Rocky Mountain Measurement Seminar

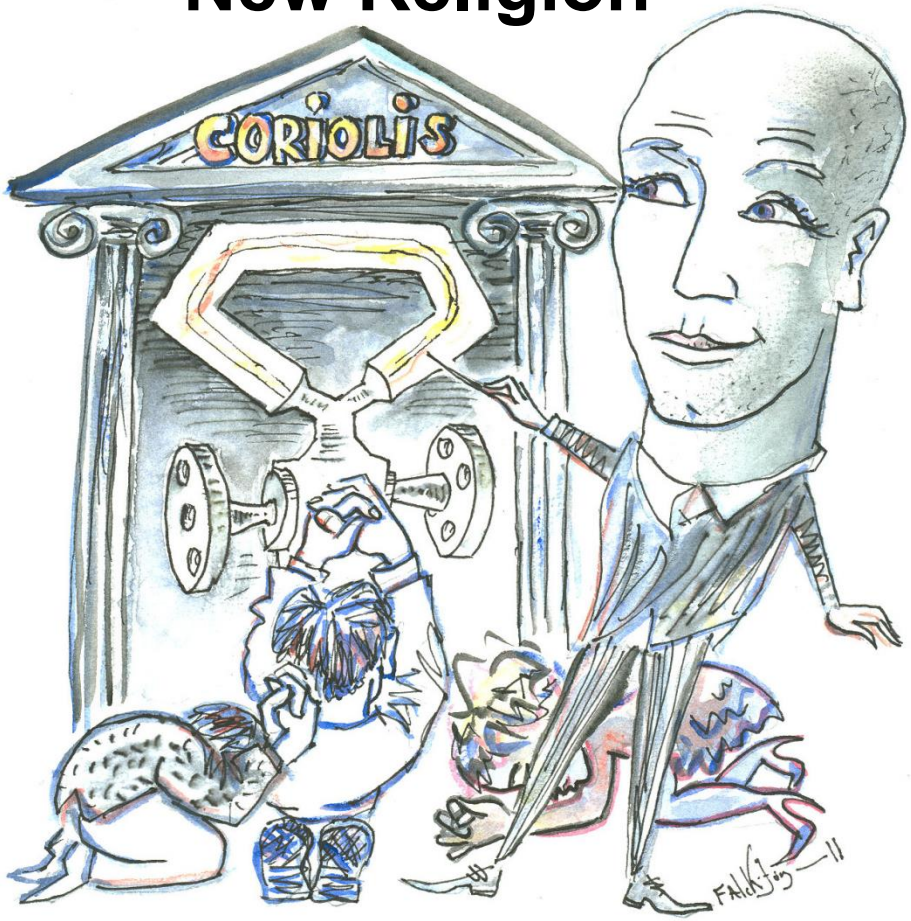
Denver

August 20, 2015

Coriolis Meters

Sales Talks from the Early Years

”New Religion”



All our worries are over....

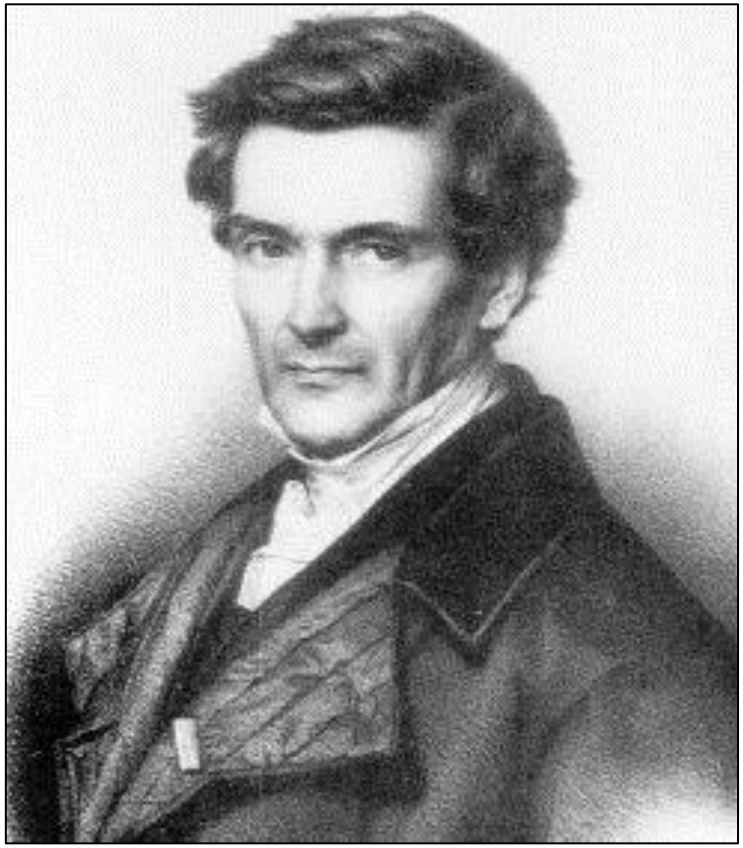
.....just install Coriolis Meters

Theory / Fundamentals

Measuring Principle

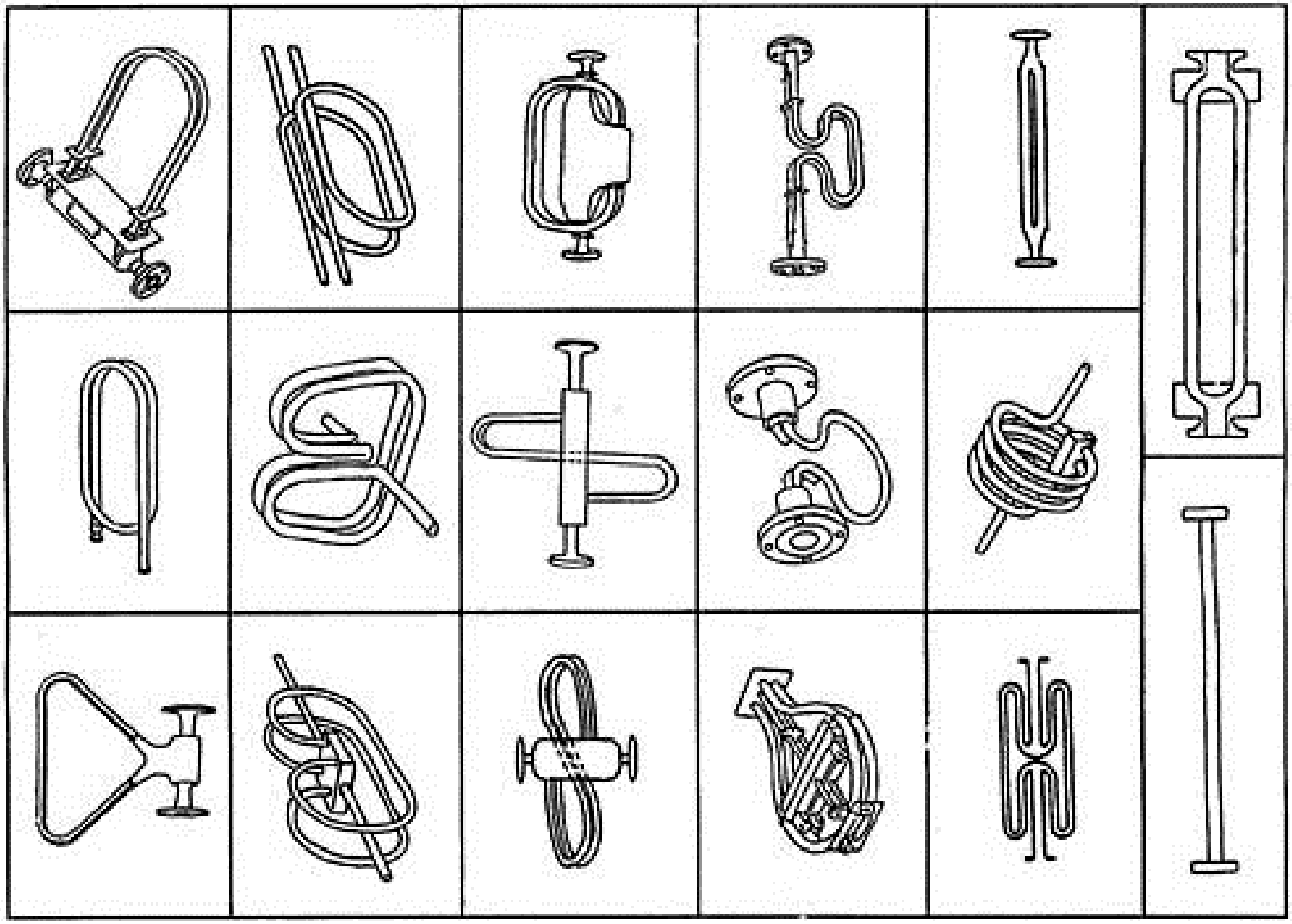
Coriolis Force

Gasparde de Coriolis



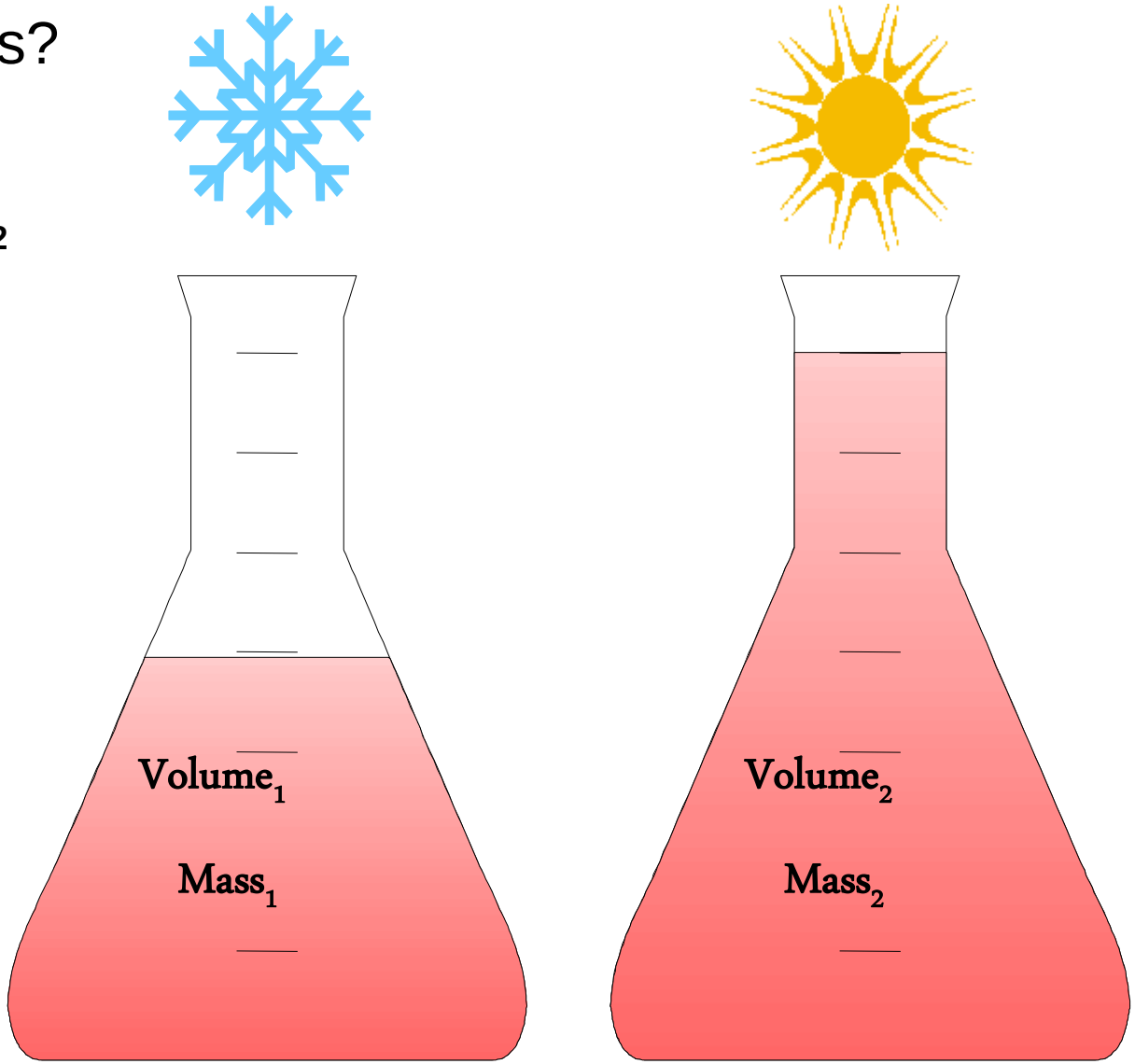
May 21, 1792 – Sept 19, 1843
French

Coriolis Flowmeter Geometries



Why Measure Mass?

- **Temperature**
- **$Volume_1 \neq Volume_2$**
- **$Mass_1 = Mass_2$**

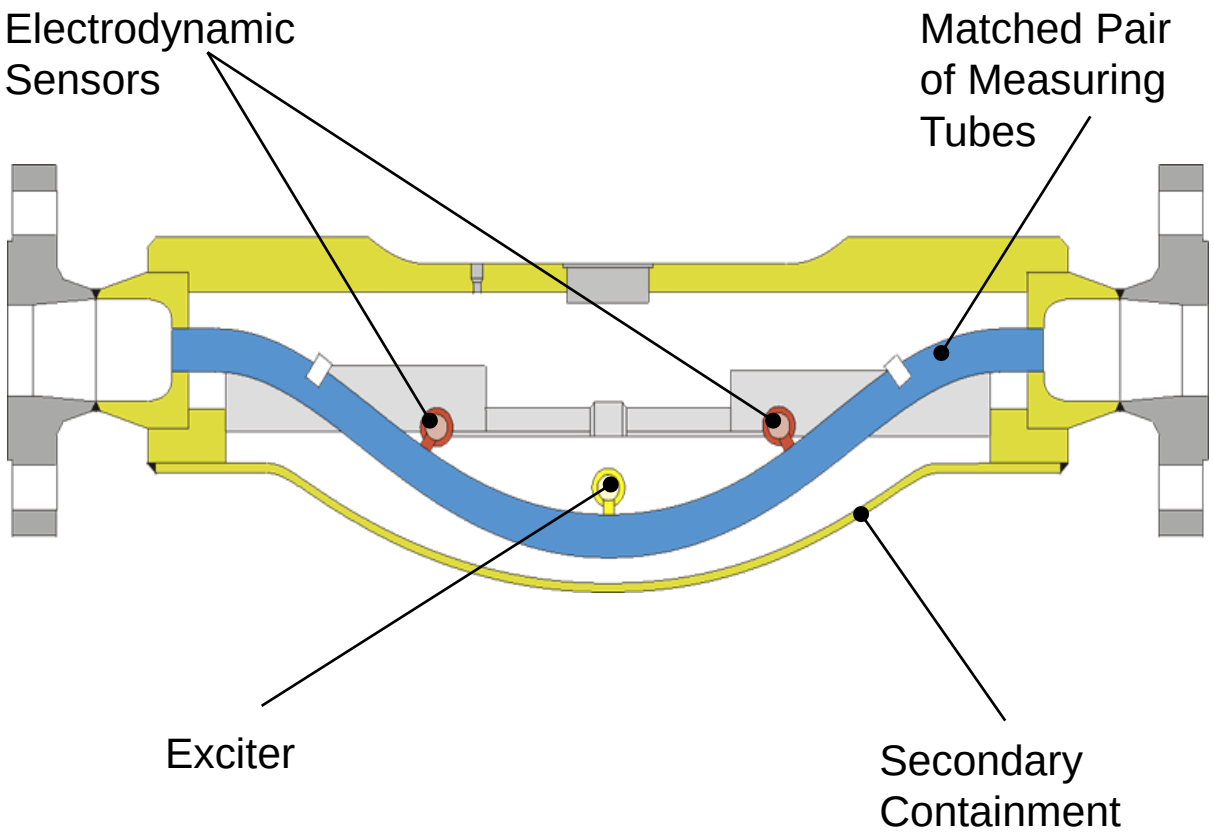


Why Use a Coriolis Meter?

