THE MIKES MEASURING SYSTEM FOR GAS MASS FLOW

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Abstract

Due to the increasing need for traceable gas flow measurements in Finland, the development of a national measurement standard for gas mass flow was initiated at the Centre for Metrology and Accreditation (MIKES) in 2002. A primary calibration system based on dynamic weighing was constructed to provide traceability directly to the national mass and time standards. The MIKES gas flow measuring system includes also a commercial calibrator based on laminar flow elements. It is used as a working standard when calibrating mass flow meters for customers. The calibration range encompasses 0,4 mg/s to 625 mg/s. The relative standard uncertainty of the gravimetric system is between 0,2 % and 0,4 %.

Introduction

Accurate gas flow measurements are based on regular calibrations of used gas flow meters. For example, the gas flow measurements carried out in pharmaceutical industry or medical treatments and health care have to be performed with very good reliability.

At the beginning of the year 2002 started the development and construction of a calibration system for small gas flow meters at the MIKES. The dynamic gravimetric method was chosen as the principle of operation for the primary standard. The calibration systems based on the same principle are in use for example in Physikalisch-Technische Bundesanstalt (PTB) and Bureau National de Métrologie-Laboratoire National d'Essais (BNM-LNE) [1], [2], [3]. Because a gravimetric standard is not very practical in routine calibration work, a commercial calibrator based on laminar flow elements (LFE) was purchased and calibrated against the primary standard.

In this paper, description of the calibration system and the uncertainty analysis for the gravimetric system is reported.

The MIKES primary and working standards for gas mass flow

The constructed primary standard is based on a direct mass flow measurement through dynamic weighing. Figure 1 shows a schematic diagram of the system.

The filling pressure of the weighed gas cylinder is 5 MPa. After the first pressure regulator, the gas pressure is reduced to 800 kPa. The coupling between the gas cylinder and the follow-through of draft shield is realised as a small PTFE tube (outer diameter 2 mm, inner diameter 1 mm). When the equilibrium of inner forces of the tube is reached, the balance is adjusted and tested by reference weights before starting measurements.

When the adjusted gas flow is regarded as stable, a measurement process is started. A computer records the readings of the balance, the time and temperature values over the measuring process.

Measuring time intervals range between 250 s and 10000 s. The time span between two recordings depends on the magnitude of the mass flow, varying from 5 s for 625 mg/s and to 25 s for 0,4 mg/s. The computer's own clock is used for time measurements. It is checked regularly against the time standard of Finland.

The mass loss of the cylinder is determined by a mass comparator with a capacity of 10,1 kg and a resolution of 1 mg. The mass loss is determined using the linear fitting in air buoyancy corrected balance readings over time values. By acting this way, it is possible to assess the gas flow stability afterwards using the calculated residuals of the mass values. If too much unstability is detected, the measurement results are rejected.
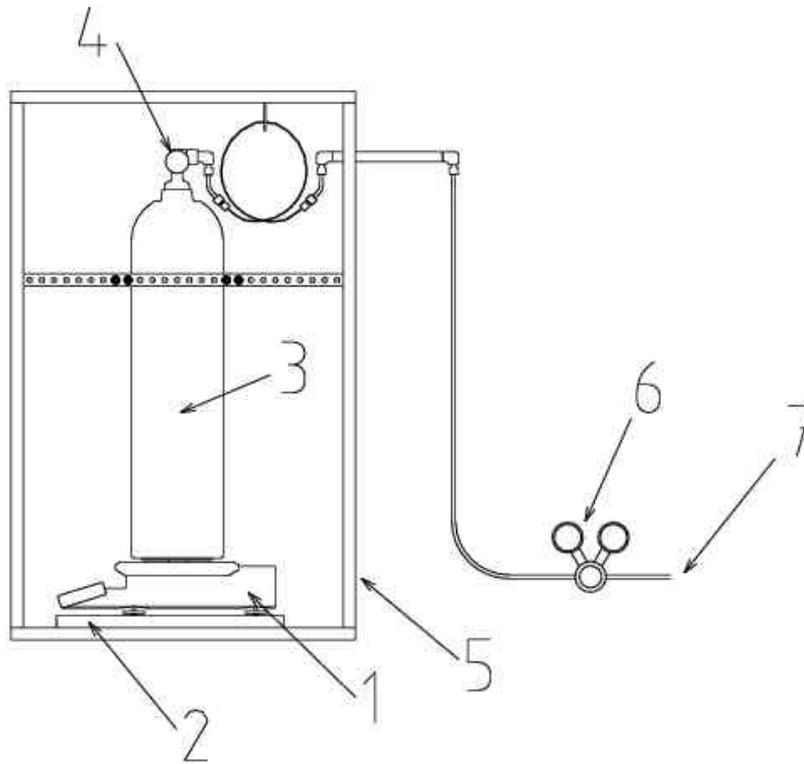

