Bilateral Key Comparison
NMIA – VSL
EURAMET Project No. 1415

Gas Flow Bilateral Comparison from 800 m³ h^{-1} to 7000 m³ h^{-1} using Air at Room Temperatures and Atmospheric Pressures

Final Report

Pilot
NMIA, Australia

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1 Introduction

A comparison was organized to determine the degree of equivalence of standards for low-pressure gas flow measurement over the range 800 $m^3\,h^{-1}$ to 7000 $m^3\,h^{-1}$ at ambient pressure and room temperature. A G6500 Elster Instromet turbine flow meter was used as the transfer standard. For this comparison, the G6500 meter was provided by VSL with NMIA acting as a pilot lab. This comparison was conducted to assist in the verification of the newly established high-flow low-pressure standard at NMIA.

2 Participants and planning

The participants and proposed planning are shown in Table 1. Each laboratory was allowed 1 month to perform the measurements (including receiving and preparation for transport). The total transport costs were estimated at AUD15k, which was covered by NMIA.

Table 1 – Participants and proposed time schedule

Country	NMI	Shipping address	Contact	remarks	delivery date	pickup date
Netherlands (PILOT)	VSL Dutch Metrology Institute	Thijsseweg 11, 2629 JA, Delft Netherlands	Peter Lucas, Gerard Blom plucas@vsl.nl gblom@vsl.nl	whole range, no limitations		March 2017
Australia	National Measurement Institute	36 Bradfield Rd, Lindfield, NSW 2070	Dr Khaled Chahine Khaled.chahine@measurement.gov.au	800 to 7000 $m^3\,h^{-1}$	March 2017	April-July 2017
Netherlands (PILOT)	VSL Dutch Metrology Institute	Thijsseweg 11, 2629 JA, Delft Netherlands	Peter Lucas, Gerard Blom plucas@vsl.nl gblom@vsl.nl	whole range, no limitations	July 2017	July-August 2017

Brief descriptions of the flow facilities, at VSL and NMIA, used in this comparison are as follows.

2.1 VSL flow facility

(N.B.: Information in this section is provided by VSL, submission was slightly modified for editorial purposes by the author of this report)

The turbine meter used for this bilateral comparison was calibrated on the 'Large Installation' facility of VSL, located on the premises of VSL at Delft, Thijsseweg 11. The installation is made up of (see Figure 1)

1. two axial blowers, one for flow rates up to 4000 $m^3\,h^{-1}$ and one for flow rates up to 15000 $m^3\,h^{-1}$,
2. a regulated heat exchanger after the blowers,
3. a data acquisition system,
4. piping, and
5. pressure transducers, temperature sensors and five reference meters.

Figure 1 – The "Large Installation" facility at VSL with a range of flowrate from 15 to 15000 $m^3\ h^{-1}$.

Details of the reference meters used in this comparison, including their type and range, are presented in *Table 2:*

Table 2: Reference meters in Large Installation at VSL

Standard nr	Type	Manufacturer	Range
2	G250 IRM-A-DUO rotor meter	Instromet	15 – 400 $m^3\ h^{-1}$
3	G650 SM-RI-X turbine meter	Instromet	175 – 1130 $m^3\ h^{-1}$
4	G2500 SM-RI-X-E turbine meter	Instromet	1000 – 4190 $m^3\ h^{-1}$
5	G4000 SM-RI-D turbine meter	Instromet	1200 – 6600 $m^3\ h^{-1}$
6	G6500 SM-RI-D Turbine meter	Instromet	3000 – 10000 $m^3\ h^{-1}$

When possible, overlap measurements between two VSL reference meters are performed to ensure repeatability and reproducibility of these meters and at the same to check for any drift or change in their calibrations. The reference meters are all traceable to national and/or international primary standards. The recommended recalibration interval of these meters is 3 years. The CMC of the installation within the range of 1000 $m^3\ h^{-1}$ to 10000 $m^3\ h^{-1}$ is ±0.15 %.

2.2 NMIA flow facility

The "Blue Spaghetti Monster Array", or BSMA, located at NMIA West Lindfield was used in this bilateral comparison, see Figure 2. This array consists of 28 critical flow Venturi nozzles connected in parallel to produce flow rates from 50 $m^3 h^{-1}$ to 7000 $m^3 h^{-1}$ at atmospheric conditions and room temperatures (flows can be generated at an increment of 25 $m^3 h^{-1}$). The diameters of the nozzles used in this comparison varies from 9 mm up to 21.2 mm. During testing, air is drawn from the laboratory through the meter under test then to the nozzles. A 140 kW suction blower is used at downstream of nozzles to maintain pressures below 75 kPa (This ensured that sonic conditions were occurring at nozzle throats). The operation of the array is fully automated in which flows are generated using pneumatic valves controlled by a PC. This enabled little intervention from the user and allows for more comprehensive testing. A schematic diagram of the setup used in the measurements is included in Appendix A.

