Go with the flow
How to verify, prove and calibrate Coriolis technology
Presentation Overview

- Calibration
  - Discuss Accredited Calibration for Flow and Density

- Verification
  - Discuss Verification and Proving Techniques. Opportunities for on-site calibration/adjustment.
**Terminology Overview**

- **Calibration**
  - According to the International Vocabulary of Metrology (VIM), calibration is a procedure to establish a relation between a quantity value given by a flowmeter, in addition to its measurement uncertainty and a reference quantity value obtained by a calibration rig, within its associated measurement uncertainty.

- **Verification**
  - Again, According to the VIM, the term verification is defined as ‘Provision of objective evidence that a given item fulfills specified requirements’
Basics of Flow Meter Calibration

- The basics of how calibration of a flow meter is accomplished
  - creating a steady state flow condition (good profile etc...)
  - diverting that flow to a measurement device for a fixed amount of time
  - determining the totalized flow by independent means
  - determining the value (or Mass) measured by the meter
  - repeating the above steps under the required number of conditions
  - adjusting the meter output to agree with the independently determined values, under all conditions
Understanding the Calibration of Flowmeters

- Why is it needed?
  - no measurement device inherently makes an accurate measurement it will be repeatable, not accurate.
  - each produced device must be “calibrated” to assure its accuracy
  - without it, we aren’t really selling a flow meter – only one with a “related” or “proportional” flow rate

- What calibration is NOT
  - re-ranging or re-scaling the output to field requirements
  - re-ranging or re-scaling the output to match an arbitrary standard (such as to the wishes of an inspector or other regulator)
  - putting the device output in agreement with another standard, at one flow rate only
ISO-4185 Calibration Method

ISO 4185:1980
Measurement of liquid flow in closed conduits -- Weighing method

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Two Main Calibration Methods for Flow Meters

- Gravimetric vs. Volumetric

- Gravimetric: The most common method. Calibration fluid is captured and weighed. If the meter being calibrated is a volumetric meter the weighed value is converted to volume by making precision measurements and calculations based upon fluid density, atmospheric buoyancy exerted on the weigh scales, etc.

- Volumetric: Often used for small volume flows. Calibration fluid is captured in a way that its volume is directly measured, such as by measuring the movement of a piston that recedes as a cylinder fills with the captured fluid. If the meter being calibrated is a mass meter, the measured volume is converted to mass by making precision measurements and calculations based upon fluid density.
Primary versus Secondary

- One fundamental requirement for carrying out a calibration is that the reference system must have traceability to the fundamental units of measurement needed to reproduce the unit flow. In this case, reference is made to a primary flow calibration rig traceable to the following measurement standards of a National Metrology Institute (NMI):
  - Mass
  - Time
  - Temperature
  - Density (for volumetric flow rate determination)

- Alternatively, a secondary flow standard such as a mobile calibration rig (or Prover) may be used as a reference where the traceability chain is split into three stages: fundamental units, primary calibration used to characterize the secondary flow standard and the mobile calibration rig.
Defining Traceability in Calibration

- **Traceability**
  - In the simple case, traceability will eventually go all the way back to an “artifact”– a “weight”, or a “ruler”, for example
  
  ![Image of artifacts]

- There is no “flow artifact”— i.e. there is no flow loop sitting at the National Institute of Standards and Testing with “10 gallon per minute” flow in it
- So our traceability must instead arise from the traceability of each of the individual measurements used to arrive at our measured flow values
Endress+Hauser: Worldwide Use of Primary Calibrations

“Accredited calibration standards” in all production locations used by Endress+Hauser for all flow meters produced.
Gravimetric Method (Primary) – Laboratory Standard

Diagram showing a flow system with components such as UUT, Flow Diverter, Optical Gate, Computer, weighing tank, Constant Flow Rate, and Water - Reservoir.
Coriolis Density Calibration Options

Coriolis meters measure direct Mass flow

Volume flow (for Coriolis meters) is a function of Mass flow and Density.

