

The Low Liquid Flow Calibration Facility

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Abstract

The low liquid flow calibration facility is developed together by Beijing Aerospace Propulsion Institute, National Institute of Metrology and Dandong Best Automatic Engineering & Meter Ltd. The facility is designed using static-gravimetric method to calibrate mass flow meters, turbine flow meters and vortex shedding flow meters, from 4 mm to 25 mm in diameter, at flow rates ranging from 8.2 kg/h to 10890 kg/h. It is designed as a integrated movable machinery, to construct a closed system to certificate flow meters. Besides, it can be combined with special test-bed systems to certificate flow meters on-line. The facility can automatically process flow adjusting, diverter switching, water tank bleeding, data acquiring, recording and printing, etc. It incorporates a diverter valve design, which greatly reduces the uncertainty associated with the flow diversion into the collection tank. This paper details design and construction novelties of the system and outlines the uncertainty of the calibration facility.

1 Introduction

The low liquid flow calibration facility have five parallel pipelines of 4 mm, 6 mm, 10 mm, 20 mm, 25

mm in diameter, with the capability of calibrating flow rates ranging from 8.2 kg/h to 10890 kg/h. It is designed as a integrated movable machinery, to construct a closed system to certificate flow meters. Besides, it can be combined with special test-bed systems to certificate flow meters on-line. The facility can automatically process flow adjusting, diverter switching, water tank bleeding, data acquiring, recording and printing, etc. The facility incorporates a diverter valve design (hereafter referred as a diverter), which reduces the uncertainty (error) associated with traditional diverter mechanisms. With the use of the diverter and better control over flow parameters, the expanded uncertainty ($k=2$) of the system is validated to be 0.03%.

In this paper, we describe the facility in detail and analyze its uncertainty.

2 Description of the Flow Facility

The low liquid flow calibration facility is a closed loop flow system; Fig. 1 shows a detailed layout of it. The facility is designed as a integrated movable machinery. Table. 1 shows the facility specifications. The facility is constructed by two dollies. One is fixed by a source water tank, a pump, and a filter (hereafter referred as a pump-dolly). The other one is equipped by flow meters, flow control valves, pipelines,

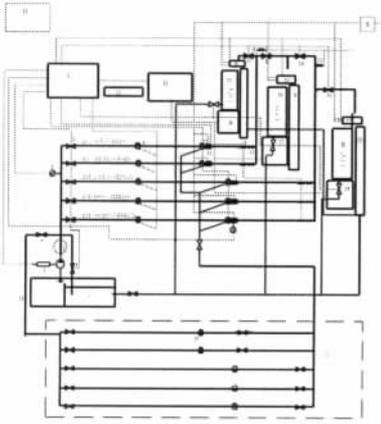


Fig. 1 sketch showing the layout of the facility

Table. 1 Facility Specifications

Feature	Tank1	Tank2	Tank3
Tank Volume, L	42	100	240
Tank Material	stainless steel	stainless steel	stainless steel
Scale Type	Scale	Scale	Scale
Scale Capacity, kg	15	60	150
Scale Resolution	0.1g(0.0082%)	2g(0.0125%)	-7g(0.0125%)
Pipe Size, mm	4 to 10	6 to 20	10 to 25
Flow Range, kg/h	8.2 to 1800	1000 to 7000	2000 to 10900
Working Pressure, MPa	0.1~1	0.1~1	0.1~1
Expanded Uncertainty	0.03%	0.03%	0.03%

multirange scale weighing system, and measuring and controlling system, etc (hereafter referred as a calibrate-dolly). The source water tank of the pump-dolly contains about 700 L of water. An adjustable velocity pump – max at 2.2 kW – can be operated to pump water from the source tank into the flow loop through a pressure adjustment filter, which removes granules and air bubbles from the water and levels off the flow pressure. Downstream the filter, the water flow into a customized manifold. The manifold splits the flow into five separate pipelines of 4 mm, 6 mm, 10 mm, 20 mm and 25 mm in diameter, a bypass of 25 mm in diameter which leads the flow return to the source water tank, and a bypass of 25 mm in diameter which leads to connect up outer system. Only one pipeline is operated at any given time. The outward bypass contains a switch ball valve that is used to cut off the flow when it loops in the facility

