Custody Transfer Measurement and Calibration Round Robin Testing for Natural Gas with Coriolis Meters

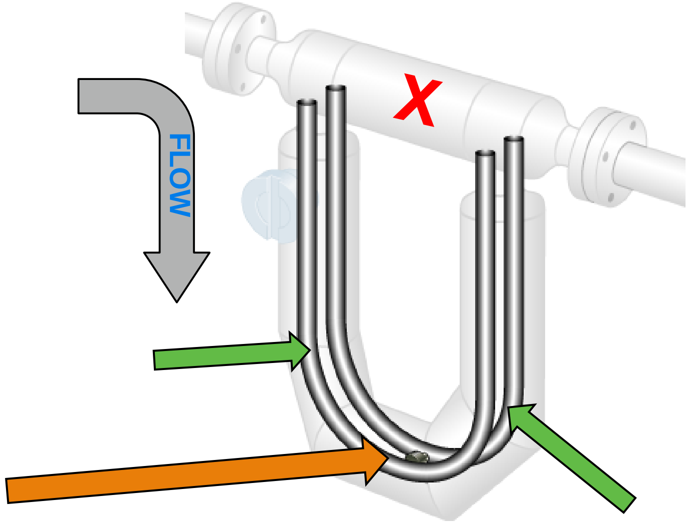
Agenda

- **Coriolis Meter Principle of Operation**
- **AGA Report No. 11**
- **Conversion of Mass to Gas Standard Volume**
- **Calibration Options**
- **Field Verification**

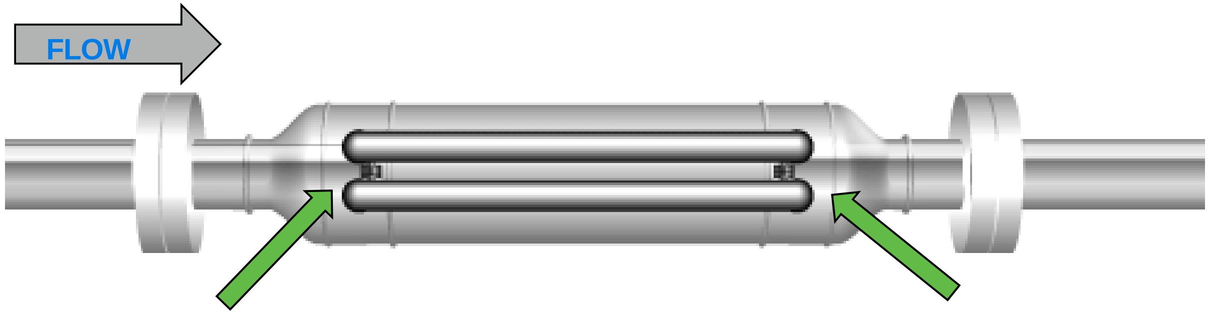
Coriolis Meter
Principle of Operation

Coriolis Meter Principle of Operation
Main Meter Components

- Process fluid enters the sensor and flow is split with half the flow through each tube



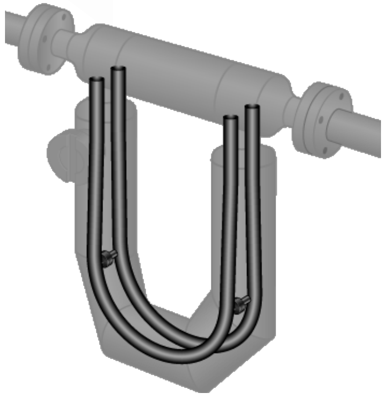
- Drive coil vibrates tubes at natural frequency

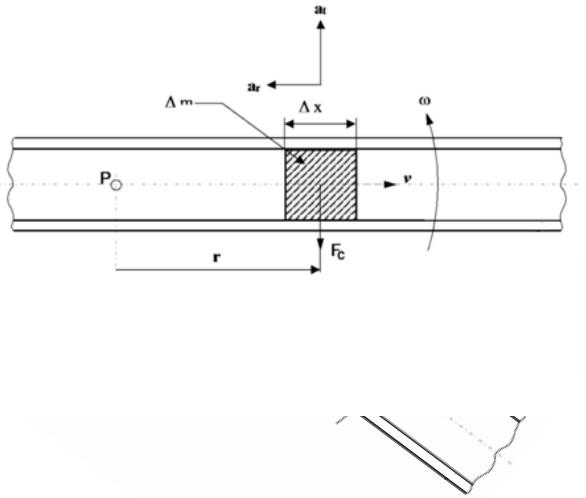


- Pick-off coils on inlet and outlet sides generate raw measurement signals

Coriolis Meter Principle of Operation
Physics of Coriolis Force

As a mass moves <u>toward</u> or <u>away</u> from the center of rotation (P) inside a rotating tube, the particle generates inertial forces on the tube.

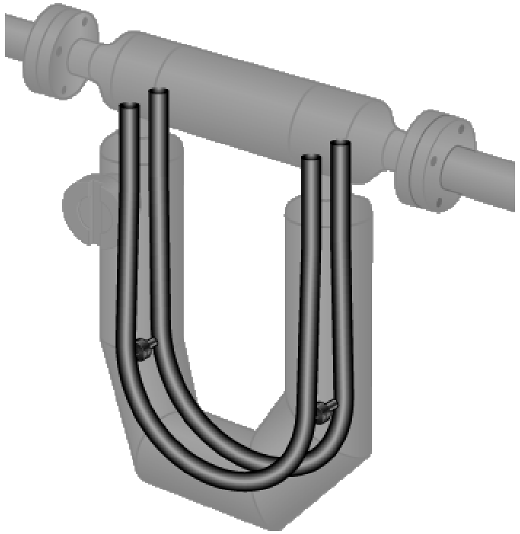




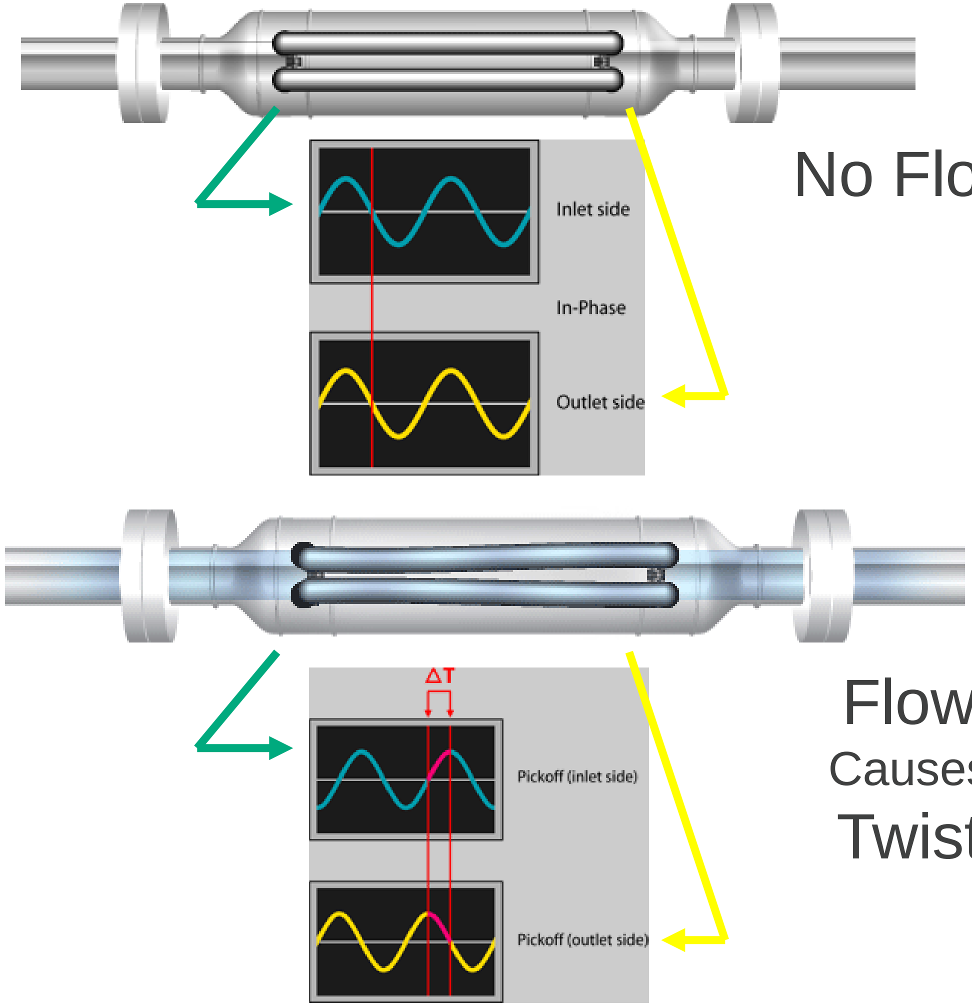
A Coriolis meter measures mass directly

- Tubes are sensitive to bulk inertial forces of the fluid mass
- Measurement is not affected by changes in fluid properties and velocity profile

