so-called SI system® comprises 7 base units: kilogram, meter, second, kelvin, ampere, mole and candela. The number of states has now grown to 51. How these units are represented lies within the jurisdiction of each country. In Germany, for example, they are administered by the Physikalisch-Technischen Bundesanstalt (PTB), in the Netherlands by the Netherlands Metrology Institute (NMI) and in Austria by the Bundesamt für Eich- und Vermessungswesen [Federal Office of Metrology and Surveying].
The current definition of the 7 base units can be found at **www.ptb.de**. The material measures or technical apparatuses that depict these units are called national measurement standards, superior measurement standards or primary measurement standards. Nowadays we try to make it possible to depict the base units with the help of natural constants such as Avogadro's number or the speed of light. Unlike the material measures (kilogram and meter), this has the advantage of displaying with less measurement uncertainty. Not until 1960 was the platinum-iridium rod replaced by a new definition. The last remaining material measure that is currently valid is thus the international kilogram prototype.

If a measuring device is calibrated against a reference that was calibrated at a national institute, the calibration is said to be "traceable to a national measurement standard". This traceability makes it possible to compare the calibration results of all measuring devices traced back to this measurement standard. The example of the international kilogram prototype demonstrates how the tracing of a measurement is structured. At the peak of achievable accuracy is the international kilogram prototype, see Figure 9.2, a platinum-iridium cylinder which by definition embodies a mass of 1 kg (material measure). Directly affiliated with this are the national kilogram prototypes of the individual member states.

[2] International System of Units. International unit system which specifies seven base units by convention. The International Office of Weights and Measures (BIPM) in France is responsible for the system.

As a rule, each member state has just one of these, to which main measurement standards made of stainless steel are in turn associated and which are recalibrated on an annual basis. Germany, in addition to the original kilogram which was damaged in the second world war, has a valid duplicate from the former DDR.

With the help of the transfer of measurements structured in this way through their traceability to a superior measurement standard, the associated measurement standards guarantee on the one hand the comparability of the measurements and on the other hand they guarantee that the consumer is getting a product whose volume lies within statutory error limits.

To make a comparable statement about the accuracy of the measurement, the measurement result is assigned the so-called measurement uncertainty. Without this information, the measurement result is incomplete. Measurement uncertainty refers to the quality or accuracy of the measurement and is usually expressed using the same unit with a "±" after the measurement result. For example, for a measured length, the information 21.0 mm ± 0.5 mm means that there is a 95% chance that the actual value of the measurement result (this can also be called the "agreed value") lies in the range of 20.5 mm to 21.5 mm. The specification of measurement uncertainty for a flowmeter generally refers to the measuring range outlined in the specifications and is usually stated as a percentage of the measured value or of the measurement range end value. Even the measured volume of flowing liquids is assigned a measurement uncertainty which depends among other things on the reference used. When it comes to precision calibrations, the flowing volume is measured using gravimetric or volumetric calibration rigs. The designation of the measurement uncertainty in this case occurs by way of an observation and evaluation of all of the input variables affecting the measurement in a so-called measurement uncertainty analysis.

As a general rule, the calibration of a measuring device does not have unlimited validity in terms of time. To counteract systematic measurement errors caused by ageing, drift, environmental influences or similar, it is necessary to calibrate measuring devices within defined time intervals. This is known as recalibration or a recalibration interval. The shorter the intervals, the sooner any systematic measurement errors can be detected and corrected.

Calibration

The determination of the relationship between the measured value or expected value of the output variable and the associated true or correct value prevailing as the input variable for observed measuring equipment with specified conditions (DIN 1319).

Adjusting

An activity that puts a measuring device into a usable state. As a rule, this refers to the determination and correction (by way of permanent intervention into the device) of a systematic measurement error.

Verification

A state government inspection of a measuring device subject to statutory metrology which is conducted by a calibration authority or a nationally recognised testing body. The verification process includes determining the measurement error, tamper-proof lead sealing and affixing the calibration seal. The measured values must lie within the maximum permissible errors. These limits depend on the measuring device and the accuracy class. The German calibration law and calibration ordinance govern all the particulars.

Conformity assessment

A test to determine whether a measuring device complies with the requirements of the European measuring instrument directive (MID). This directive defines various conformity assessment procedures which may contain metrological tests. The conformity assessment replaces the initial verification and unlike it, the assessment is valid throughout the entire European Economic Area.

Systematic measurement error

Mean value resulting from an unlimited number of measurements of the same quantity, conducted under reproducible conditions minus a true value of the quantity being measured. The value of a measurement standard is generally taken as the "true value". However, because the true value is based on an endlessly large number of measurements, it is also known as the "correct value" or "agreed value".