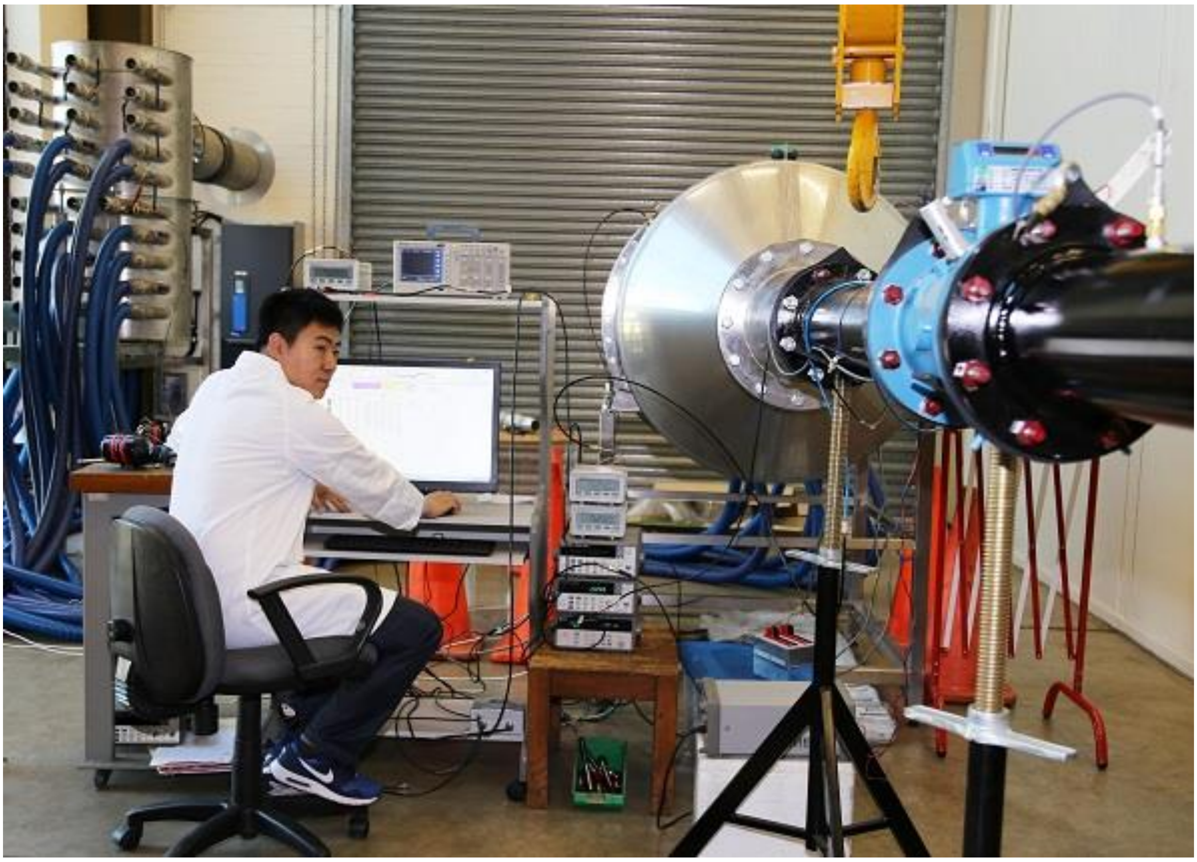

Figure 2 – The Blue Spaghetti Monster Array, or BSMA, at NMIA's Lindfield site consists of 28 critical flow Venturi nozzles with diameter varying from 9 mm to 21.2 mm to produce a flow range from 50 $m^3 h^{-1}$ to 7000 $m^3 h^{-1}$ at atmospheric pressures and temperatures.

The nozzles were calibrated at NMIA with an uncertainty of ±0.12%. These calibrations are traceable to NMIA's bell and mercury sealed piston provers [1]. Typically for turbine meters (similar to the one used in this bilateral comparison), the expected uncertainties can vary from ±0.15% to ±0.18% depending on the repeatability of the meter and the measurement conditions; pulse output count, temperature, pressure and relative humidity measurements at inlet/outlet of the meter.

3 Transfer standard

An Instromet Turbine meter model G6500, shown in Figure 3, was used in this comparison with the following specifications.

Type:	SM-RI-X-L Turbine meter
Manufacturer:	Instromet
G-value:	G6500
Q_{min}	800 $m^3\ h^{-1}$
Q_{max}	10000 $m^3\ h^{-1}$
Serial number:	65515
P_{max} :	10 bar
Pulse output (HF1 and HF2)	313.597 pulses m^{-3}
Inside diameter:	DN 400
Flange type and pressure schedule:	DIN 2632 PN10
Remarks:	NMIA used their own flanges to connect the meter to the upstream and downstream pipes.

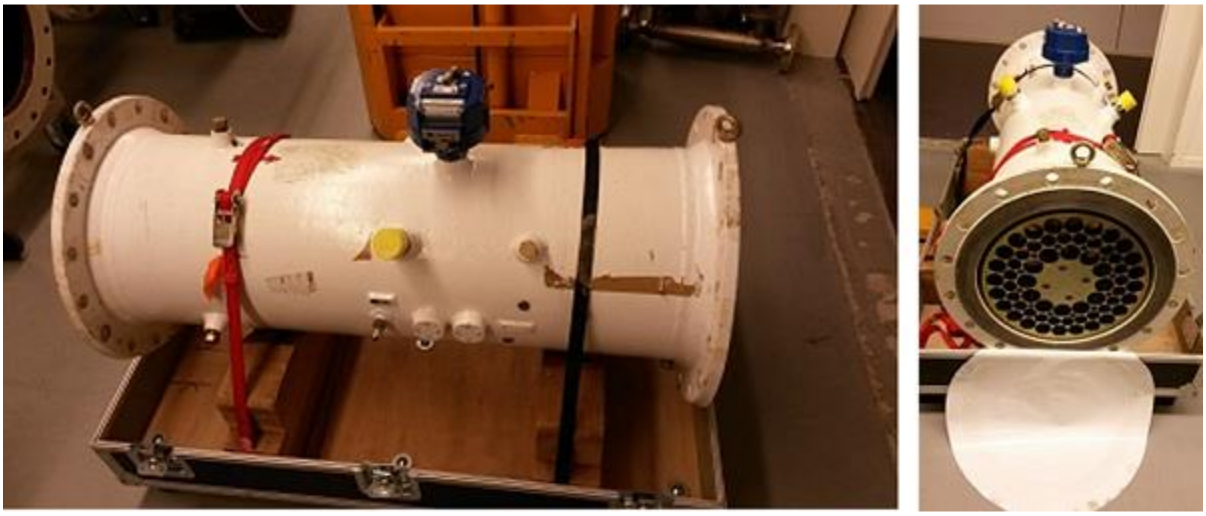

Figure 3 – Instromet turbine meter G6500

4 Measurement procedures

4.1 Calibration protocol

The participating labs were advised to use their usual calibration test method. Both labs provided detailed descriptions of their test methods used (see Appendix A). Guidelines for recommended measurement procedures were given as follows:

- The transfer standard is to be tested in the horizontal position.
- The straight upstream pipe length should be at least 5 times the internal diameter of the pipe, whereas the downstream length should be at least 3 times this diameter.
- The pressure at the transfer standard is measured at the port labelled "P_r" (e.g.: the pressure tap located on the meter body close to the turbine wheel). The meter has various pressure taps, however the one to use is labeled accordingly.
- The temperature at the transfer standard is taken as the upstream temperature. If that is not possible then use the downstream one but this needs to be indicated when reporting final results.
- It is necessary that measurements are taken using the HF pulse connection. There may be various HF connections; however the one to use is labeled accordingly.
- The flow points should be measured from the highest flow rate to the lowest; measurement should start at the highest flow rate that can be achieved by the lab. Furthermore, prior to the commencement of measurements the meter needs to be operated for a period of time of 5 minutes or more.
- The test at each flow rate should be repeated at least 3 times. The flow rate has to be set within ± 3% of the required value.
- At each set flow point, ensure that the generated flow rate is stabilized prior to taking measurements. This will depend on the facility and can take up to several minutes to achieve.