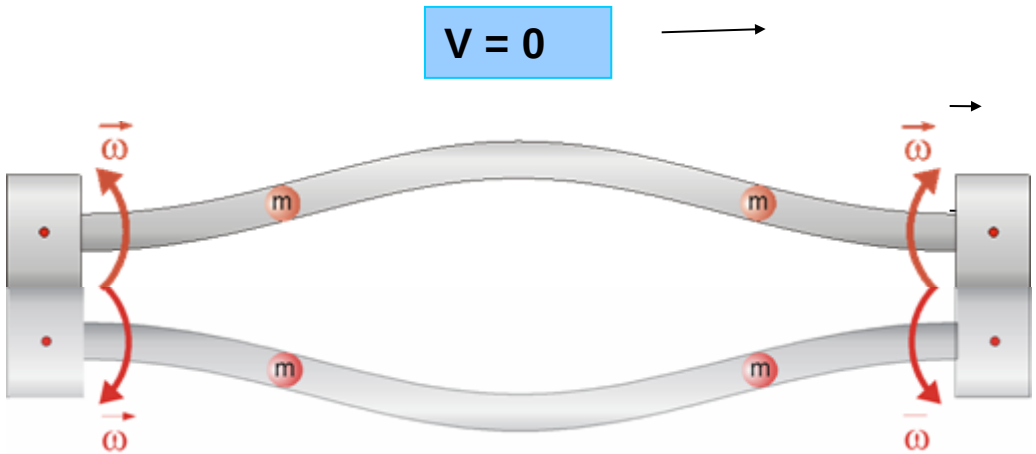
1. Multi-variable measurements:
   - → Mass flow
   - → Volume
   - → Density
   - → Rate
   - → Temperature
2. Can be used to measure practically anything – cement slurries to crude oil.
3. No wearing parts, reduced maintenance cost.
4. Industry acceptance – API MPMS, Chapter 5 - Metering, Section 6 – Measurement of Liquid Hydrocarbons by Coriolis Meters, First Edition, October 2002
5. Proves just like a PD or turbine.

Sensor Design

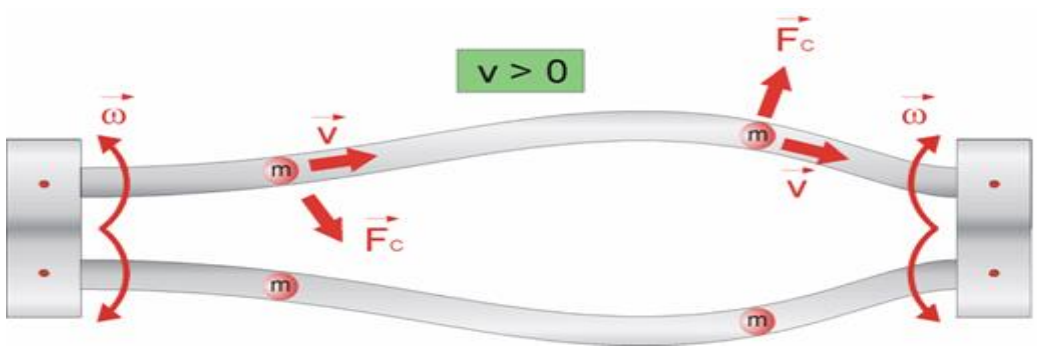
- Flow manifolds
- Flow tubes
- Drive system
- Pick-up sensors
- RTD
- Transmitter



Theory of Operation: Coriolis Force in Action

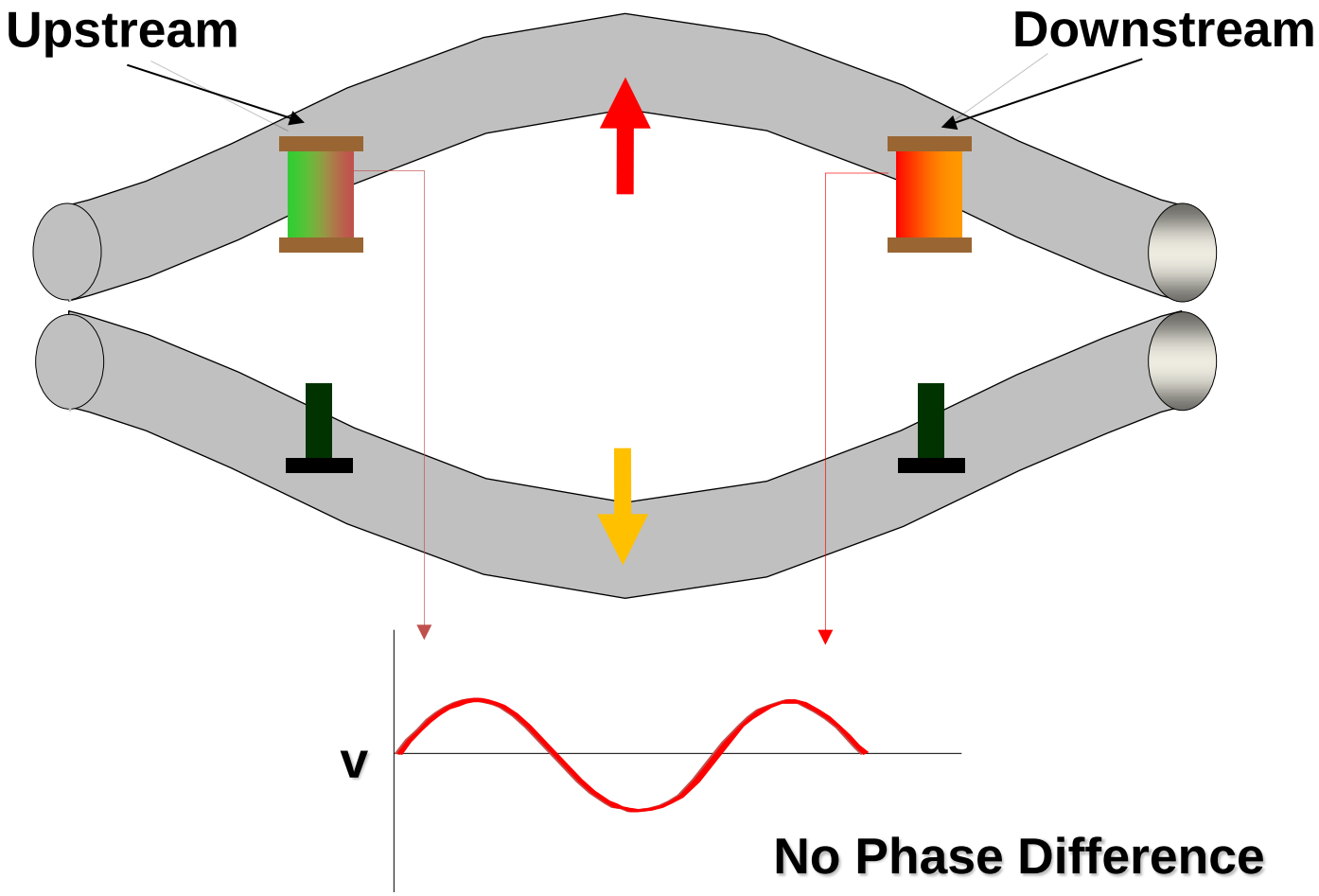


- m = Fluid flow units
- w = Angular velocity
- v = Radial velocity
- Fc = Coriolis force