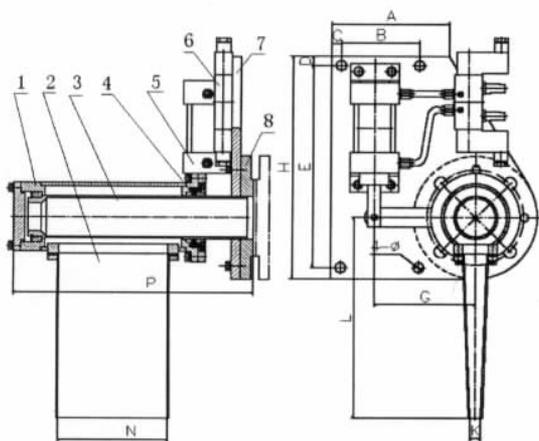
only. The return bypass contains a control ball valve that is used, in conjunction with the control valves on each pipeline and the adjustable velocity pump, to control the flow and working pressure within the test loop. The control valves of the four larger pipelines in diameter are fine control ball valves which are controlled by a electric actuator equipped with a 0 - 10 V position sensor. The control valve of the pipeline of 4 mm in diameter is a fine adjustment valve which is controlled by a electric actuator equipped with a 4 - 20 mA position sensor.

Each pipeline is fitted with a turbine flow meter, located downstream of the manifold, which helps measuring and controlling system to determine if the flow is in the test loop. Each pipeline has a straight section prior to the meter under test. The straight section provides an upstream straight length of about 22 diameters for the 25 mm pipeline. Straight lengths of 27, 55, 91 and 137 diameters, respectively, are available for the smaller pipelines. There are a compressed air clamp in each pipeline after the meter under test, Which drawtube can freely stretch out and draw back controlled by the compressed air to clamp the meter under test. Downstream the clamp there are two valves in each pipeline. One is a control ball valve which controls the flow and working pressure within the test loop. The other is a switch ball valve which switches the pipelines to allow flow pass through. Once the flow in each pipeline passes through the switch ball valve, it is flow into another two customized manifolds. The smaller two pipelines in diameter combine with a manifold, the other three pipelines combine with another manifold. Downstream the two manifolds, the flow is combined and split through three switch ball valves into three diverters. Each diverter corresponds to a weighing system. This framework allows the collection of fluid in smaller tanks if a low flow collection is needed.

2.1 The diverter

A typical static-gravimetric liquid flow calibration system uses a diverter valve, which, during the calibration cycle directs the calibration flow to either a bypass or a collection tank. The diverter error can be considered to be an uncertainty in the calibration time, and its error is a bias that cannot be reduced statistically by increasing the number of calibrations considered. Fast diverter actuation, longer collection time (i.e., larger collection tank), and symmetric timer actuation are techniques commonly used for reducing the diverter error. While these traditional techniques have attempted to minimize the diverter error, the approach described here seeks to eliminate the diverter error all together using a new diverter design.

The diverter uses a dual-directional diverter valve, which eliminates the bulk of the diverter error. Fig. 2 shows the diagram of the diverter assembly. The nozzle connects with the inside tube where the flow coming from. The inside tube is mounted on a pair of



1—Outside Tube; 2—Nozzle; 3—Inside Tube; 4—Axial Bearing;
5—Air Cylinder; 6—Electromagnetic Valve; 7—Underprop;
8—Incoming Flange.

Fig. 2 Diverter

axial bearings which are fitted in the outside tube and pivots about its axis to direct the flow from one side to the other. The movement of the nozzle is limited to a

maximum angle of 10 degrees from vertical on each side in order to minimize liquid splashing. The nozzle connected with the inside tube is controlled by the air cylinder which is driven by compressed air. The switch of the compressed air is controlled by the electromagnetic valve. Below the diverter there is a divider, which cuts the flow, and directs it between the collection tank and the bypass to the source tank. The uncertainty of the three diverter has been shown not to exceed 0.0025%.

2.2 The Measuring and Controlling System

The measuring and controlling system of the facility is designed to manage the calibration process automatically. The flow can be adjusted in two ways. One is to change the velocity of the pump, the other is to adjust the control ball valves. The process of the adjusting can be made by the measuring and controlling system automatically. The system manage the process by the rule of JJG897-1995 (for mass flow meters), and JJG198-1994 (for turbine flow meters and vortex shedding flow meters). The system uses a industrial controlling computer to deal with the process of adjusting the velocity of the pump, controlling the valves, measuring the flow and weight, calculating uncertainty, etc. Once operator installs the meter under test on the right pipeline and initializes the calibration software, all of he should do the next is just click the mouse to record the data and print the report, the measuring and controlling system will deal with the whole process. If he want to make some change of the process, he can interrupt the process at any time. The operating interface of the system is very friendly and can be master quickly. Fig. 3 shows the program of the calibration process of mass flow meters.