Coriolis Meter Principle of Operation
Signal Processing



Isometric View
At No Flow

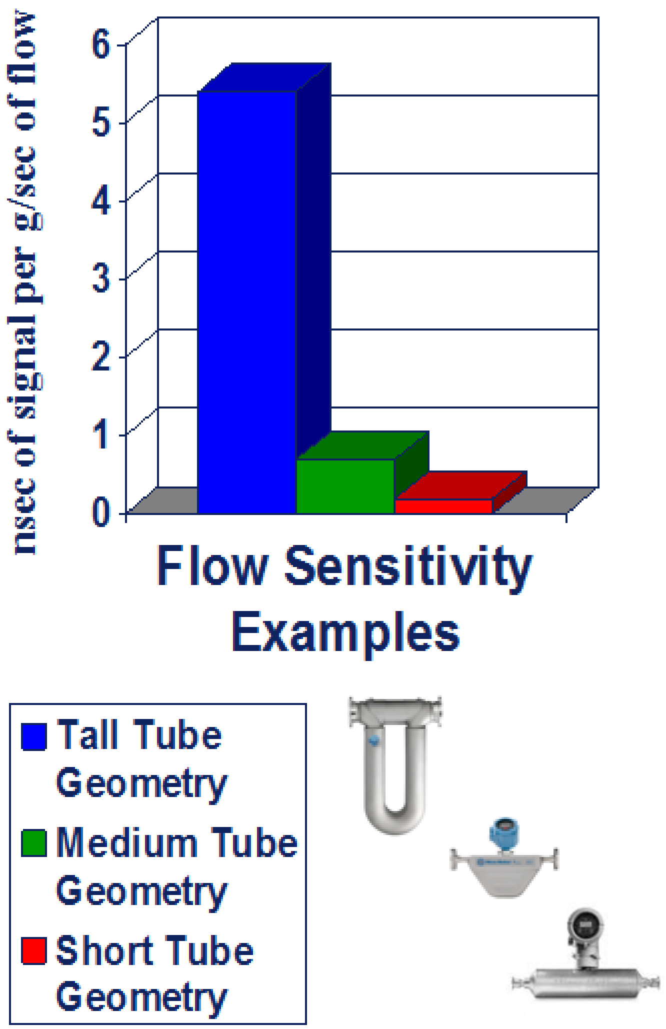


No Flow

Flow
Causes
Twist

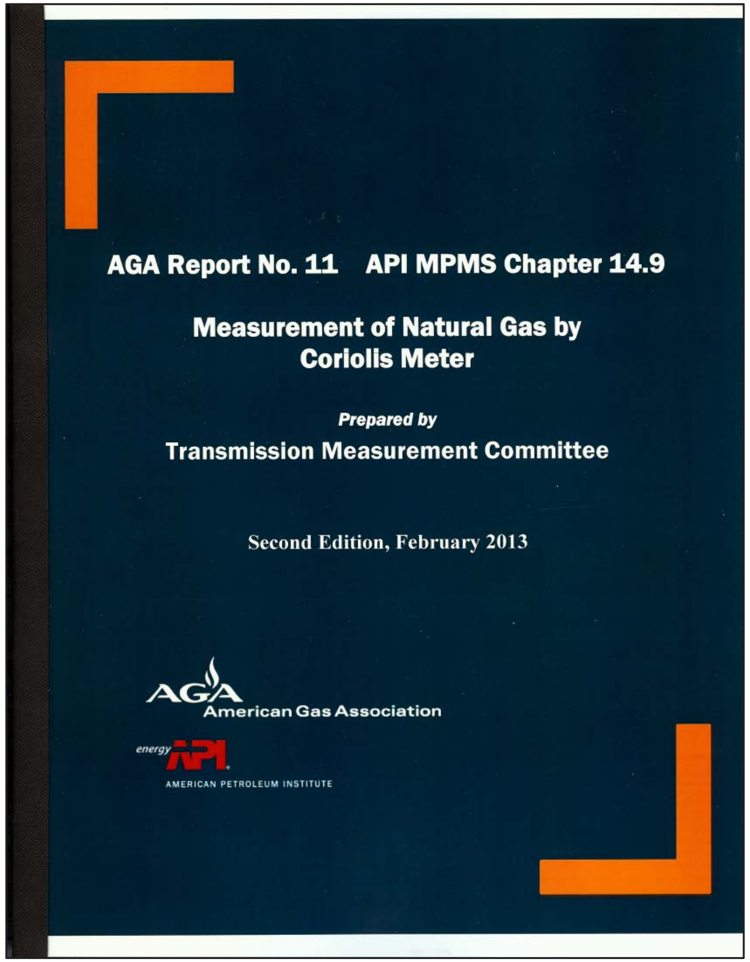
Coriolis Meter Raw Sensitivity Varies with Design

- **Raw Sensitivity Depends on Tube Geometry**
- **Signal to Noise Ratio Depends on Raw Sensitivity and Stability**
- **Calibration Flexibility, Immunity to Secondary Effects, and Diagnostic Capabilities Depend on Signal to Noise Ratio**



AGA Report No. 11 / API MPMS Ch. 14.9

Measurement of Natural Gas by Coriolis Meter



- **2nd Edition**
  - **Published February 2013**
  - **Covers all single phase natural gases as pure or a mixture of hydrocarbons and diluents**
- **API Standard**
  - **API MPMS Chapter 14.9**
- **Recommended Practice**
  - **Specification, calibration, installation, operation, maintenance, and verification**

What's changed in the 2nd Edition?

AGA Report No. 11 / API MPMS Ch. 14.9
Measurement of Natural Gas by Coriolis Meter

- **Tightening of performance requirements from ± 1.0% to ± 0.7%**
- **Water calibration transfers to gas only when the manufacturer has proof of testing by a 3rd party.**
- **Additional meter "verification" steps will guide the user on the need to flow test**
- **Flow testing can be performed in the field per new guidelines**
- **New appendices added:**
  - **Coriolis Gas Flow Measurement System**
  - **Coriolis sizing equation**
  - **Coriolis Uncertainty section and Example Uncertainty Calculation**

Conversion of MASS to VOLUME at Standard Conditions

- Coriolis meters measure <u>Mass</u> directly

- This eliminates the need to quantify gas Volumetrically at <u>flowing</u> conditions
  - There is no need to measure flowing pressure and temperature
  - There is no need to calculate compressibility (Z)

- You simply need to know the gas density at base conditions

Conversion of Mass to Volume at Standard Conditions

$$Nm^3 = \frac{Mass}{\rho_b}$$

AGA11 Eqn. D.2

kg/day ÷ kg/m³ = m³/day

$$\mathrm{N}m^3 = \frac{Mass}{\left[\frac{P_b \times Mr_{(Gas)}}{Z_b \times R \times T_b}\right]}$$

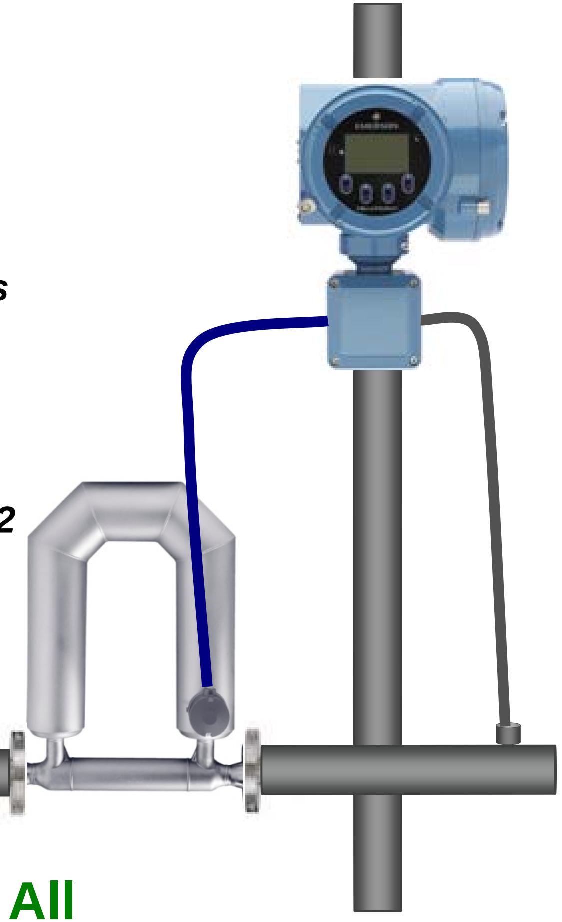
AGA8 Detail

Non-ideal gas law:
P_b, T_b, R are constants

Note: Z_b does not vary more than 0.02% at base conditions.