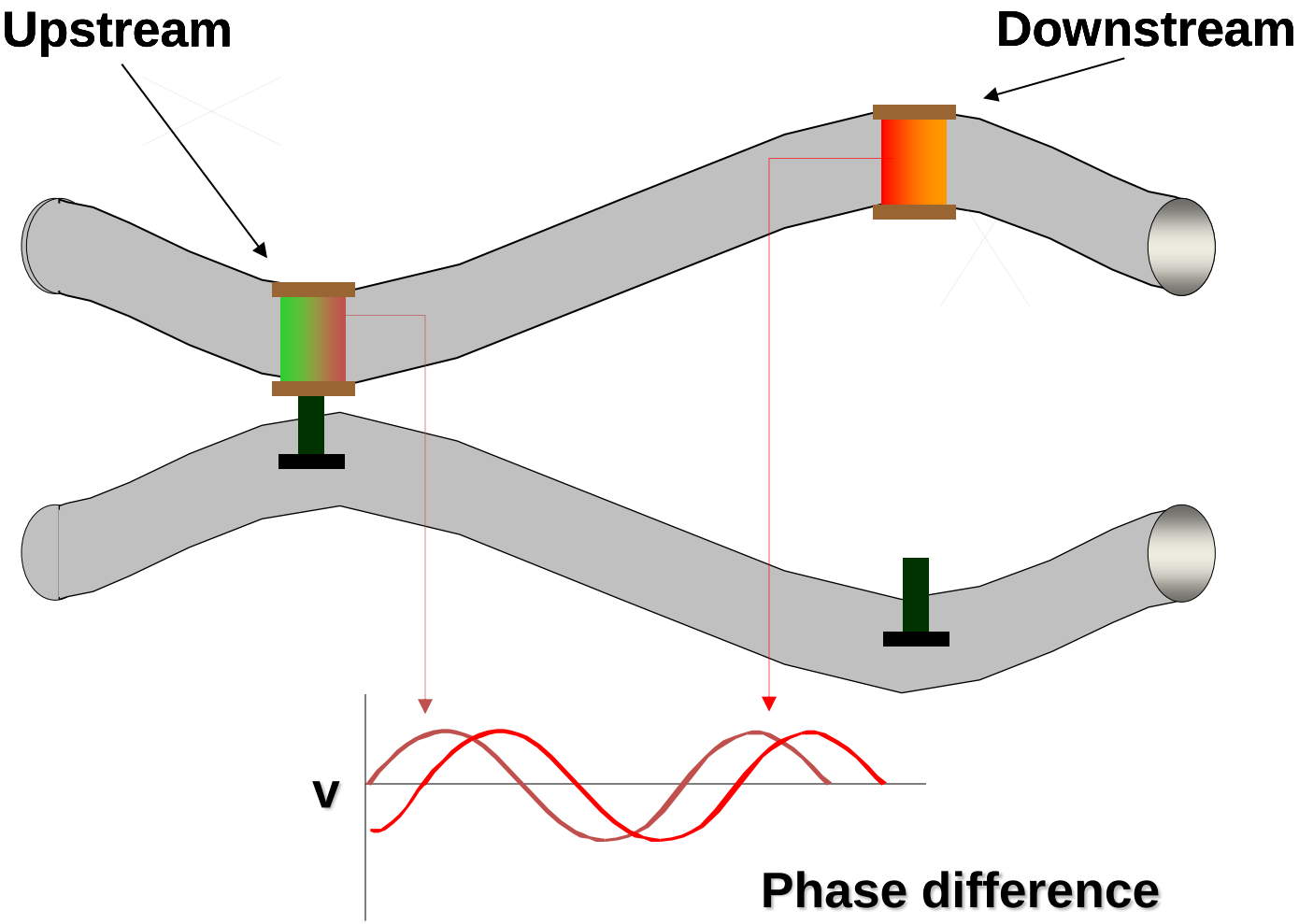


$$\vec{F_c} = -2m \cdot \vec{v} \cdot \vec{\omega}$$

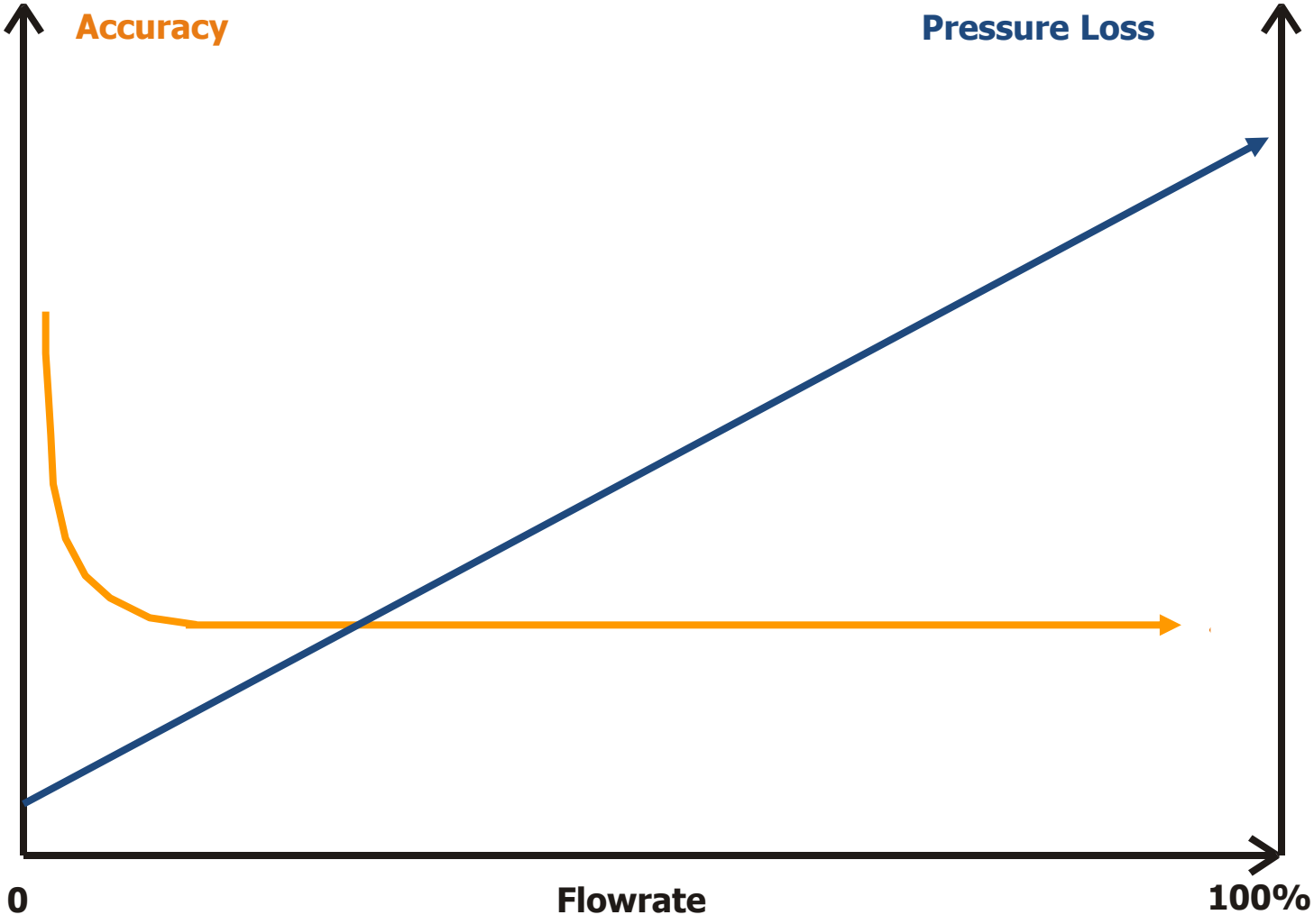
"No-Flow" Mode Shape



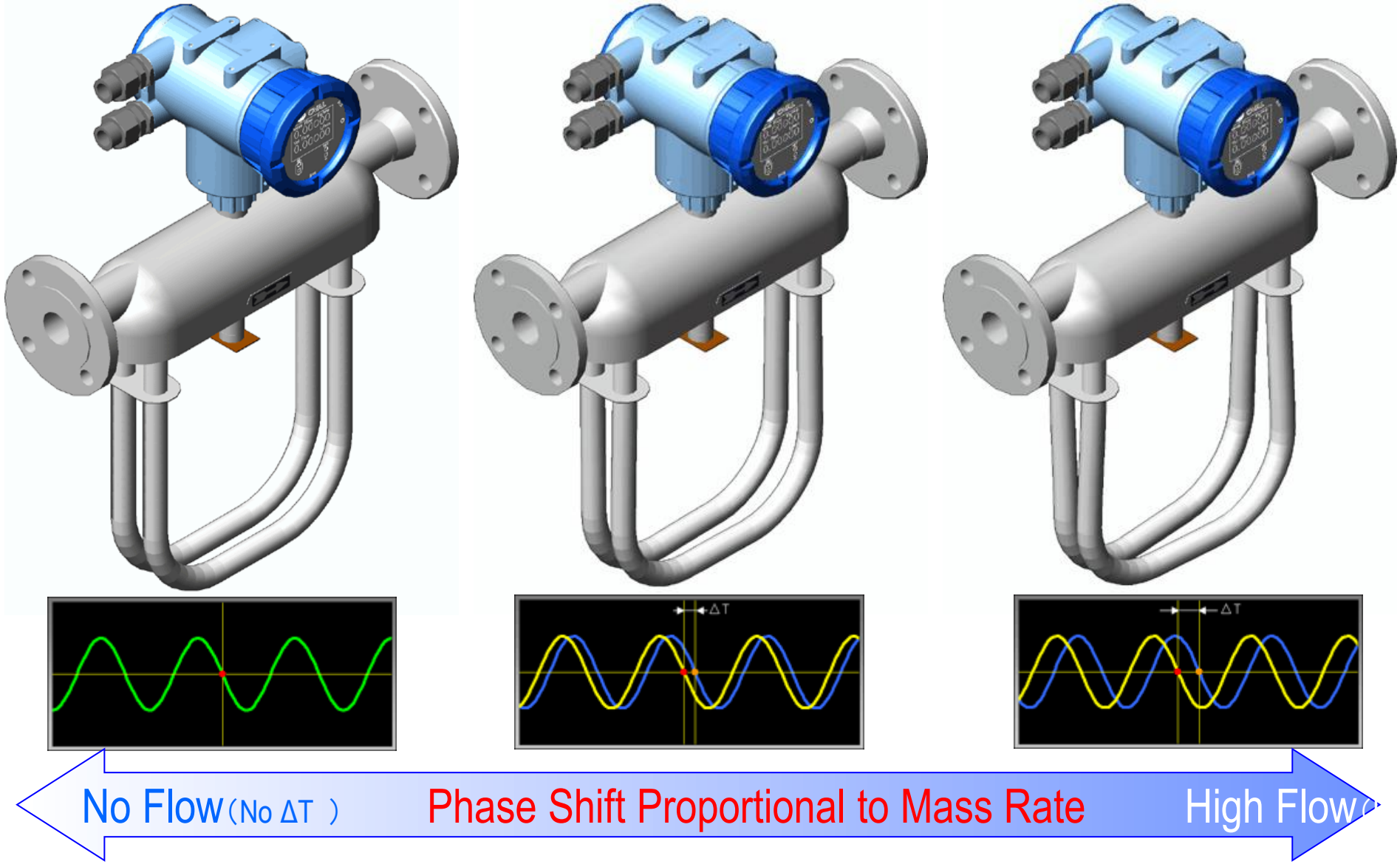
"With Flow" (Coriolis) Mode Shape



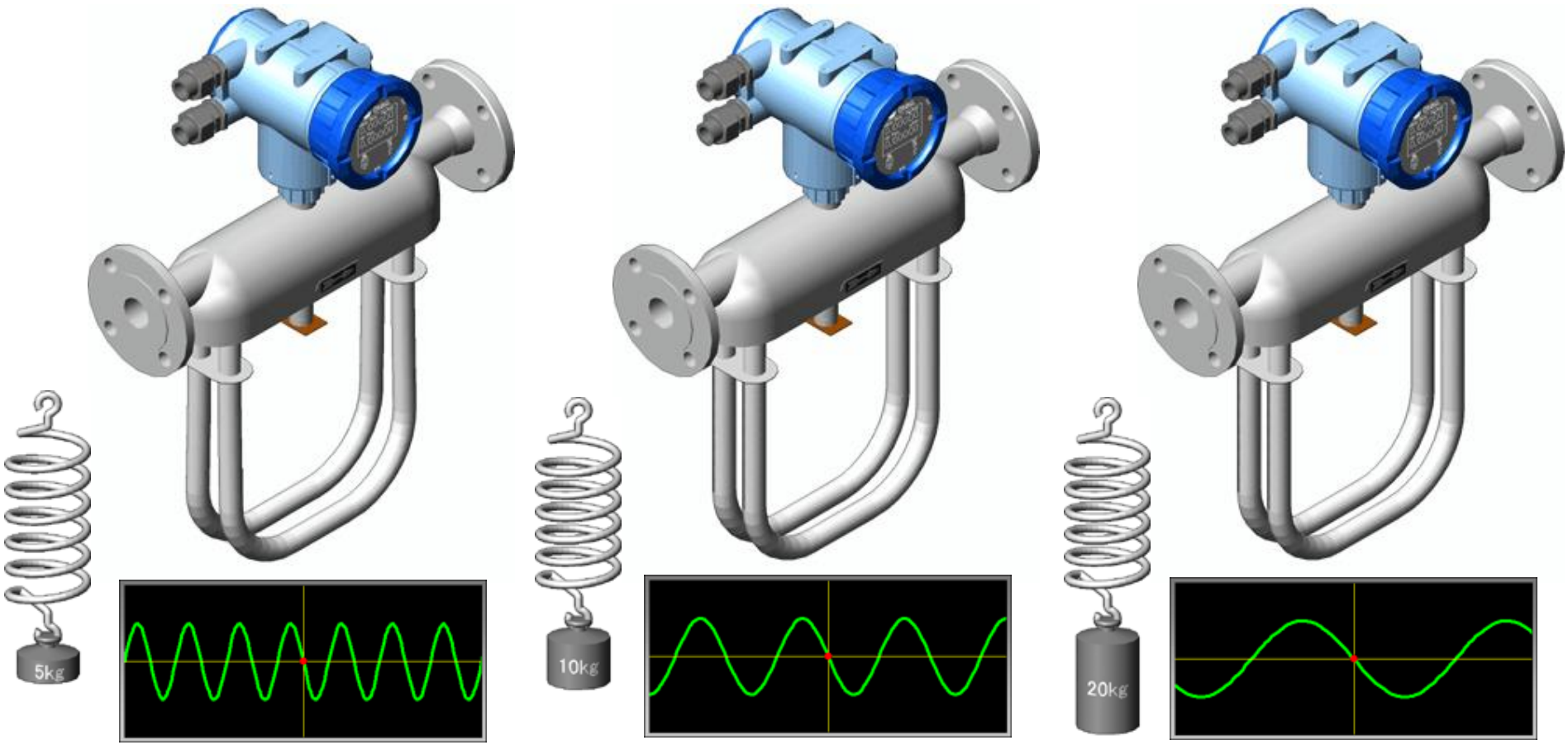
Pressure Loss vs. Accuracy



Coriolis Basics – Mass Flow



Coriolis Basics – Density



Low Density (High Frequency) ⟷ High Density (Low Frequency)

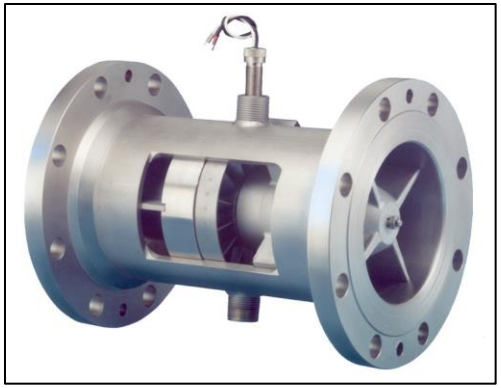
Coriolis Meter Advantages

- <u>Multivariable Transmitter</u>
  - One instrument provides mass flow, volume, rate, density & temperature
- <u>Independent of Fluid Characteristics</u>
  - Flow profile does not affect measurement. no flow conditioning required
- <u>Direct Mass Flow Measurement</u>
  - No compensation necessary for temperature or density changes

Coriolis Meter Advantages

- <u>High Accuracy</u>
  - Accuracies of ±0.1% of reading over a wide measuring range on mass flow
  - Density measurement within 0.0005 g/cc
- <u>Wide Dynamic Range</u>
  - Turndown of 100:1 enables measurements over a wide range
  - 30% to 80% of operating range for normal measurement
- <u>Low Cost of Ownership</u>
  - Easy to install
  - No wearing parts
  - Long term stability

Mechanical vs. Electronic Meters



Mechanical meters are fairly easy to troubleshoot

Electronic meters
are not quite as easy to troubleshoot for most of us

In the Real World….

Paying attention to the installation and meter station design, coriolis meters can be successfully used in the hydrocarbon applications in both line balance and custody transfer applications.

Just like any with any meter, proper design of the installation and managing the process conditions are the keys to successful metering installations & systems.

General Recommendations

General Recommendations

Flow Rates

- Selecting a meter that will cover a wide range of flow rates does not mean it will be accurate at all ranges without proving the meters at the various flow rates.

- Coriolis meters are generally quite linear, but there are occasions when the meter may be sized for 4,000 bbls/hr but may flow at 50 bbls/hr when the line is down and draining up. One good thing is that the risk of inaccuracy is much less at 50 bbls/hr than it is at 4,000 bbls/hr.

General Recommendations

Inconsistent Flow

- If the line or system runs under the same conditions all the time, there is not too much to worry about.
- Meters that are subjected to wide and varying flow rates, such as truck loading or unloading can cause problems with meter factor linearity. A meter should be proved at the varying rates to determine each meter's linearity.

General Recommendations

Pressure Drop

- Meters need to be sized properly according to the flow rate, density, vapor pressure and viscosity of the product.
- A poor understanding of these items could lead to a meter that is under-sized due and cause excessive pressure drop across the meter.
- Pressure drop can cause a significant waste in pump horsepower and throughput. This leads to inefficiencies and wasted money. 14.7 PSIG or 1 bar = +8% energy costs or higher.
- 6 inch piping does not necessarily equate to a 6 inch meter.
- The manufacturer can help with the sizing.

General Recommendations

Backpressure

- **Insufficient Backpressure** - As with any metering system, insufficient backpressure CAN cause inaccurate measurement. When meters are not full they may cause inaccurate measurement.

- **Entrained Gas** - A Coriolis meter will also indicate the wrong density if there is entrained gas in the liquid or it is flashing.

- **Density Errors** - A meter showing a lighter density than the true density will show higher flow rates due to the method the meter uses to calculate flow. **Volume = Mass / Density**

- **Maintaining 1-½ times** vapor pressure is a good rule of thumb. But on low vapor pressure products that doesn't necessarily work well. It's important to maintain adequate backpressure to ensure the meter is fluid packed all of the time.

General Recommendations

Product Density

- Unlike mechanical meters, Coriolis meters provide density msmt.
- The meter can be setup to measure an enormous range of products from hydrogen to peanut butter. Check the factory default setting to verify its configuration
- The **"SLUG FLOW"** or **"EPD"** sets the allowable density range the meter can read and should be set tight enough to cover your products but not wide enough to allow other problems to crop up.
- For example a propane meter with a density of .500 might have its range be .45-.55 g/cc. This will eliminate "ghost counts" under less than ideal conditions. When a meter is at or near vapor pressure when not operating it can sometimes have ghost counts if the slug flow is not set properly.

General Recommendations

Poor Piping / Installation

- Coriolis meters do not have upstream or downstream pipe length requirements. Coriolis meters require the piping to have good flange alignment with no undue stress on the flanges.

- Poor installation practices can cause a multitude of problems such as zero shift and poor repeatability during provings.

General Recommendations

Meter Zero

- The zero flow condition is vital for accurate measurement. A meter that is showing flow, positive or negative, at zero will likely be inaccurate at all ranges.
- It is imperative that the operator understand what the meter's zero condition looks like. This doesn't mean the meter needs to be zeroed, but that the zero stability is known.
- If the meter is zeroed, the meter should be proved after the zeroing.

General Recommendations

Additional Concerns

Since Coriolis meters can be installed in several different orientations, it is important to understand the characteristics of the products being measured.

- Is the meter measuring Gas or Liquid?
- Does the liquid have entrained gas?
- Does the gas have entrained liquid?
- How do you orient the meter in your piping?
- What is the density of the product?
- Does the line run most of the time or does it have periods of being idle?
- Meter Zero

Meter Selection

Sizing Program

Sizing Flow Dimensioning of flow meters

Measuring task	Monitoring/Control	Principle/Sensor	Promass F (80, 83, 84)
Fluid	Oil, Crude 40° API	Transmitter	83
State/Standard	Liquid / Supporting Points	Flow meter	Promass 83F

Process data — Reference values

	minimum	nominal	maximum	Unit
Requested flow	103	680	1 700	USBPH_petro
Pressure		70		psi_g
Temperature		86		°F
Density		51.009		lb/ft3
Viscosity		6.4268		cSt
Sound velocity		5 991		ft/s
Pressure (min/max)	70		70	psi_g
Temp. (min/max)	86		86	°F
Vapor pressure	0.5466	0.5466	0.5466	psi_a

Sensor / Pipe

Connection standard	ANSI
Material (Sensor)	SS 1.4539 / 904L
Process connection	Cl 150 ANSI / 316L/1.4404 ASME B16.5 flange

Pressure rating

Warnings/ Messages

Meter operating range

	minimum	maximum	Unit
Operating range	0	2 694.27	USBPH_petro

Calculated results

	minimum	nominal	maximum	Unit
Requested flow	103	680	1 700	USBPH_petro
Pressure loss	0.092	3.014	16.42	psi
Velocity	3.624	23.93	59.82	ft/s
Measured error Volume ☑	0.1	0.1	0.1	%
Measured error Mass ☑	0.1	0.1	0.1	%
Meas. error Mass-PremiumCal ☑	0.1	0.05	0.05	%
Reynolds no.		58 101		

PED Info result — Application meets PED (Art.3.3)

Meter size: 4"

Configurator | Print Sizing | ->> Selection | Reset

->> Goto Sizing Energy

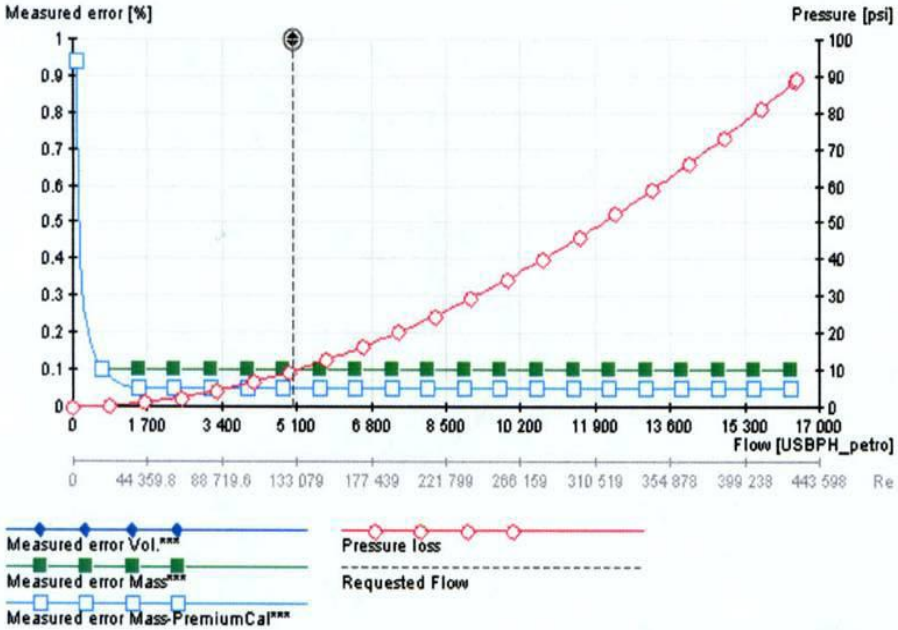
TAG

Pressure Drop

Chart Sheet

Flowmeter :