4.2 Measurement conditions and flow points

The range of this bilateral comparison was for flowrates from 800 $m^3\ h^{-1}$ to 7000 $m^3\ h^{-1}$. Testing was conducted at atmospheric pressures with an allowable range of temperatures between 19.5°C and 23.5°C. The ambient pressure, temperature and relative humidity were measured and recorded. The nominal flow rates for this comparison are given in Table 3.

Table 3. Nominal flows for bilateral comparison between VSL and NMIA.

Transfer standard	**Diameter**	**Nominal Flow Rates ($m^3\ h^{-1}$)**
G6500	DN400	800, 1000, 2000, 3000, 4000, 5000, 6000, 7000

4.3 Reporting the results

The following measured parameters should be reported:

1. absolute pressure at the meter location,

2. temperature at the meter location,
3. differential pressure across the meter,
4. relative humidity of the air, and
5. relative error of the meter and the uncertainty in the reference flow at *k*=1 (evaluated at *k*=2, however the data template has been set up for a value of *k*=1).

For the uncertainty in the reference flow one can use the CMC of the facility. According to WG-FF guidelines [2], the CMC can be determined using:

$$U_{CMC} = 2\sqrt{u_{\text{base}}^2 + \left(\frac{t_{95}}{2}\frac{s_{\text{repeat, BED}}}{\sqrt{n}}\right)^2}$$

where s is the sample standard deviation of n repeatability measurements and t_{95} is 95% confidence level t-value for n-1 degrees of freedom

The relative error of the transfer standard ε in (%) is the quantity that will be used to compare the results. It is defined as the difference between the volume rate indicated by the transfer standard and the volume rate as measured by the labs represented by the following equation:

$$\varepsilon = \frac{Q_{TS} - Q_{ref}}{Q_{ref}} \qquad (1)$$

where ε is the relative error of the transfer standard (%),
Q_{TS} is the volume rate indicated by the transfer standard ($m^3\ h^{-1}$),
Q_{ref} is the volume rate measured by the reference ($m^3\ h^{-1}$).

Based on the reported results the following values are computed (@*k*=2): the average reference flow rate ($m^3\ h^{-1}$), the average indicated flow rate ($m^3\ h^{-1}$), the standard deviation of ε and the uncertainty of the calibration (%).

The headings given in Table 4 are to be used for reporting all the above terms.

Table 4. Example of the table layout required for the VSL-NMIA bilateral comparison.

Nominal flow rate	id	absolute pressure at TS	pressure loss over TS	temperature at TS	reference flow rate (Q_{ref})	indicated flow rate (Q_{TS})	Error (ε)	uncertainty of the reference flow (*k*=1)
($m^3\ h^{-1}$)	(-)	(Pa)	(Pa)	(°C)	($m^3\ h^{-1}$)	($m^3\ h^{-1}$)	(%)	(%)

5 Evaluation of Measurement Results

The meter was firstly tested at VSL on 29 March 2017 then shipped to NMIA. After measurements were taken at NMIA on 29 June 2017, the meter was shipped back to VSL and the measurements were repeated on 24 August 2017. Using the headings of Table 4 and the results reported by both laboratories, the results were tabulated and are presented in Appendix B; see Tables B.1, B.2 and B.3.

The VSL measurements in Tables B.1 and B.3 are averaged with standard deviations calculated at each flowrate and are presented in Tables 5 and 6.

Table 5. Summary of VSL measurements dated 29th of March 2017 (before shipping to NMIA).

Nominal Flow	Reference Flow (Q_{Ref})	Indicated Flow (Q_{TS})	Standard Deviation	Uncertainty (@k=2)
($m^3\ h^{-1}$)	($m^3\ h^{-1}$)	($m^3\ h^{-1}$)	(%)	(%)
800	799.8	801.1	0.003	±0.150
1000	1001.9	1002.8	0.001	±0.150
2000	2000.8	2003.4	0.003	±0.150
3000	3000.3	3006.3	0.002	±0.150
4000	4002.3	4009.1	0.004	±0.150
5000	4996.5	5002.1	0.005	±0.150
6000	6007.0	6010.3	0.006	±0.150
7000	7002.9	7002.9	0.005	±0.150

Table 6. Summary of VSL measurements dated 24th of August 2017.

Nominal Flow	Reference Flow (Q_{Ref})	Indicated Flow (Q_{TS})	Standard Deviation	Uncertainty (@k=2)
($m^3\ h^{-1}$)	($m^3\ h^{-1}$)	($m^3\ h^{-1}$)	(%)	(%)
800	801.9	803.2	0.004	±0.150
1000	1000.0	1000.9	0.006	±0.150
2000	1997.2	1999.8	0.002	±0.150
3000	3001.1	3007.2	0.002	±0.150
4000	3998.0	4004.6	0.003	±0.150
5000	4999.2	5004.1	0.006	±0.150
6000	5999.2	6001.9	0.003	±0.150
7000	7004.1	7004.0	0.006	±0.150

On the other, NMIA results in Table B.2 were fitted to a 6th order polynomial equation as follows:

$$Q_{Ref} = C_0 + C_1 Q_{TS} + C_2 Q_{TS}^2 + C_3 Q_{TS}^2 + C_4 Q_{TS}^4 + C_5 Q_{TS}^5 + C_6 Q_{TS}^6 \qquad (2)$$

where

Q_{Ref} is the reference flow as measured by NMIA in $m^3\ h^{-1}$,

Q_{TS} is the indicated flow by the transfer standard,

C_0 = -15.215 [$m^3\ h^{-1}$],

C_1 = 1.03607,

C_2 = -2.9554×10^{-5} [$m^3\ h^{-1}$]$^{-1}$,

C_3 = 1.1160×10^{-8} [$m^3\ h^{-1}$]$^{-2}$,

C_4 = -2.1734×10^{-12} [$m^3\ h^{-1}$]$^{-3}$,

C_5 = -2.1670×10^{-16} [$m^3\ h^{-1}$]$^{-4}$, and

C_6 = -8.7365×10^{-21} [$m^3\ h^{-1}$]$^{-5}$.

Using equation (2), the reference and indicated flows can be calculated at any nominal flow value, which are calculated for various flowrates and presented in Table 7.

Table 7. Summary of NMIA measurements dated 29th of June 2017.