So, for Volumetric flow, the Density accuracy has a significant impact.
Coriolis Density Calibration Options

- All Coriolis meters are calibrated on air and water at ambient “reference” conditions

- Reference conditions are defined for:
  - Fluid, (air, water or other fluids)
  - Temperature, (conditions of the fluid and laboratory)
  - Pressure (line conditions defined for each calibration rig used)
  - Reference conditions can vary by manufacturer
Standard Density Calibration: Two Fluids

- Standard density calibrations: ±0.01 g/cm³
Custom Density: Endress+Hauser

- NIST traceable solution – wider temperature – multiple densities
- Special density calibration: ±0.001 g/cm³
Traceability of an accredited calibration rig

The International Prototype Kilogram (at BIPM, France)
- International Prototype Kilogram (IPK) - global reference and basic unit of mass. The Bureau International des Poids et Mesures (BIPM), founded in 1875, keeps the IPK under lock and key in a vault on its premises in Sèvres near Paris (France).
- In 1954, 1991 and 2003 comparison measurements for verification took place between the IPK and Switzerland’s replica No. 38.
- Measuring uncertainty of the verification: +0.000001% ($\pm$0.1 microgram).

The national standard (national institute of metrology)
- Verification of the standard weights used by Endress+Hauser every 5 years by the Swiss Federal Office of Metrology METAS, using a mass comparator and national reference weights (national reference standards).
- Measuring uncertainty of the METAS 500 kg reference weight (class 2A): ±0.0001% (0.5 gram to 500 kg).
- Regular verification of the reference weights against Switzerland’s replica No. 38 of the IPK every 10 years.

The gravimetric scales (Endress+Hauser)
- Gravimetric scales of the PremiumCal calibration rig for measuring the reference flow values.
- Regular verification of the scales every 2 weeks with standard weights (internal reference standard).
- Measuring uncertainty of the standard weights (class 2F1): ±0.001%.

The calibration rig (Endress+Hauser)
- PremiumCal calibration rig for testing Promass B3/P/B4/P.
- Measuring uncertainty: ±0.015%.
- Accredited to ISO/IEC 17025 by the Swiss Accreditation Service (SAS).
- Annual SAS audits of the facility.

The meter (in customer’s production plant)
- Promass B3/P/B4/P for metering mass flow:
  – Exact balancing of material flows
  – Precise dosing of costly active ingredients
- Measuring accuracy: ±0.05%.
- Reference meter for onsite calibration (measuring uncertainty of mobile calibration rig: ±0.25 to 0.3%).
Traceable Calibration Protocol to ISO-17025

- Laboratory calibration
- Defines meter type, size, model number, serial number, resulting meter K-factor and zero point
- Identifies the calibration rig uses
- Uses five test points of varying velocities
- Bandwidth for uncertainty
- Requires operator signature and date
- Identifies compliance to ISO/IEC and ISO-5168
Proving

In-situ methods, provers, master meters, governmental and industry compliance requirements
**Terminology Overview**

- **What Proving IS**
  - The process of generating an external meter factor based on a unique fluid under process conditions
  - A concept which identifies a flow device repeatability
  - Proof of the long term stability of the flow device (i.e. meter factor shift)
  - A means to account for differences from laboratory calibration conditions
  - Using a device which may only be two times more accurate than the UUT
When is Proving a Required?

- Governmental conformance
  - Compliance to the Federal Regulations
- Quality system conformance
  - As dictated by ISO or internal quality management system
- Industry conformance
  - API, AGA, AER
- Long term confidence in meter performance or results
- Reduce loss
- Maintain quality
- Custody transfer or contractual trade
Types of Provers

- **Displacement Prover**
  - Consist of a calibrated section of pipe with a piston or spherical displacer in the pipe. The flow goes through the meter to be tested into the prover. The known volume then is compared to the indicated volume of the meter.

- **Tank Provers**
  - Comparison of a known volume in a tank to the indicated volume that passes through a meter.

- **Master Meter System**
  - A master meter is used to transfer the quantity or unit flow of a primary standard (displacement or tank prover) to the meter under test by measuring the same flow at the same time to establish a meter factor.
  - Ultrasonic and Coriolis meters have been approved by API as Master Meters.
API - Manual of Petroleum Measurement Standards

- Chapter 4 – Proving System
  - Section 4.5 - Master Meter Provers
    - Current revision includes Coriolis flow meters as master meter provers
  - Section 4.8 – Operation of Proving Systems
    - Current revision defines Coriolis flow master meter proving considerations

- Chapter 5 – Flow Meters
  - Section 5.6 – Use of Coriolis flow meters for hydrocarbon measurement
    - Potential uses include allocation metering, point of measurement, point of sale measurement, and master meters

- Chapter 12 – Calculation of Petroleum Quantities
  - Section 2 Part 3 – Proving Report
Bi-directional Proving of Coriolis

NMI approvals now include bidirectional use of the Promass Coriolis meter for custody transfer!!!
Master Meter Concept

- The calibration system has to have a significantly lower uncertainty than the meter under test, otherwise the test results of the meter under calibration cannot be used, because its uncertainty would be increased.