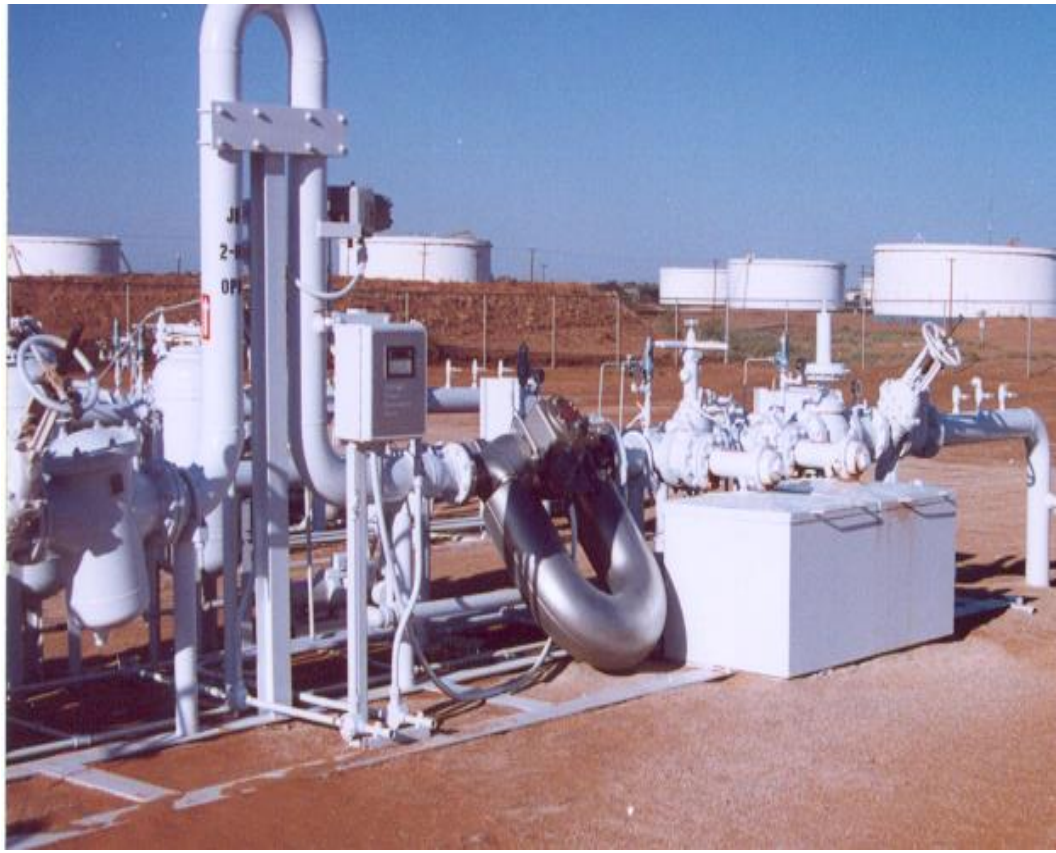
Meter Size	10"
Minimum Flow	0 USBPH_petro
Maximum Flow	16 514 USBPH_petro



***For error calculation, the specified reference conditions for the calibration of the flowmeter according to ISO/IEC 17025 apply. Further information in technical documentation.

Meter Station Design

- Physical Size
- Meter Turndown
- Pressure drop
- Piping Stresses
- Ease of zeroing
- Ease of electrical connections
- Means of configuring
- Access to pulses for proving
- Flow rate versus prover capacity



Where you can get into trouble

- Flow damping with small volume prover

  Damping should be set to zero
- K-factor set too high for prover counter

  10,000 pulses per barrel is normally fine
- Slug flow limits within range of flowing density

  Meter will not count, for example, if air comes through and the low limit is set to 0.5 gm/cc.
- Low Flow cutoff not set high enough to eliminate false counts when there is no flow

  With no flow, it is possible for the fluid to heat up enough to begin to expand in the tubes causing the meter to count
- Flow direction not set to forward direction

  Meter will count with reverse flow if the flow direction is set up bidirectional

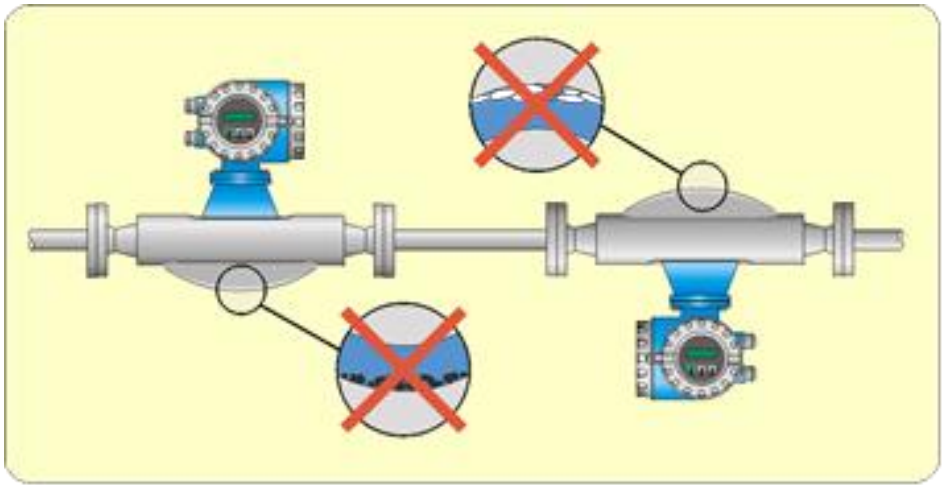
Meter Installation

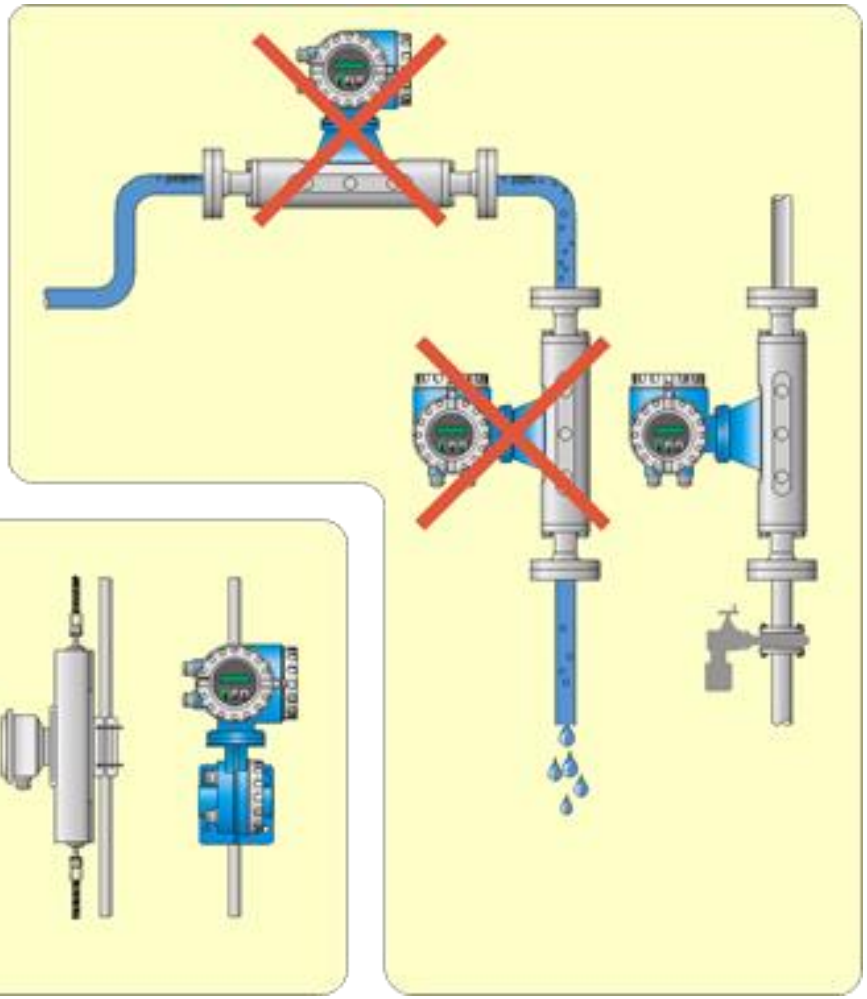
Optional Tube Orientation

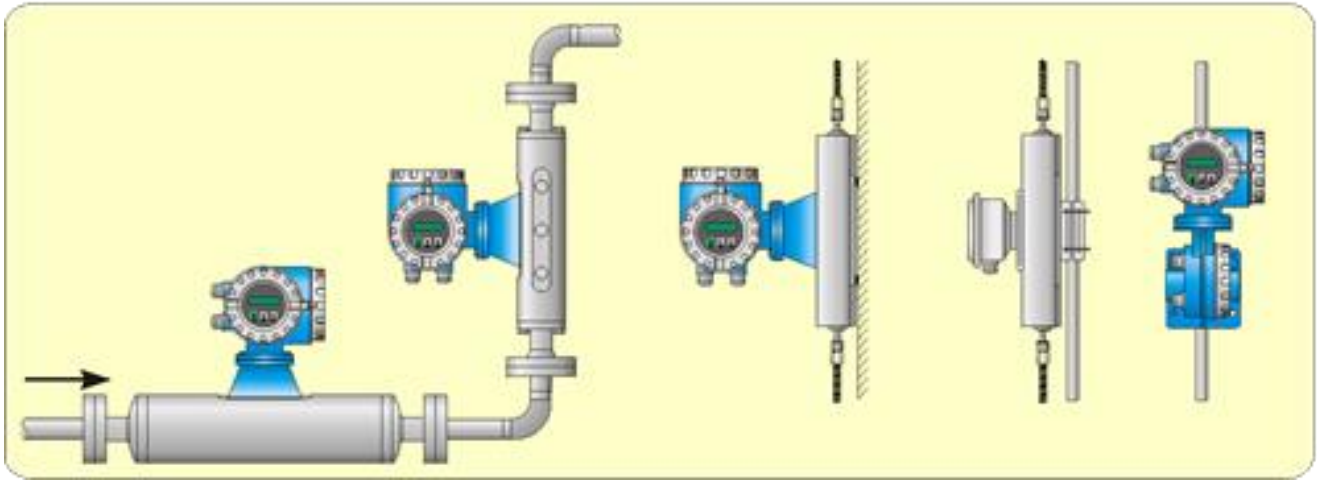
Tube Orientation for varying products

Truck Mounted

Proper Installation & Orientation







Configuration & Programming

Configuration & Programming

Laptop Configuration

Display Keypad Input

Configuration

- Net or Gross

- Gross

External Process RTD Required

Configuration

Multi-Variable Instrument

Output Signals

- Analog 4-20+Freq
- Digital (Modbus)
- Ethernet (TCP/IP)

- Alarms
- Sink or Source
- Independently configurable

Output Expansion Box

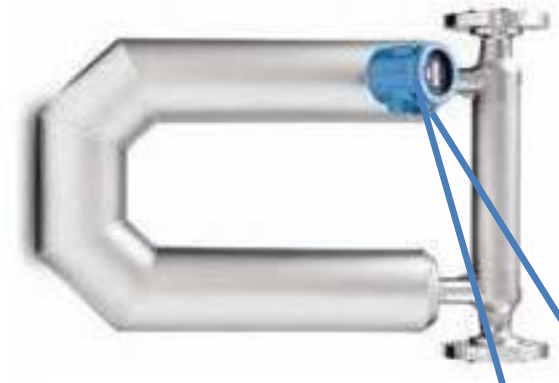
Components

- 24 Vdc Power Supply
- Pulse divider (PLC)
- 2) 10 amp Plug in Relays
- 1) 10,000 ppb output sink
- 2) prover connections

Provides output for:

- Temperature Averager
- Sampler
- SCADA
- Proving

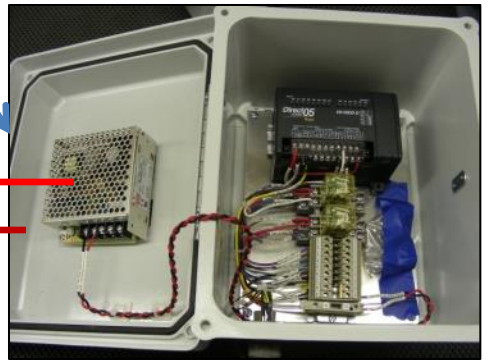
Configuration



Analog Outputs

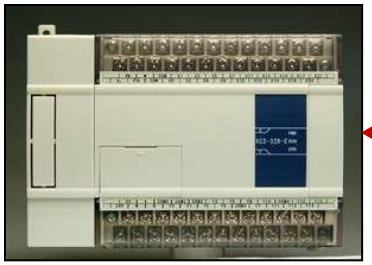
Sink or source

Output Expansion



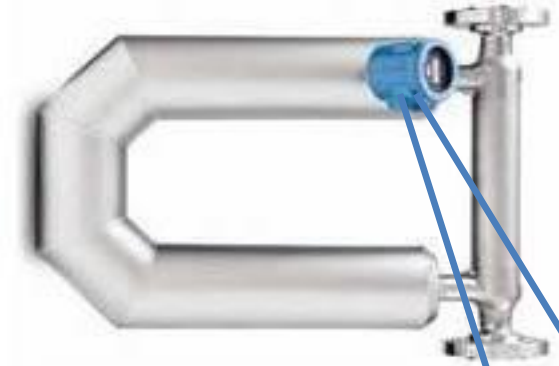
Flow Computer

Batch Controller



SCADA

Prover Truck



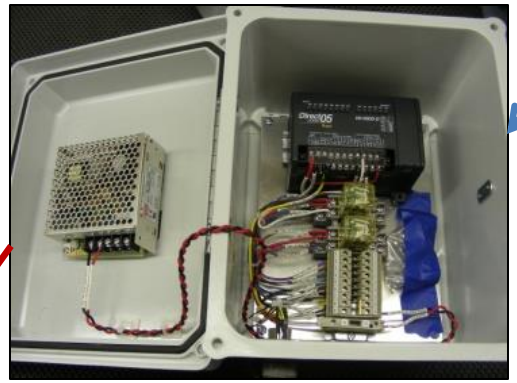
Configuration

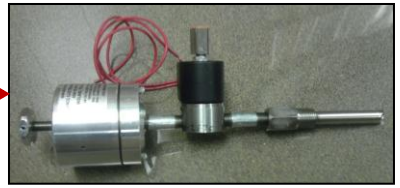
Analog Outputs

Sink or source

Output Expansion

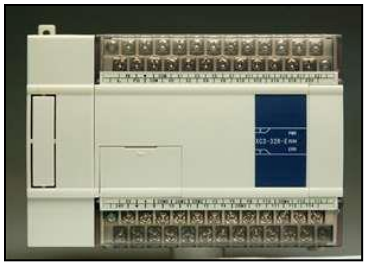
Temp Avg





Sampler

Prover Truck



SCADA

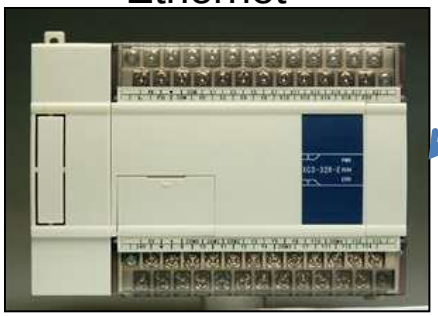
Configuration

Analog + Digital

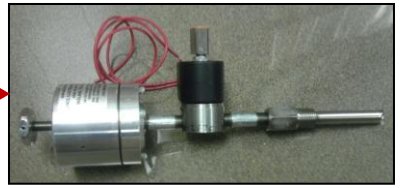
Outputs

Modbus/Profibus

Ethernet



Temp Avg



Sampler

Prover Truck


DISCOVER CAMERON
Upstream to Downstream, Onshore to Offshore, We're There.™

Operation

Meter Performance Issues

Device/Mechanical

Process Conditions

Device/Mechanical Concerns

1. Zero Shift
2. Erosion/Abrasion
3. Corrosion
4. Coating
5. Cable Failure(s)
6. Display
7. Catastrophic Device Failure
8. Sensor Failure
   A. Temperature
   B. Exciter/Driver Coil(s)
   C. Pick off Coil(s)

Coriolis Flow Meter Concerns

Abrasion/Erosion

Most manufacturers can set threshold limits on how much erosion is allowed

Effects of corrosion/erosion

↑ Resonant frequency of tubes will drift upward

↓ Density measurement will drift downward

Coriolis Meter Concerns

Coating

What kind of influence has coating on the measuring tubes of a Coriolis Meter?