$$\mathrm{N}m^3 = \frac{Mass}{\left[Gr_{(Gas)} \times \rho_{(Air)}\right]}$$

AGA8 Gross 1 or 2



No pressure or Temperature Measurement Required to Convert from Mass to Standard Volume

Base Density, Molar Weight, Base Compressibility, and Specific Gravity Are All Determined by Gas Composition

Coriolis Volume Recalculation Methods

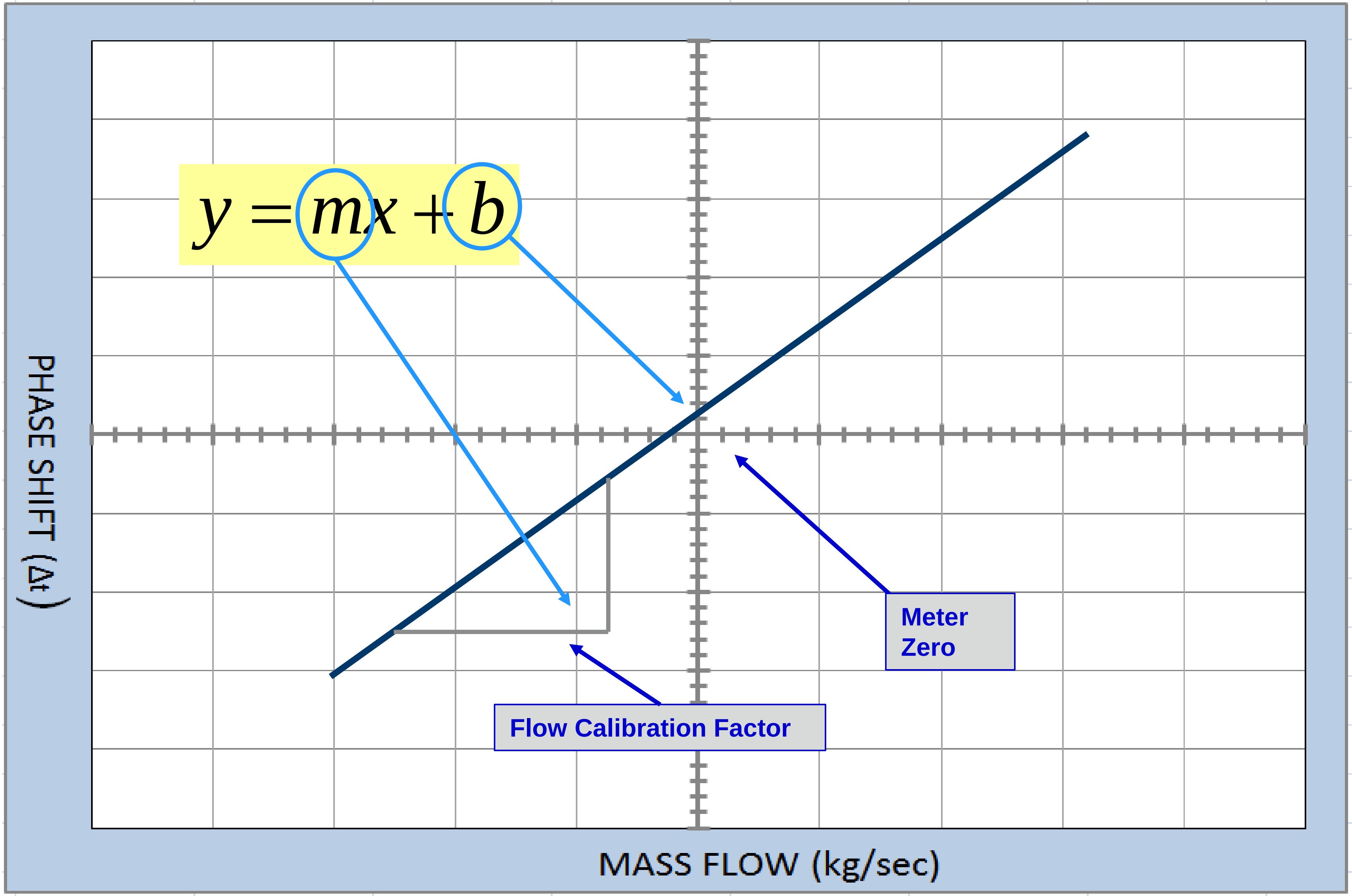
Relative Density Recalculation Method

$$SCF_{Gr(New)} = SCF_{Gr(Old)} \frac{G_{r(Old)}}{G_{r(New)}}$$

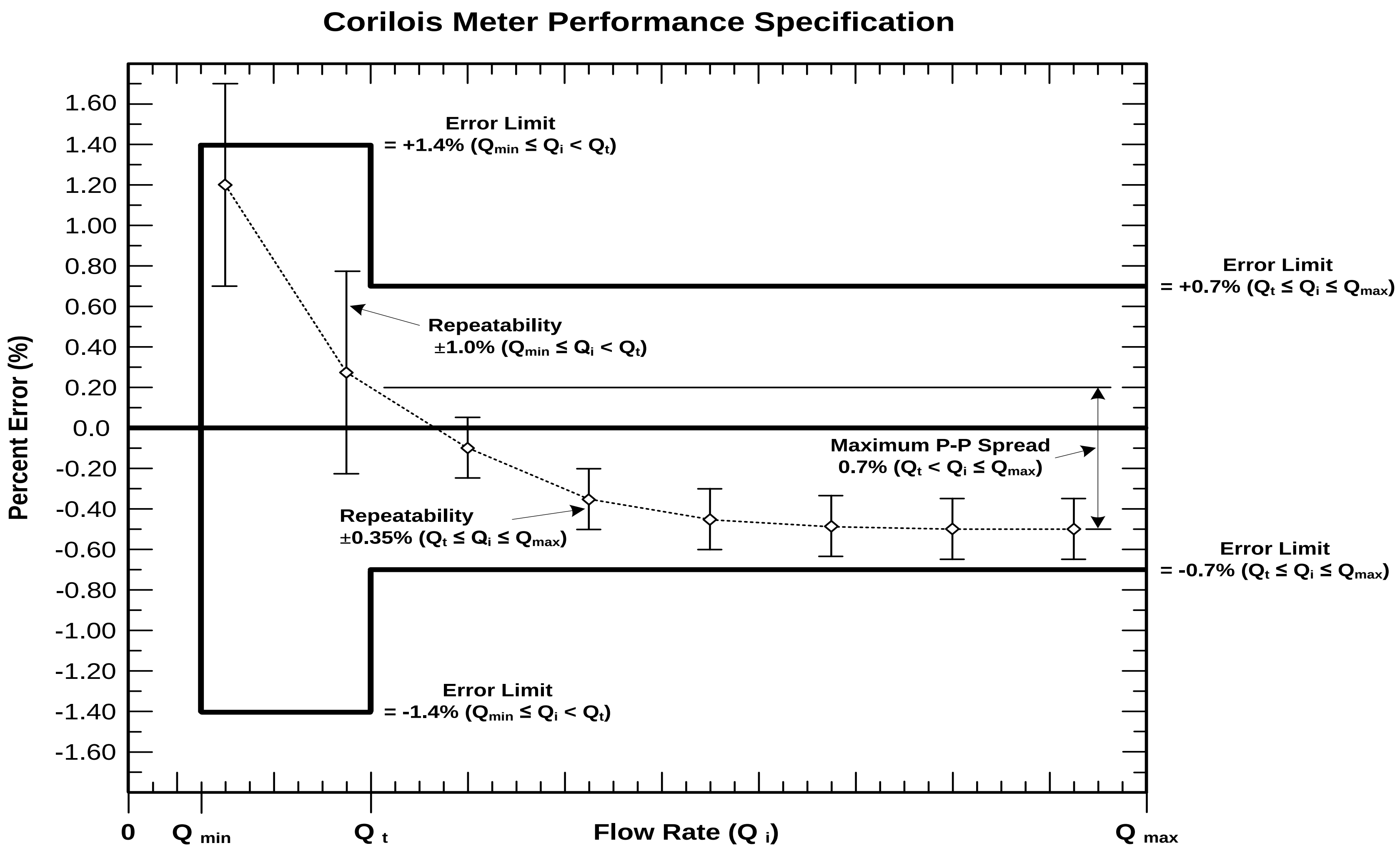
Base Density Recalculation Method

$$SCF_{\rho_b(New)} = SCF_{\rho_b(Old)} \frac{\rho_{b(Old)}}{\rho_{b(New)}}$$

Calibration: Span vs. Zero



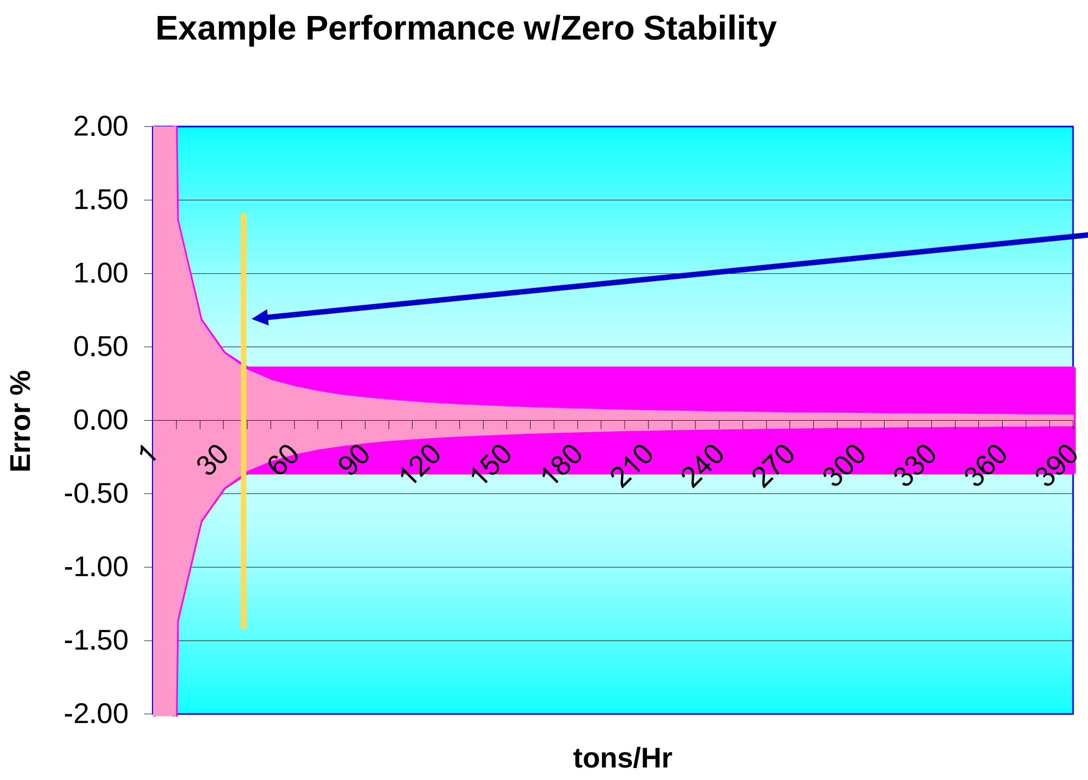
AGA 11 Section 6.1
Minimum Performance Requirements



Coriolis Accuracy Specification

Zero Stability and Base Accuracy Spec

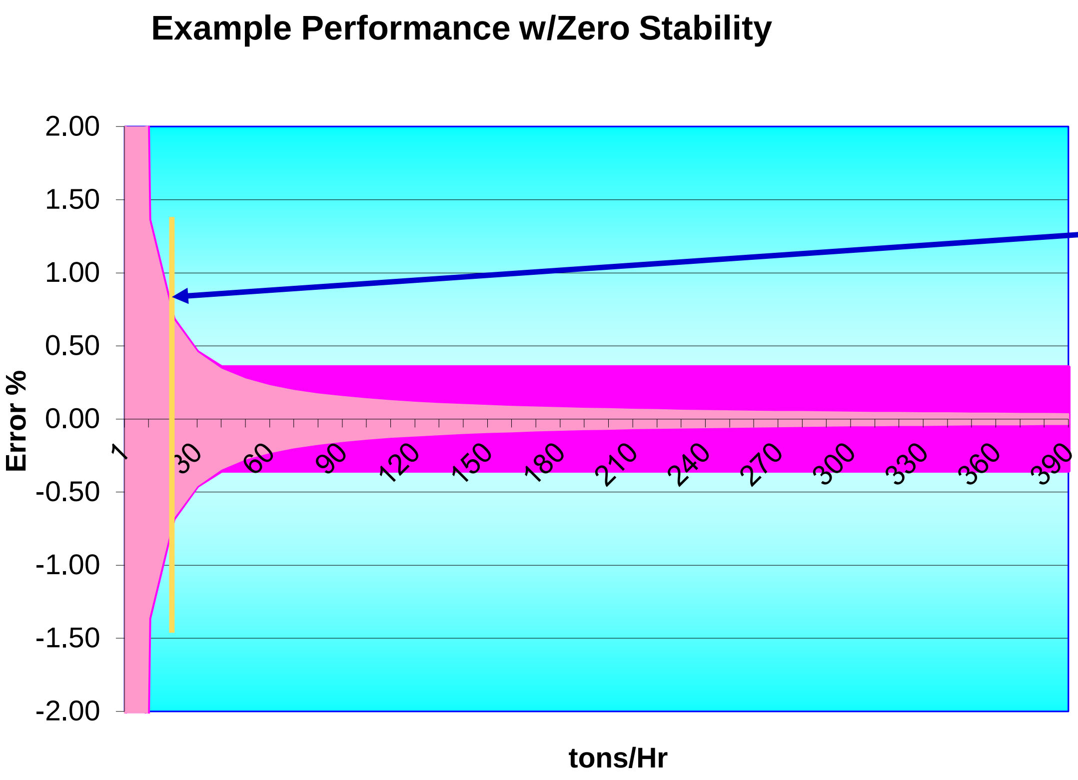
Q_t based on **manufacturer's specifications**



Example
Calculation of Qt

$$Q_t = Zero\ Stability / Base\ Spec$$
$$Q_t = 100\ (kg/h)/0.25\%$$
$$Q_t = 0.1\ (ton/h)/0.0025$$
$$Q_t = 40\ (ton/h)$$

Coriolis Accuracy Specification
Zero Stability and Base Accuracy Spec
Q_t based on **AGA 11 Requirements**



Example
Calculation of Qt

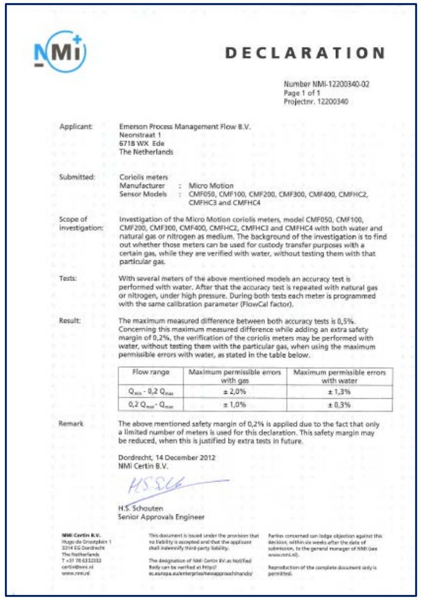
$$Q_t = Zero\ Stability/Base\ Spec$$
$$Q_t = 100\ (kg/h)/0.70\%$$
$$Q_t = 0.1\ (ton/h)/0.0070$$
$$Q_t = 14\ (ton/h)$$

Calibration Fluid Flexibility
Purpose and Benefits

“Calibration fluid flexibility” is a capability that allows a traceable gas OR liquid calibration media to be used for traceable gas measurements

- Gas medium meter calibration
