ITRI
Industrial Technology Research Institute

Report on Activities and Measurement Capabilities in Mass and Related Quantities of CMS/ITRI

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ITRI
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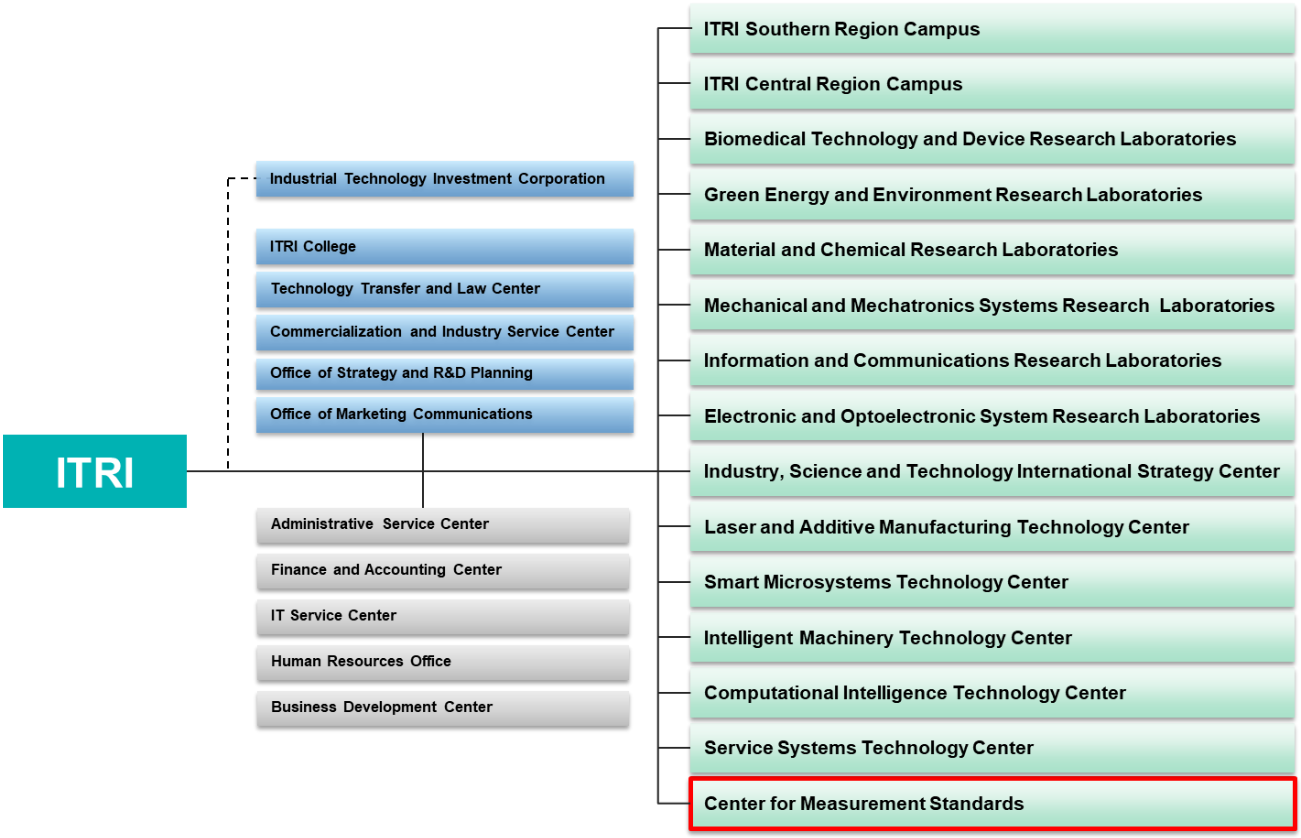
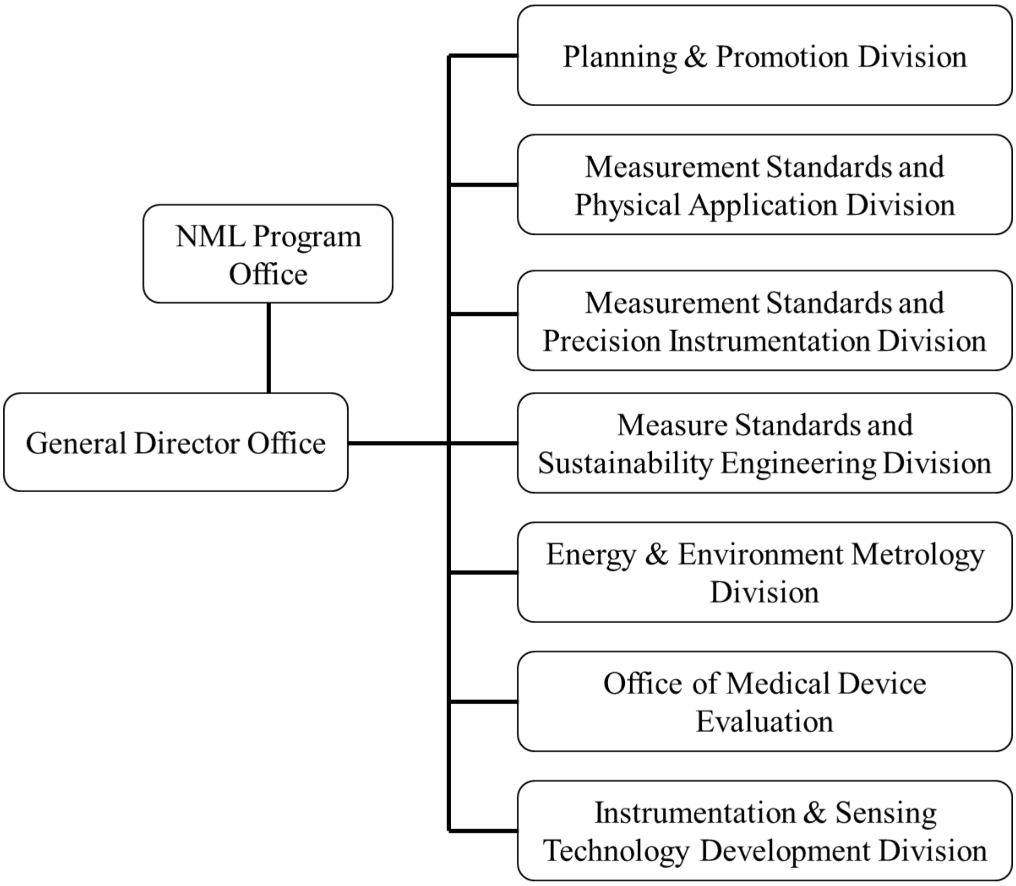
Introduction

Industrial Technology Research Institute (ITRI) is a nonprofit R&D organization engaging in applied research and technical services for innovating a better future. Founded in 1973, ITRI has been dedicated to helping industries stay competitive and sustainable. Over the years, ITRI has nurtured more than 260 companies, including well-known global semiconductor leaders such as TSMC and UMC. Meanwhile, it has cultivated over 140 CEOs in the local high-tech industry. ITRI has played a vital role in Taiwan's economic growth as it shifted the industry from a labor-intensive business into a value-added, technology-driven one.



Organization Chart of ITRI

Center for Measurement Standards (CMS) was founded by ITRI in 1985 to carry out the Weight and Measures Calibration project of the Ministry of Economic Affairs (MOEA). In 1987, MOEA designated the established laboratory as National Measurement Laboratory (NML). The initial intended mission of CMS was to establish and maintain the national measurement standards. From the experiences and capacities built of the primary standards techniques conforming to the world's metrology society, CMS expands R&D scope to instrumentation and sensing, smart sensing, medical device evaluation, and energy and environment metrology. The core technologies of these fields are developed to help the industry gaining the international market competition with advanced technology and quality assurance. There are 7 divisions in CMS. The businesses of NML are operated by three primary divisions, namely the Measurement Standards and Physical Application Division, Measurement Standards and Precision Instrumentation Division and Measure Standards and Sustainability Engineering Division. Two laboratories under these divisions are responsible for the metrology of Mass and Related Quantities, namely Mechanics & Medical Metrology Research Laboratory and Flow & Green Energy Metrology Laboratory. Currently, there are 27 staffs working in these two laboratories.



Organization Chart of CMS

National Measurement Laboratory (NML)

Mission of NML

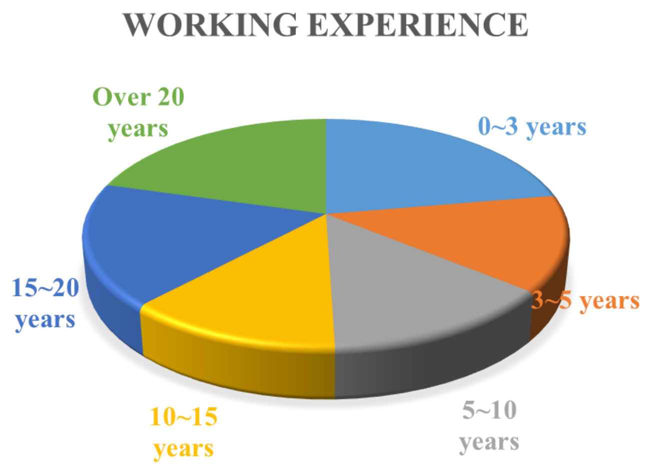
The National Measurement Laboratory (NML) of Taiwan was established in 1987, and soon began providing measurement services to government agencies and the private sector.