Effects of coating

Resonant frequency of tubes will drift downward

Density measurement will drift upward

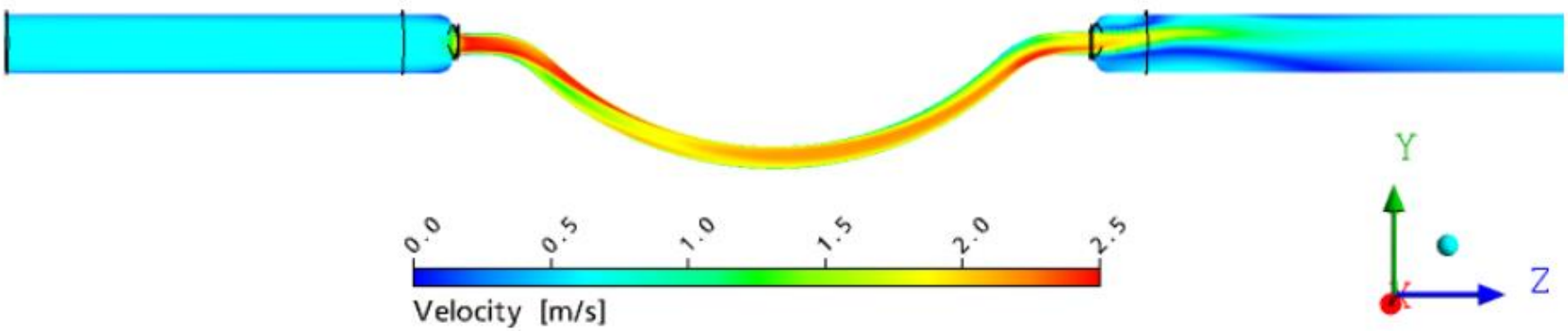
Process Condition Concerns

1. Zero Shift
2. Entrained Air
3. Back Pressure
4. Vibration
5. Viscosity
6. Entrained Solids
7. Harmonics
8. Resonant frequency of the meter

Coriolis Meter Concerns

Velocity!

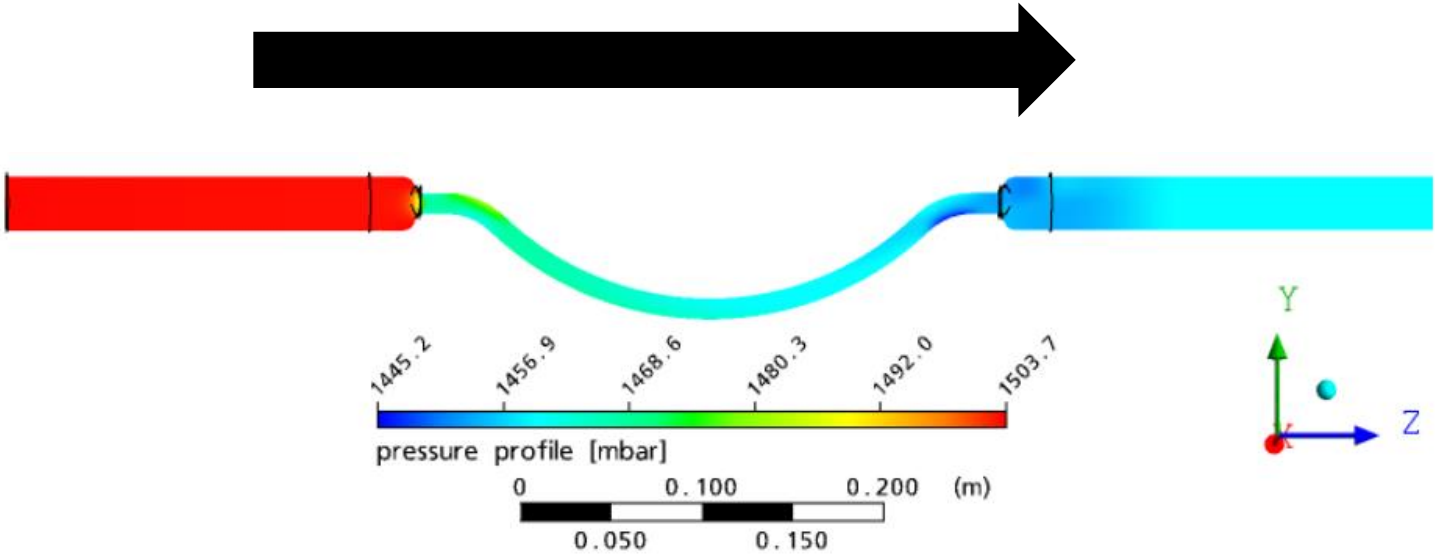
The velocity distribution leads to centrifugal forces and increased abrasion along the wall



Coriolis Meter Concerns

Cavitation

Process pressure inside the measuring tube of a Coriolis Meter

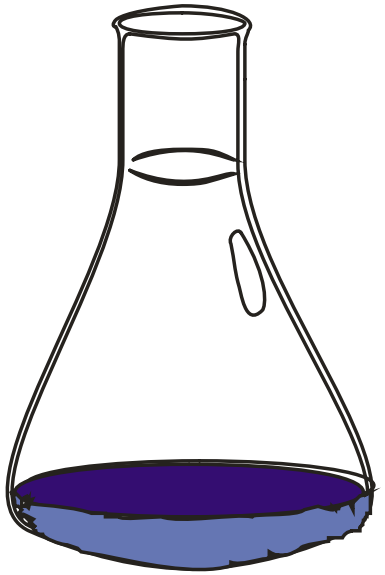


Most critical at the outlet of the flowmeter where the pressure is lowest and closest to vapor pressure

Coriolis Meter Concerns

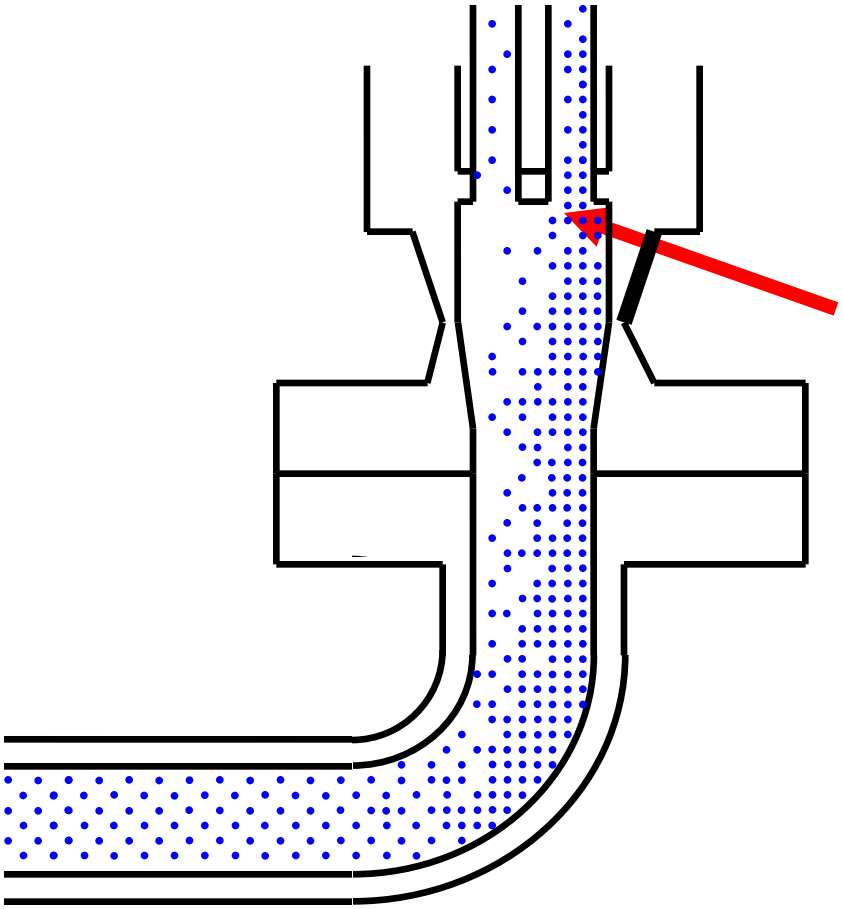
Solids Content

The medium must be homogeneous.
If sedimentation occurs within 1 minute,
the medium might cause measurement problems.



Coriolis Meter Concerns

Metering Liquids with solid content



Flow distributor:

=> Heavy (slow acting) particles move to the outside, light particles will be pushed to the inside

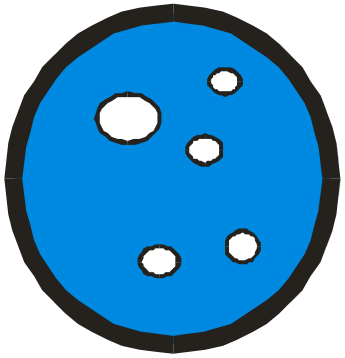
90° bend

Coriolis Meter Concerns

Viscous Fluids

The pressure loss must be considered

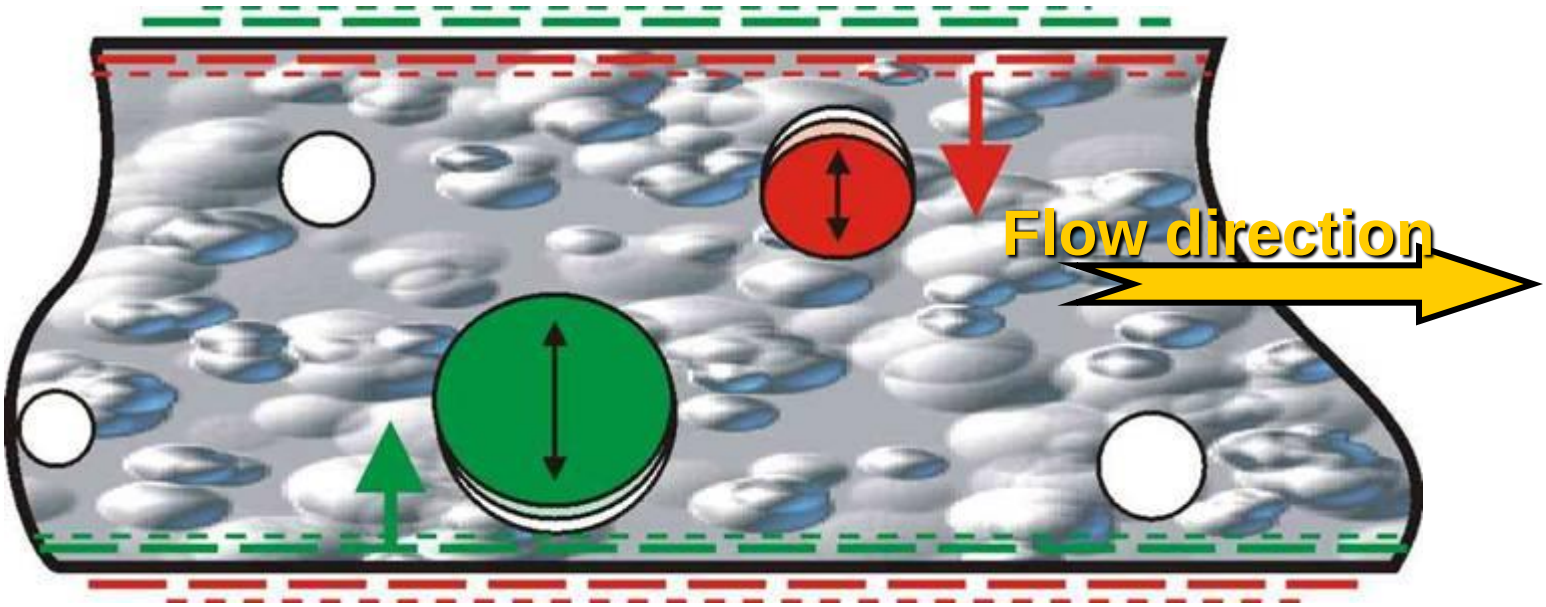
- **Higher viscous mediums often have air trapped**
- **The possibility of a Non-Newtonian fluid must be considered**