  - Required by law in Canada, Norway, and other jurisdictions
  - Allows for Piece-Wise Linearization (PWL) adjustment
  - Ultimate accuracy will depend on the lab uncertainty and the meter design

- Liquid medium (e.g., water) meter calibration
  - Recognized in AGA Report No. 11 / API MPMS Ch. 14.9
    - Manufacturer must demonstrate acceptable provenance for each Coriolis meter design
  - Included with every meter as part of the manufacturing process
    - Lower cost
    - Greater safety
    - Easier to control liquid system uncertainties
  - Meter can be ready to measure as shipped directly from the manufacturer



NMi

DECLARATION

Number NMi-12200340-02
Page 1 of 1
Projectnr. 12200340

Applicant: Emerson Process Management Flow B.V.
Neonstraat 1
6718 WX Ede
The Netherlands

Submitted: Coriolis meters
Manufacturer : Micro Motion
Sensor Models : CMF050, CMF100, CMF200, CMF300, CMF400, CMFHC2, CMFHC3 and CMFHC4

Scope of investigation: Investigation of the Micro Motion coriolis meters, model CMF050, CMF100, CMF200, CMF300, CMF400, CMFHC2, CMFHC3 and CMFHC4 with both water and natural gas or nitrogen as medium. The background of the investigation is to find out whether those meters can be used for custody transfer purposes with a certain gas, while they are verified with water, without testing them with that particular gas.

Tests: With several meters of the above mentioned models an accuracy test is performed with water. After that the accuracy test is repeated with natural gas or nitrogen, under high pressure. During both tests each meter is programmed with the same calibration parameter (FlowCal factor).

