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

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Center for Measurement Standards

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Industrial Technology Research Institute
a nonprofit R&D organization engaging in applied research and technical services

2030 Technology Strategy & Roadmap

Smart Living
Enjoying High Quality Living & Lifestyle

Quality Health
Keeping Healthcare Good & Affordable

Sustainable Environment
Creating a Low-Carbon, Energy-Saving & Circular Community

Intelligentization Enabling Technologies for boosting multiple applications
Center for Measurement Standards

- ITRI’s largest linking center
- One of the DIs for Chinese Taipei’s participation in CIPM MRA
- National Measurement Laboratory (NML) Project - Establishing and maintaining national measurement standards in area of AUV, EM, L, M, PR, QM and T
Center for Measurement Standards

2021 Project Executed by NML

- Standards Maintenance and International Equivalence
  - International Equivalence
  - Industrial Service
  - System Maintenance

- Industrial Metrology
  - Nano-particle Analysis and Standard Technologies
  - Critical Dimension Metrology for Advanced Semiconductor Manufacturing Processes
  - Optical Measurement Technology for Lithography Process

- Development of Legal Metrology Technology
  - Technical Regulation for Type Approval of Active Electrical Energy Meters
  - Pre-research on Battery Metering Mechanism of Electric Scooter
  - Draft Technical Regulation for Initial and Subsequent Verification of Gas-oil Ratio Detectors

- National Metrology Infrastructure Refinement
  - Single Particle ICP Mass Spectroscopy
  - Hydraulic Force Calibration Machine
  - Microwave Scattering Parameter and Impedance Measurement
  - High Pressure Gas Flow Calibration
# Fluid Flow Standards

<table>
<thead>
<tr>
<th>Standard and calibration system</th>
<th>Measurement range</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F01</strong>: Large Water Flow Calibration System</td>
<td>(10 to 8000) L/min</td>
<td>Primary standard</td>
</tr>
<tr>
<td><strong>F02</strong>: Small Water Flow Calibration System</td>
<td>(2 to 700) L/min</td>
<td>Primary standard</td>
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<tr>
<td><strong>F03</strong>: Low-Viscosity Oil Flow Calibration System</td>
<td>(60 to 6000) L/min @ 2.6 mm²/s to 4.8 mm²/s</td>
<td>Primary standard</td>
</tr>
<tr>
<td><strong>F04</strong>: High-Viscosity Oil Flow Calibration System</td>
<td>(60 to 6000) L/min @ 37 mm²/s to 150 mm²/s</td>
<td>Primary standard</td>
</tr>
<tr>
<td><strong>F05</strong>: High Pressure Gas Flow Calibration System</td>
<td>(15 to 12000) Sm³/h</td>
<td>Primary standard</td>
</tr>
<tr>
<td><strong>F06</strong>: Low Pressure Gas Flow Calibration System - Piston Prover</td>
<td>(0.002 to 24) L/min</td>
<td>Primary standard</td>
</tr>
<tr>
<td><strong>F08</strong>: Low Pressure Gas Flow Calibration System – (Bell Prover:600 L)</td>
<td>(20 to 1000) L/min</td>
<td>Primary standard</td>
</tr>
<tr>
<td><strong>F10</strong>: Air Speed Calibration System</td>
<td>(0.5 to 25) m/s</td>
<td>Primary standard</td>
</tr>
<tr>
<td><strong>F11</strong>: Micro Flow Calibration System</td>
<td>0.1 μL/min to 10 mL/min</td>
<td>Primary standard</td>
</tr>
<tr>
<td><strong>F12</strong>: Low Pressure Gas Flow Calibration System (PVTt) – PVTt Method</td>
<td>0.01 L/min to 300 L/min</td>
<td>Primary standard</td>
</tr>
</tbody>
</table>
Force Standards

Calibration by comparison with a reference force transducer

Deadweight FSM

Electrostatic or mass balance method

Electrostatic micro-force standard: 50 nN ~ 200 μN

N01: 5 kN ~ 50 kN
N02: 500 N ~ 5 kN
N03: 500 kN ~ 2 MN
N04: 50 kN ~ 500 kN
N09: 10 N ~ 500 N
N10: 0.02 mN ~ 0.01 N
N11: 0.01 N ~ 10 N
Gravimetry Standards

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/s²

Superconducting gravimetry
- High quality continuously recording gravimeters
- Sensitivity of the instrument reaches the level of $10^{-12}$ nm/s²

Relative Gravimeter
- LACOSTE-ROMBERG gravity meters #1184 and #1200
- Standard uncertainty is 100 nm/s²
Hardness Standards

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

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 %.

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 %.

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.
Mass Standards

Pt-Ir No. 78

1 mg ~ 1000 kg Standard Weights

High Capacity Weighing System

Mettler Toledo New M_One

Low Capacity Weighing System

1 mg  1 g  1 kg  1000 kg
Pressure Standards

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.