Coriolis Meter Concerns

Liquids with Gas content

Oscillating measuring tube

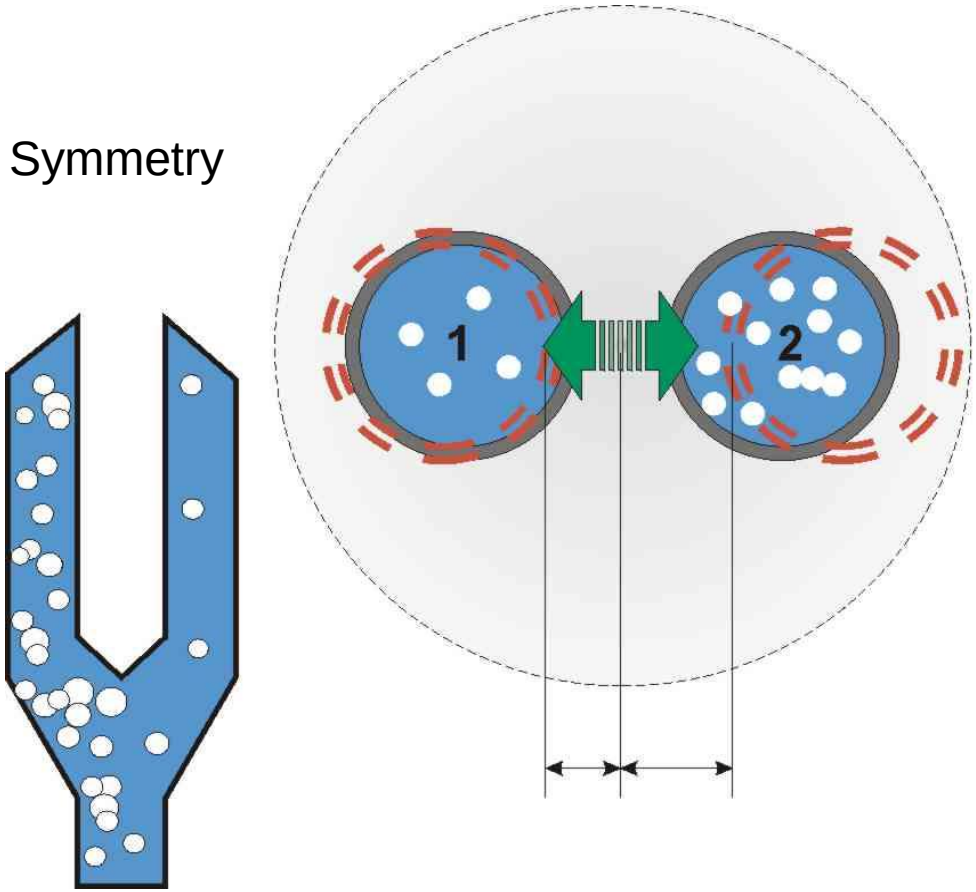


Coriolis Meter Concerns

Liquids with Gas content

Effects of an uneven distribution of gas in a dual tube system

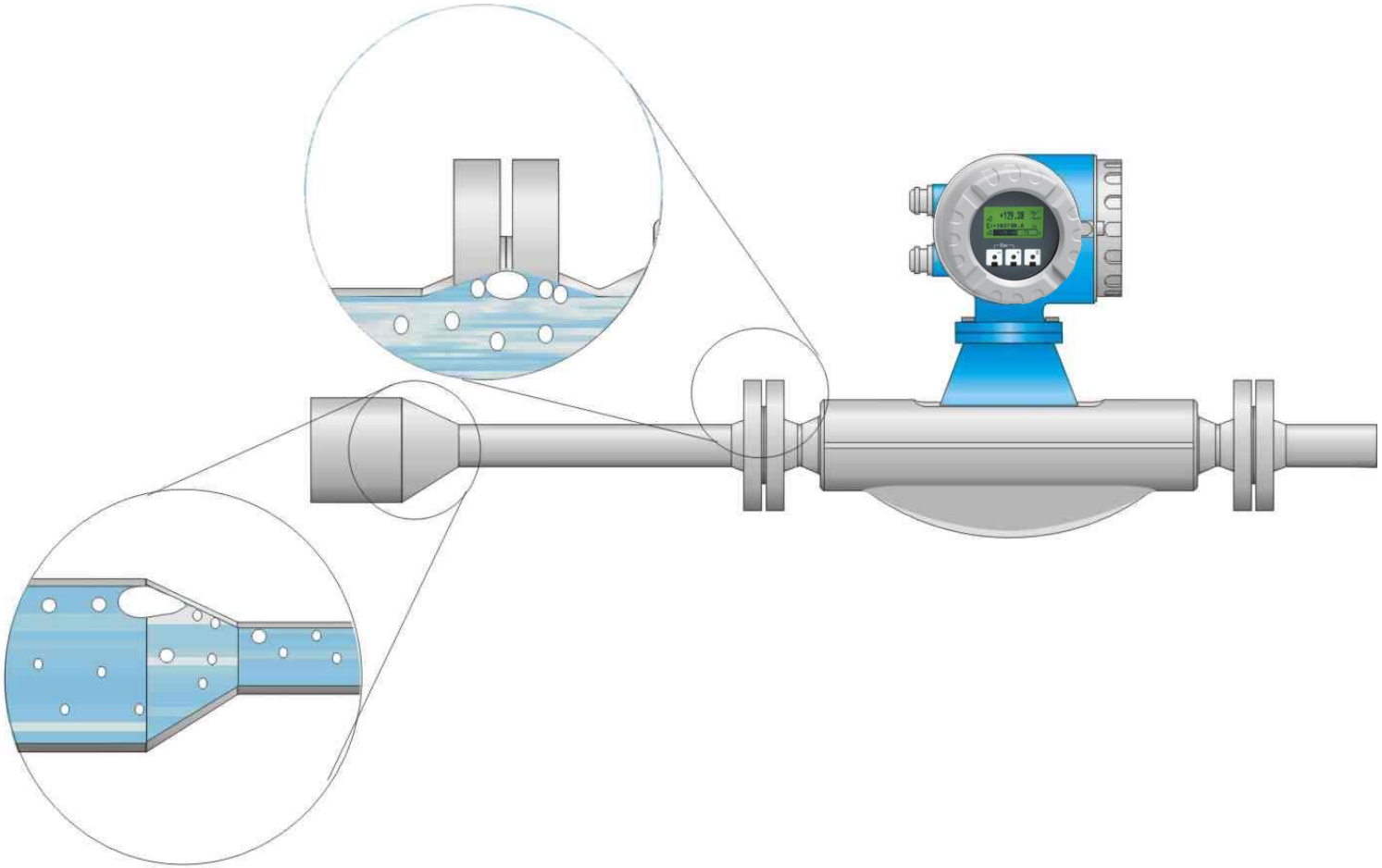
Symmetry



Different Gas Content = Different Oscillating Amplitude

Coriolis Meter Concerns

Air traps



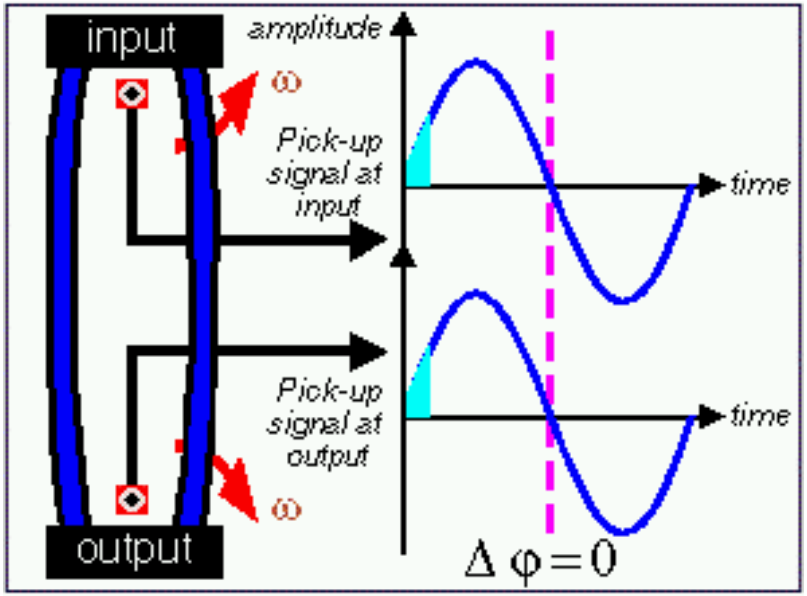
Zeroing The Meter

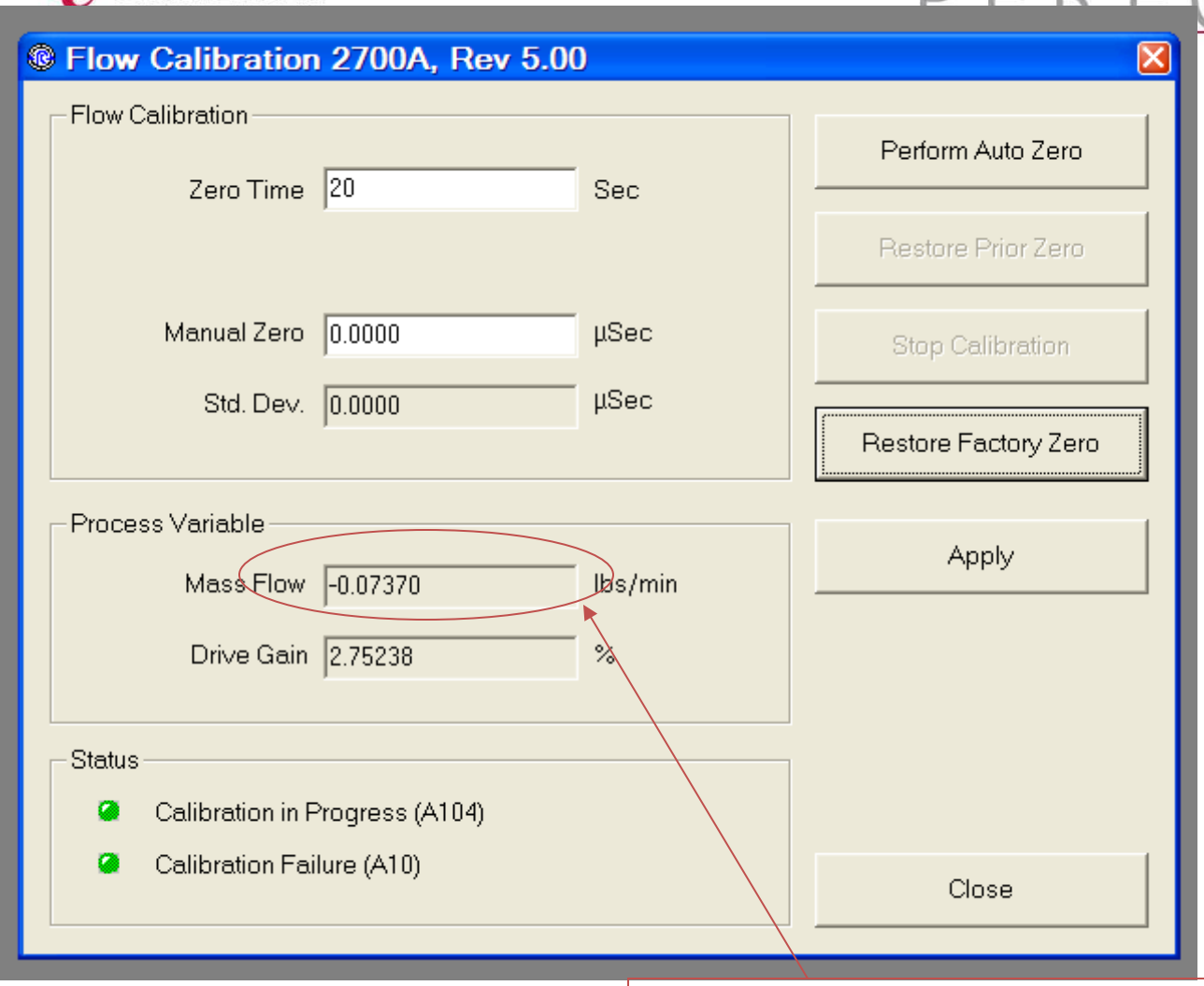
Reasons for zero-point error

Imperfections In Measuring System

Tubes are matched and balanced during manufacturing process in order to minimize zero offset of each flowmeter, but a perfectly balanced tube system doesn't exist, there is always some imperfection in the zero-point of a Coriolis meter, especially as temperature changes, fluid changes, meter undergoes wear due to normal operation.

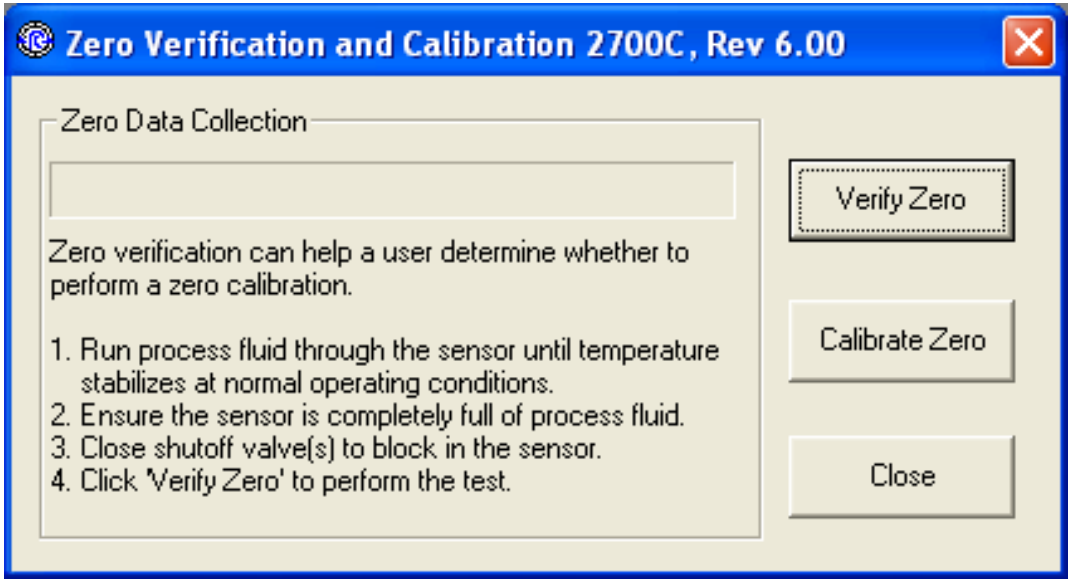
Perfect Zero:

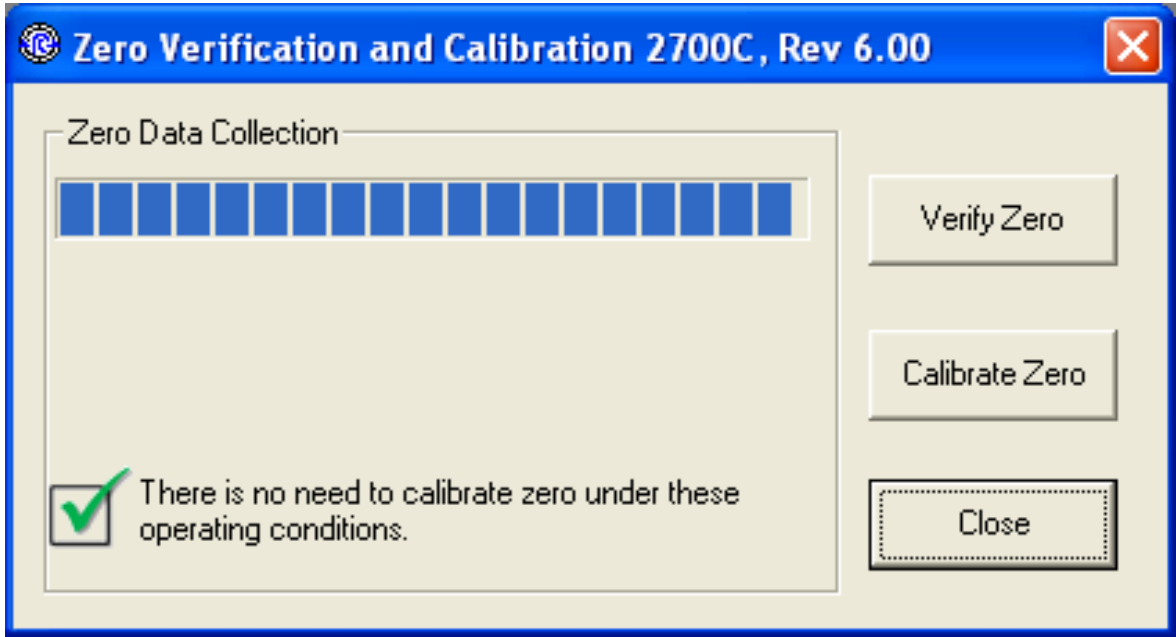




Once the meter is blocked in and your mass flow cutoff is set to zero, this value should vary positive to negative if the zero is valid.