Random measurement error

Measuring result minus the mean value that would be arrived at from an unlimited number of measurements performed under reproducible conditions.

Reference

A standard, measuring device, reference material or measuring system whose purpose it is to determine, represent, conserve or reproduce a unit or one or more values of a quantity.
(International Dictionary of Metrology, 2nd Edition 1994)

DKD

Abbreviation for the "Deutscher Kalibrierdienst" [German calibration service]. An amalgamation of German calibration laboratories in industrial enterprises, research institutions and technical authorities whose aim it is to formally approve the actions of the German national institute as regards measurement tasks, to privatise parts of the national duties and responsibilities and ultimately to reduce trade barriers.

LITERATURE

[1] Weights and Measures Act (Verification Act) from 23 March 1992 (Federal Law Gazette I pg. 711), last amended by: Art. 2 G from 3 July 2008

[2] Calibration regulations from 12 August 1988 (Federal Law Gazette I pg. 1657), last amended by Art. 3 § 14 G vom 13.12.2007 I 2930

[3] DIN EN 1319: Grundlagen der Messtechnik [Fundamentals of Metrology], Beuth Verlag GmbH, Berlin, 1995

[4] Leitfaden zur Angabe der Unsicherheit beim Messen [Guide to the Expression of Uncertainty in Measurement], 1st Edition, Beuth Verlag GmbH, Berlin, 1995

[5] Adunka, F.: Messunsicherheiten – Theorie und Praxis [Measurement Uncertainty – Theory and Practice], 3rd Edition, Vulkan-Verlag GmbH, Essen, 2007

[6] Measuring instruments directive (MID) 2004/22/EC

[7] Mathies, N.; Wendt, G.; Rose; J.; Mickan, B. ; Schupp, R.: "Mengen- und Durchflussmessung strömender Medien" [Measuring the Quantities and Flow Rates of Flowing Media], technical measuring, Oldenbourg Wissenschaftsverlag, München, 79. Year, Edition 2-2012, pg.120-128

KALIBRIERPRÜFZERTIFIKAT DIN 55 350 - 18 - 4.2.2

Calibration Test Certificate
Certificate d´étalonnage

KROHNE Ref. No.:

KROHNE
KROHNE Meßtechnik GmbH & Co. KG
Duisburg

Kunde / Customer / Client: Mustermann

Best.Nr / Ord.no / N°de com.

Produkt / Product / Materiel: KROHNE Schwebekörper-Durchlussmesser / Flow Meter

Typ / Type / Type: H250/RR/M9 **Articel / Article n°:** P999123456

VK-Auftrag /Sales order / : 999999 **Pos.:** 041

Serien.Nr./ Ser.no./ N°de sér.: 6 / 123456 . 001 **Tag.No.:** 123456789

Genauigkeitsklasse/accuracy class/classe de précision : **1,6** Code: **123456**

Wir bestätigen hiermit, daß das o.g. Meßgerät kalibriert und auf Meßgenauigkeit geprüft wurde. Die Umrechnung der Meßstoffdaten auf Kalibrierdaten erfolgte nach der Richtlinie VDI/VDE 3513. Das Meßgerät entspricht der o.a. Genauigkeitsklasse nach VDI/VDE Richtlinie 3513, Blatt 2. Kalibrierverfahren nach VAW 09 TDP-012

This is to certify that the a.m. KROHNE measuring instrument has been calibrated and tested on accuracy. The calculation for calibration data is performed according to VDI/VDE 3513. The instrument appropriates to the a.m. accuracy class according to VDI/VDE 3513, sheet 2. Calibration acc. to procedure VAW 09 TDP-012

Par la présente, nous certifions que l´appareil KROHNE mentionné ci-dessus été calibré et testé selon la norme. Le calcul pour les données de calibration respecte la norme VDI/VDE 3513. L´appareil est testé selon la norme VDI/VDE 3513, Partie 2, avec la classe de précision.ci-dessus. Calibration acc. to procedure VAW 09 TDP-012

MESSBEREICH / RANGE

Skale/scale: 5 ... 50 Nm³/h

transmitter ...