Nominal Flow	Reference Flow (Q_{Ref})	Indicated Flow (Q_{TS})	Standard Deviation	Uncertainty (@k=2)
($m^3\ h^{-1}$)	($m^3\ h^{-1}$)	($m^3\ h^{-1}$)	(%)	(%)
800	799.6	800.0	0.004	±0.170
1000	1000.5	1000.0	0.006	±0.170
2000	1999.6	2000.0	0.002	±0.170
3000	2998.6	3000.0	0.002	±0.170
4000	4000.2	4000.0	0.003	±0.170
5000	5003.6	5000.0	0.006	±0.170
6000	6008.6	6000.0	0.003	±0.170
7000	7013.0	7000.0	0.006	±0.170

Values of the relative error of the transfer standard ε, as defined in equation (1), are calculated using values of Q_{Ref} and Q_{TS} in Tables 5, 6 and 7. These values are presented graphically in Figure 2.

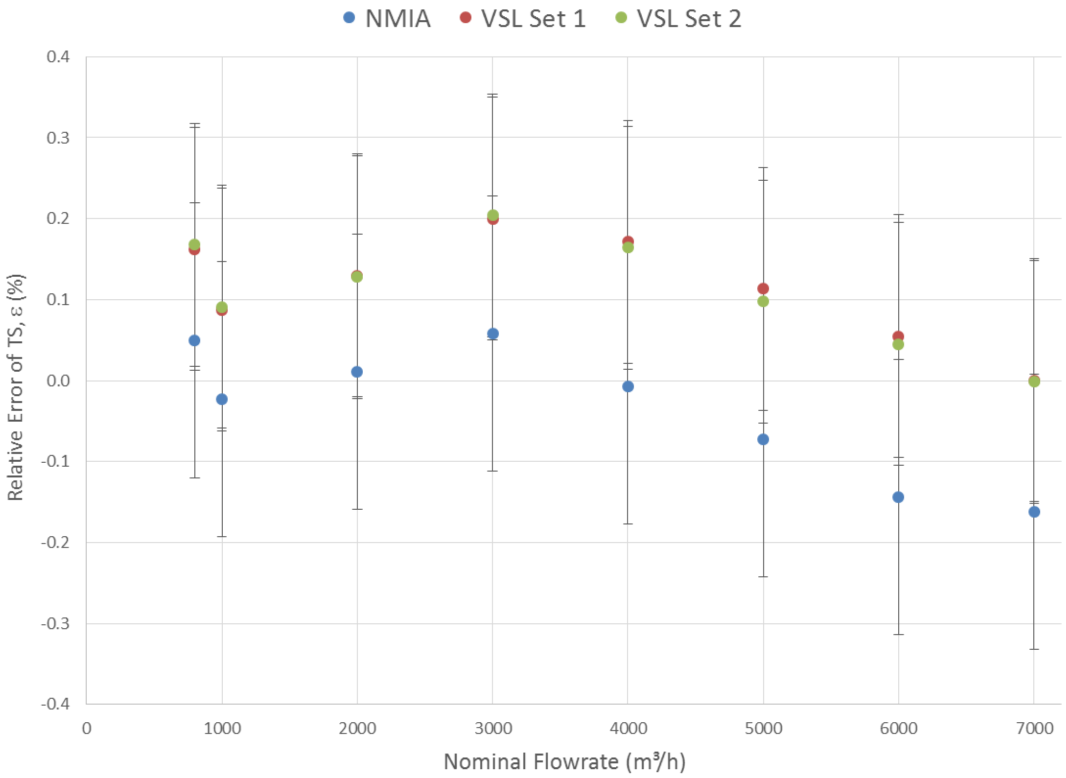

Figure 2, plots of the relative errors along with their error bars at flowrates range from 800 $m^3\,h^{-1}$ to 7000 $m^3\,h^{-1}$ measured by VSL and NMIA using an Instromet G6500 turbine meter as a transfer standard.

It can be deduced from the graph in Figure 2 that the drift of the measurements taken by VSL before shipping the standard to NMIA and after its return are less than 0.016%, which is considered negligible when compared to a total expanded uncertainty of 0.15%. The average of both VSL measurements can then be calculated and compared to the ones taken by NMIA with negligible increase to VSL reported measurement uncertainties. Using the average values of VSL and the measurements of NMIA, the E_n ratio can be used to compare the results of both labs, which is given by the following equation:

$$E_n = \frac{|\varepsilon_{VSL} - \varepsilon_{NMIA}|}{\left(U_{VSL}^2 + U_{NMIA}^2\right)^{0.5}} \tag{3}$$

where

ε_{VSL} is the relative error calculated by VSL at each flowrate,

ε_{NMIA} is the relative error obtained by NMIA,

U_{VSL} is the expanded uncertainty reported by VSL, and

U_{NMIA} is the expanded uncertainty reported by NMIA

The E_n ratio was calculated at each nominal flowrate and the results are presented in Table 10.

Table 8. Comparison of VLS and NMIA measurements using E_n ratio.

Nominal Flow	Relative Error of TS, ε		Uncertainty, U		E_n
	VSL	NMIA	VSL	NMIA	
(m^3 h^{-1})	(%)	(%)	(%)	(%)	
800	0.17	0.05	0.15	0.17	0.51
1000	0.09	-0.02	0.15	0.17	0.50
2000	0.13	0.01	0.15	0.17	0.52
3000	0.20	0.06	0.15	0.17	0.63
4000	0.17	-0.01	0.15	0.17	0.77
5000	0.11	-0.07	0.15	0.17	0.79
6000	0.05	-0.14	0.15	0.17	0.86
7000	0.00	-0.16	0.15	0.17	0.71

As can be observed from Table 8, all E_n ratio values are less than unity and therefore comparison results between VSL and NMIA are deemed to be acceptable.

6 Conclusions

The results of the bilateral comparison between VSL and NMIA support the CMCs claimed by each of this laboratory. This is evident by the E_n ratio values obtained in Table 8, which show all values to be less than unity.

On the other hand, it can be observed that the results of VSL and NMIA have a systematic error of around 0.15%. The difference is within the specified uncertainty given by both labs however it is recommended that this error is investigated.

References

[1]. Chahine, K. (2005), Comparison of Low Pressure Gas Flow Standards. Flomeko 2005; Peebles, Scotland. 2005

[2]. WGFF, WGFF Guidelines for CMC Uncertainty and Calibration Report Uncertainty, technical report, October 2013, available online at http://www.bipm.org/utils/en/pdf/ccm-wgff-guidelines.pdf

[3]. Valeta, T., EURAMET project 1296, pilot CMI, protocol and final report can be found via http://www.euramet.org/index.php?id=tc-f-projects

[4]. Lucas, P. and Blom, G., EURAMET project No. 1333, pilot VSL, protocol and final report can be found via http://www.euramet.org/index.php?id=tc-f-projects

Appendix A

NMIA Facility

Schematic diagram of the NMIA setup used in the bilateral comparison between NMIA and VSL using an Instromet G6500 turbine meter is shown in Figure A.1.