Result: The maximum measured difference between both accuracy tests is 0,5%. Concerning this maximum measured difference while adding an extra safety margin of 0,2%, the verification of the coriolis meters may be performed with water, without testing them with the particular gas, when using the maximum permissible errors with water, as stated in the table below.

Flow range	Maximum permissible errors with gas	Maximum permissible errors with water
Q_{min} - 0,2 Q_{max}	± 2,0%	± 1,3%
0,2 Q_{max} - Q_{max}	± 1,0%	± 0,3%

Remark The above mentioned safety margin of 0,2% is applied due to the fact that only a limited number of meters is used for this declaration. This safety margin may be reduced, when this is justified by extra tests in future.

Dordrecht, 14 December 2012
NMi Certin B.V.

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Senior Approvals Engineer

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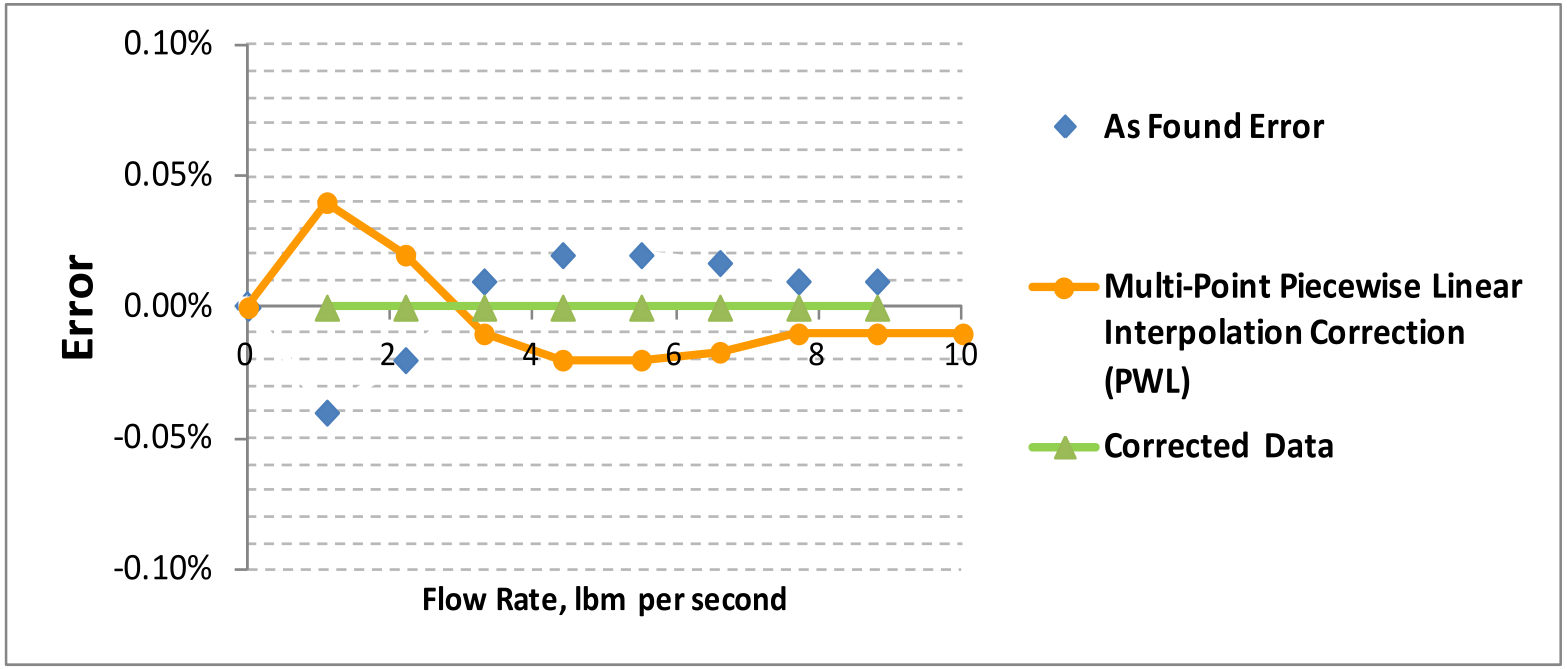
Multi-Point Piecewise Linear Interpolation



- Correction at linearization points opposite to average of as-found points
- Correction between points by linear interpolation
- Correction above highest flow rate are held constant
- Correction below the lowest point is linear interpolation to zero error at zero flow
  - Use meter zero in situ to maintain best accuracy below Q_t

Best Practices for Gas Calibration and PWL Fine-Adjustment

Procedure at Third-Party Lab:

1. Install and check meter zero
2. Calibrate meter zero, if necessary
3. Verify meter pressure compensation is active
4. Collect as-found data
5. Program meter with up to 10 linearization points from the as-found data
6. Collect as-left data to verify accuracy of linearization

Best Practices:

- Pay attention to the uncertainties of the gas lab reference standards
- Check the meter zero carefully before starting
- Collect as-found data with meter pressure compensation enabled
- Choose up to 10 flow-rate points
- Only use points above the meter Q_t flow rate
- Verify with intermediate flow rates included

Meter Zero Setting - Best Practices

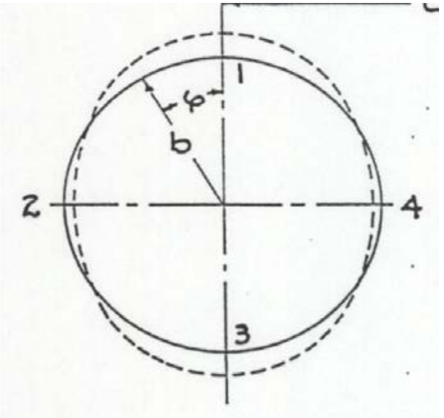
- Always Perform a Meter Zero Verification first
- Do not calibrate zero unless zero verification test indicates a need
- Most applications – use factory zero

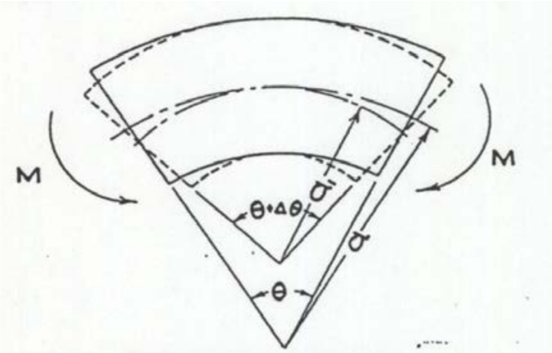
To calibrate zero:

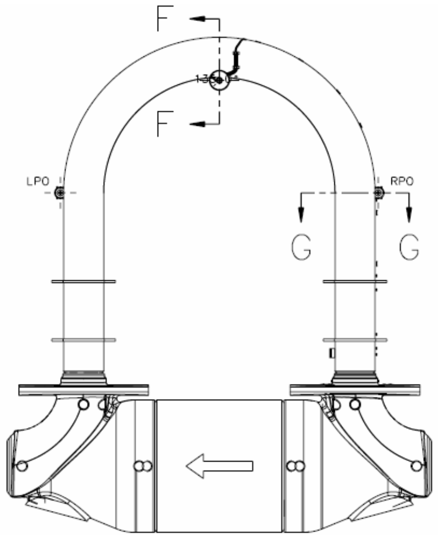
- Insure no flow condition
- Insure meter is full
- Insure process conditions are stable
  - Some zero verification tools will check both process stability and current zero value to predict the need for and likely success of a field zero calibration

Effect of Pressure on Coriolis Meters

- Internal pressure changes the shape of the flow tube
  - Tube ovality becomes round
  - Tube bends straighten
- Changes in flow tube shape increases stiffness of flow tube
- Changes in tube stiffness directly affects sensor calibration
- Magnitude of effect varies by meter size and design