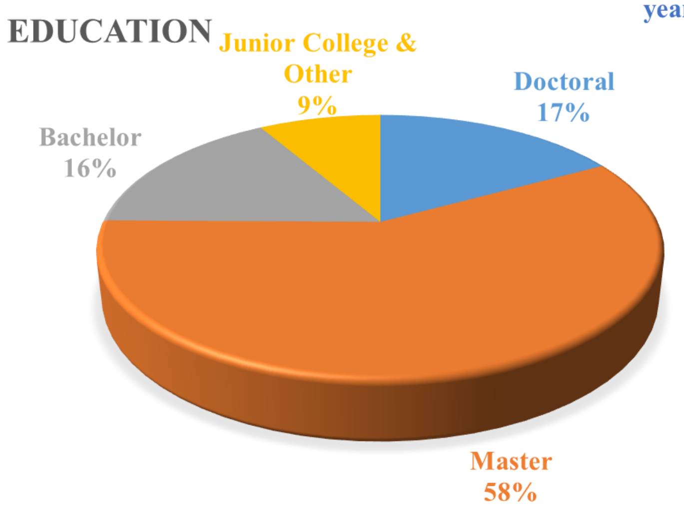
To assure traceability and global conformity, NML actively participates in the comparison programs carried out by the BIPM and regional/international metrology organizations. In 2002, we joined CGPM as an

Associate and signed the global Mutual Recognition Arrangement, the calibration and measurement capabilities (CMCs) have been incorporated in BIPM's key comparison database (KCDB). It declares that NML's CMCs have gained international recognition and its availability of offering measurement service worldwide.

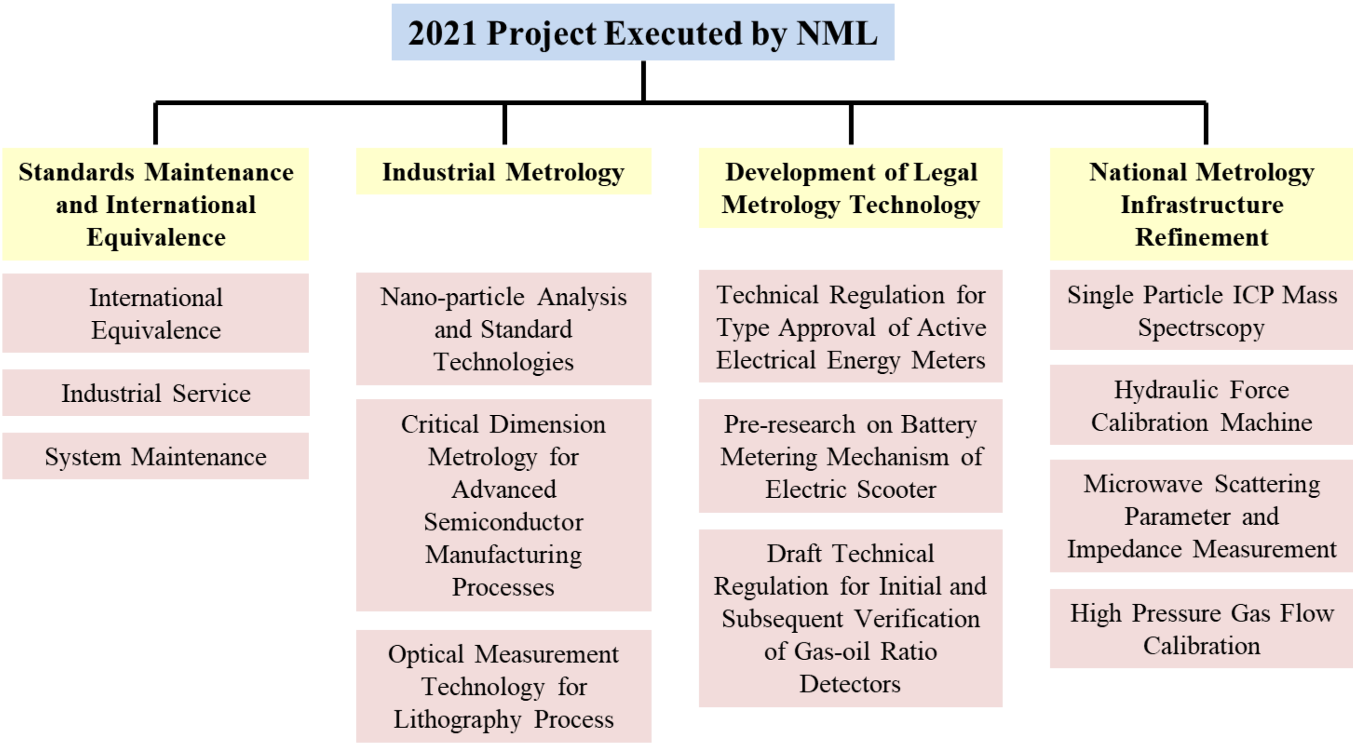
NML has established national measurement standards in 15 fields of electricity, magnetics, microwave, luminous intensity, temperature, humidity, chemistry, vibration, acoustics, dimension, mass, force, pressure, vacuum, and flow. Based on the well-established national standards, extensive calibration services are made available to industry.

Human Resource of NML





Major Projects at NML



Quality System

The quality system of NML conforms to ISO/IEC 17025:2017 for calibration laboratory. The reassessment in Mass and Related Quantities was held in September, 2020 by the Taiwan Accreditation Foundation (TAF). The Certificate of Accreditation, with certificate number of N0882 is effective since January, 01 2021.

Metrology for Mass and Related Quantities at NML/CMS

Fluid Flow

Flow measurement closely relates to economic development and people's daily life, such as supply of tap water, gas and fuel, and even the air pollution monitoring. NML/CMS has 10 fluid flow national calibration systems (as table 1 showing) that include water, hydrocarbon, gas, air speed system etc. With participating in or piloting BIPM and APMP international key comparisons, NML/CMS maintains its national flow standards and international equivalence in fluid flow measurement.

Table1: Fluid Flow standard in NML/CMS

【F01】Large Water Flow Calibration System	(10 to 8000) L/min	Primary standard
【F02】Small Water Flow Calibration System	(2 to 700) L/min	Primary standard
【F03】Low-Viscosity Oil Flow Calibration System	(60 to 6000) L/min @ 2.6 mm^2/s to 4.8 mm^2/s	Primary standard
【F04】High-Viscosity Oil Flow Calibration System	(60 to 6000) L/min @ 37 mm^2/s to 150 mm^2/s	Primary standard
【F05】High Pressure Gas Flow Calibration System	(15 to 12000) Sm^3/h	Primary standard
【F06】Low Pressure Gas Flow Calibration System - Piston Prover	(0.002 to 24) L/min	Primary standard
【F08】Low Pressure Gas Flow Calibration System – (Bell Prover:600 L)	(20 to 1000) L/min	Primary standard
【F10】Air Speed Calibration System	(0.5 to 25) m/s	Primary standard
【F11】Micro Flow Calibration System	0.1 µL/min to 10 mL/min	Primary standard
【F12】Low Pressure Gas Flow Calibration System (PVTt) – PVTt Method	0.01 L/min to 300 L/min	Primary standard

A brief introduction/summary of FF metrology.

Force and Torque

CMS/ITRI has established a set of force standards in the range from 50 nN to 2 MN consisting of a electrostatic sensing & actuating micro-force standard of full capacity of 10 µN, a mass balance based small force standard of full capacity of 10 N, deadweight force standard machines of full capacity of 500 N, 5 kN and 50 kN, and three hydraulic force generation and comparison machines of full capacity of 200 kN, 500 kN and 2 MN. For torque standard, there is only one deadweight type torque standard machine of full capacity of 5 kNm.

Gravimetry

The gravimetric activities of CMS aim to realize and maintain a precise standard of gravity for Taiwan. The absolute value of g was measured for metrology purpose as well as to calculate geoid models for geospatial applications. Taiwan gravity reference stations were equipped with two absolute gravimeters FG5#224 and FG5#231 and the superconducting gravimeter OSG-048 in Hsinchu. Regular monitoring absolute g measurements are carried out at the reference stations for the Taiwan gravity reference system. The long-term measurement showed that the absolute g value was within 20 nm/s^2 over 15 years. The differences between absolute g measurements and with superconducting gravimeter can achieve a standard uncertainty of about 10 nm/s^2.

Hardness

The Mechanical and Medical Metrology Laboratory provides the standard measurements in the fields of Mechanical Properties of Materials. One of the most common mechanical properties is hardness measurement. For macro hardness measurements, Vickers and Rockwell instrument were adopted to measure the hardness of bulk metal materials. For micro and nano hardness measurements, a nano-indentation system was also used to measure the hardness of thin-film materials. In addition, a nano tensile testing system has been established for measuring the young's modulus of thin-film materials. We provide technology and technical services to customers in the field of bio-application, metal-processing, semiconductor industry and so on.

Mass

The national primary mass standards of Taiwan are maintained by CMS/ITRI. The National Pt-Ir Prototype No.78 is a copy of the international prototype of the kilogram (IPK) made of platinum-iridium alloy. Being calibrated by BIPM every ten years, the mass of No.78 is disseminated to the stainless steel kilogram Standard. The stainless steel kilogram Standard is used to calibrate and disseminate to the reference standard weights down to 1 mg and up to 1000 kg.
CMS/ITRI has installed a number of high performance mass comparator and a sets of reference standard weights to provide weight calibration service to laboratories, government and industry. The class of the reference standard weights and the corresponding nominal mass are listed below:
1. Class E1: 1 mg to 50 kg,
2. Class F1: 100 kg to 1000 kg.
In response to the new kg definition based on a fixed value of the Planck constant $h = 6.626\ 070\ 15\times10^{-34}$, CMS/ITRI adopted the X-ray-crystal-density (XRCD) method to realize the new kg definition with the transmission of the information and technical support from the PTB (Germany). The development of the combined XRF (X-ray fluorescence)/XPS (X-ray photoelectron spectroscopy) surface analysis system enables the quantitative surface-layer analysis of Si spheres. The measured surface layer mass is to be combined with the core mass to give the mass of the Si-sphere in vacuum. The employment of a set of sorption artefacts and an M_one mass comparator vacuum chamber allows the mass standard transferred from vacuum to air by sorption effect measurement.

Pressure and Vacuum

CMS/ITRI has established pneumatic and hydraulic national pressure calibration systems, vacuum comparison calibration systems and an orifice-flow primary vacuum system. CMS/ITRI has participated in several APMP international key comparisons to maintain our CMCs and international equivalence in pressure and vacuum areas. The pressure and vacuum calibration and measurement systems are contributed to the metrological traceability and technology development in different fields such as food, shipbuilding, defense industries and manufactories.