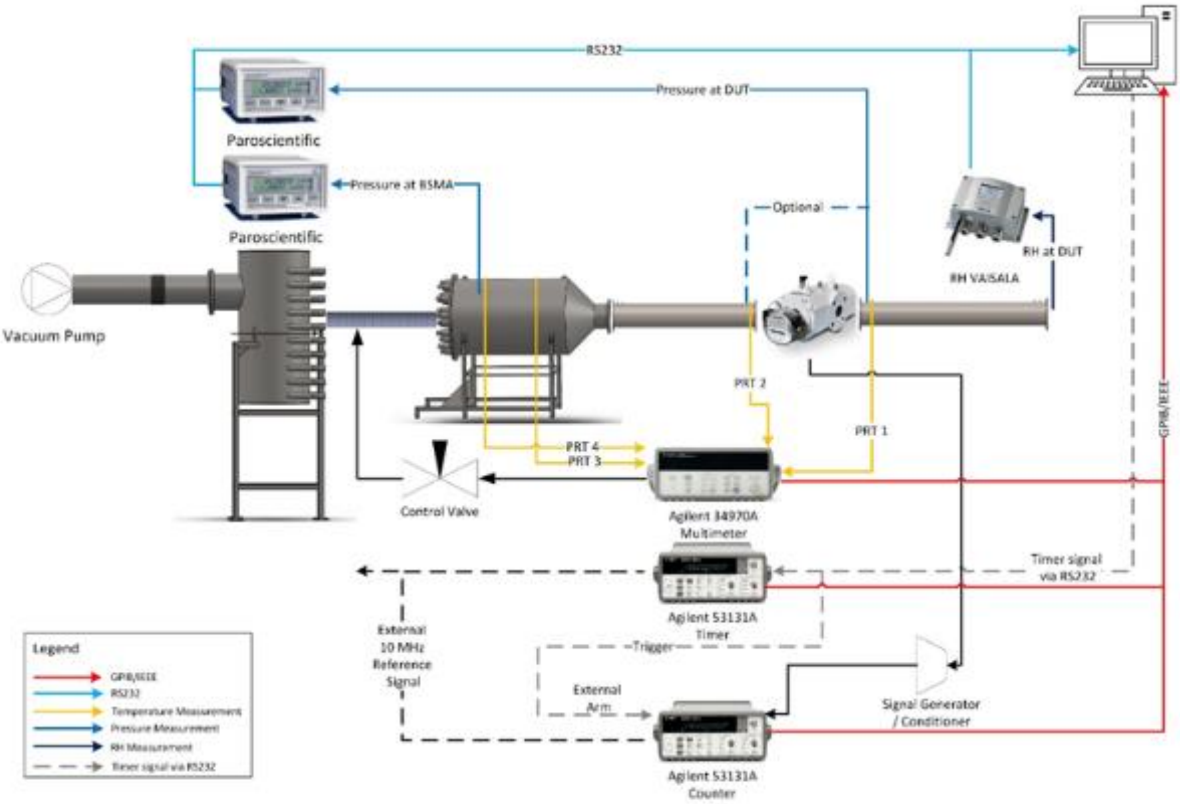

Figure A.1. Schematic diagram of the setup used at NMIA to calibrate turbine meter for flow range up to 7000 m³ h⁻¹

As can be seen from Figure A.1, the Blue Spaghetti Monster Array (or BSMA) consists of 28 critical flow Venturi nozzles placed in parallel with diameters varying from 9 mm to 21.2 mm. The array can produce flowrates from 50 $m^3 h^{-1}$ to 7000 $m^3 h^{-1}$ at an increment of 25 $m^3 h^{-1}$. A 140 kW vacuum blower is used downstream of the array to ensure a pressure drop across nozzles is greater than 20 kPa (needed to achieve sonic conditions at nozzle throats). All nozzles are calibrated internally by comparing them to other smaller size nozzles; these smaller nozzles are calibrated using the bell and mercury sealed piston provers at NMIA. Note that calibration of nozzles were carried out at two different upstream pressures: atmospheric and 5 kPa lower. This was done to evaluate the pressure dependency of the nozzle coefficient. The measurement uncertainty of nozzles used in the BSMA was calculated to be ±0.12%.

During testing, the meter is placed upstream of the nozzle array, in which air is drawn from the laboratory through the meter then to the nozzle array. Two pipes are used at inlet and outlet of the meter to act as flow straighteners (the tube lengths exceeded the recommended ones). Temperatures were measured at inlet and outlet of the meter using 100Ω platinum resistance thermometers, PTRs. Pressures were measured at meter port and meter outlet, which were used to calculate the pressure drop across the meter. Relative humidity of the lab was also measured. Measurements of pressure and temperature at upstream of nozzles were recorded and used to calculate the mass flowrate. Using this calculated value along with pressure and temperature measurements at meter location, volume flowrates were calculated at meter conditions.

All instrumentations were connected to a PC via either their serial communication ports or their GPIB/IEEE interfaces. This allowed for automating the measurements with minimum user intervention. The measurements were conducted at 250 $m^3 h^{-1}$ interval and were repeated at least 4 times at each flowrate.

VSL Facility

The G6500 turbine meter used for this inter-comparison has been calibrated on the 'Large Test Facility' at VSL, located in the VSL Low Pressure Flow laboratory in Delft, Thijsseweg 11, The Netherlands (refer to Figure 1 and Table 2 for more details about transfer VSL) standards. The facility consists of two axial blowers, one for low flow rates (up to 4000 $m^3 h^{-1}$) and one for high flow rates (up to 15000 $m^3 h^{-1}$), a regulated heat exchanger after the blowers, a data acquisition system, software, piping, pressure and temperature sensors and five reference meters.

In this inter-comparison reference meter with number 5 and 6 are used within the range of the G6500 turbine meter. When possible, overlap measurements between the two VSL reference meters have been performed.

The reference meters are all traceable to primary and/or (inter) nationally accepted measurement standards. The recalibration interval of the reference meters is three years.

The CMC of the installation within the range of 15 – 15000 $m^3 h^{-1}$ is ±0.15 %.