PHYSIKALISCHE DATEN

Medium:	Stickstoff	Ref.Medium	Luft/Air
Temperatur	20 °C	Temperatur	20 °C
Druck:	6 bar abs.		
Dichte:	6,9 kg/m³		
Viskosität:	0,02 mPa.s		

Skale/ scale	Kalibrierstand/ calibration rig			max%	Transmitter / transmitter			max%
test point	ref. flow Sollwert	test flow Istwert	F % measured value v.MW	VDI/VDE 3513sheet2	ref. value Sollwert	test value Istwert	F % measured value v.MW	KROHNE VAW
Nm³/h	m³/h	m³/h		1,60				1,60
5	2,021	2,1	3,91%	5,20%				10,60%
10	4,042	4,05	0,20%	3,20%				5,60%
20	8,084	8,1	0,20%	2,20%				3,10%
30	12,13	12,3	1,40%	1,87%				2,27%
40	16,17	16,4	1,42%	1,70%				1,85%
50	20,21	20,5	1,43%	1,60%				1,60%

Kalibrierstanddaten: *calibration rig data* Serial No: Certifikate No :

Duisburg, 10. Jan. 07

Hersteller-Prüfbeauftragter
QA-Division / Service QA

gedruckt *10. Jan. 07* Seite 1 von 1

KROHNE Meßtechnik GmbH & Co. KG
Postfach 10 08 62 - 47008 Duisburg
Telefon (0203) 301 - 0
Telefax (0203) 301 - 389 / 322

TÜV CERT DIN ISO 9001

KROHNE

Calibration Certificate - Kalibrierzertifikat - Certificat d'étalonnage
DIN 55 350-18-4.2.2

Product / Produkt / Produit :
Type / Typ / Type : **OPTIFLUX 4000** **DN 50 mm/ 2 inch**
Sales Order / VK-Auftrag / Commande de vente :
Serial Number / Seriennummer / Numéro de série :
Tag Number / Tagnummer / Repère :

Calibration Method / Kalibriermethode / Méthode d'étalonnage

The flow sensor has been calibrated against a piston-prover. The calibration certificate of this prover documents the traceability to national standards, which realize the physical units of measurements according to the International System of Units (SI).

Die Prüfung des Durchflussmessgeräts erfolgt im Vergleich zu einem Piston-Prover. Die Kalibrierung des Provers ist rückführbar auf Nationale Standards. Die physikalischen Einheiten sind nach dem SI-System definiert.

Le capteur de mesure a été étalonné avec un piston étalon. Le certificat d'étalonnage de cet étalon prouve la traçabilité aux étalons nationaux qui utilisent des unités de mesures physiques selon le Système International (SI).

Test Equipment Data / Kalibrierstanddaten / Données du banc d'étalonnage

Serial Number / Seriennummer / Numéro de série : A3
Calibration fluid / Kalibrierflüssigkeit / Fluide d'étalonnage : Water / Wasser / Eau
Uncertainty / Unsicherheit / Incertitude : 0.02 %

Calibration Results / Kalibrier Resultats / Résultats d'étalonnage

Flow Rate Durchflussmenge Débit (%)	Set Flow rate Gewählte Durchfluss Débit réglé (m3/h)	Deviation Abweichung Ecart (%)
98.90	49.45	-0.07
49.40	24.70	-0.02
9.90	4.95	-0.05
5.00	2.50	+0.2

Calibration Data / Kalibrierdaten / Données d'étalonnage

GK : 2.4408 GKh :
GKl : 4.6179 GKw :
Date / Datum / Date : 2007-12-11

This certificate is produced with EDP and valid without signature / Dieses Zertifikat wurde maschinell erstellt und ist ohne Unterschrift gültig / Ce certificate a été généré par un système automatisé, il est valide sans signature

KROHNE Altometer, Kerkeplaat 12, 3313 LC Dordrecht, Nederland, Tel.:+31 (0)78 6306 300, Fax.:+31 (0)78 6306 390, www.KROHNE.com

KROHNE

Calibration – Certificate
Kalibrier – Zertifikat
Certificat d´étalonnage

In accordance with / gemäß / selon DIN 55 350-18-4.1.2
Customer / Kunde / Client :
Product / Produkt / Produit : OPTIMASS 1000 S15
Sales Order / VK-Auftrag / Commande de vente :
Order Number / Bestellnummer / Numéro de commission :
KROHNE Ref. No. :
Serial Number / Seriennummer / Numéro de série : G070000008300179
Tag No / Tagnummer / Numéro de étiquette :

Test Equipment Data

Weighing Scale Type	: ID1+/KCC300	Scale Certificate Number	: PT1509
Scale Serial Number	: 2492804/2491654	Calibration Fluid	: WATER
Scale Calibration Date	: 19/09/2006	No.of test runs per point	: Minimum 2
		Flow Rig Uncertainty (1)	: 0.035%

The calibration was performed in mass flow rigs using static weighing techniques in start / stop operation. All weighing scales are annually calibrated by a UKAS accredited laboratory.