Figure 1. The MIKES primary standard for small gas flows. 1 balance, 2 stone plate, 3 gas cylinder, 4 shut-off valve, 5 draft shield, 6 two stage pressure regulator, 7 gas supply to the device under test (DUT)

Figure 2 shows the LFE-based calibration set-up at the MIKES. The system consists of two LFEs connected to a computation unit. The nominal flows for the LFEs are 20 mg/s and 625 mg/s. During routine calibrations, a 50 dm³ gas cylinder, filled with nitrogen, is used for calibration gas supply. The gas flow is controlled by a pressure regulator and a manual needle valve. The pressure before the LFE is approximately 270 kPa. A computer is used for controlling the system and for collecting the results from the calibrator and a device under test.
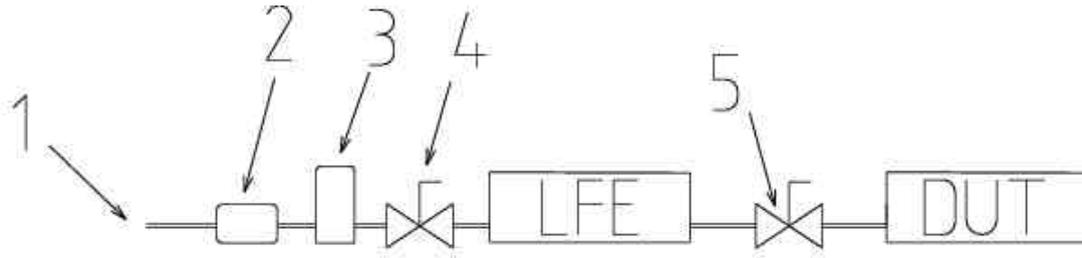
Figure 2. The routine calibration set-up for small gas flows at the MIKES. 1 calibration gas supply, 2 filter, 3 single stage pressure regulator, 4 shut-off valve, 5 control valve, LFE: laminar flow element

<u>Uncertainty analysis of the MIKES dynamic gravimetric method</u>

During measurements, the net force F acting to the weighing pan is

$$F = m_c g - r_a g V_0 + dF_U + dF_{conv},$$ (1)

where m_c is the mass of the gas cylinder, r_a density of air, V_0 volume of the gas cylinder, dF_U parasitic force caused by plastic connecting tube and dF_{conv} force caused by natural convection. From eq. (1) we can derive an equation for m_c:

$$m_c = L + dL + r_a V_0 - dm_U - dm_{conv},$$ (2)

where L is balance indication and dL correction due to the nonideal balance. The acceleration of gravity is supposed to be constant and its uncertainty insignificant. Thus an equation for $\dot{m}$ is

$$\dot{m} = \dot{L} + d\dot{L} + V_0 \dot{r}_a + r_a \dot{V}_0 - d\dot{m}_U - d\dot{m}_{conv}$$

(5)

and

$$\dot{m} \approx \frac{1}{\Delta t}\left(\Delta L + \Delta dL + V_0 \Delta r_a + r_a \Delta V_0 - \Delta dm_U - \Delta dm_{conv}\right),$$

$$\equiv G\left(\Delta L, \Delta dL, V_0, \Delta V_0, r_a, \Delta r_a, \Delta dm_U, \Delta dm_{conv}, \Delta t\right)$$ (6)

where ΔL is a measured gas mass loss during the measurement process, ΔV_0 calculated change in the cylinder's gas volume and Δr_a the change in air density. Assuming that variables are independent to each other, the combined standard uncertainty can be calculated in the following way [4]:

$$u_c^2(\dot{m}) = \sum_{i=1}^{9}\left(\frac{\partial G}{\partial y_i}\right)^2 u^2(y_i) \qquad y_i \in \{\Delta L, \Delta dL, V_0, \Delta V_0, r_a, \Delta r_a, \Delta dm_U, \Delta dm_{conv}, \Delta t\}$$ (8)