Calibration and Measurement Capabilities (CMCs)

Since 2006, the calibration and measurement capabilities (CMCs) in the area of Mass and Related Quantities have been published in BIPM's Key Comparison Data Base and latest revised on January 2015 for mass, force, hardness, pressure and vacuum; on December 2017 for fluid flow. Due to the outbreak of

COVID-19, the on-site peer review planed in 2020 was postponed and will be carried out later when the pandemic is mitigated.

International Comparisons

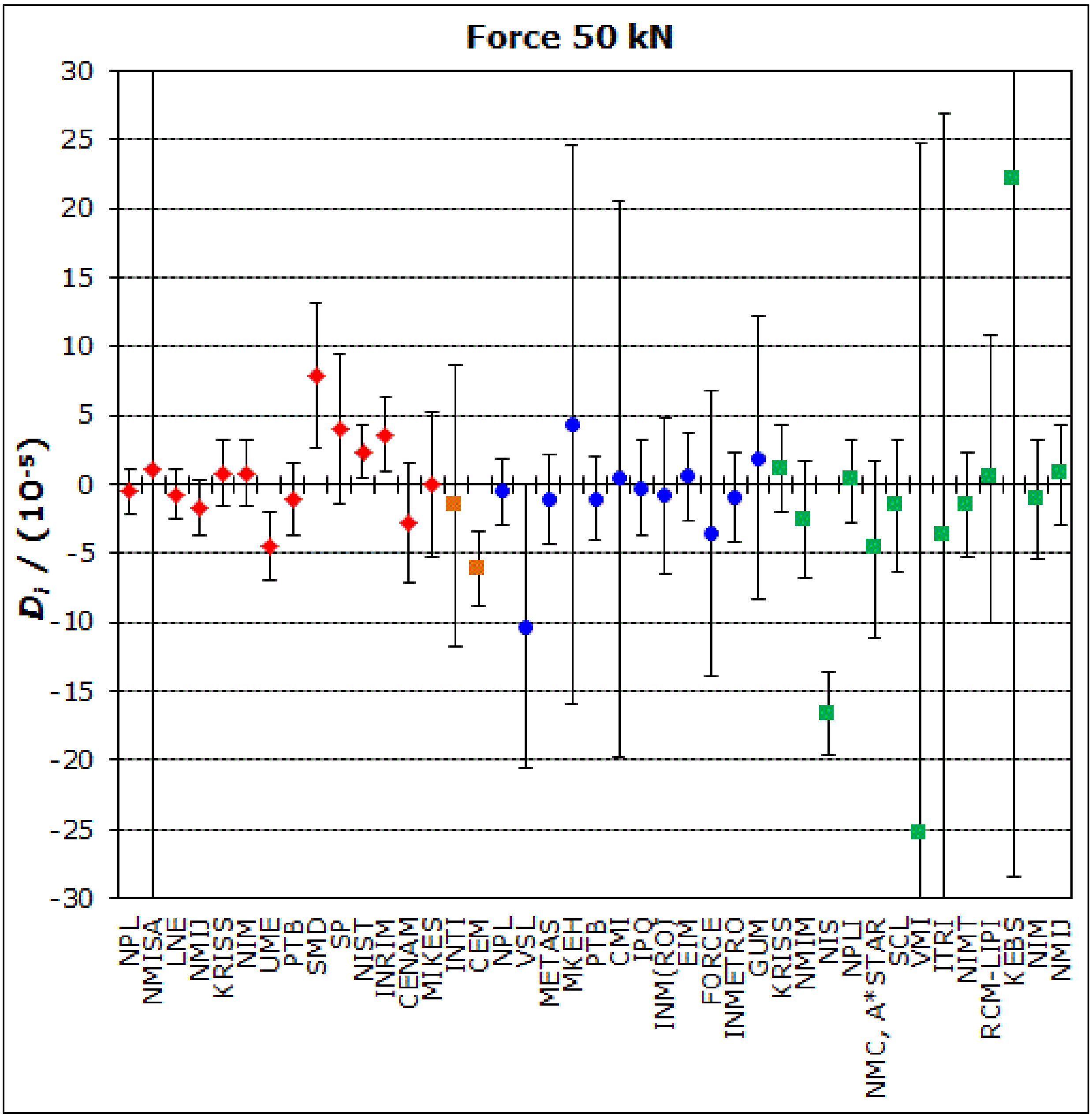
CMS/ITRI has actively piloted or participated in the following comparisons conducted by APMP and CCM.

Identifier	Date	Description and Measurand	Participation
APMP.M.F-K4.b	2005 - 2006	Very high force measurement at 2 MN	Participant
APMP.M.F-K2.a and APMP.M.F-K2.b	2007-2014	Medium force measurements at force of 50 kN and 100 kN.	Participant
APMP.M.H-K1.b and APMP.M.H-K1.c	2003 - 2005	3 reference blocks in different hardness levels, i.e., 200 HV, 600 HV and 900 HV with 3 different testing force, i.e., 9.807 N, 98.07 N and 294.2 N	Participant
APMP.M.M.K5	2015-2018	Mass five nominal mass values: 2 kg, 200 g, 50 g, 1 g, and 200 mg	Participant
CCM.FF-K1.2015	2016-2017	Water flow from (30 to 200) m^3/h	Participant (Draft B)
CCM.FF-K2.2015	2014-2015	Liquid hydrocarbon flow from (60 to 300) m^3/h	Participant (Final)
CCM.FF-K3.2011	2013-2015	Air speed from (0.5 to 40) m/s	Participant (Final)
CCM.FF-K2.1.2011	2013-2015	Water and Hydrocarbon flow (5 to 60) kg/min	Participant (Draft B)
CCM.FF-K6.2011	2010-2012	Low pressure gas flow from (2 to 100) m^3/h	Participant (Final)
CCM.FF-K5.b	2004-2005	High pressure gas flow from (65 to 1000) m^3/h at	Participant (Final)

		(5, 10, 20, 40) bar	
APMP.M.FF-K6.2018	2018-2021	Low pressure gas flow from (10 to 100) m^3/h	Coordinator (on going)
APMP.M.FF-K3.2020	2020-2021	Air speed from (0.5 to 30) m/s	Pilot Lab. (on going)
APMP.M.FF-k2.a	2013	Liquid Hydrocarbon Flow, Reynolds numbers of 70000, 100000 and 300000	Participant (Final)
APMP.M.FF-K3.2010	2009	Air speed from (2 to 20) m/s	Participant (Final)
CCM.G-K1	2009	Free-fall acceleration, absolute gravity measurements	Participant
CCM.G-K2	2013	Free-fall acceleration, absolute gravity measurements	Participant
APMP.M.P-K9	2009 - 2013	Pressure, 10 kPa to 110 kPa (absolute mode)	Participant (Final)
APMP.M.P-K13	2010 - 2013	Hydraulic gauge pressure, 50 MPa to 250 MPa	Participant (Final)
APMP.M.P-K15	2013 - 2014	Comparison of absolute pressure in the range 0.1 mPa to 1 Pa	Participant
APMP.M.P-K4	2015 - 2016	Absolute pressure: 1 Pa to 10 kPa	Participant

Some recent published results of key and supplementary comparisons years are shown below.

- APMP.M.F-K2



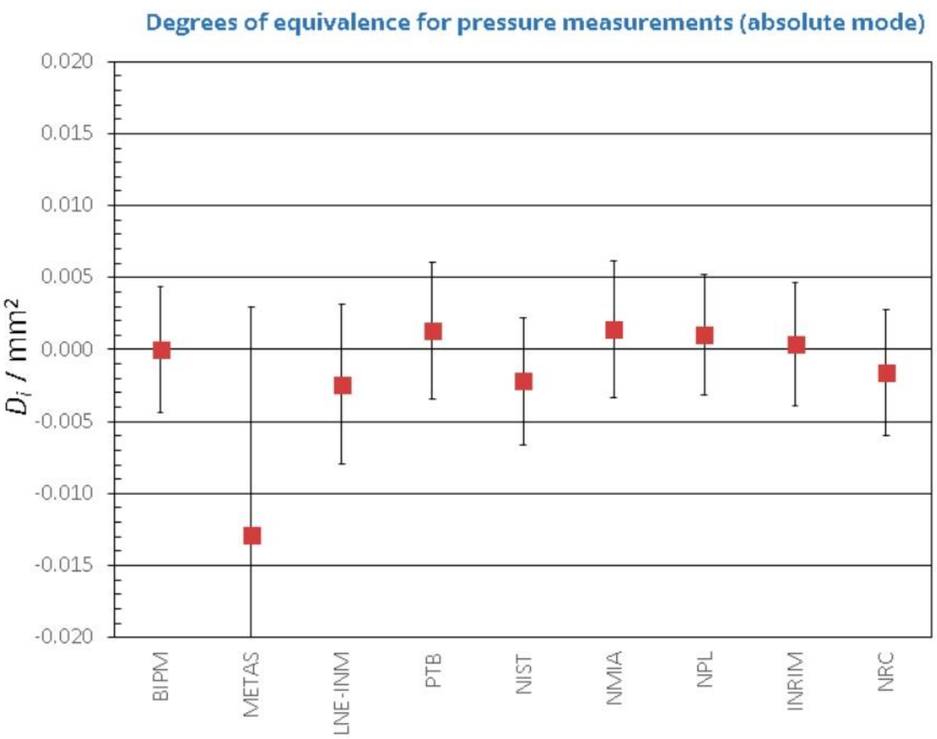
- CCM.FF-K2.2015, Liquid hydrocarbon flow from (60 to 300) m3/h: The degree of equivalence (Ei) of the calibration result selected to determine the KCRV and its standard uncertainty at Re of 70000, 100000 and 300000 were showed at below table.