The test procedure used by VSL is the test procedure as outlined in the Technical Protocol for EUROMET Project No. 1415. As an addition to this procedure the temperature of the reference meters and the meter under test are monitored during each flow rate. Once stabilization has occurred, the measurement is started.

Appendix B

Tables B.1, B.2 and B.3 contain the results of VSL first testing dated on 29 March 2017, NMIA testing on 29 June 2017 and VSL second testing on 24 August 2017 respectively.

Table B.1 First set of VSL results dated 29th of March 2017 (before shipping to NMIA).

Nominal flow rate	id	absolute pressure at TS	pressure loss over TS	temperature at TS	reference flow rate (Q_{ref})	indicated flow rate (Q_{TS})	Error (ε)	uncertainty of the reference flow (*k*=1)
		(Pa)	(Pa)	(°C)	($m^3 h^{-1}$)	$m^3 h^{-1}$	(%)	(%)
800	1	102327	2.8	19.878	799.783	801.063	0.160	0.075
	2	102324	2.7	19.881	799.713	801.019	0.163	0.075
	3	102324	2.7	19.887	799.844	801.120	0.160	0.075
	4	102328	2.8	19.897	799.663	800.972	0.164	0.075
	5	102328	2.8	19.903	800.145	801.479	0.167	0.075
1000	6	102329	3.8	19.816	1001.953	1002.830	0.088	0.075
	7	102333	3.6	19.823	1001.739	1002.624	0.088	0.075
	8	102333	3.8	19.830	1001.877	1002.742	0.086	0.075
	9	102331	3.9	19.831	1001.853	1002.734	0.088	0.075
	10	102331	3.8	19.839	1002.181	1003.042	0.086	0.075
2000	11	102319	13.1	19.999	2000.866	2003.397	0.126	0.075
	12	102319	13.1	19.998	1999.757	2002.368	0.131	0.075
	13	102320	13.2	20.000	2001.362	2003.943	0.129	0.075
	14	102323	13.2	20.001	2001.227	2003.911	0.134	0.075
	15	102323	13.2	19.997	2000.576	2003.176	0.130	0.075
3000	16	102321	31.0	19.999	3000.972	3006.877	0.197	0.075
	17	102321	30.6	20.009	2999.551	3005.573	0.201	0.075
	18	102321	30.7	20.013	2999.588	3005.576	0.200	0.075
	19	102315	31.0	20.005	3000.131	3006.194	0.202	0.075
	20	102325	31.2	19.999	3001.208	3007.182	0.199	0.075
4000	21	102320	55.1	19.980	3998.593	4005.363	0.169	0.075
	22	102316	55.2	19.980	4000.253	4007.243	0.175	0.075
	23	102315	55.6	19.989	4004.408	4011.302	0.172	0.075

	24	102317	55.2	19.984	4004.761	4011.726	0.174	0.075
	25	102311	55.3	19.987	4003.302	4009.941	0.166	0.075
5000	26	102297	89.0	19.923	4994.828	5000.784	0.119	0.075
	27	102295	88.9	19.938	4994.874	5000.522	0.113	0.075
	28	102297	89.4	19.947	5000.204	5006.008	0.116	0.075
	29	102297	88.5	19.954	4996.555	5002.133	0.112	0.075
	30	102288	89.1	19.958	4995.825	5001.106	0.106	0.075
6000	31	102279	131.5	19.856	6012.741	6015.701	0.049	0.075
	32	102278	130.4	19.870	6004.555	6007.897	0.056	0.075
	33	102278	130.2	19.874	6004.797	6008.344	0.059	0.075
	34	102269	130.8	19.886	6007.385	6010.295	0.048	0.075
	35	102262	131.0	19.890	6005.649	6009.393	0.062	0.075
7000	36	102230	177.2	19.915	7004.017	7003.750	-0.004	0.075
	37	102227	178.0	19.905	7002.300	7002.007	-0.004	0.075
	38	102228	179.2	19.891	7005.431	7005.479	0.001	0.075
	39	102230	177.2	19.879	6999.613	6999.694	0.001	0.075
	40	102231	177.8	19.870	7003.092	7003.653	0.008	0.075

Table B.2. NMIA results dated 29th of June 2017.

Nominal flow rate	id	absolute pressure at TS	pressure loss over TS	temperature at TS	reference flow rate (Q_{ref})	indicated flow rate (Q_{TS})	Error (ε)	uncertainty of the reference flow (*k*=1)
		(Pa)	(Pa)	(°C)	(m^3 h^{-1})	m^3 h^{-1}	(%)	(%)
800	1	101142	0.9	17.914	745.618	745.799	0.02	0.070
	2	101112	0.8	18.445	747.086	747.183	0.01	0.070
	3	101013	1.0	18.961	748.214	748.666	0.06	0.070
	4	100894	1.2	19.202	748.329	749.311	0.13	0.070
	5	100736	1.1	19.096	748.255	749.079	0.11	0.070
	6	100761	1.1	19.199	748.440	749.223	0.10	0.070
	7	100733	1.2	19.285	748.535	749.317	0.10	0.070
	8	100703	1.1	19.519	748.993	749.604	0.08	0.070
1000	9	101135	2.2	17.872	993.914	992.999	-0.09	0.070
	10	101111	2.3	18.390	995.778	994.781	-0.10	0.070
	11	101003	2.6	18.815	997.417	997.353	-0.01	0.070