Zero Validation





Reasons for zero-point error

- Change in mechanical stress on meter (installation effects)
- Entrained air or solids
- High fluid viscosity
- Flow tubes mechanically unbalanced by corrosion or erosion
- Flow tubes mechanically unbalanced by buildup/coating

Zero-point problems caused by solids

- Uneven coating of tubes causes mechanical zero shift
- Settling solids can be seen by meter as flow, even when valves are closed and there is no flow through meter
- Solids that don’t stay in solution, such as frac sand, can’t be successfully measured once concentration becomes too high

Entrained air issues

Small Air Bubbles Throughout Fluid

- Meter stays in balance when small air bubbles are throughout the fluid because the fluid is the same in both tubes, or from one end of the meter to the other
- Driving flowmeter tubes requires more energy / higher current excitation because air bubbles are compressed during tube vibration – this absorbs energy and increases excitation current because the meter is designed to maintain a constant amplitude for tube vibration
- When excitation current is unstable or drive circuit saturates at 100 mA, the meter's accuracy will be compromised

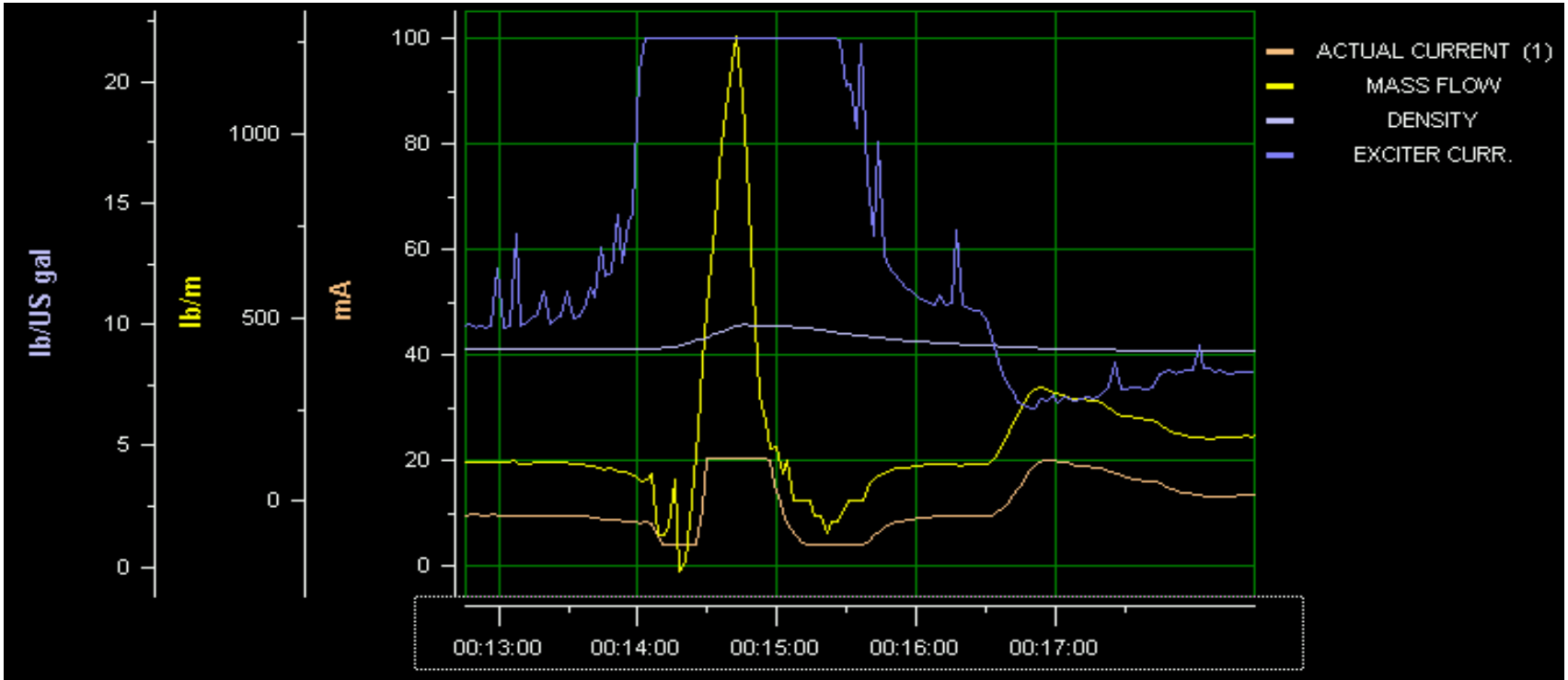
Proving

Proving Checklist for Meter

- Is the product composition stable? Drive gain? Noise?
- Is the product temperature and pressure and flow rate stable?
- Is the frequency output to the pulse counter or flow computer within limits?
- If sending pulses to multiple devices, are both devices receiving the correct amount?
- Is the transmitter configured properly?
- Is the DC frequency/pulse signal in conduit with AC power?
- Is the meter properly grounded?
- For contract proving, is the connection to the transmitter's pulse output solid?
- 10,000 PPB for 1-4" meters
- 5,000 PPB might be recommended for 6" and larger meters.

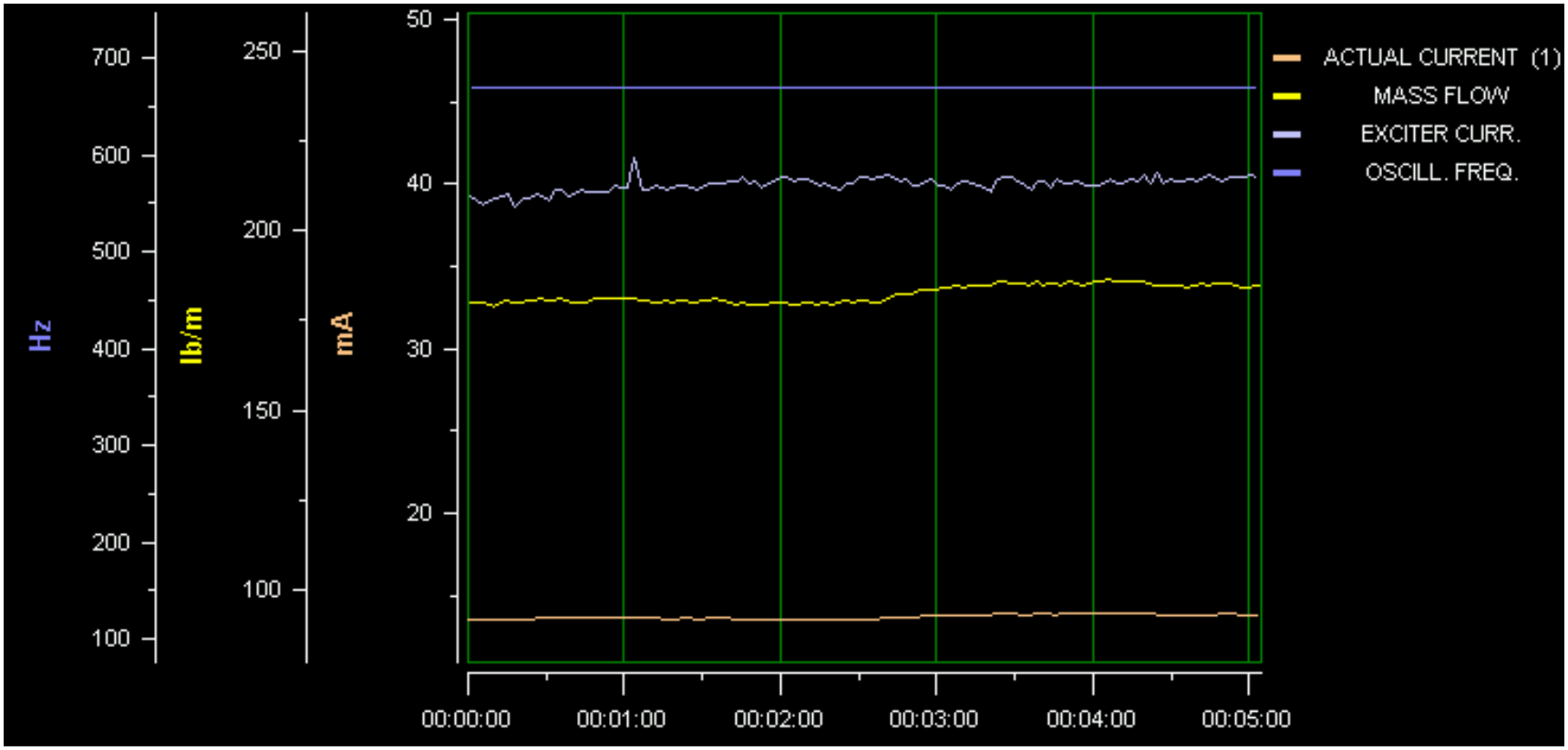
Effects of Entrained Air In Liquid Cheese

- Excitation current unstable--non-repeatable measurement vs. scale
- When excitation current maxes out (100 mA), meter isn't capable of providing good measurement
- Zero-point isn't stable/repeatable during static zero adjustment



Same fluid – With Backpressure On Meter

- Current excitation remains low and stable (air bubbles are compressed)
- Mass flow rate (internal to meter) and current output are stable



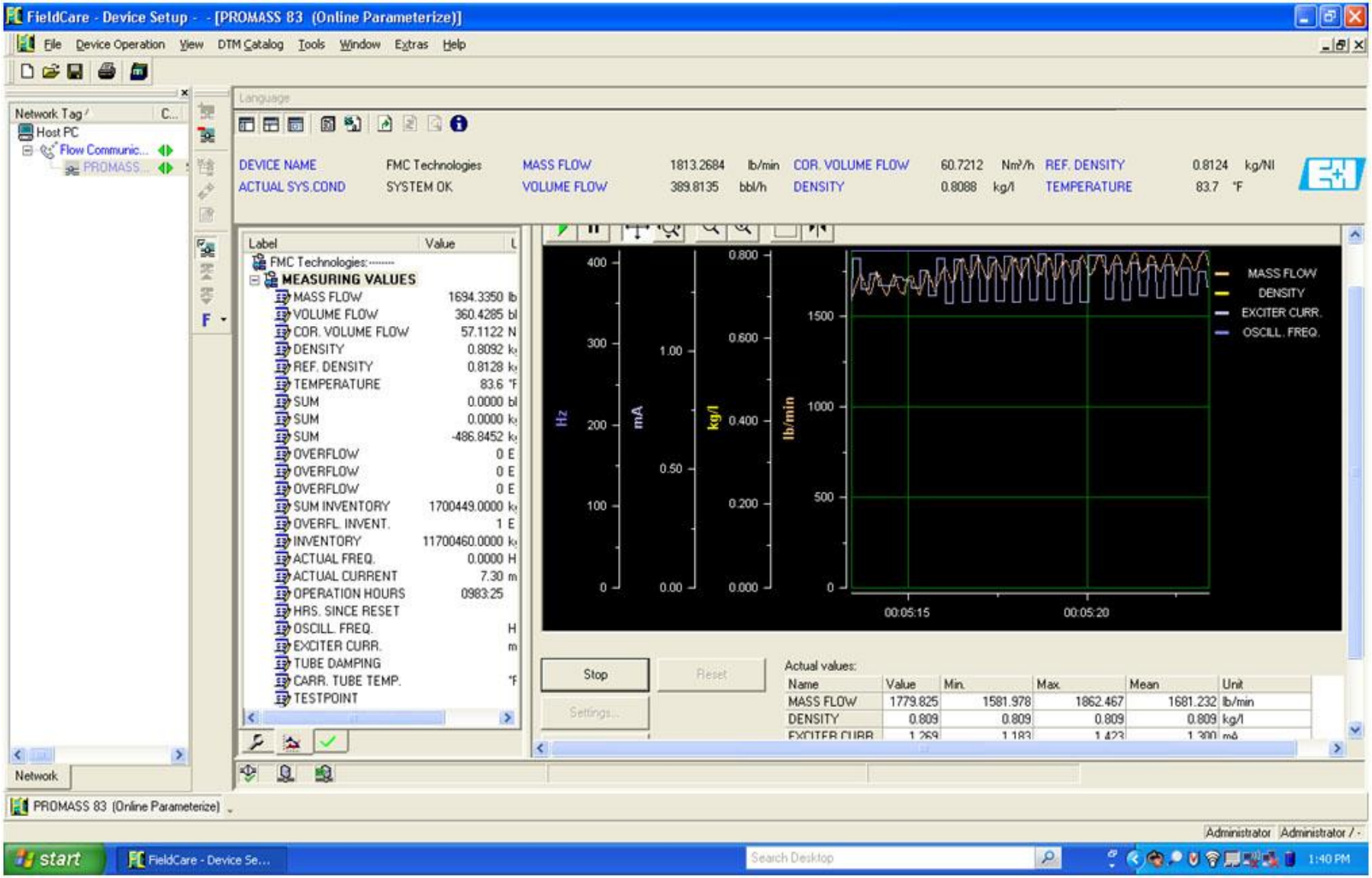
Troubleshooting

Troubleshooting

1. **Wiring** – is the wiring properly connected? They ARE polarity sensitive.
2. **Configuration** – Is the meter configured properly?
3. **Good Installation**? - Piping stresses?
4. **Orientation?**
5. **Process Conditions**?
6. **Other Devices** - What other devices are on the metering system?
7. **Meter Diagnostics?**