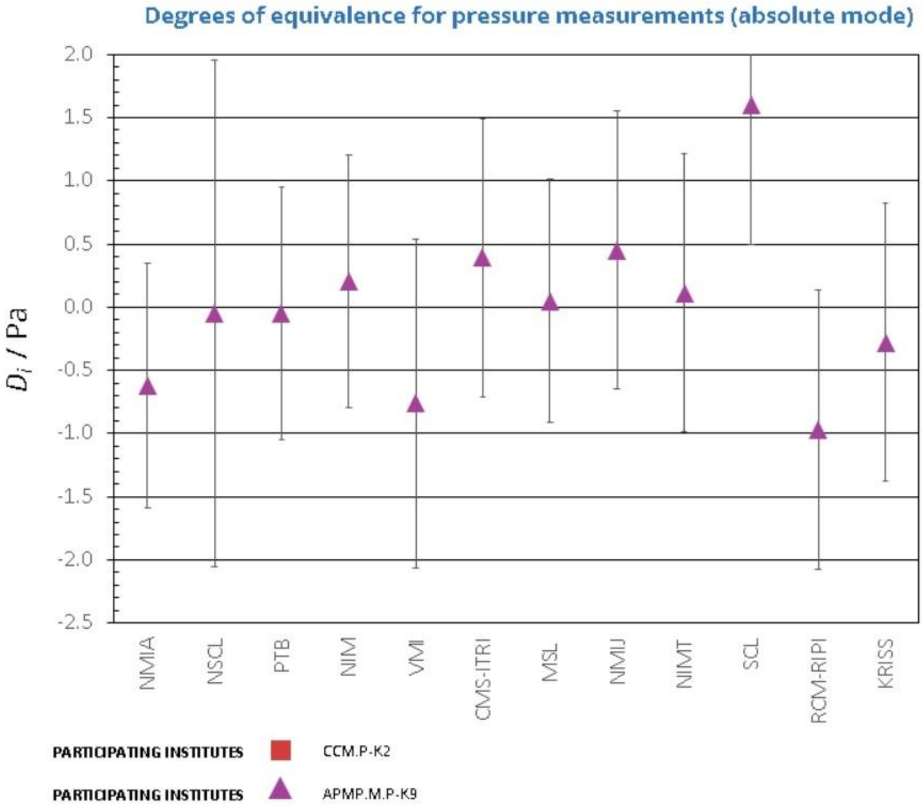
Re (-)	NMI	Liquid, Temp.	d_i (%)	$U(d_i)$ (%)	E_i
70 000	CENAM	Diesel	-0.013 5	0.037	0.37
	CMS	Light oil, 20 °C	0.023 3	0.048	0.49
	NEL	Kerosene	0.027 2	0.030	0.92
	NMIA	D130	-0.021 4	0.030	0.72
	NMIJ	Light oil, 20 °C	-0.006 6	0.030	0.22
100 000	BEV	D60	-0.066 2	0.069	0.96
	CENAM	Diesel	-0.026 4	0.043	0.61
	CMS	Light oil, 20 °C	0.024 4	0.048	0.50
	NEL	Kerosene	0.023 1	0.038	0.61
	NMIA	D130	-0.030 2	0.040	0.76
	NMIJ	kerosene, 20 °C	0.006 6	0.029	0.23
	TRAPIL	Jet Fuel	0.029 5	0.049	0.60
300 000	NMIA	Norpar 12	-0.015 5	0.026	0.59
	NMIJ	Kerosene, 20 °C	0.003 4	0.026	0.13
	TRAPIL	Jet Fuel	0.024 8	0.044	0.57

- CCM.FF-k6.2011, low pressure gas flow from 2 to 100 m3/h: The degree of equivalence with the KCRV is a measure of the agreement of the results of each participating laboratory with the KCRV. The “lab to KCRV” equivalence degrees Eni were summarized in below table.

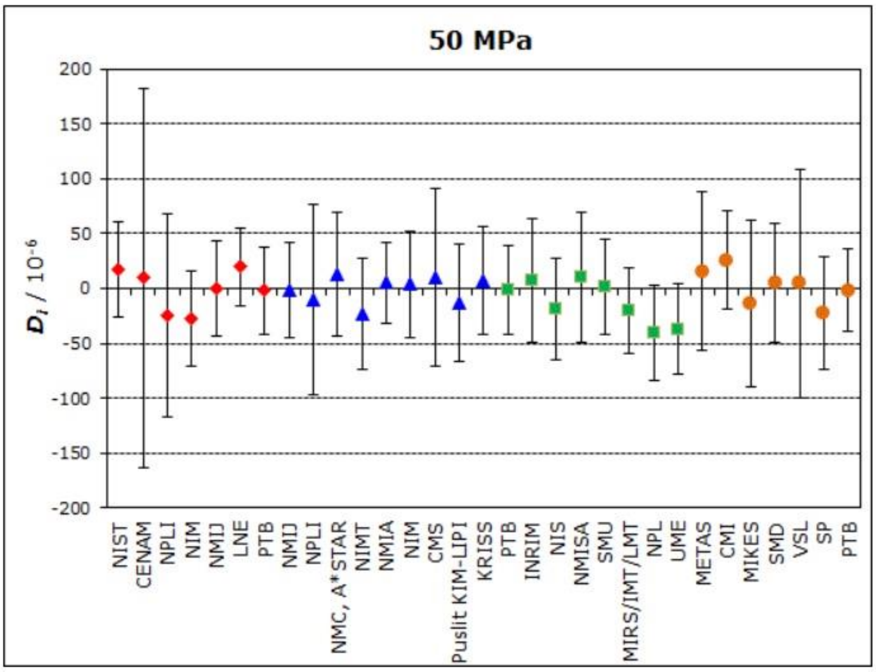
Flow/(m^3/h) → NMI	Slovakia SMU	Germany PTB	Ukraine GP Ivano-Frankivs'ks tandart-metrologia	Australia NMI	USA NIST	Mexico CENAM	Korea KRISS	China NIM	Chinese Taipei CMS	Japan NMIJ/ AIST	France LNE-LADG
2	0.19	0.50	0.23	0.73	0.14	0.49	-	-	0.58	-	-
4.5	0.67	0.70	0.67	0.48	0.17	0.22	-	-	0.24	-	-
6.6	0.64	0.70	0.69	0.44	0.25	0.30	-	-	0.52	0.26	-
9.1	0.61	0.46	0.84	0.94	0.27	0.11	0.46	0.28	0.40	-	-
13.1	0.57	0.47	0.74	0.91	0.31	0.01	0.35	0.17	0.26	0.06	0.11
16	0.65	0.13	0.83	0.76	0.24	0.42	0.01	0.08	0.35	0.16	0.06
24	0.60	0.02	0.68	0.73	0.19	0.52	0.07	0.17	0.20	0.17	0.09
32	0.63	0.07	0.36	0.71	0.28	0.36	0.23	0.20	0.17	0.01	0.03
40	0.64	0.01	0.70	0.74	0.18	0.43	0.11	0.31	0.11	0.01	0.00
50	0.58	0.12	0.46	0.78	0.10	0.39	0.09	0.38	0.00	0.16	0.01
60	0.46	0.15	0.63	0.72	0.06	0.25	0.10	0.48	0.06	0.10	0.01
70	0.38	0.20	0.35	0.74	0.10	0.18	0.12	0.53	-	0.21	0.13
80	0.27	0.16	0.35	0.63	0.10	0.12	0.01	0.54	-	0.20	0.04
90	0.07	0.05	0.37	0.51	0.20	0.04	0.01	0.52	-	0.19	0.19
100	0.13	0.17	0.47	0.50	0.24	0.01	0.16	0.48	-	0.44	0.21

- 3. CCM.P-K2 and APMP.M.P-K9, NOMINAL PRESSURE, 90 kPa





- CCM.P-k13 and APMP.M.P-K13 comparison result



Red diamonds: participants in CCM.P-K13
Blue triangles: participants in APMP.M.P-K13
Green squares: participants in EURAMET.M.P-K13
Orange circles: participants in EURAMET.M.P-K7