- Calibration should, when possible, be performed using products and conditions as close as possible to those for the intended use.

- Before calibration with a master meter, the master meter should be confirmed against another traceable flow, preferably a Primary Standard.
Portable Proving Solutions

- Internal ISO procedures and official regulations require regular check of instrumentation
- Portable master meter allows recalibration on site
  - Down time reduction
  - Cost reduction
  - No need to have spool piece or spare meter
  - Full traceability of certified calibration
- Calibration cart is now also used to validate level devices in the tanks
Mobile Proving Solutions
Fixed Proving Solutions
Verification

Long term stability and repeatability of Coriolis meters in concert with regulatory or conformance activities
Terminology Overview

- What Verification IS
  - evidence that a flow meter fulfills certain technical requirements of functionality as defined by the manufacturer.
  - a very detailed functional test to confirm sensor and/or transmitter stability and produces a qualitative outcome
  - A verification system acquires a number of flow meter parameters related to the flow meter response
  - A dedicated algorithm with system parameter reference values.
  - A result based on the current status of flowmeter functionality.
  - A qualitative assessment report based on a pass-fail criterion
  - A concept that must define the long term stability of the test system, the stability of internal references, and metrologically traceable factory references for user confidence
Verification - Fieldcheck

- Verification for In-situ Meter Checks
  - Verification of the calibration relative to a simulated flow input, transmitter processing, and outputs
  - Is NOT a calibrator
  - Permits long term meter evaluation
  - Provides a meter thumbprint technique for long term analysis
  - Provides an unalterable record
  - Supports extension of proving or wet calibrations
  - Allows record comparison for deviation analysis
Fieldcheck™ as an NIST Verification Standard

- Fieldcheck™ is used by customers in the Canada and the US as a traceable verification device for governmental conformance with growing acceptance:

  - AER per Directive 17
  - Treasury Taxation Bureau – BATF per (CFR Title 25)
  - Departments of Environmental Management throughout U.S.
Endress+Hauser FieldCheck™ – Operation

• Field operation

• Workshop operation
Coriolis Verification - Fieldcheck

- Transmitter
  - Check of the zero point for the outputs
  - Verification of signal processing
  - Linearity of the amplifier
  - I/O processing
    - Current output(s)
    - Frequency (including pulse) output(s)
- Sensor
  - Excitation circuit
  - Frequency parameter
  - Temperature elements
  - Pick-up coils
Fieldcheck Verification Certificate

Flowmeter Verification Certificate

Customer

Order code
PROMASS R3 F DN40

Device type
3504802000

Serial number
V1.06.00

Software Version Transmitter
07.07.2005

Verification date

Verification result: Passed

Test item | Result | Applied Limits
--- | --- | ---
Amplifier | Passed | 0.5 %
Density | Passed | 0.5 %
Temperature Measuring tube | Passed | 1.0 %
Temperature Carrier tube | Passed | 1.0 %
Current Output 1 | Passed | 0.05 mA
Pulse Output 1 | Not testable |
Test Sensor | Passed |

FieldCheck Details

Simbus Details
8621459

Software Version
V1.00.00

Last Calibration Date
17.07.2003

FieldCheck - Result Tab

Customer | Order code | PROMASS R3 F DN40
Device type | Device type |
3504802000 | 3504802000
Serial number | Serial number |
V1.06.00 | V1.06.00
Software Version | Software Version |
V1.03.00 | V1.03.00
Verification date | Verification date |
07.07.2005 | 07.07.2005

Verification Flow end value (100 %): 997,000 lbm
Flow speed 6.0 m/s
Verification range: Standard range
Type of flow unit: MASS FLOW

Passed/Failed | Test item | Simul. Signal | Limit Value | Deviation
--- | --- | --- | --- | ---
Test Transmitter