Table 1 shows the uncertainty calculation at gas mass flows 0,4 mg/s, 300 mg/s and 625 mg/s. $u(\Delta L)$ is the uncertainty due to flow stability, estimated as a deviation of mass residuals. Resulting from the balance unidealities, the uncertainty of a mass loss from the weighed gas cylinder $u(\Delta dL)$, has estimated to 10 mg at maximum. The uncertainty of the cylinder volume $u(V_0)$ was 0,58 dm³. Correspondingly, the change in the volume of the gas cylinder $u(\Delta V_0)$ caused by pressure diminution was determined taking into account the magnitude of gas flow and the used measuring time. Because the computer's measuring program causes drift to time measurements, the

uncertainty of the measuring time $u(\Delta t)$ was 0,5 s and the effect of the connecting tube dm_U was investigated by means of tests performed by reference weights. The magnitude of the force resulting from natural convection was studied theoretically and experimentally. The resulting standard uncertainty was under 0,2 mg/s at worst.

Table 1. Example of uncertainty budgets for dynamic gravimetric method at gas mass flows 0,4 mg/s, 200 mg/s and 625 mg/s. u_c* is the relative standard uncertainty

y_i	Unit	0,4 mg/s			300 mg/s			625 mg/s		
		c_i	$u(y_i)$	$c_i u(y_i)$	c_i	$u(y_i)$	$c_i u(y_i)$	c_i	$u(y_i)$	$c_i u(y_i)$
$u(DL)$	kg	9,98E-05	1,08E-05	1,08E-09	3,92E-03	1,17E-05	4,57E-08	3,92E-03	2,19E-05	8,58E-08
$u(DdL)$	kg	9,98E-05	1,00E-05	9,98E-10	3,92E-03	1,00E-05	3,92E-08	3,92E-03	1,00E-05	3,92E-08
$u(V_0)$	m³	2,66E-07	5,77E-04	1,54E-10	1,02E-06	5,77E-04	5,92E-10	6,30E-07	5,77E-04	3,64E-10
$u(DV_0)$	m³/s	1,20E-04	1,22E-07	1,47E-11	4,70E-03	2,30E-06	1,08E-08	4,69E-03	4,78E-06	2,24E-08
$u(r)$	kg/m³	2,12E-11	1,45E-03	3,07E-14	1,56E-08	1,45E-03	2,26E-11	3,25E-08	1,44E-03	4,69E-11
$u(Dr)$	kg/m³	1,06E-06	3,82E-05	4,04E-11	4,16E-05	1,26E-05	5,24E-10	4,16E-05	5,80E-06	2,41E-10
$u(Dt)$	s	4,26E-11	5,00E-01	2,13E-11	1,17E-06	5,00E-01	5,83E-07	2,44E-06	5,00E-01	1,22E-06
$u(D\ dm_U)$	kg	9,98E-05	7,00E-06	6,98E-10	3,92E-03	5,00E-06	1,96E-08	3,92E-03	7,00E-06	2,75E-08
$u(D\ dm_{conv})$	kg	9,98E-05	9,27E-11	9,25E-15	3,92E-03	4,01E-08	1,57E-10	3,92E-03	8,36E-08	3,28E-10
u_c	kg/s			1,64E-09			5,84E-07			1,22E-06
u_c*	%			**0,4**			**0,2**			**0,2**

The maximum relative standard uncertainty of the MIKES dynamic gravimetric weighing system of mass flows greater than 5 mg/s is 0,2 %. For smaller mass flows the relative standard uncertainty increases up to 0,4 %.

Conclusions

At the present configuration, the MIKES primary mass flow standard is used for calibration of LFEs and other high precision flow meters. The relative standard uncertainty of the gravimetric system is 0,2 % to 0,4 %.

During the construction phase, numerous different variations of the connecting tube were tested to find the best solution. The present solution of the tube has been detected to work well. Finding the right form and material of the tube was the most problematic part of the construction process.

The usability of the LFE-based calibration system makes it possible to do gas flow meter calibrations at the relative strandard uncertainty of 0,3 % to 0,5 %. By developing the usability and automation of the LFE calibration system, the capacity of the working standard can be improved. Performed test calibrations have been shown that it is difficult to cover the whole mass flow range with two LFEs. At gas flow regions under 10 % of LFE nominal flows, the instability of the LFE-based calibrator increases. By introducing one or two additional LFEs, the accuracy at these lower flow regions can be improved. More stable gas flow can be obtained by introducing thermal mass flow controllers.

By research and development will be lowered the uncertainty level and expanded the gas flow measurement scale of the MIKES calibration system.

References

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