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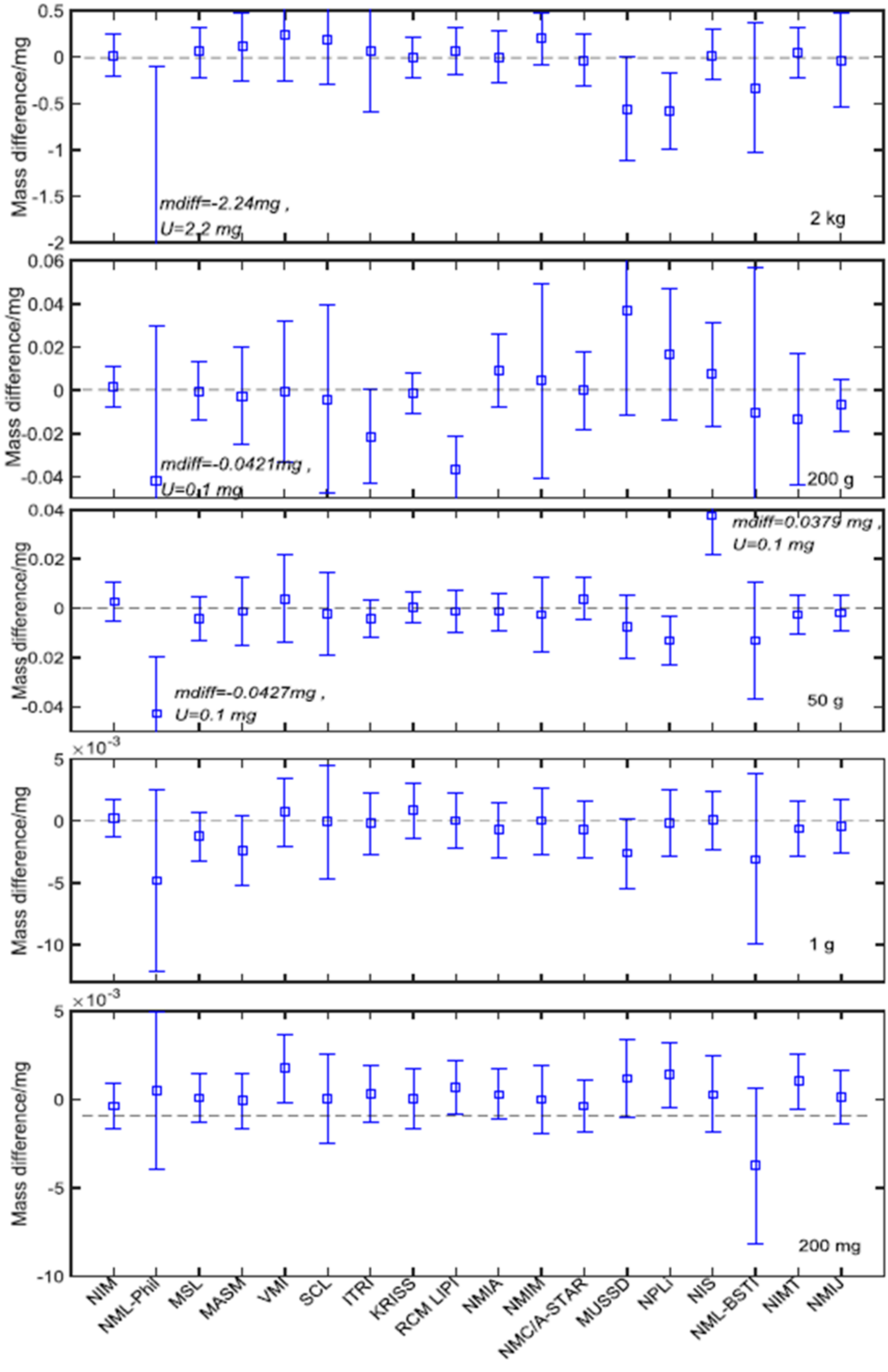
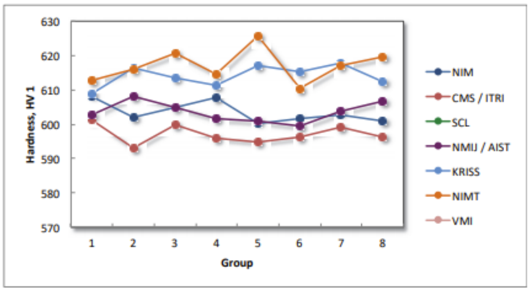
- APMP.M.M.K5

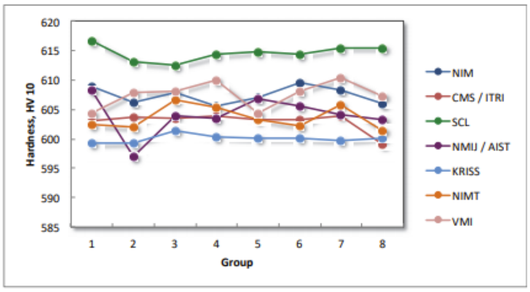


- APMP.M.H-K1.b and APMP.M.H-K1.c

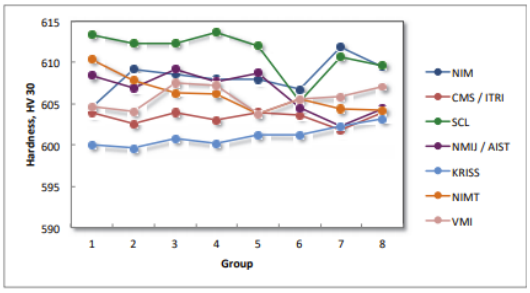
The comparison item is Vickers hardness for 200 HV 1, 200 HV 10, 200 HV 30, 600 HV 1, 600 HV 10, 600 HV 30, 900 HV 1, 900 HV 10, and 900 HV 30. The results for 200 HV 1, 600 HV 1 and 900 HV 1 scales are linked to CCM.H-K1b, and the results for 200 HV 30, 600 HV 30 and 900 HV 30 scales are linked to CCM.H-K1c. The Degree of Equivalence (DoE) was indicated by the relative deviation from reference values. The measurement results of CMS/ITRI show good agreements in this key comparison.



4 Hardness distribution of 600 HV block evaluated by all participants in HV 1



Hardness distribution of 600 HV block evaluated by all participants in HV 10

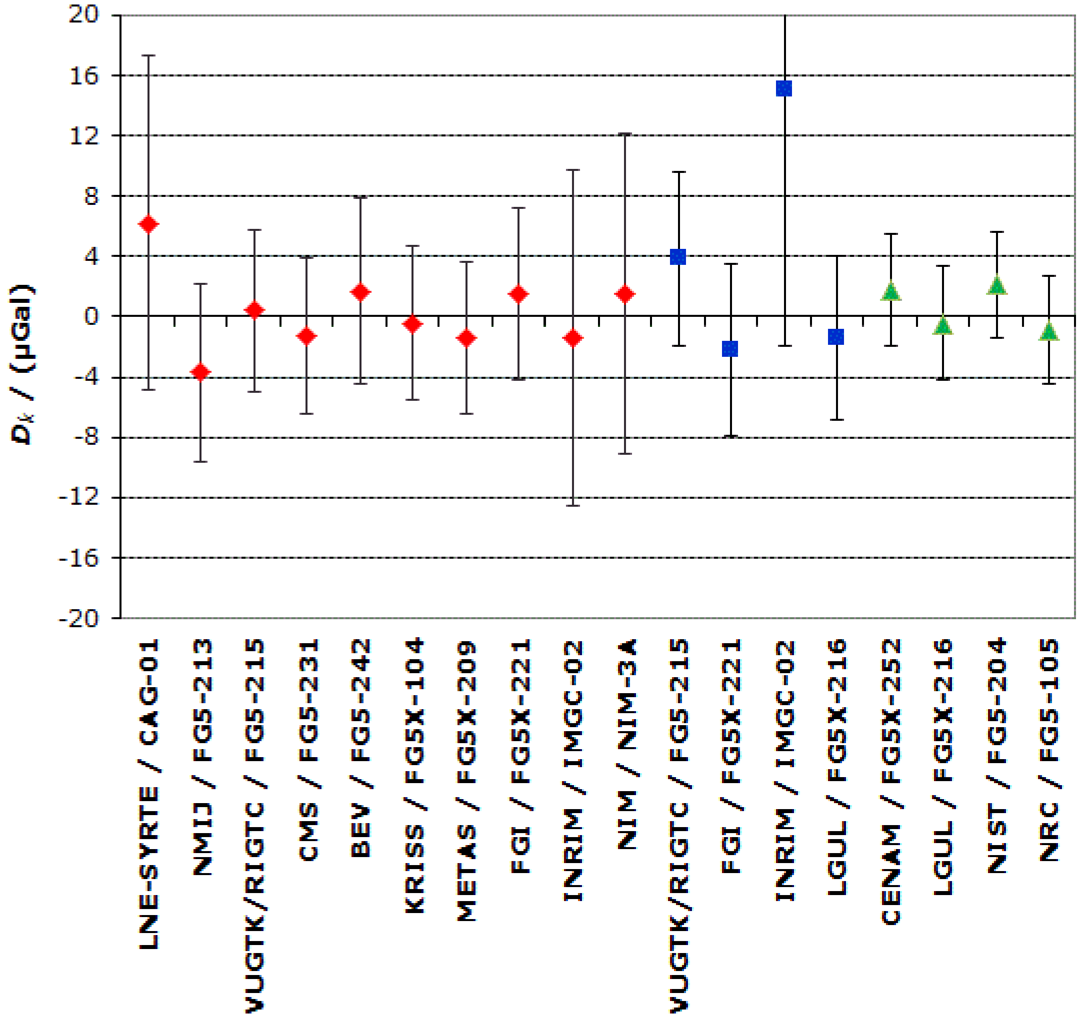


Hardness distribution of 600 HV block evaluated by all participants in HV 30

E_n number: unilateral analysis, for Vickers hardness HV1.

Institute	200 HV 1	600 HV 1	900 HV 1
KRISS	0.96	0.33	0.24
NIM	-0.83	-0.30	-0.18
CMS / ITRI	-0.17	-0.44	-0.38
NIMT	-0.01	0.27	-0.03
NMIJ / AIST	-0.34	-0.18	-0.05

* CCM.G-K2



Red diamonds: participants in CCM.G-K2
Blue triangles: participants in EURAMET.M.G-K2
Grren diamonds: participants in SIM.M.G-K1

Research Projects

The research projects in the MRQ area in recent years are listed below:

- Development of Micro-force measurement standard
- Development of small force (10 mN) and dynamic force measurement standard
- Development of the combined XRF/XPS surface analysis system towards new kilogram realization via the x-ray-crystal-density method based on the Planck constant.
- Development of sorption effect measurement for mass dissemination technology.
- Optical pressure standard

- Natural gas/hydrogen metrological research
- Green energy metrological research
- Legal metrology for gas/water meters
- Technology of water resources management

Measurement Facilities

Some measurement facilities in the MRQ area at CMS/ITRI are described below.

<table>
<tr><td>Description of the measurement facility</td><td>Picture of the measurement facility</td></tr>
<tr><td>Water Flow Calibration System and Oil Flow Calibration System
• The flow rate range of water flow calibration system is (2 to 8000) L/min. The relative expanded uncertainty of the water flow calibration system is 0.03 % to 0.06 % in the flow rate range of (2 to 700) L/min. The relative expanded uncertainty is 0.04 % in the flow rate range of (100 to 8000) L/min. The largest pipe size is 300 mm.
• The calibration method for water flow calibration system is static weighing that carried out in the flying-start-and-finish method. The system uses the diverter to manipulate flow along its bypass loop or towards the weighing tank.
• The flow rate range of oil flow calibration system is (60 to 6000) L/min. The relative expanded uncertainty of the oil flow calibration system is 0.05 %. The largest pipe size is 150 mm.
• The calibration method for oil flow calibration system is static weighing that carried out in the standing-start -and-finish method.</td><td></td></tr>
</table>

High Pressure Gas System

High pressure gas flow calibration system for the calibration of sonic nozzles or flowmeters by weighing method. The calibration capacity of the High Pressure Gas Flow System is as follows:

-The volume flow rate of system: (15 to 12000) Sm^3/h. The relative expanded uncertainty of the calibration system is 0.12 %. The largest pipe size is 150 mm.