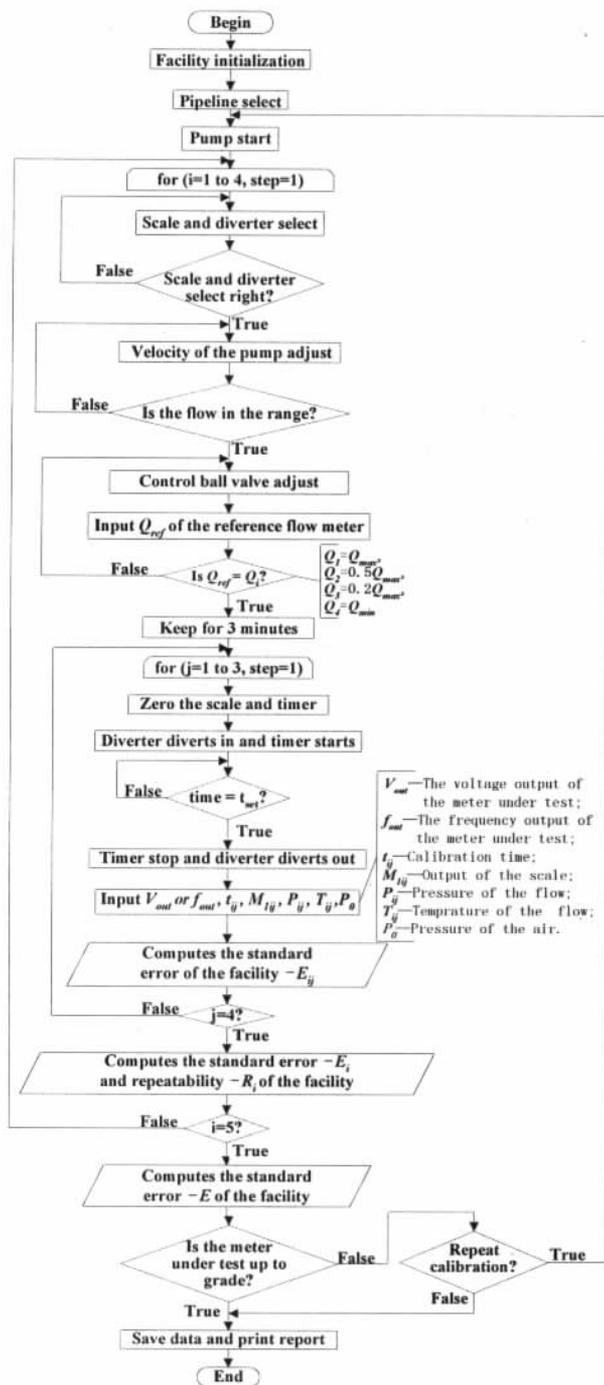


Fig. 3 Program of the calibration process of mass flow meters

2.2.1 The Measurement Principle

A conventional static-gravimetric liquid flow calibration facility is composed of a liquid reservoir, a pumping system, a pipeline to the meter under test, the meter under test, piping connecting the meter under

test to a timed collection system, a diverter valve, and a fluid weighing collection system. The diverter valve is used to direct flow either into the collection system or into a bypass, which returns the flow to the reservoir. The calibration flow is determined by collecting a prescribed mass of steadily flowing fluid over a measured time interval. During the calibration, other quantities (e.g., fluid temperature and pressure) are measured as needed to determine pertinent fluid properties.

Such static-gravimetric systems are, in fact, mass flow measurement facilities. The mass flow is defined by

$$q_S \equiv \frac{M_S}{\Delta t} \quad (1)$$

where q_S is the mass flow, M_S is the liquid mass through the tested meter during the time interval Δt .

2.2.2 The Uncertainty Analysis

The combined uncertainty of the flow facility is calculated by the rule of JJG164-2000, which use the root-sum-square (RSS) method to couple the uncertainty components that arise from the collected mass, collection time, and diverter

$$u = \sqrt{s_1^2 + s_2^2 + s_5^2 + s_6^2 + u_1^2 + u_2^2 + u_4^2 + u_F^2} \quad (2)$$

where u is the combined standard uncertainty of the facility, and $s_1, s_2, s_5, s_6, u_1, u_2, u_4,$ and u_F are the A and B class standard uncertainties of the timer, the weighing scale, the diverter, and the weight, respectively. The definition for measurement uncertainty is given in the following sections, and the uncertainties are discussed in the following sections and summarized in Table 2. A coverage factor of $k=2$ is used to convert the combined standard uncertainty to the expanded uncertainty with a 95% approximate level of confidence:

$$U = k \cdot u \quad (3)$$

2.2.2.1 The Uncertainty of the Timer

In the standard facilities for liquid flowrate (JJG 164-2000) the uncertainty of the timer is designed by:

A class relative standard uncertainty:

$$s_1 = \frac{1}{t_{\min}} \left[\frac{\sum_{i=1}^n (\Delta t_i - \Delta t)^2}{n-1} \right]^{\frac{1}{2}} \times 100\% \quad (4)$$

B class relative uncertainty:

$$u_1 = \frac{\Delta t}{2t_{\min}} \times 100\% \quad (5)$$

$$\Delta t = \frac{1}{n} \sum_{i=1}^n \Delta t_i$$

$$\Delta t_i = t_i - t_{0i}$$

where s_1 is the A class relative standard uncertainty of the timer, u_1 is the B class relative standard uncertainty of the timer, t_{\min} is the minimum calibration time span of the facility, t_i is the output of the timer, t_{0i} is the output of the standard timer, n ($n \geq 10$) is the repeat times of calibration..