	12	100897	2.5	19.182	997.935	998.112	0.02	0.070
	13	100761	2.5	19.082	997.900	997.830	-0.01	0.070
	14	100741	2.6	19.153	998.012	997.836	-0.02	0.070
	15	100717	2.6	19.295	998.291	998.205	-0.01	0.070
	16	100701	2.6	19.316	998.285	998.174	-0.01	0.070
1250	17	101126	3.9	17.743	1241.999	1240.910	-0.09	0.070
	18	101101	3.9	18.229	1244.179	1242.786	-0.11	0.070
	19	101002	4.3	18.765	1246.754	1246.287	-0.04	0.070
	20	100908	4.2	19.245	1247.770	1247.384	-0.03	0.070
	21	100772	4.5	19.075	1247.556	1246.884	-0.05	0.070
	22	100717	4.2	19.110	1247.449	1246.949	-0.04	0.070
	23	100715	4.2	19.325	1248.091	1247.503	-0.05	0.070
	24	100694	4.3	19.291	1247.854	1247.525	-0.03	0.070
1500	25	101587	6.5	18.819	1494.029	1493.765	-0.02	0.070
	26	101574	6.5	19.726	1496.545	1495.852	-0.05	0.070
	27	101592	6.5	19.520	1495.212	1495.067	-0.01	0.070
	28	101631	6.4	18.989	1493.969	1494.016	0.00	0.070
	29	101120	5.7	17.739	1490.298	1488.917	-0.09	0.070
	30	101095	5.9	18.094	1492.563	1491.740	-0.06	0.070
	31	101003	6.2	18.864	1496.543	1495.347	-0.08	0.070
	32	100909	6.4	19.281	1497.405	1496.811	-0.04	0.070
1750	33	101567	8.8	18.709	1741.572	1741.797	0.01	0.070
	34	101554	9.1	19.618	1744.659	1744.335	-0.02	0.070
	35	101570	9.3	19.757	1744.445	1744.482	0.00	0.070
	36	101609	9.4	18.986	1742.035	1742.716	0.04	0.070
	37	101112	8.1	17.653	1738.443	1737.125	-0.08	0.070
	38	101076	8.0	18.026	1741.043	1740.278	-0.04	0.070
	39	101009	8.6	18.745	1745.280	1744.433	-0.05	0.070
	40	100902	8.7	19.272	1746.786	1746.376	-0.02	0.070
2000	41	101555	12.1	18.638	1989.599	1990.569	0.05	0.070
	42	101529	11.9	19.461	1992.836	1993.350	0.03	0.070
	43	101536	11.9	20.032	1994.593	1994.920	0.02	0.070
	44	101584	12.0	18.935	1990.263	1991.386	0.06	0.070
	45	101126	11.4	17.283	1985.489	1984.930	-0.03	0.070
	46	101048	11.1	17.912	1989.494	1989.087	-0.02	0.070
	47	101011	11.1	18.619	1993.893	1992.895	-0.05	0.070
	48	100898	12.1	19.140	1995.532	1995.343	-0.01	0.070
2250	49	101530	15.4	18.644	2237.856	2239.493	0.07	0.070
	50	101505	15.5	19.325	2241.047	2241.907	0.04	0.070
	51	101509	15.1	20.157	2244.457	2244.781	0.01	0.070
	52	101552	15.7	18.905	2238.443	2240.296	0.08	0.070

2500	53	101506	19.2	18.853	2487.435	2489.138	0.07	0.070
	54	101475	19.2	19.275	2489.613	2490.658	0.04	0.070
	55	101477	19.7	20.156	2493.687	2494.090	0.02	0.070
	56	101518	19.1	18.948	2486.738	2489.230	0.10	0.070
2750	57	101479	23.6	18.968	2736.467	2738.366	0.07	0.070
	58	101439	23.4	19.054	2736.805	2738.556	0.06	0.070
	59	101439	23.8	20.066	2742.471	2742.826	0.01	0.070
	60	101483	24.0	19.168	2736.503	2738.965	0.09	0.070
3000	61	101458	28.2	19.068	2986.187	2987.900	0.06	0.070
	62	101401	28.0	19.045	2984.951	2987.277	0.08	0.070
	63	101399	28.9	19.865	2990.563	2991.366	0.03	0.070
	64	101440	28.5	19.622	2987.953	2990.197	0.08	0.070
3250	65	101421	34.0	18.997	3234.764	3236.255	0.05	0.070
	66	101362	34.1	19.483	3237.792	3239.129	0.04	0.070
	67	101355	35.3	19.474	3237.456	3238.203	0.02	0.070
	68	101393	34.9	19.698	3238.107	3239.284	0.04	0.070
3500	69	101385	39.3	18.920	3483.846	3484.913	0.03	0.070
	70	101323	39.9	19.722	3489.944	3490.021	0.00	0.070
	71	101312	40.6	19.514	3488.328	3489.132	0.02	0.070
	72	101350	39.9	19.575	3486.924	3487.769	0.02	0.070
3750	73	101329	46.1	18.664	3730.822	3731.845	0.03	0.070
	74	101280	46.7	19.531	3739.003	3739.126	0.00	0.070
	75	101266	47.0	19.560	3738.984	3738.910	0.00	0.070
	76	101298	45.6	19.386	3734.976	3736.729	0.05	0.070
4000	77	100627	55.0	19.874	3995.214	3993.809	-0.04	0.070
	78	100680	53.6	19.562	3992.803	3992.458	-0.01	0.070
	79	100675	54.6	20.088	3997.341	3996.223	-0.03	0.070
	80	100698	54.1	19.671	3993.826	3993.666	0.00	0.070
	81	101285	52.3	18.559	3979.171	3979.975	0.02	0.070
	82	101231	54.1	19.464	3988.460	3987.718	-0.02	0.070
	83	101215	54.0	19.683	3988.764	3988.193	-0.01	0.070
	84	101243	53.9	19.482	3986.744	3986.774	0.00	0.070
4250	85	100573	60.9	19.876	4245.113	4243.374	-0.04	0.070
	86	100624	61.2	19.460	4241.795	4240.773	-0.02	0.070
	87	100620	61.8	19.996	4246.802	4245.034	-0.04	0.070
	88	100642	60.2	19.593	4242.908	4242.511	-0.01	0.070
	89	101230	60.7	18.539	4228.615	4228.680	0.00	0.070
	90	101177	60.3	19.320	4235.814	4234.915	-0.02	0.070
	91	101160	60.7	19.792	4238.097	4237.206	-0.02	0.070
	92	101186	62.5	19.542	4235.891	4235.241	-0.02	0.070
4500	93	100520	67.4	19.933	4495.665	4493.062	-0.06	0.070