-Upstream pressure of DUT: (5 to 60) bar.
-Temperature range of DUT: Ambient temperature.

Low Pressure Gas System

Low pressure gas flow calibration system includes Piston Prover, PVTt system and Bell Prover.
The flow rate range of these systems are form 0.002 L/min to 1000 L/min. The higher end of operating pressure is up to 7 bar.

• Piston Prover
-Working fluid: dry air, N_2, Ar, O_2.
-Flow rate range: 0.002 L/min to 24 L/min.
-Relative expanded uncertainty is 0.11 %.

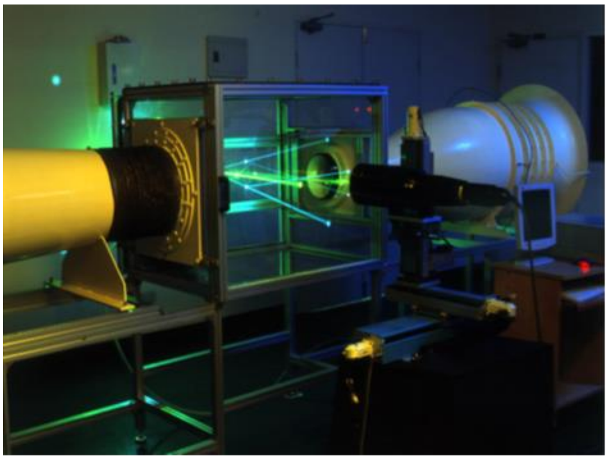
• PVTt
-Working fluid: dry air, N_2.
-Flow rate range: 0.01 L/min to 300 L/min.
-Relative expanded uncertainty is 0.10 %.

• Large Bell Prover
-Working fluid: dry air.
-Flow rate range: 20 L/min to 1000 L/min.
-Relative expanded uncertainty is 0.12 %.



Air Speed Calibration System

- The air speed calibration system consists of the wind tunnel and transfer standard LDV.
- The wind tunnel is an open loop design with total length of 6 m and an inlet diameter of 1.5 m, a 9:1 contraction ratio, a nozzle diameter of 200 mm and test chamber of 800 mm by 800 mm.
- The air speeds range are 0.5 m/s to 25 m/s in the test section in the contracted section.
- The velocity standard used is a LDA placed on a three-axis traversing system.
- In order to trace air speed measurement to the International System of Units,(SI).The spinning disk as a velocity standard.
- Based on the measurements and analysis on the flow in wind tunnel. The expanded uncertainty is estimated under 95% level of confidence. u_{base} = 0.25 %, u_{BED} = 0.04 %,k = 2.06,U_{CMC} = 0.52 %.



Micro Flow Calibration System

- The flow rate range of micro flow calibration system is 0.1 μL/min to 10 mL/min. The relative expanded uncertainty of the micro flow calibration system is 0.2 % to 2.0 %.
- The system utilizes a pressure regulator which adjusts the pressure within the liquid tank or a liquid flow pump to drive the liquid into the weighing vessel, and calibrates (micro) flowmeters or flow pumps using dynamic weighing method.

50 kN Deadweight Force Standard Machine • Measurement range 500 N to 50 kN • Expanded Uncertainty: 2×10^{-5} (relative) • This machine is used to provide calibration services for several types of force measuring instruments including Proving Rings, Force Transducers, Load Cells, Ring Dynamometers and Force Gauges.	
5 kN Deadweight Force Standard Machine • Measurement range 50 N to 5 kN • Expanded Uncertainty: 2×10^{-5} (relative) This machine is used to provide calibration services for several types of force measuring instruments including Proving Rings, Force Transducers, Load Cells, Ring Dynamometers and Force Gauges.	
500 N Deadweight Force Standard Machine • Measurement range 10 N to 500 N • Expanded Uncertainty: 2×10^{-5} (relative) This machine is used to provide calibration services for several types of force measuring instruments including Proving Rings, Force Transducers, Load Cells, Ring Dynamometers and Force Gauges.	

2 MN Force Comparison Calibration System • Measurement range 100 kN to 2 MN • Expanded Uncertainty: 5×10^{-4} (relative) This machine is used to provide calibration services for several types of force measuring instruments including Proving Rings, Force Transducers, Load Cells, Ring Dynamometers and Force Gauges.	
500 kN Force Comparison Calibration System • Measurement range 10 kN to 500 kN • Expanded Uncertainty: 2×10^{-4} (relative) This machine is used to provide calibration services for several types of force measuring instruments including Proving Rings, Force Transducers, Load Cells, Ring Dynamometers and Force Gauges.	
50 kN Force Comparison Calibration System • Measurement range 5 kN to 50 kN • Expanded Uncertainty: 2×10^{-4} (relative) This machine is used to provide calibration services for several types of force measuring instruments including Proving Rings, Force Transducers, Load Cells, Ring Dynamometers and Force Gauges.	

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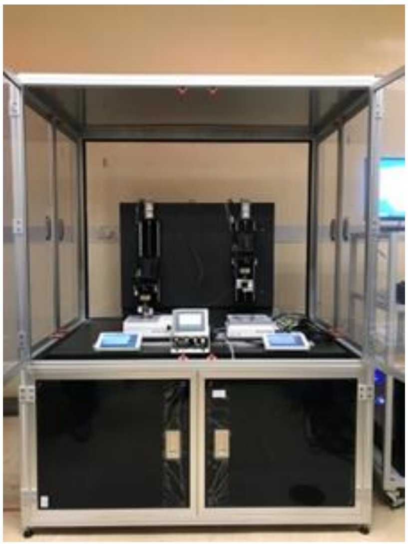
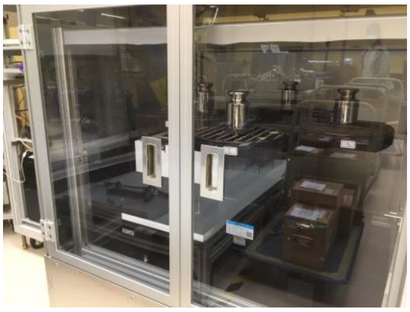
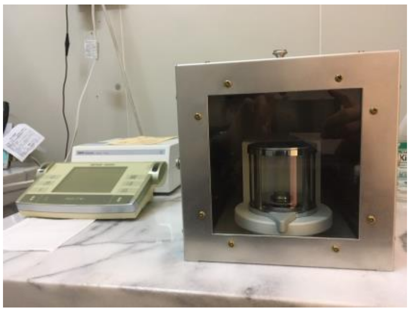
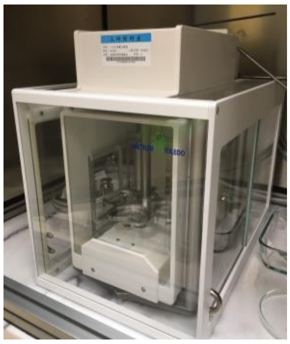
Small Force Calibration System • The system provides calibration for small force with a measurement range of 10 mN to 10 N, the relative uncertainty is 1.0 %.	
Absolute gravity measurements system • CMS has two FG5 (#224 and #231) absolute gravimeters as national standard of the acceleration of free fall. • Standard uncertainty is 20 nm/s^2.	
Superconducting gravimetry • High quality continuously recording gravimeters. • sensitivity of the instrument reaches the level of 10^{-12} nm/s^2.	
Relative Gravimeter • LACOSTE-ROMBERG gravity meters #1184 and #1200 • Standard uncertainty is 100 nm/s^2.	

<table>
<tr>
<td>Rockwell Hardness Calibration System
• The system provides calibration for hardness with a measurement range of 29.4 N to 1470 N, the uncertainties are as follows,
0.30 HRA
0.40 HRB
0.30 HRC</td>
<td></td>
</tr>
<tr>
<td>Vickers Hardness Calibration System
• The system provides calibration for hardness with a measurement range of 9.8 N to 294.2 N, the relative uncertainty is 3.0 %.</td>
<td></td>
</tr>
<tr>
<td>Micro Vickers Hardness Calibration System
• The system provides calibration for hardness with a measurement range of 489.46 mN to 9789.14 mN, the relative uncertainty is 6.7 %.</td>
<td></td>
</tr>
</table>

Nanoindentation Calibration System • The system provides calibration for hardness and reduced modulus with a measurement range of 0.2 mN to 10 mN, the relative uncertainty is 2.4 % and 3.1 %, respectively.	
Kilogram Mass Standard System • The system provides mass dissemination for the mass of kilogram prototype or silicon sphere to stainless steel weights with measuring range of 1 kg and the expanded uncertainty of 51 μg (k=2). • The number of scale intervals is $n = Max/d$=1 kg/0.1 μg.	
High-Capacity Mass Weighing System • The system provides mass calibration from 2 kg to 10 kg, 20 kg to 50 kg, 100 kg to 500 kg and 500 kg to 1000 kg. The uncertainty is from 0.88 mg to 3.3 g. • The weighing principles for calibration range from 2 kg to 10 kg is mass comparator with automatic weight-exchange mechanism with 4 positions. The number of scale intervals are Max/d=10.05 kg/ 0.01 mg. • The weighing principles for calibration range from 20 kg to 50 kg is mass comparator with automatic weight-exchange mechanism with 4 positions. The number of scale intervals are Max/d=64.26 kg/ 0.1 mg. • The weighing principles for calibration range from 100 kg to 500 kg is mass comparator	  

with full electromagnetic force compensation. The number of scale intervals are Max/d=600 kg/ 0.1 g. • The weighing principles for calibration range from 500 kg to 1000 kg is mass comparator with full electromagnetic force compensation. The number of scale intervals are Max/d=1100 kg/ 0.5 g.	
Low-Capacity Mass Weighing System • The system provides mass calibration from 1 mg to 2 g, 5 g to 100 g and 200 g to 1 kg. The uncertainty is from 0.7 µg to 69 µg. • The weighing principles for calibration range from 1 mg to 2 g is mass comparator with full electromagnetic force compensation. The number of scale intervals are Max/d=5.1 g/ 0.1 µg. • The weighing principles for calibration range from 5 mg to 100 g is mass comparator with automatic weight-exchange mechanism with 6 positions. The number of scale intervals are Max/d=111 g/ 1 µg. • The weighing principles for calibration range from 200 mg to 1 kg is mass comparator with automatic weight-exchange mechanism with 4 positions. The number of scale intervals are Max/d=1011 g/ 1 µg.	  
Gas pressure calibration system The system provides calibration for gas pressure gauges with the measurement range from 1 Pa to 10 kPa with the uncertainty of 0.25 Pa and the measurement range from 5 kPa to 7000 kPa with relative uncertainty of 3.4E-05 to 4.2E-05.	 