Amplifier | ok | 0.5 % | 0.5 % | 0.13 %

Density | ok | 0.5 % | 0.5 % | 0.13 %

Temperature Measuring tube | ok | 1.0 % | 1.0 % | 0.13 %

Temperature Carrier tube | ok | 1.0 % | 1.0 % | 0.13 %

Current Output 1 | ok | 0.05 mA | 0.05 mA | 0.00 %

Pulse Output 1 | nok |

Test Sensor

Endress+Hauser

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Extended Reliability Tests for Coriolis

- Long term shifts in pick-ups, temperature elements, coils and drivers can be traced
- Comparative results allow for trending for individual meters
- Electronic shifts in mass flow and density performance can be pinpointed
- Non-detected faults can be found leading to preventative maintenance (NAMUR NE-107)

FieldCheck - Result Tab Sensor Verification

<table>
<thead>
<tr>
<th>Passed/Failed Test Item</th>
<th>Measured value</th>
<th>Limit Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal-GND ↔ Housing-GND</td>
<td>5.05 Ohm</td>
<td>5 – 100 Ohm</td>
</tr>
<tr>
<td>Excitation coil resistance</td>
<td>113 Ohm</td>
<td>Dependent of temp.</td>
</tr>
<tr>
<td>Pick-up coil 1 resistance</td>
<td>24.2 Ohm</td>
<td>Dependent of temp.</td>
</tr>
<tr>
<td>Pick-up coil 2 resistance</td>
<td>31.5 Ohm</td>
<td>Dependent of temp.</td>
</tr>
<tr>
<td>Temp Sensor M</td>
<td>1.39 kOhm</td>
<td>Dependent of temp.</td>
</tr>
<tr>
<td>Temp Sensor T</td>
<td>1.39 kOhm</td>
<td>Dependent of temp.</td>
</tr>
<tr>
<td>Pick-up Coil 1 ↔ Pick-up Coil 2</td>
<td>&gt; 120 MOhm</td>
<td>&gt; 5 MOhm</td>
</tr>
<tr>
<td>Pick-up Coil 1 ↔ Temp. Sensor M</td>
<td>&gt; 120 MOhm</td>
<td>&gt; 5 MOhm</td>
</tr>
<tr>
<td>Pick-up Coil 1 ↔ Temp. Sensor T</td>
<td>&gt; 120 MOhm</td>
<td>&gt; 5 MOhm</td>
</tr>
<tr>
<td>Pick-up Coil 2 ↔ Temp. Sensor M</td>
<td>&gt; 120 MOhm</td>
<td>&gt; 5 MOhm</td>
</tr>
<tr>
<td>Pick-up Coil 2 ↔ Temp. Sensor T</td>
<td>&gt; 120 MOhm</td>
<td>&gt; 5 MOhm</td>
</tr>
<tr>
<td>Temp. Sensor M ↔ Temp. Sensor T</td>
<td>&gt; 120 MOhm</td>
<td>&gt; 5 MOhm</td>
</tr>
<tr>
<td>Temp. Sensor M ↔ Excitation Coil</td>
<td>&gt; 120 MOhm</td>
<td>&gt; 5 MOhm</td>
</tr>
<tr>
<td>Temp. Sensor T ↔ Excitation Coil</td>
<td>&gt; 120 MOhm</td>
<td>&gt; 5 MOhm</td>
</tr>
<tr>
<td>T/¥ Pick-up Coil 1 ↔ Signal GND</td>
<td>&gt; 1200 MOhm</td>
<td>&gt; 10 MOhm</td>
</tr>
<tr>
<td>T/¥ Pick-up Coil 2 ↔ Signal GND</td>
<td>&gt; 1200 MOhm</td>
<td>&gt; 10 MOhm</td>
</tr>
<tr>
<td>T/¥ Excitation Coil ↔ Signal GND</td>
<td>&gt; 1200 MOhm</td>
<td>&gt; 10 MOhm</td>
</tr>
<tr>
<td>T/¥ Temp. Sensor M ↔ Signal GND</td>
<td>&gt; 1200 MOhm</td>
<td>&gt; 10 MOhm</td>
</tr>
<tr>
<td>T/¥ Temp. Sensor T ↔ Signal GND</td>
<td>&gt; 1200 MOhm</td>
<td>&gt; 10 MOhm</td>
</tr>
</tbody>
</table>