Hydraulic 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 Standards

**Vacuum Gauge Comparative Calibration System**
The system provides calibration for vacuum gauges with a measurement range of $0.1 \text{ Pa to } 100 \text{ kPa}$, the relative uncertainty is $1.8\%$.

**Dynamic Expansion Vacuum Calibration System**
The system provides calibration for vacuum gauges with a measurement range of $5\times10^{-6} \text{ Pa to } 8.6\times10^{-3} \text{ Pa}$, the relative uncertainty is between $4\%$ to $9\%$. 
Research & Development

- New kg realization via XRCD method
- Development of Optical Pressure Standard
- Micro-force/small mass standard
- Natural gas metrological research
New kg realization via XRCD method

Evaluate the mass of the Si-sphere under vacuum

\[ m_{sphere} = \frac{8V_{core} \sum_i x(Si)A_r(Si) 2hR_{\infty}}{a^3 A_r(e) \alpha \alpha^2} - m_{defect} + m_{SL} \]

**m**<sub>core</sub>

XRF/XPS surface analysis system for the measurement of \( m_{SL} \)

**Total mass deposition of oxygen:** \( 36.68 \pm 3.37 \mu\text{g} \)

Evaluate \( m_{sphere} \) under vacuum based on \( m_{SL} \) and other pre-determined parameters of \( m_{core} \)
New kg realization via XRCD method

- Vacuum-air transfer the mass from the Si-sphere to the stainless steel kg standard

\[ m_{ss,air} = m_{ss,\text{vac}} + A_{ss} \cdot s \]

\[ s = \frac{\Delta m_{\text{vac}} - \Delta m_{\text{air}}}{\Delta A} \]

- Sorption coefficient \( s \) estimated by measuring the mass difference of sorption artefacts in air and vacuum with vacuum mass comparator.

<table>
<thead>
<tr>
<th>( \Delta m_{\text{vac}} ) (mg)</th>
<th>( \Delta m_{\text{air}} ) (mg)</th>
<th>( \Delta A ) (cm(^2))</th>
<th>( s ) (μg/cm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.1865</td>
<td>-0.1717</td>
<td>434.4310</td>
<td>0.0342</td>
</tr>
</tbody>
</table>
Development of Optical Pressure Standard

**Direct SI traceable:** $p_{gas} = \rho_{gas} k T$

![Diagram of optical pressure standard setup]

- **Laser 1**
- **Laser 2**
- **Dual FPI**
- **Vacuum pump**
- **Photodetector**

Temperature stabilized vacuum chamber:

Temperature drift of copper vacuum chamber:

$u_{rel}(T) = 8.7 \times 10^{-6}$

FPI of high finesse: 24200 ± 240

Ring down effect: data & curve fitting

Fabry-Perot Interferometer for refractive index measurement

Temperature vs. time graph:

- SPRT
- PT100
- PT100
- PT100

Temperature drift of copper vacuum chamber.

$\rho_{gas} = \frac{p_{gas}}{k T}$

- $k$: Boltzmann constant
- $T$: Temperature
- $p_{gas}$: Gas pressure
Microforce/small mass Standard

Electrostatic Sensing and Actuating Force Balance

- Range: \( \leq 200 \, \mu\text{N} \)
- Uncertainty: \( \sqrt{(4.7 \times 10^{-9})^2 + (1.4 \times 10^{-4}\Delta f_e)^2} \, \text{N} \)

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**Diagram:**

- Monolithic flexure stage
- Laser
- ITF
- Sensing/actuating electrodes
- Electrostatic force actuation
- Digital controller
- Deflection signal

**Graph:**

- Force, \( \text{mN} \)
- 1 mg weighing
- 10 mg weighing
- Deadweight
- Electrostatic force

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Natural gas metrological research

Natural Gas Metering and Industry Status of Taiwan

Self-produced gas/buy gas → Delivery gas → Distribution gas → transaction

Self-produced gas (Hsinchu, Miaoli)

Land pipeline delivery

CPC distribution station

20% dosage 50 billion/year

Orifice plate

Large industrial users (450 users)

People’s Livelihood meter

Hotel, restaurant

General industrial users

337 million home users

Large industrial users (25 users)

Gas company of town

Kada, Indonesia, Malaysia

Wing on, Taichung

Land & land pipeline delivery

LNG ship

80% dosage 200 billion/year

CPC distribution station

Ultrasonic Meter · Turbine Meter

NG power plant (13 units)
Participation in International Standardized Committees

• **CCM**
  – Member of CCM-WGM
  – Observer of CCM-WGPV

• **APMP** – Asia Pacific Metrology Programme
  – Full Member since 1992
  – Technical Committee for Mass and Related Quantities: 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
Future works

• Commissioning the XRF/XPS surface analysis system
  – XPS is under test and final integration
  – Contribute to the future kg realization comparisons

• Dynamic Measurements
  – Development of dynamic force/torque standard under way
  – Other mechanical quantities under evaluation

• Establishing quantum based optical pressure standard