Liquid pressure calibration system The system provides calibration for liquid pressure gauges with a measurement range from 2.8 MPa to 280 MPa with the relative uncertainty of 3.3E-05 to 7.4E-05.	 
Vacuum Gauge Comparative Calibration System • The system provides calibration for vacuum gauges with a measurement range of 0.1 Pa to 100 kPa, the relative uncertainty is 1.8 %.	
Dynamic Expansion Vacuum Calibration System The system provides calibration for vacuum gauges with a measurement range of 5×10^{-6} Pa to 8.6×10^{-3} Pa, the relative uncertainty is between 4 % to 9 %.	

Technical Services

Calibration services in MRQ

Quantity and item	Instrument type or Method	Measurand Level or Range	Expanded Uncertainty
Weight	Direct Comparison Method	1 mg ~ 1 kg	0.0007 mg ~ 0.069 mg
Weight	Mettler-Toledo New M_One	1 kg	0.032 mg
Weight	Sartorius CC50000S Mass Comparator	10 kg ~ 50 kg	5.2 mg ~ 21 mg
Weight	Sartorius CCE10000UL	1 kg ~ 10 kg	0.17 mg ~ 3.3 mg

	Mass Comparator		
Weight	Mettler KC1000 Mass Comparator With ID5 Terminal	50 kg ~ 1000 kg	1.1 g ~ 3.3 g
Force	DW NML 500 N DW Morehouse 5 kN DW NML 50 kN HBM 500 kN HBM 2 MN	10 N ~ 2 MN	2.0E-5 ~ 5.0E-4
Micro/nano mechanical property specimen	MTS, Nano UTM	Young's modulus with the following measurands: Displacement 0.1 mm ~ 50 mm Force 10 mN ~ 200 mN	3.1 %
Rockwell hardness block	CMS/HRJ-150; ISO 6508-3	HRA, HRB, HRC	0.3 HRA, 0.4 HRB, 0.3 HRC
Vickers hardness block	AKASHI/SHT-41; ISO 6507-3	100 HV ~ 900 HV	3.0 %
Micro-Vickers hardness block	AKASHI/HM-124; ISO 6507-3	100 HV ~ 900 HV; HV0.05 HV0.1 HV0.2 HV0.3 HV0.5 HV1	 6.1 % 5.3 % 4.9 % 4.7 % 4.6 % 4.5 %
Nanoindentation specimen	Hysitron, TriboIndenter	Indentation Hardness Reduced modulus with the following measurands: displacement 50 nm ~ 300 nm force 0.5 mN ~ 10 mN	2.7 % 3.1 %
Pressure; Gas lubricated piston pressure gauge	Ruska 2465; DHI PG7607	5 kPa ~ 7 MPa	3.4E-05 ~4.2E-05
Pressure; Gas lubricated piston	Laser interferometer mercury manometer ITRI-	1 kPa ~ 120 kPa	0.31 Pa ~ 2.3 Pa (absolute pressure)

pressure gauge	CMS-HG1-120-2004		
Pressure; Gas lubricated piston pressure gauge	Laser interferometer mercury manometer for low pressure standard ITRI-CMS-LIML1-10-2005; Force balance piston gauge DHI FPG 8601	1 Pa ~ 10 kPa	0.25 Pa (gauge pressure)
Oil lubricated piston pressure gauge	Oil lubricated piston gauge Ruska 2485 (Cross-float method)	2.8 MPa ~ 28 MPa 28 MPa ~ 180 MPa	3.3E-05 (gauge pressure) 7.4E-05 (gauge pressure)
Mercury manometer, pressure gauge	Pressure controller/calibrator DHI PPC4	1 kPa ~ 700 kPa	0.32 kPa (absolute and gauge pressure)
Vacuum; Spinning rotor viscosity vacuum gauge	MKS SRG	0.0006 Pa ~ 1 Pa	0.029p (p in Pa)
Ionization vacuum gauge	Hot cathode ionization vacuum gauge Leybold IM 520	5E-06 Pa ~ 0.0001 Pa 0.0001 Pa ~ 0.008 Pa	0.074p (p in Pa) 0.069p (p in Pa)
Capacitance diaphragm vacuum gauge	MKS 390HA-01000 MKS 390HA-00010SP05	0.1 Pa ~ 100 kPa	0.018p (p in Pa)
Sonic nozzle	Gyroscopic scale (WOHWA /9631)	18 kg/h ~ 14000 kg/h 15 m^3/h ~ 12000 m^3/h	0.12 % 0.12 %
Sonic nozzle, laminar, differential Pressure meter	Constant volume tank (CMS/500 L, CMS/30 L, CMS/2 L)	0.01 L/min ~ 300 L/min 0.2 mg/s ~ 6000 mg/s	0.10 % 0.10 %
Sonic nozzle, laminar, Coriolis, thermal-mass, differential-pressure, turbine, ultrasonic, vortex flowmeters	Sonic nozzle (HIRAI/-)	18 kg/h ~ 14000 kg/h 15 m^3/h ~ 12000 m^3/h	0.19 % 0.19 %
Sonic nozzle, thermal-mass, differential	Laminar flowmeter (DHI/MOLBLOC, DHI/MOLBOX1)	0.04 mg/s ~ 480 mg/s 0.002 L/min ~ 24 L/min	0.13 % 0.13 %

pressure, laminar, bubble, variable-area, piston-prover flowmeters			
Sonic nozzle, thermal-mass, differential pressure, laminar, bubble, variable-area, piston-prover flowmeters	sonic nozzle (FLOW SYSTEMS/d=0.204, d=0.100, d=0.049, d=0.024)	0.13 g/s ~ 2 g/s 6.5 L/min ~ 100 L/min 2 g/s ~ 20 g/s 100 L/min ~ 1000 L/min	0.18 % 0.18 % 0.14 % 0.14 %
Sonic nozzle, thermal-mass, differential pressure, laminar, variable- area flowmeters	sonic nozzle (CMS/SN0583, CMS/SN0836, CMS/SN1190, CMS/SN1757, CMS/CMS/--, CMS/--, CMS/CMS/--, CMS/--, HIRAI/SN003, HIRAI/SN005, HIRAI/SN008, HIRAI/SN010, HIRAI/SN015, HIRAI/SN020, HIRAI/SN030, HIRAI/SN040, HIRAI/SN060)	0.8 mg/s ~ 6000 mg/s 0.04 L/min ~ 300 L/min	0.13 % 0.13 %
Sonic nozzle, thermal-mass, differential-pressure, laminar, variable-area flowmeters	sonic nozzle (HIRAI/SN003, HIRAI/SN005, HIRAI/SN008, HIRAI/SN010, HIRAI/SN015, HIRAI/SN020, HIRAI/SN030, HIRAI/SN040, HIRAI/SN060, HIRAI/SN085,	0.8 mg/s ~ 6000 mg/s 0.04 L/min ~ 300 L/min	0.11 % 0.12 %

	HIRAI/SN120, HIRAI/SN170, HIRAI/SN240)		
Sonic nozzle, thermal-mass, laminar, piston-prover, differential-pressure, variable-area flowmeters	bell prover (Brooks/1093)	0.4 g/s ~ 20 g/s 20 L/min ~ 1000 L/min	0.12 % 0.12 %
Sonic nozzle, thermal-mass, laminar, piston-prover, differential-pressure, variable-area flowmeters	piston prover (Brooks/1050-5)	0.04 mg/s ~ 480 mg/s 0.002 L/min ~ 24 L/min	0.11 % 0.11 %
Coriolis, positive-displacement, differential-pressure, turbine, ultrasonic, vortex, electromagnetic, variable area flowmeters	Weighing scale (Mettler Toledo/KES1500, Mettler Toledo/KG6000)	1.67 kg/s 133 kg/s 6 m^3/h ~ 480 m^3/h	0.05 % 0.05 %
Coriolis, positive-displacement, differential-pressure, turbine, ultrasonic, vortex, electromagnetic, variable area flowmeters	Weighing scale (Mettler Toledo/KCS600)	0.16 kg/s ~ 11.67 kg/s 0.6 m^3/h ~ 42 m^3/h 0.033 kg/s ~ 0.16 kg/s 0.12 m^3/h ~0.6 m^3/h	0.04 % 0.04 % 0.06 % 0.06 %
Thermal mass , differential-pressure, Coriolis, variable area, time of flight flowmeters, liquid metering pump	Weighing scale (Mettler Toledo/AX205)	0.1 mm^3/min ~ 10 cm^3/min 0.1 mg/min ~ 10 g/min	2.0 % ~ 0.3 %