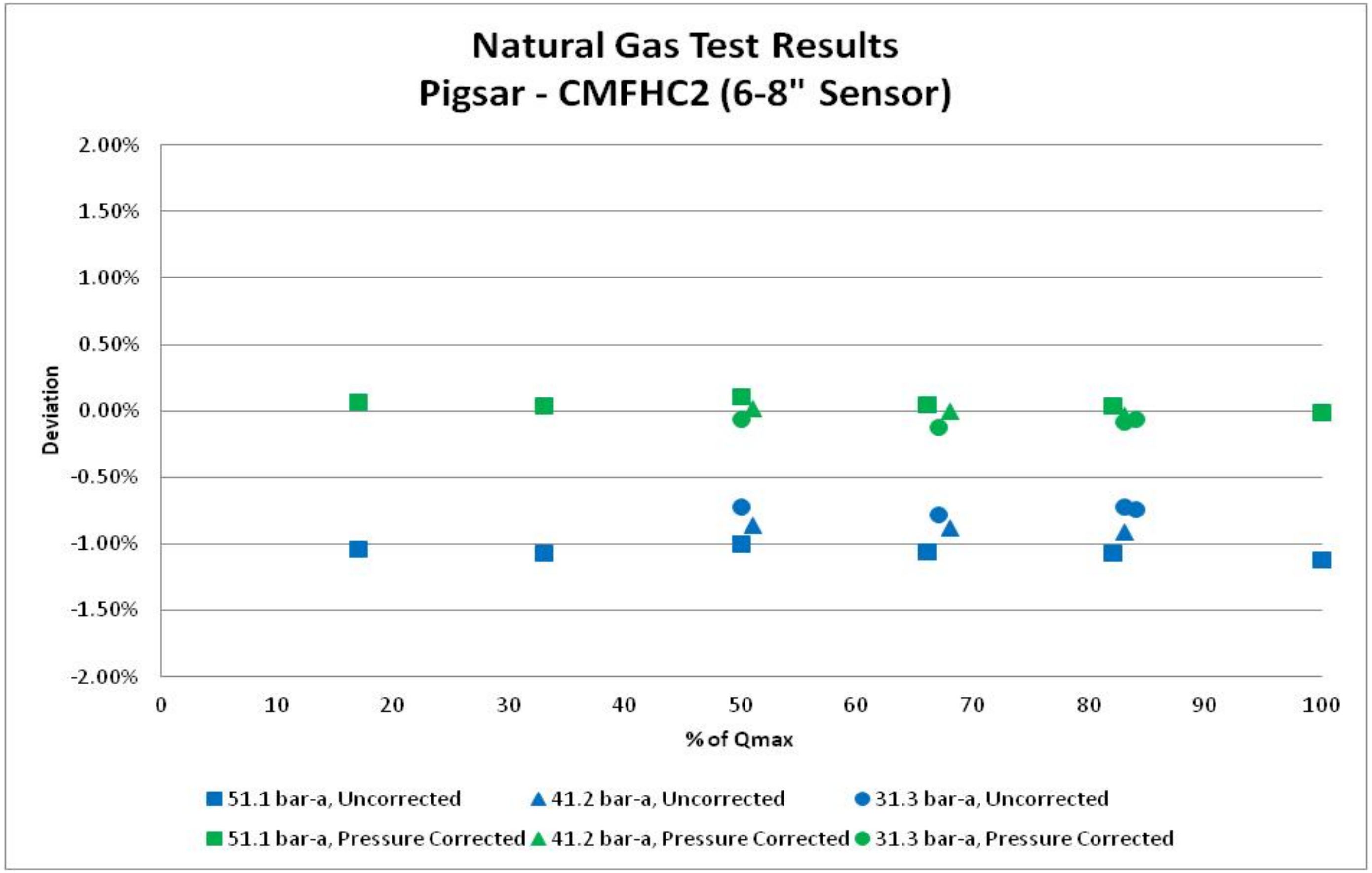






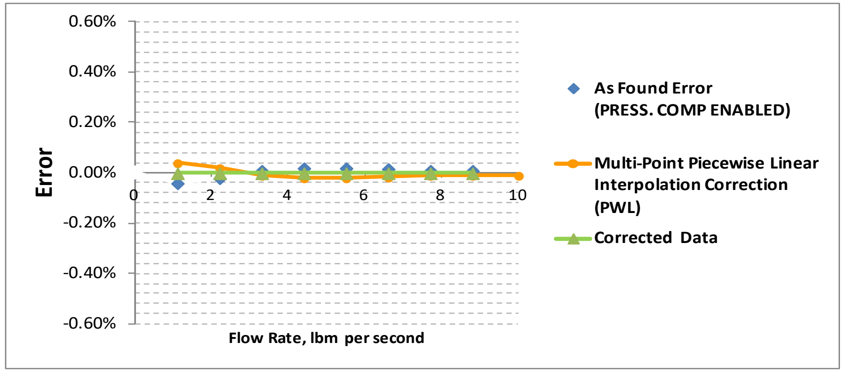
Example of Pressure Effect Compensation
Large Meter Gas Test Results

- All data collected on natural gas using meter factory calibration on water
- Data shown with and without standard F_P pressure compensation
- Max deviation of all compensated data < 0.25%

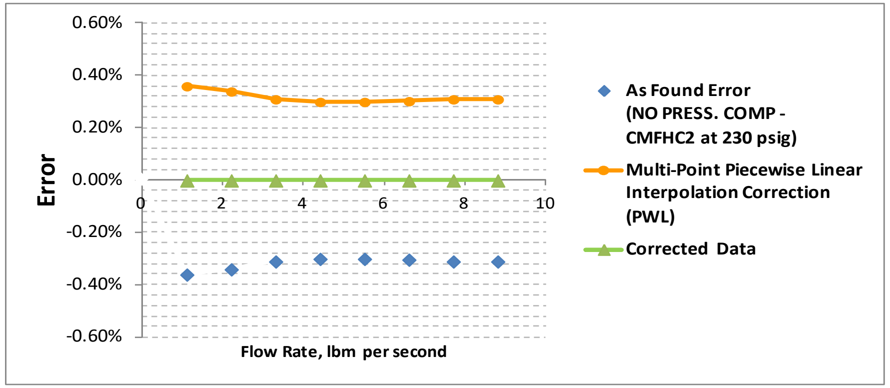


PWL and Pressure Compensation
How to Use Them Together

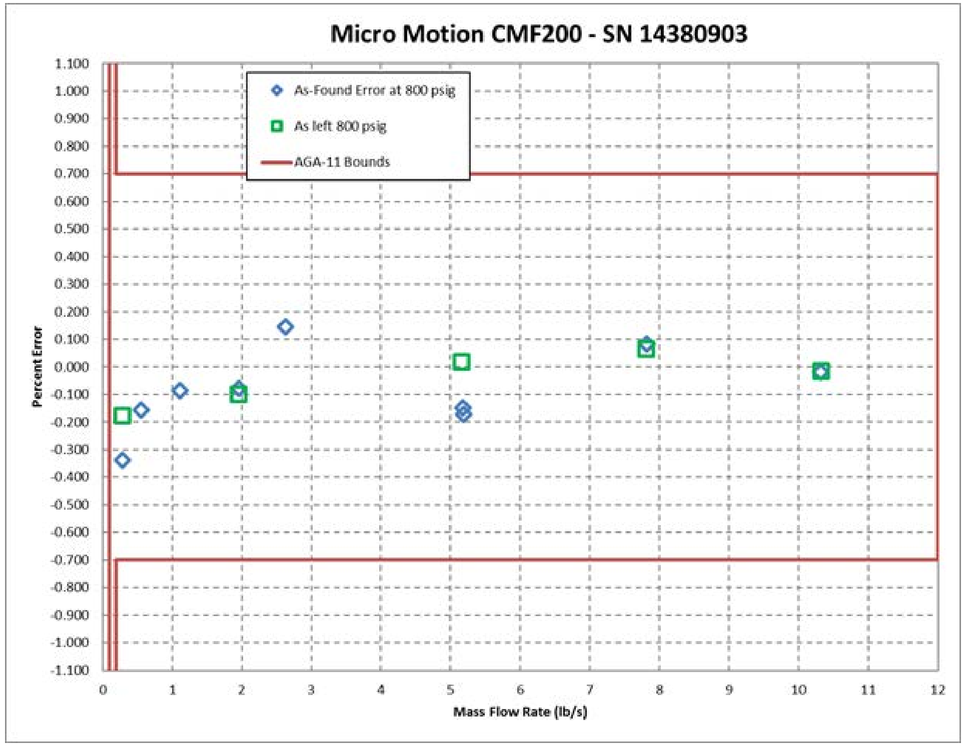
- PWL As-Found Data Collected with Pressure Compensation Active
  - P_{Cal} remains the original factory water calibration pressure
  - This method keeps pressure compensation and linearization independent from each other



- Alternative Method:
  PWL As-Found Data Collected with Pressure Compensation Inactive
  - Change baseline pressure (P_{Cal}) to the gas lab As-Found pressure for future pressure compensation
  - This method resets the pressure compensation baseline pressure to the gas lab test pressure