Application Reference Data

| Excitation coil resistance | 113 Ohm |
| Pick-up coil 1 resistance | 24.2 Ohm |
| Pick-up coil 2 resistance | 31.5 Ohm |
| Excitation Current | 1.93 mA |
| Excitation Frequency | 397 Hz |
| Signal amplitude | 291 mV |
| Actual Flow Value | 0.3280 lpm |
| Summ. / Asymmetry | -0.28 % |
| Temperature meas. Tube | 22.4 °C |
| Temperature carrier-Tube | 22.1 °C |
Output Specifics on Verification Report

- The complete meter output configuration can be archived or printed

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### FieldCheck: Flowmeter Parameters

<table>
<thead>
<tr>
<th>Customer</th>
<th>Order code</th>
<th>Plant</th>
<th>Tag Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Device type | PROMAG 53 DN25 | K-Factor | 0.8494/0.8494 |
| Serial number | 28007991000 | Zero point | 4 |
| Software Version Transmitter | V1.04.00 | Software Version I/O-Module | V1.02.01 |
| Verification date | 24.08.2003 | Verification time | 18:47 |

<table>
<thead>
<tr>
<th>Current Output</th>
<th>Assign</th>
<th>Current Range</th>
<th>Value 0-4mA</th>
<th>Value 20 mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screw 26/27</td>
<td>VOLUME FLOW</td>
<td>4-20 mA</td>
<td>0.0 gal/m</td>
<td>70.00 gal/m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency Output</th>
<th>Assign</th>
<th>Start value frequency</th>
<th>End value frequency</th>
<th>Value f low</th>
<th>Value f high</th>
<th>Output signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screw 24/25</td>
<td>VOLUME FLOW</td>
<td>0 Hz</td>
<td>2000 Hz</td>
<td>0.0 gal/m</td>
<td>70.00 gal/m</td>
<td>Passive/Positive</td>
</tr>
</tbody>
</table>
Self-verification by Heartbeat Technology

- Verification of flowmeter functionality based on flowmeter internal factory references and corresponding specifications
- During production process these factory references are calibrated based on traceable references to establish a factory baseline
Traceability of verification references?

- What is the relation between calibration and verification results?

Calibration rig

Verification report

Calibration report
Verification by Heartbeat Technology

- Heartbeat Technology verifies the manufacturer specification of the measuring device by verifying secondary variables correlated with measurement output (e.g.: flow, density, temperature...).
- Verification ensures confidence in the measuring results

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Passed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet pickup coil</td>
<td>Passed</td>
</tr>
<tr>
<td>Outlet pickup coil</td>
<td>Passed</td>
</tr>
<tr>
<td>Measuring tube temperature sensor</td>
<td>Passed</td>
</tr>
<tr>
<td>Carrier tube temperature sensor</td>
<td>Passed</td>
</tr>
<tr>
<td>Pickup coil symmetry</td>
<td>Passed</td>
</tr>
<tr>
<td>Frequency lateral mode</td>
<td>Passed</td>
</tr>
<tr>
<td>Frequency torsion mode</td>
<td>Passed</td>
</tr>
<tr>
<td>Sensor integrity</td>
<td>Passed</td>
</tr>
<tr>
<td>Sensor electronic module</td>
<td>Passed</td>
</tr>
<tr>
<td>Zero point tracking</td>
<td>Passed</td>
</tr>
<tr>
<td>Reference clock</td>
<td>Passed</td>
</tr>
<tr>
<td>Reference temperature</td>
<td>Passed</td>
</tr>
<tr>
<td>I/O module</td>
<td>Passed</td>
</tr>
</tbody>
</table>
Metrological traceability?

**Flowmeter verification**

Compares secondary references (e.g.: frequency, voltage, sensor integrity...)

**Flow calibration**

Compares intended quantity (measurand, e.g.: flow, density...)

Endress+Hauser
Confidence based on long term stability

Proline 2
Periodic recalibration of Fieldcheck Verificator (typically annually)

Fieldcheck

Proline
Long term stability analysis of internal references

Heartbeat Verification

Long term stability
**Summary**

- Calibration capability
  - The calibration is based on which procedure?
  - Which calibration concept is used?
  - Calibration capability is confirmed by third party calibration institutes acc. to ISO 17025

- Verification is not Calibration
  - Qualitive check to confirm that the device is still fulfils specific requirements within defined parameters.
Any questions?