(1) The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements. The equipment complies with the stated specification, as data sheet 7.02445.24.00, at the measured points, due allowance having been made for the uncertainty of measurements, comprising of flow rig uncertainty and specified repeatability.

Calibration - Result / Kalibrier – Resultat / Resultats de tests

Flow Rate Durchflussmenge Débit [%]	Set Flow Rate Gewählte Durchflussmenge débit voté [kg/h]	Measured Mass Gemessene Masse Masse mesuré [kg]	Actual Mass tatsächliche-Masse Masse réelle [kg]	Error Fehler Erreur [%]
14	691	64.3758	64.3410	0.054
52	2507	47.6075	47.5895	0.038
78	3748	48.2026	48.1991	0.007

Calibration Data / Kalibrierdaten / Données étalonnage

CF1: 22.1	CF2: 463.68	CF3: 300.00	CF4: 92.950310	CF5: 71733.648
CF6: 7.9334989	CF7: 0.0000000	CF8: 0.0000000	CF9: Generated from DCF's	CF10: Generated from DCF's
CF11: 175.20566	CF12: 23.256237	CF13: 0.0000000	CF14: 0.0000000	CF15: -75.850952
CF16: -61.402340	CF17: 0.0000000	CF18: 0.0000000	CF19: 1029.8513	CF20: 379.62173
CF21: 0.0000000	CF22: 0.0000000	CF23: 0.0000000	CF24: 0.0000000	CF25: 0
CF26: 0.0000000	CF27: 0.0000000			
DCF1: 2	DCF2: 998.61432	DCF3: 0.9948139	DCF4: 64.147560	DCF5: 0
DCF6: 0.0000000	DCF7: 1.0000000	DCF8: 56.681160		

Calibration Date / Kalibrierdatum / Date d´étalonnage : 2007-20-06

Signature / Unterschrift / Signature :

QK 44

FE-Ser.No. 00681578 FE-SW V2.1 BE-Ser.No. 673720 BE-SW 3.2.0_ Connections: 1/2" ANSI 150

KROHNE Ltd, Rutherford Drive, Park Farm Industrial Estate, Wellingborough, Northants NN8 6AE Tel.: +44 (0) 1933 408500, Fax: +44 (0) 1933 408501, www.krohne.co.uk

KROHNE

Calibration Test Certificate – Kalibrierprüfzertifikat – Certificat d'étalonnage

In accordance with / Gemäß / Selon: DIN 55 350 – 18-4.2.2

Product / Produkt / Produit: Optiswirl 4070
Serial Number / Seriennummer / Numéro de série: D090000000045215
Production Order / Produktionsauftr./ Numéro de production:
Customer Order / Bestellnummer / Commande de client:
TAG Number / TAG-Nummer / Repère:
Sales Order / VK-Auftrag / Commande de vente:
Customer / Kunde / Client:

Calibration Method / Kalibriermethode / Méthode d'étalonnage

This flowmeter was calibrated against an electromagnetic flow meter as a reference. This reference is traceable through NMi to international standards. Calibration was carried out with water.

Das Durchflussmessgerät ist mittels eines magnetisch induktiven Durchflussmessgeräts kalibriert worden. Dieses ist durch das NMI auf internationalen Standard rückführbar. Die Messung ist mit Wasser durchgeführt worden.

Ce débitmètre a été calibré par un débitmètre électromagnétique qui se réfère au standard international du NMI. Cette mesure a été réalisée avec de l'eau.

Test Equipment Data / Kalibrierstanddaten / Données du banc d'étalonnage
Serial Number / Seriennummer / Numéro de série: BP380

Calibration Results / Kalibrierdaten / Résultats d'étalonnage

Flow Rate Durchfluss Débit m_/h	Deviation Abweichung Déviation %
15,4	0,22%
46,4	0,05%
77,5	-0,22%

K-Factor: 2866,12 **pulses/ m_**

Additional Data / Zusatzdaten / Données complémentaires
Connections / Anschluss / Connexion: DN80 PN40
Pickup / Sensor / Capteur: 013002745.038

Date / Datum / Date:

Signature / Unterschrift / Signature:

DIN EN ISO 9001

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KROHNE Product overview

- Electromagnetic flowmeters
- Variable area flowmeters
- Ultrasonic flowmeters
- Mass flowmeters
- Vortex flowmeters
- Flow controllers
- Level meters
- Temperature meters
- Pressure meters
- Analysis products
- Measuring systems for the oil and gas industry
- Measuring systems for sea-going tankers

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