Varying Flow Rates

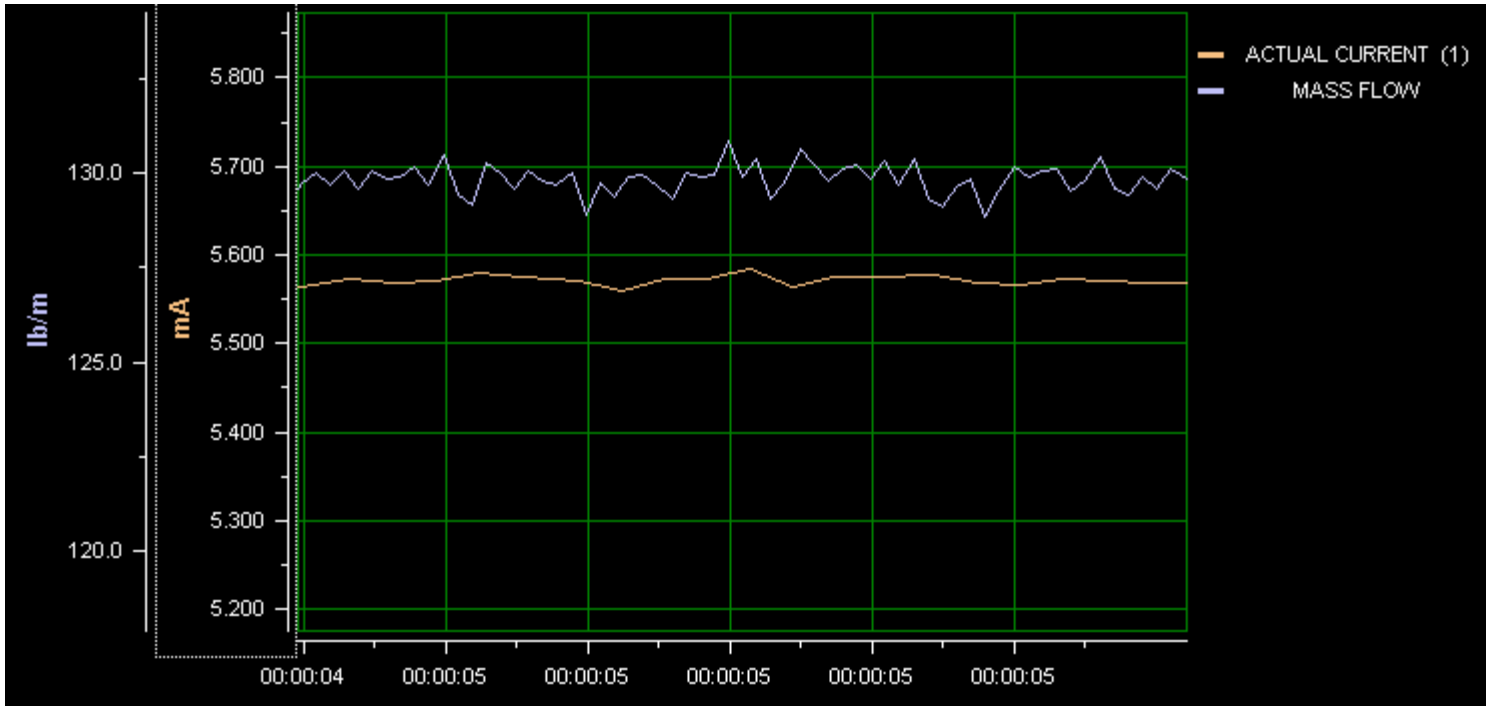
Diagnostic Program



Effect of flow damping

Mass Flow (Internal to meter) and Current Output

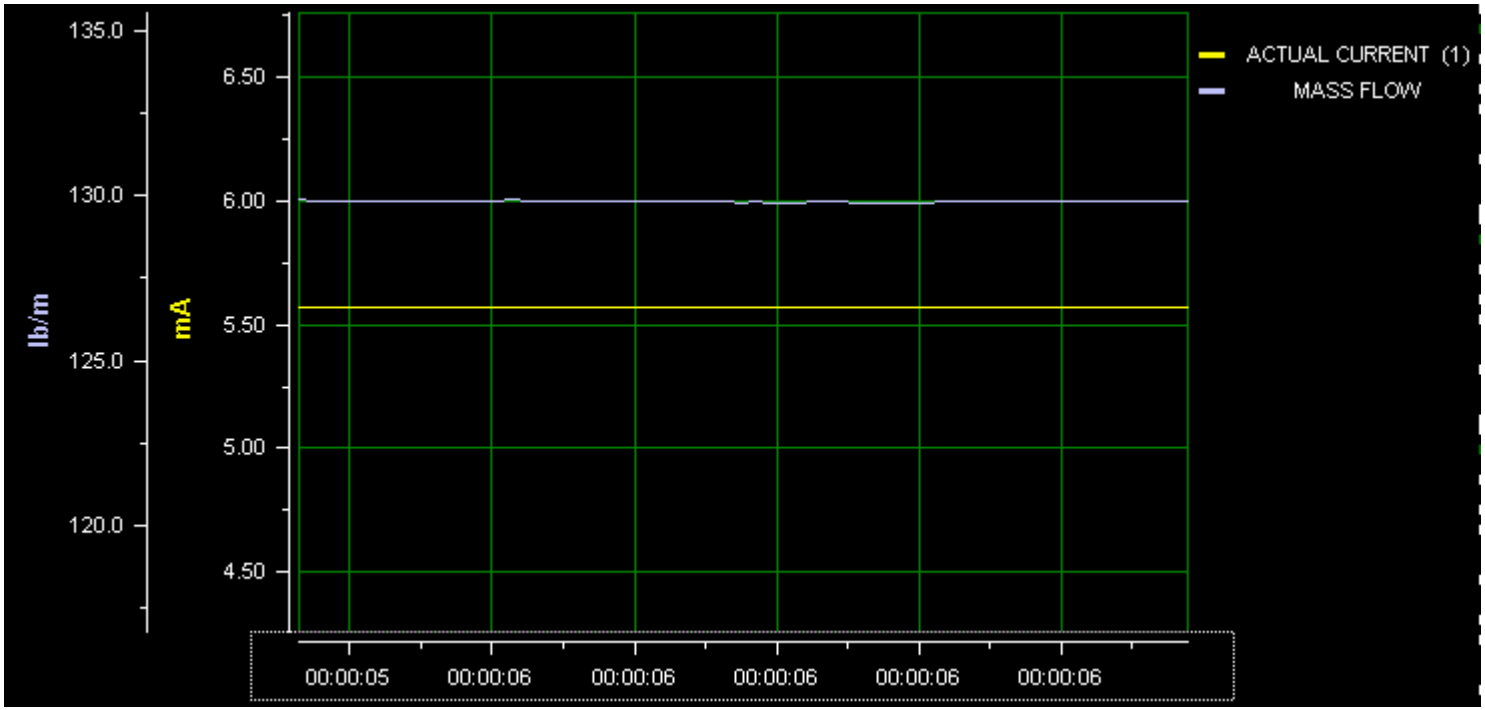
Flow Damping = 0 sec
Current Output Time Constant = 0.01 sec



Effect of flow damping

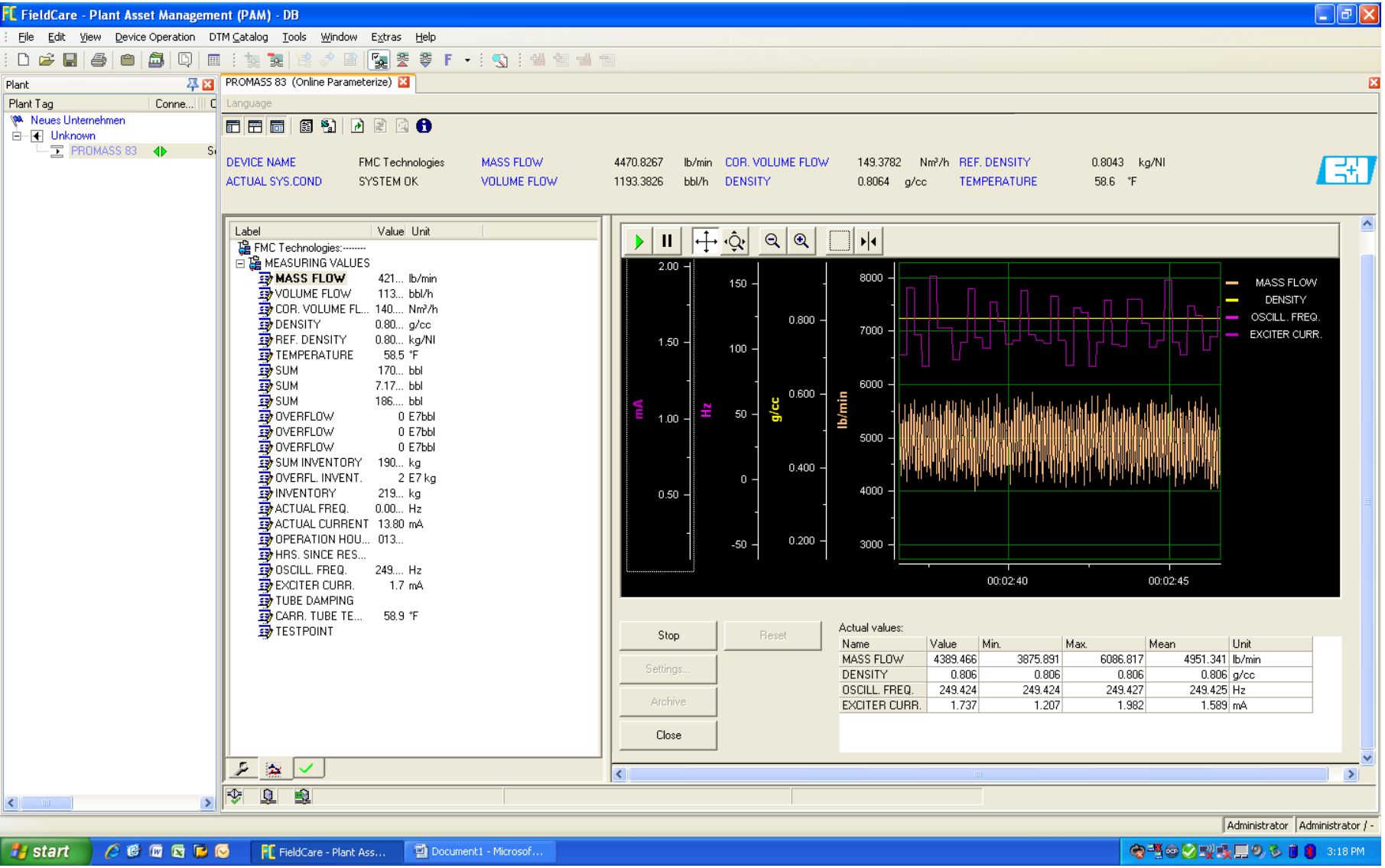
Mass Flow (Internal to meter) and Current Output

Flow Damping = 1.0 sec
Current Output Time Constant = 0.01 sec



Hi Frequency Pumps

Diagnostic Program



“DP” Noise from Run #2 Valve

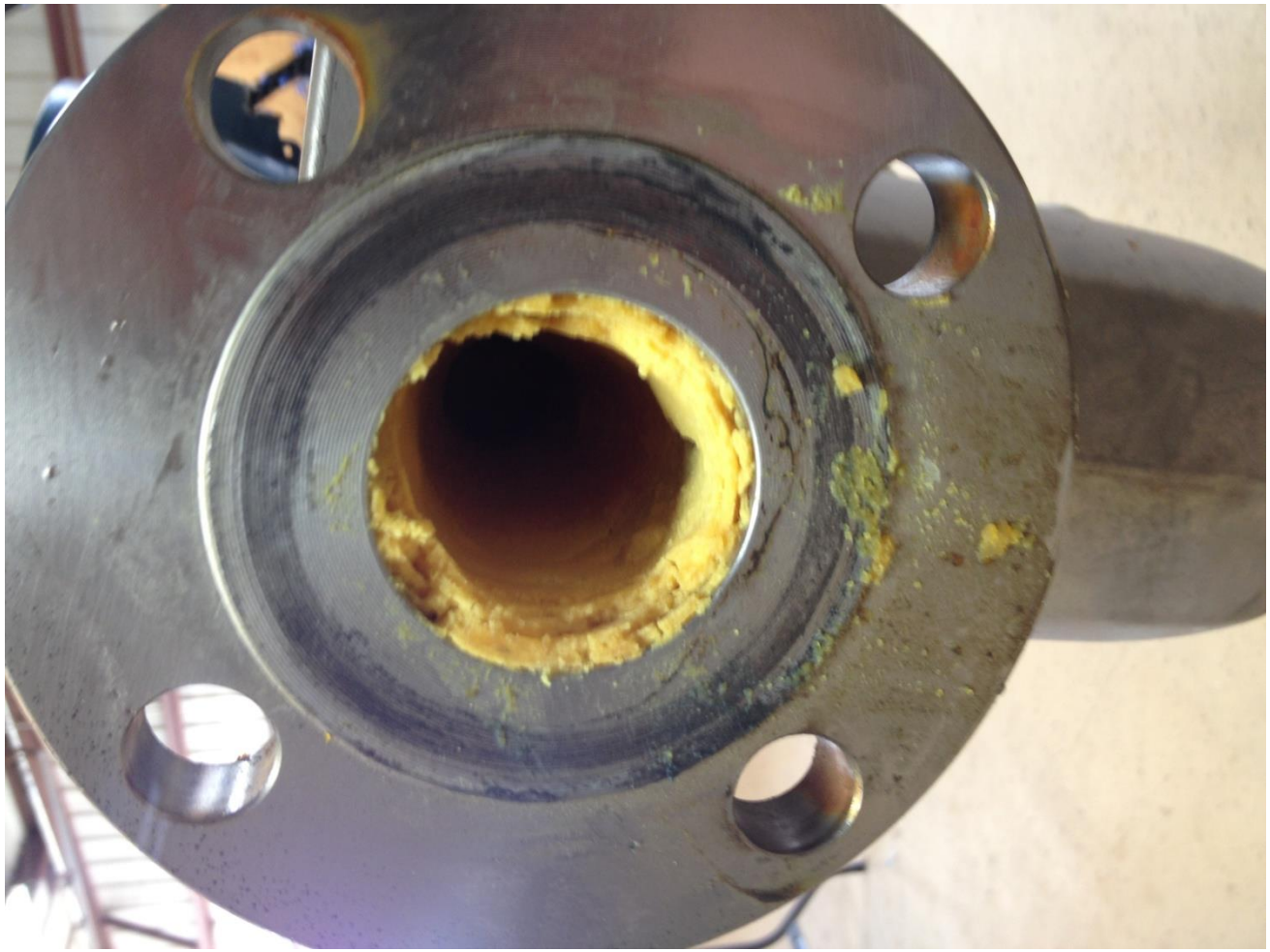
Poor flange alignment

Poor flange alignment

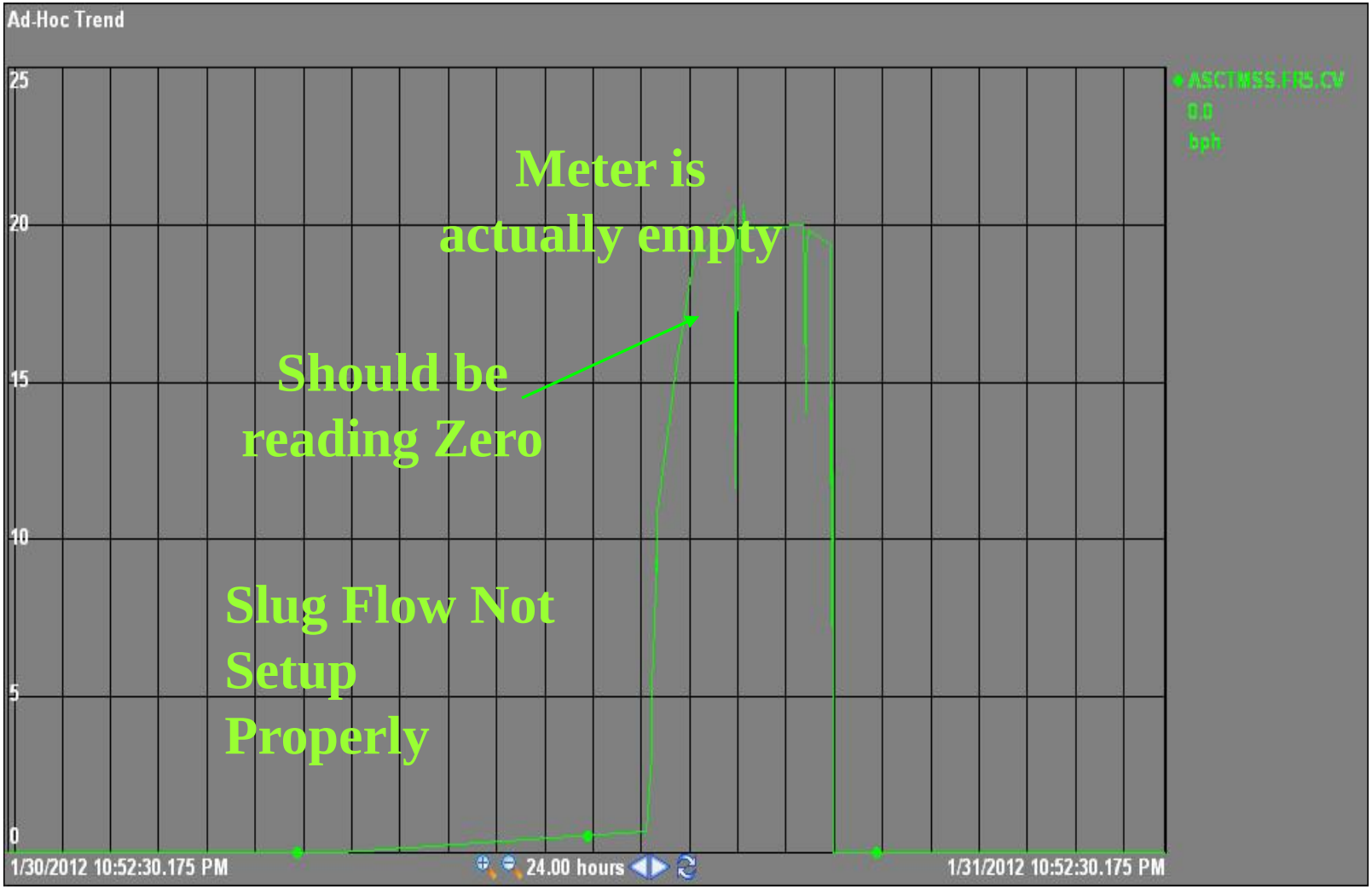
Alignment Problem

Good Installation

Paraffin Buildup



Ghost Counts



Summary of Coriolis Meters

- Is the wiring connected correctly?
- Is the meter configured correctly?
- Concerns of external vibration and installation effects (alignment?)
- Zero point stability – Does the meter have good zero stability
- Tube vibration frequency – What vibration frequency does the meter have? Are there competing resonant frequencies?
- Flow rate stability?
- Are the process conditions stable?
- Pressure Drop?
- “Ghost” Counting of barrels??
- What diagnostics are available on the meter?
- Laptop Computer Diagnostics - a Configuration & Diagnostic tool

Questions?