2.2.2.2 The Uncertainty of the Scale

A class relatively standard uncertainty of number j single measurement is :

$$s_{2j} = \frac{1}{m_j + R_0} \left[\frac{\sum_{i=1}^n (\Delta m_i - \Delta m)^2}{n-1} \right]^{\frac{1}{2}} \times 100\% \quad (6)$$

B class relatively standard uncertainty of number j single measurement is :

$$u_{2j} = \frac{\Delta m}{2(m_j + R_0)} \times 100\% \quad (7)$$

A class relatively standard uncertainty:

$$s_2 = (s_{2j})_{\max} \quad (8)$$

B class relatively standard uncertainty:

$$u_2 = (u_{2j})_{\max} \quad (9)$$

$$\Delta m_i = R_{mi} - (m_j + R_0) \quad (10)$$

$$\Delta m = \frac{1}{n} \sum_{i=1}^n \Delta m_i \quad (11)$$

where m_j is the mass of the standard weight in number j times measurement, kg, R_0 is the average mass of n times measurement of the empty tank, kg, R_{mi} is the output of the standard weight which mass is m_i .

The uncertainty in the mass standards used to calibrate the scale, u_F , is 0.0005%.

2.2.2.3 The Uncertainty of the Diverter

There are two methods to calibrate the uncertainty of the diverter, and the more using is the distance dispersion method.

A class relatively standard uncertainty:

$$s_5 = \frac{1}{t_{\min}} \left[\frac{\sum_{i=1}^n (t_{1i} - t_1)^2}{n-1} \right]^{\frac{1}{2}} \times 100\% \quad (12)$$

$$s_6 = \frac{1}{t_{\min}} \left[\frac{\sum_{i=1}^n (t_{2i} - t_2)^2}{n-1} \right]^{\frac{1}{2}} \times 100\% \quad (13)$$

$$t_1 = \frac{\sum_{i=1}^n t_{1i}}{n} \quad (14)$$

$$t_2 = \frac{\sum_{i=1}^n t_{2i}}{n} \quad (15)$$

B class relatively standard uncertainty:

$$u_4 = \frac{t_1 - t_2}{4t_{\min}} \times 100\% \quad (16)$$

where t_{1i} is the time span of number i times that the diverter diverts in, t_{2i} is the time span of number i times that the diverter diverts out, t_{\min} is the minimum calibration time span of the facility.

Table 2. Mass Flow Measurement Uncertainty

		Scale 1	Scale 2	Scale 3
		%	%	%
1. Timer	s_1	0.0050	0.0050	0.0050
	u_1	0.0010	0.0010	0.0010
	Crystal Surge Stabilization	0.0001	0.0001	0.0001
	Standard Timer	Model: BLJ-2 Veracity: 5×10^{-7} Certificate: WXpj2004-0843		
2. Collected Water Mass Measurement	s_2	0.0082	0.0125	0.0125
	u_2	0.0082	0.0062	0.0018
	Usable Range	(1.2~15) kg	(16~60) kg	(50~150) kg
3. Diverter	s_5	0.0007	0.0006	0.0015
	s_6	0.0022	0.0005	0.0015
	u_4	0.0047	0	0
	Method	Distance Difference Method		
4. Standard Weight	u_F	0.0005	0.0005	0.0005
	Certificate	1e200309010	1e200203105	1e200203105
5. Flow Stabilization		0.35%		
6. Least Calibration Time		30s		
7. Flow Range		(0.0082~1.8) t/h	(1~7) t/h	(2~10.9) t/h
8. The Uncertainty of the Facility	Standard Uncertainty u	0.014	0.015	0.015
	Expanded Uncertainty $U (k=2)$	0.03	0.03	0.03

3 Conclusions

The low liquid flow calibration facility is designed using static-gravimetric method to calibrate mass flow meters, turbine flow meters and vortex shedding flow meters from 4 mm to 25 mm in diameter, at flow rates from 8.2 kg/h to 10890 kg/h. With the use of the diverter and better control over flow parameters, the expanded uncertainty ($k=2$) of the system is validated to be 0.03%.

4 Acknowledgement

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5 References

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