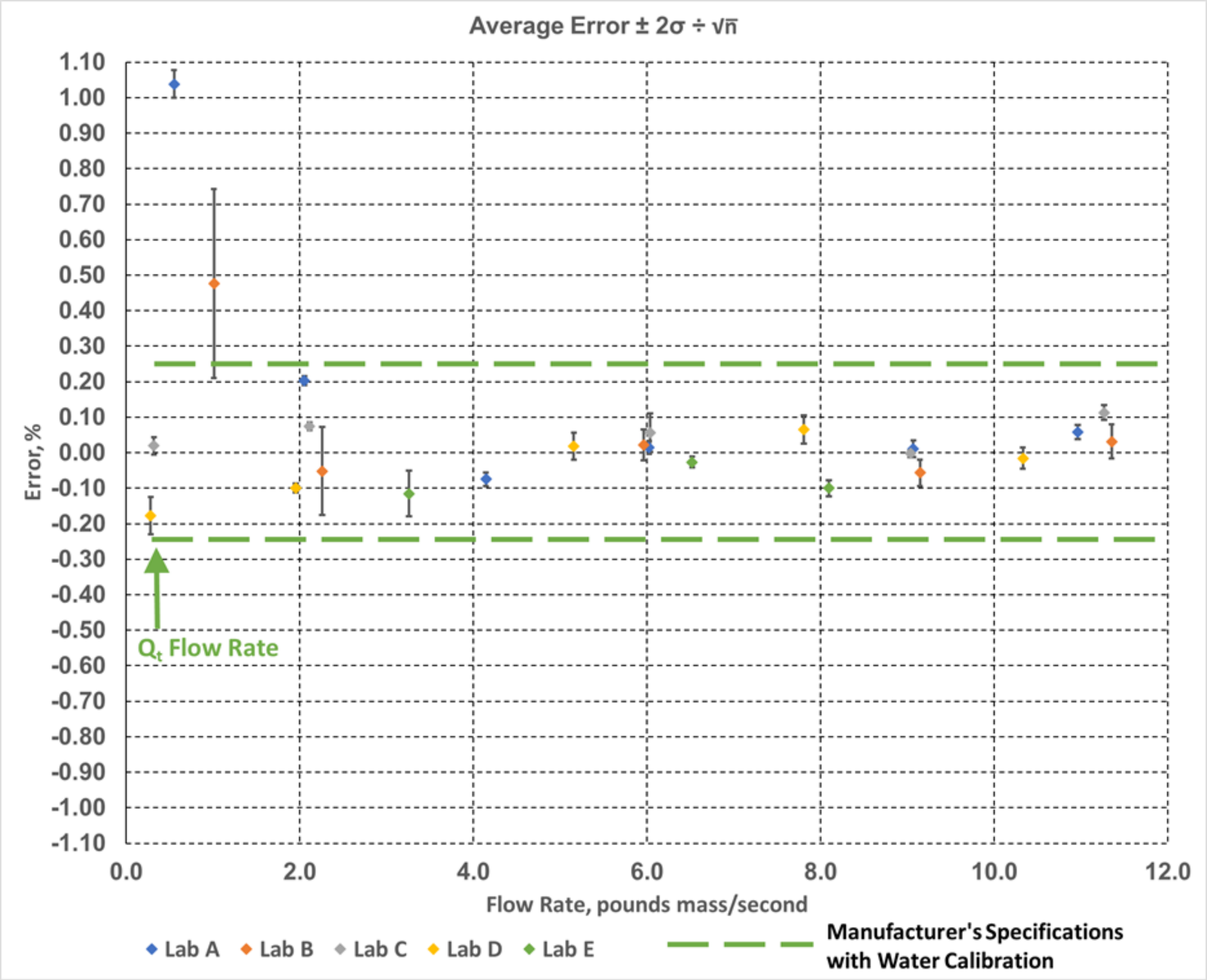


Potential Benefits of Gas Calibration and PWL
Round Robin Testing Results with 50 mm (2-inch) Coriolis Meter Artifact

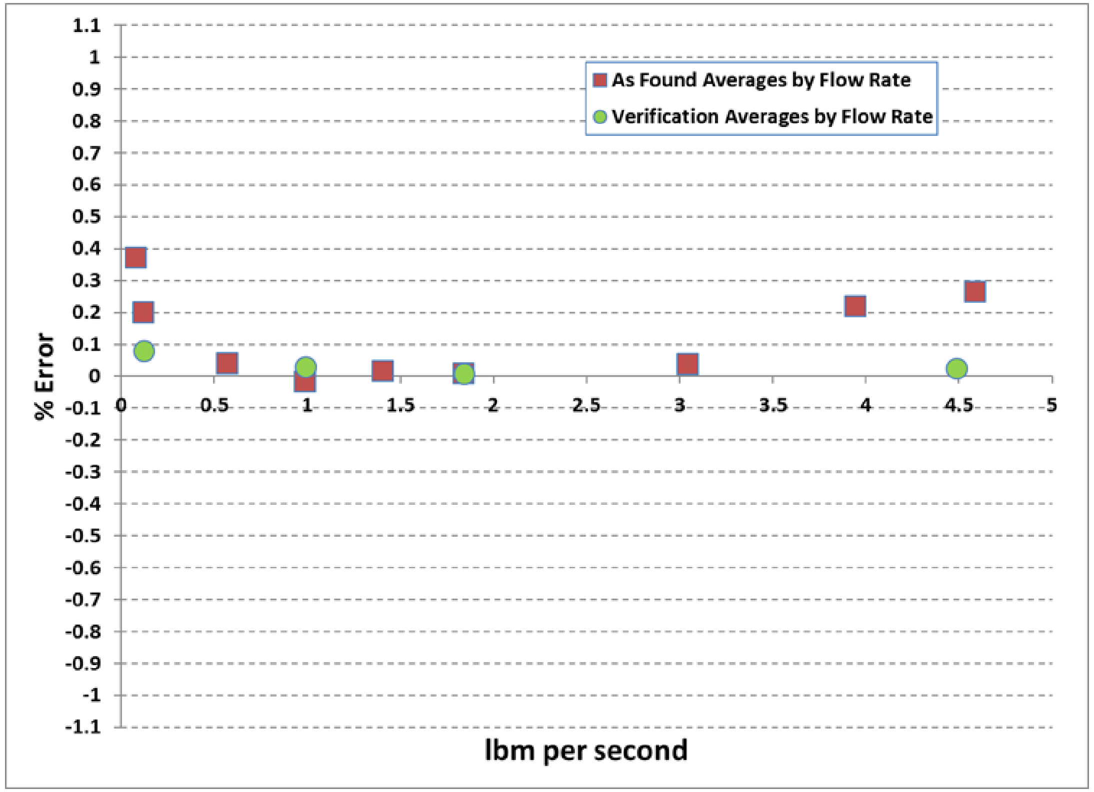


Initial PWL adjustment before Round Robin testing

Round Robin results
with linearization held constant

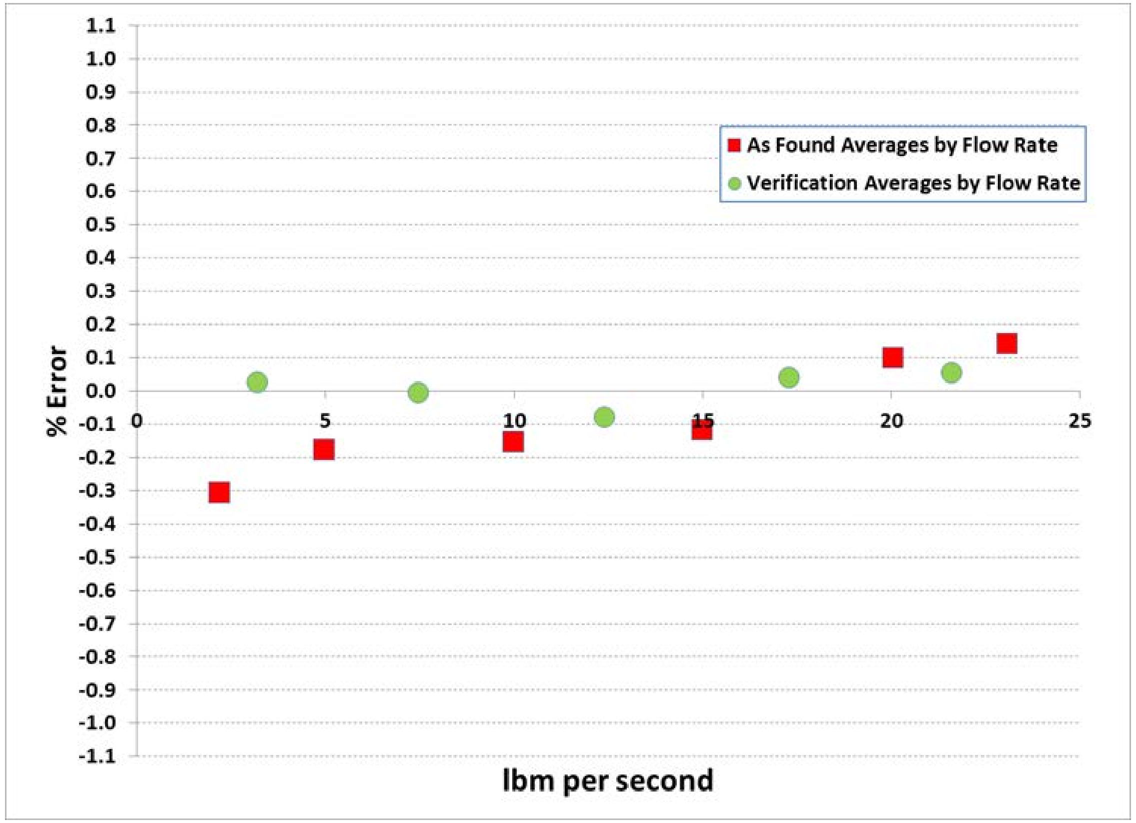


Potential Benefits of Gas Calibration and PWL
Linearization Results on Coriolis Meters of Other Sizes