	94	100563	67.4	19.424	4490.739	4489.504	-0.03	0.070
	95	100560	69.0	19.899	4495.898	4493.477	-0.05	0.070
	96	100585	68.3	19.627	4493.426	4492.439	-0.02	0.070
	97	101180	69.6	18.407	4475.868	4476.046	0.00	0.070
	98	101119	68.5	19.024	4481.202	4480.515	-0.02	0.070
	99	101105	69.5	20.043	4490.132	4487.267	-0.06	0.070
	100	101125	70.1	19.496	4483.587	4482.237	-0.03	0.070
4750	101	100462	77.2	19.868	4744.418	4741.919	-0.05	0.070
	102	100497	77.3	19.469	4740.786	4739.148	-0.03	0.070
	103	100499	78.0	19.832	4745.765	4742.457	-0.07	0.070
	104	100523	78.0	19.523	4742.182	4740.237	-0.04	0.070
5000	105	100400	87.4	20.030	4995.932	4991.275	-0.09	0.070
	106	100431	84.6	19.575	4990.720	4988.046	-0.05	0.070
	107	100440	87.0	19.651	4993.226	4988.747	-0.09	0.070
	108	100458	86.0	19.438	4991.042	4987.868	-0.06	0.070
5250	109	100338	96.6	20.167	5246.522	5241.373	-0.10	0.070
	110	100364	93.2	19.799	5241.789	5237.967	-0.07	0.070
	111	100377	95.7	19.509	5240.975	5235.758	-0.10	0.070
	112	100392	94.4	19.362	5239.035	5235.135	-0.07	0.070
5500	113	100265	107.6	20.478	5500.454	5492.356	-0.15	0.070
	114	100286	106.8	20.475	5499.189	5491.955	-0.13	0.070
	115	100310	104.6	19.365	5487.369	5482.636	-0.09	0.070
	116	100314	105.3	19.307	5487.519	5482.044	-0.10	0.070
5750	117	100197	117.1	20.219	5747.049	5737.889	-0.16	0.070
	118	100210	116.4	20.418	5748.254	5740.207	-0.14	0.070
	119	100234	116.1	19.454	5736.819	5731.544	-0.09	0.070
	120	100243	112.3	19.260	5734.779	5729.902	-0.09	0.070
6000	121	100113	126.6	20.049	5994.649	5984.356	-0.17	0.070
	122	100133	126.8	20.262	5995.552	5986.694	-0.15	0.070
	123	100162	126.5	19.769	5989.054	5981.591	-0.12	0.070
	124	100163	126.0	19.369	5984.058	5978.445	-0.09	0.070
6250	125	100039	137.6	19.858	6240.455	6229.392	-0.18	0.070
	126	100055	137.9	20.137	6243.562	6232.932	-0.17	0.070
	127	100087	141.3	20.193	6243.738	6233.497	-0.16	0.070
	128	100081	136.2	19.634	6236.172	6228.131	-0.13	0.070
6500	129	99960	149.9	19.681	6487.687	6475.075	-0.19	0.070
	130	99973	149.3	20.030	6491.072	6479.156	-0.18	0.070
	131	100006	150.8	20.073	6491.138	6480.457	-0.16	0.070
	132	100001	149.5	19.994	6489.672	6479.472	-0.16	0.070
6750	133	99878	160.2	19.504	6733.076	6720.875	-0.18	0.070
	134	99883	163.4	19.997	6739.072	6726.596	-0.19	0.070

	135	99925	161.1	19.928	6738.381	6726.433	-0.18	0.070
	136	99919	160.9	20.136	6741.537	6729.038	-0.19	0.070
7000	137	99796	172.2	19.507	6980.696	6968.348	-0.18	0.070
	138	99794	173.3	19.907	6986.795	6973.038	-0.20	0.070
	139	99840	170.8	19.820	6985.492	6973.287	-0.17	0.070
	140	99831	177.0	20.181	6990.584	6977.578	-0.19	0.070

Table B.3. Second set of VSL results dated 24th of August 2017.

Nominal flow rate	id	absolute pressure at TS	pressure loss over TS	temperature at TS	reference flow rate (Q_{ref})	indicated flow rate (Q_{TS})	Error (ε)	uncertainty of the reference flow (*k*=1)
		(Pa)	(Pa)	(°C)	(m^3 h^{-1})	m^3 h^{-1}	(%)	(%)
800	1	101646	2.8	19.937	800.150	801.508	0.170	0.075
	2	101647	2.7	19.939	801.563	802.950	0.173	0.075
	3	101648	2.7	19.937	802.131	803.454	0.165	0.075
	4	101645	2.8	19.938	802.571	803.891	0.164	0.075
	5	101650	2.8	19.937	802.912	804.252	0.167	0.075
1000	6	101631	3.8	19.977	999.260	1000.268	0.101	0.075
	7	101632	3.6	19.974	1000.955	1001.890	0.093	0.075
	8	101637	3.8	19.968	1000.913	1001.797	0.088	0.075
	9	101637	3.9	19.970	998.887	999.741	0.085	0.075
	10	101638	3.8	19.966	999.988	1000.869	0.088	0.075
2000	11	101621	13.1	20.010	1998.183	2000.748	0.128	0.075
	12	101623	13.1	20.010	1997.195	1999.781	0.129	0.075
	13	101623	13.2	20.011	1995.953	1998.535	0.129	0.075
	14	101624	13.2	20.006	1998.290	2000.763	0.124	0.075
	15	101625	13.2	20.006	1996.438	1998.981	0.127	0.075
3000	16	101597	31.0	20.023	3000.327	3006.434	0.204	0.075
	17	101597	30.6	20.024	3001.217	3007.304	0.203	0.075
	18	101597	30.7	20.026	3001.002	3007.053	0.202	0.075
	19	101598	31.0	20.028	2999.974	3006.130	0.205	0.075
	20	101600	31.2	20.034	3002.737	3008.934	0.206	0.075
4000	21	101574	55.1	19.994	3996.487	4003.081	0.165	0.075

	22	101574	55.2	20.000	3998.231	4004.797	0.164	0.075
	23	101570	55.6	20.002	4001.211	4007.549	0.158	0.075
	24	101582	55.2	20.005	3995.080	4001.727	0.166	0.075
	25	101582	55.3	20.012	3999.197	4005.832	0.166	0.075
5000	26	101530	89.0	19.932	4994.652	4999.313	0.093	0.075
	27	101527	88.9	19.939	5002.415	5007.671	0.105	0.075
	28	101527	89.4	19.945	4999.730	5004.877	0.103	0.075
	29	101526	88.5	19.957	5001.296	5005.992	0.094	0.075
	30	101527	89.1	19.965	4997.901	5002.520	0.092	0.075
6000	31	101474	131.5	19.824	5999.204	6002.059	0.048	0.075
	32	101474	130.4	19.836	5996.934	5999.769	0.047	0.075
	33	101473	130.2	19.847	5995.665	5998.228	0.043	0.075
	34	101477	130.8	19.855	5996.852	5999.635	0.046	0.075
	35	101476	131.0	19.854	6007.418	6009.890	0.041	0.075
7000	36	101401	177.2	19.830	7003.337	7003.906	0.008	0.075
	37	101401	178.0	19.817	7003.884	7003.705	-0.003	0.075
	38	101403	179.2	19.813	7008.861	7008.664	-0.003	0.075
	39	101402	177.2	19.813	7002.386	7002.056	-0.005	0.075
	40	101405	177.8	19.800	7001.932	7001.514	-0.006	0.075