Positive-displacement, Coriolis, thermal, turbine, ultrasonic, vortex flowmeters	Sonic nozzle (HIRAI/-)	< 200 m^3 @ (15 to 12000) m^3/h	0.19 %
Positive-displacement flowmeters	bell prover (Brooks/1090)	< 60 L @ (4 to 100) L/min	0.17 %
Positive-displacement flowmeters	Laminar flowmeter (DHI/MOLBLOC, DHI/MOLBOX1)	< 500 L @ (0.002 to 24) L/min	0.14 %
Positive-displacement flowmeters	sonic nozzle (FLOW SYSTEMS /d=0.204, d=0.100, d=0.049, d=0.024)	< 1000 L @ (6.5 to 100) L/min < 10000 L @ (100 to 1000) L/min	0.18 % 0.14 %
Positive-displacement flowmeters	bell prover (Brooks/1093)	< 600 L @ (20 to 1000) L/min	0.13 %
Turbine, ultrasonic, rotary flowmeters	Gyroscopic scale (WOHWA/9631)	< 200 m^3 @ (15 to 12000) m^3/h	0.12 %
Coriolis, positive-displacement, turbine, ultrasonic, vortex, electromagnetic flowmeters	Weighing scale (Mettler Toledo/KES1500, Mettler Toledo/KG6000)	375 kg to 6000 kg 0.375 m^3 to 6 m^3	0.04 %
Coriolis, positive-displacement, turbine, ultrasonic, vortex, electromagnetic flowmeters	Weighing scale (Mettler Toledo/KCS600)	20 kg ~ 600 kg 20 L ~ 600 L	0.06 % ~ 0.03 %
Coriolis flowmeter, liquid metering pump	Weighing scale (Mettler Toledo/AX205)	0.025 cm^3 ~100 cm^3 0.025 g ~ 100 g	2.0 % ~ 0.2 %
Positive-	Weighing scale (Mettler	0.47 m^3 ~ 7.4 m^3	0.05 %

displacement, turbine, Coriolis, ultrasonic flowmeters	Toledo/KES3000, Mettler Toledo/KG6000)	375 kg ~ 6000 kg	0.04 %
Positive-displacement, turbine, Coriolis flowmeters	Weighing scale (Mettler Toledo/KES3000, Mettler Toledo/KG6000)	0.43 m^3 ~ 6.9 m^3 375 kg ~ 6000 kg	0.05 % 0.04 %
Thermal, ultrasonic, differential-pressure, vane, Laser-Doppler anemometer	Laser Doppler velocimeter (DANTEC/Fiber Flow)	0.2 m/s ~ 25 m/s	0.52 %

Related Measurement and Technical Consulting Services

- Measurement and analysis of outgassing characteristics of vacuum component
- Consultancy services for establishment of calibration systems for vacuum gauges
- Vacuum pump performance test
- Measurement and analysis of mechanical characteristics (hardness and modulus) of materials
- Consultancy services for establishment of calibration systems for material metrology
- Calibration for liquid and gas flowmeters
- Calibration for air flow speed meters (anemometers)
- Calibration for pressure meters
- Flow and pressure measurement/calibration automation system designing and constructing.
- Consultancy services for flow measurement laboratory accreditation
- Flow field measurement and numerical simulation
- Air permeability tester construction design and performance test
- Calibration for pressure meters
- Consultancy services for pressure measurement laboratory accreditation
- Consultancy services for establishment of calibration systems for pressure gauges
- Training course in mass metrology
- Calibration for relative gravimeters.
- Gravity measurements

ITRI Industrial Technology Research Institute

Participation in International Standardization Committees

CCM - Consultative Committee for Mass and Related Quantities
- Member of CCM-WGM
- Observer of CCM-WGPV

APMP - Asia Pacific Metrology Programme:
- Full member since 1992
- Technical Committee for Mass and Related Quantities (TCM): Member, Chair (2019 ~ 2021)
- Medical Metrology Focus Group: Member, Chair (2015 ~ 2019)

APMF - Asia-Pacific Measurement Forum on Mechanical Quantities:
- International Program Committee Member
- Hosting Organization (APMF 2013)

IMEKO TC16 (Pressure and Vacuum Measurement):
- Member

Selected Publications (2017~2021)

Journal Papers

1. CIPM Key Comparison of Air Speed, 0.5 m/s to 40 m/s Final Report, Metrologia, 2017
2. Final Report on the APMP Key Comparison Liquid Hydrocarbon Flow, Metrologia, 2017
3. The Traceability Improvement and Comparison of Bell Prover as the Indonesian National Standard of Gas Volume Flow Rate, MAPAN-Journal of Metrology Society of India, 2020/9 accepted
4. Dakota Piorkowski, Chen-Pan Liao, Anna-Christin Joel, Chung-Lin Wu, Niall Doran, Sean J. Blamires, Nicola M. Pugno, I-Min Tso, Adhesion of spider cribellate silk enhanced in high humidity by mechanical plasticization of the underlying fiber, **Journal of the Mechanical Behavior of Biomedical Materials**, 114 (2021) 104200
5. Sean P. Kelly, Kun-Ping Huang, Chen-Pan Liao, Riza Ariyani Nur Khasanah, Forest Shih-Sen Chien, Jwu-Sheng Hu, Chung-Lin Wu, I-Min Tso, Mechanical and structural properties of major ampullate silk from spiders fed carbon nanomaterials, **PLOS ONE**, (2020), 0241829
6. Dakota Piorkowski, Todd A. Blackledge, Chen-Pan Liao, Anna-Christin Joel, Margret Weissbach, Chung-Lin Wu, I.-Min Tso, Uncoiling springs promote mechanical functionality of spider cribellate silk, **Journal of Experimental Biology**, (2020)
7. Koichiro Hattori, Chung-Lin Wu, Nae-Hyung Tak, Ping Yang, Tassanai Sanponpute, Raymond

Leung, Pham Thanh Ha, Satoshi Takagi, Final report of the key comparison of Vickers hardness: APMP.M.H-K1.b and APMP.M.H-K1.c., **Metrologia**, 57 (2020) 07010

8. D. Piorkowski, T. A. Blackledg, C.-P. Liao, N. E. Doran, Chung-Lin Wu, S. J. Blamires, I. M. Tso, Humidity-dependent mechanical and adhesive properties of Arachnocampa tasmaniensis capture threads, **Journal of Zoology**, (2018)
9. D. Piorkowski, S. J. Blamires, N. E. Doran, C.-P. Liao, Chung-Lin Wu, I.-M. Tso, Ontogenetic shift toward stronger, tougher silk of a web-building, cave-dwelling spider, **Journal of Zoology**, (2017)
10. Sheng-Jui Chen, Sheau-Shi Pan, Yu-Shan Yeh and Yi-Ching Lin, “Measurement of Cantilever spring constant using an electrostatic sensing and actuating force measurement system”, Meas. Sci. Technol. 26 (2014) 115006
11. Sheng-Jui Chen and Sheau-Shi Pan, “A force measurement system based on an electrostatic sensing and actuating technique for calibrating force in a micronrewton range with a resolution of nanonewton scale”, Meas. Sci. Technol., 22 (2011) 045104
12. Sheng-Jui Chen, Sheau-Shi Pan and Ta-Chang Yu, “System for measuring vacuum-pump performance using the standard throughput method”, ACTA IMEKO, 7 (2018), 65
13. Y.-H. Wu, L. Tsao, J.-Y. Chiu, S.-J. Chen, M. Kolbe, R. Fliegauf, E. Beyer, F. Haertig, J. H. Scofield, “Development of a combined XRF/XPS surface-analysis system for the surface-layer quantification of ^{28}Si spheres”, ACTA IMEKO, 10 (2021) pp. 290-294.
14. L. Tsao, Y. H. Wu, S. J. Chen, “Measurement of sorption effect for dissemination of new kilogram standard”, APMF 2019, Niigata.
15. C.-F. Tuan, S.-C. Chen, L. Tsao, Y. H. Wu, S. J. Chen, “Performance Test of Fully Automatic Mass Comparator System of Capacity 100 g”, APMF 2019, Niigata.
16. Y.-H. Wu, L. Tsao, J.-Y. Chiu, S.-J. Chen, “Development of a combined XRF XPS surface analysis system”, APMF 2019, Niigata

Conference Papers

1. Establishment and verification of mercury-sealed piston prover for primary standard, 18th FLOMEKO, Ying-Chun Lin, Win-Ti Lin, Chun-Lin Chiang, 2019
2. Experimental study on blockage effect of water meters, IWA-ASPIRE Conference and Exhibition, Ching-Yuan Lu, Yu-Kuo Tsai, Wen-Chih Li, Jian-Yuan Chen, Yi-Lin Ho, Ching-Yi Kuo, Chun-Chieh Tsao, Kung-Hsien Shao, 2019
3. Development of micro-scale anemometer, 10th ISFFM, Sheng-Cyuan Fan, Jiann-Hua Jeng, Ying-Chun Lin, Jiunn-Haur Shaw, 2018
4. The installation issues affect Coriolis mass flow meter measure accuracy, 10th ISFFM, Chun-lin Chiang, Che-Wei Yeh, 2018
5. Systematic investigations of cylindrical nozzles acc. ISO 9300 down to throat diameters of 125 μm, 10th ISFFM, Bodo Mickan, Ching-Yi Kuo, Min Xu, 2018

6. Study on a mathematical model of a rotary gas meter, International Conference on of Engineering and Technology Innovation, Ching-Yi Kuo, Fong-Ruey Yang, Yi-Lin Ho, Jen-Tsung Luo, 2018
7. Use multiphysics simulations and resistive pulse sensing of study the effect of metal and non-metal nanoparticles in different salt concentration, ASME 2017 FEDSM, Chun-Lin Chiang, Che-Yen Lee, Yu-shan Yeh, 2017
8. Sih-Chieh Chen, Chung Lin Wu, Weileun Fang and Sheng Jui Chen, Development of a CMOS-MEMS Three-axis Force Sensor, **Asia Pacific Measurement Forum on Mechanical Quantities**, (2019)
9. Wei-Chien Lin, Chao-Lin Cheng, Chung-Lin Wu, and Weileun Fang, Sensitivity Improvement for CMOS-MEMS Capacitive Pressure Sensor Using Double Deformable Diaphragms with Trenches, **International Conference on Solid-State Sensors, Actuators and Microsystems**, (2017)
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