25 mm (1-Inch) Meter

75 mm (3-Inch) Meter



Secondary Verification
Purpose and Benefits

"Secondary Verification" is a capability that allows an alternative method to confirm flow measurement accuracy, without the need for a traceable flow reference standard

- Reduce overall uncertainty with the capability to perform more frequent checking without adding cost
- Work practices may use statistical data and secondary verification results to extend primary calibration intervals
- Recognized in AGA Report No. 11 / API MPMS Ch. 14.9

Smart Meter Verification Delivers Confidence in Coriolis Measurement

Sensor Calibration + Electronics Performance + Process Effects = **Measurement Confidence**

Sensor Calibration
- Accuracy
- Flow Calibration Factor
- Stiffness

+

Electronics Performance
- Electronics failure
- Zero verification
- Configuration changes
- Custody transfer security breach
- Temperature sensor

+

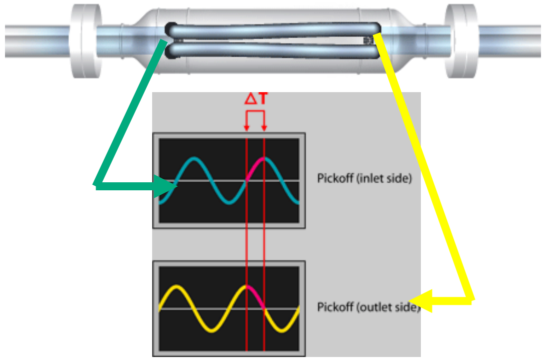
Process Effects
- Multiphase
- Operating flow rate
- Coating

=

Mass and Density Calibration Factors are Directly Related to Coriolis Tube Stiffness

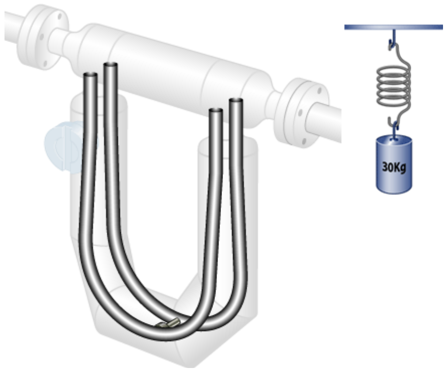
Mass Flow

- Tube phase shift



Density

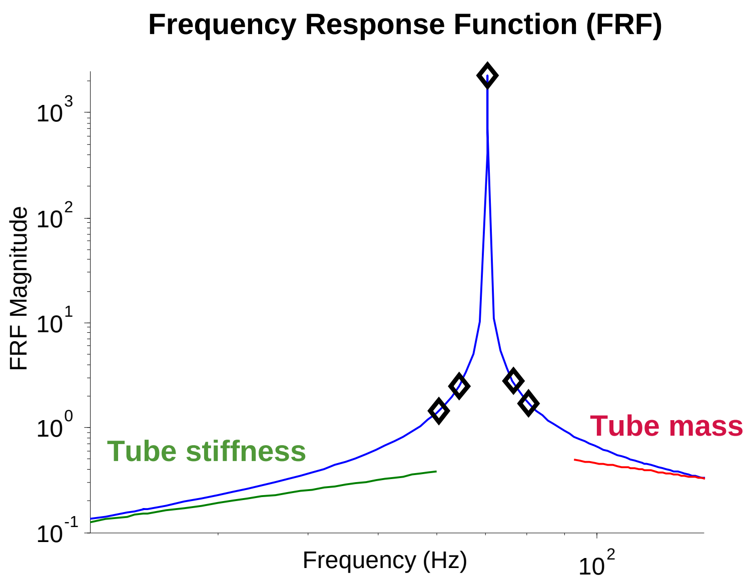
- Tube natural frequency

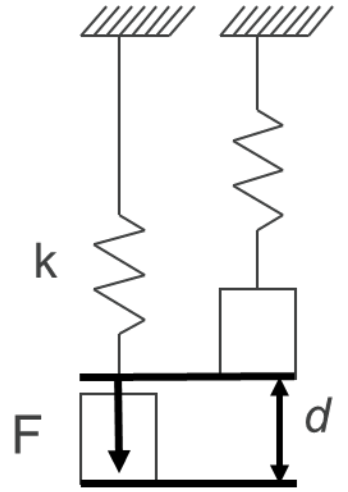


Calibrations directly proportional to
tube stiffness

How Stiffness is Measured

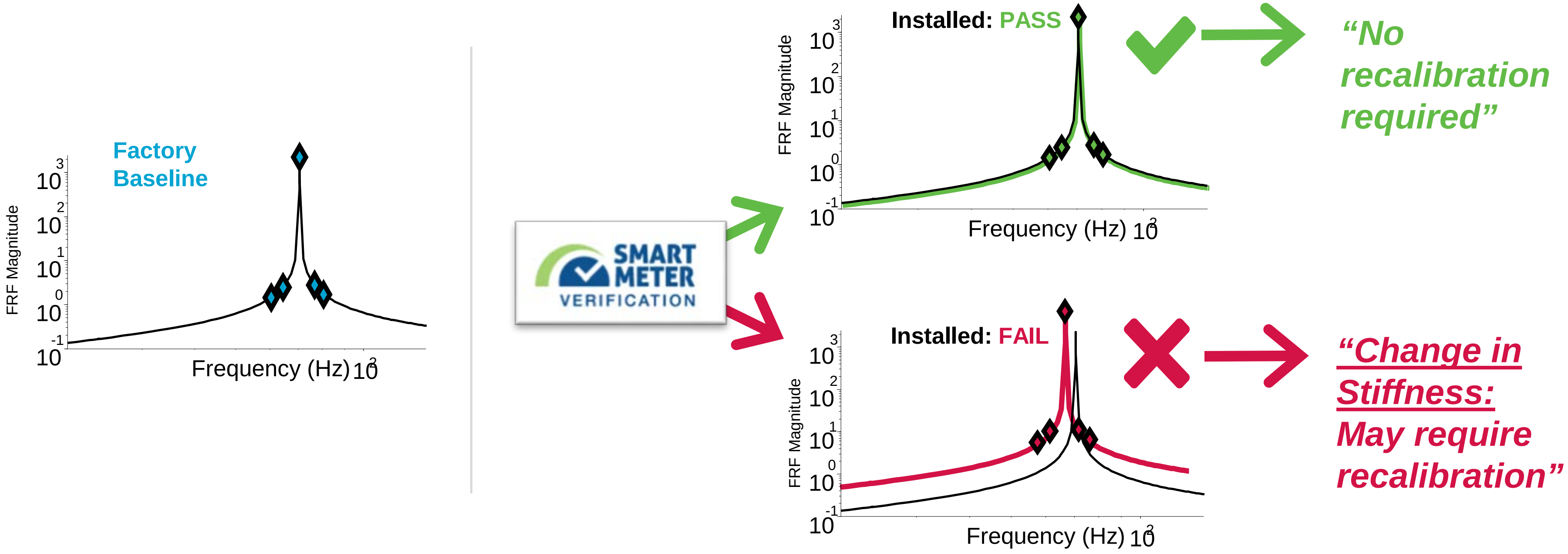
- Coriolis meter’s Frequency Response Function (FRF) is a function of the **mass**, **damping**, and **stiffness**
    - **“3 unknowns”**
- SMV drives meter at 5 frequencies to define current FRF
    - **5 frequencies** = over-defined
    - 2 frequencies = under-defined, requires assumption that dampening (viscosity) is constant, so change in viscosity can lead to false stiffness measurement results
- Current FRF is compared to stored factory baseline





SMV **Calibration Verification** Evaluates Flow Calibration Factor In-Situ

- **Meter damage** causes a **change in tube stiffness**
- If a **change in stiffness** is detected, the meter is likely to require recalibration or replacement



Conclusions

- Coriolis meters offer many benefits for natural gas custody transfer measurements

- Coriolis meters now offer Piece-Wise Linearization for enhanced gas calibration results

- Coriolis meters have demonstrated capability to be calibrated on water in order to measure gas

- Secondary verification methods exist to confirm Coriolis meter accuracy after primary flow calibrations

Thank You!