Gas Measurement via Coriolis Flow meters - Fundamentals to Optimization

Canadian Gas Association

Endress+Hauser
People for Process Automation

Presenter

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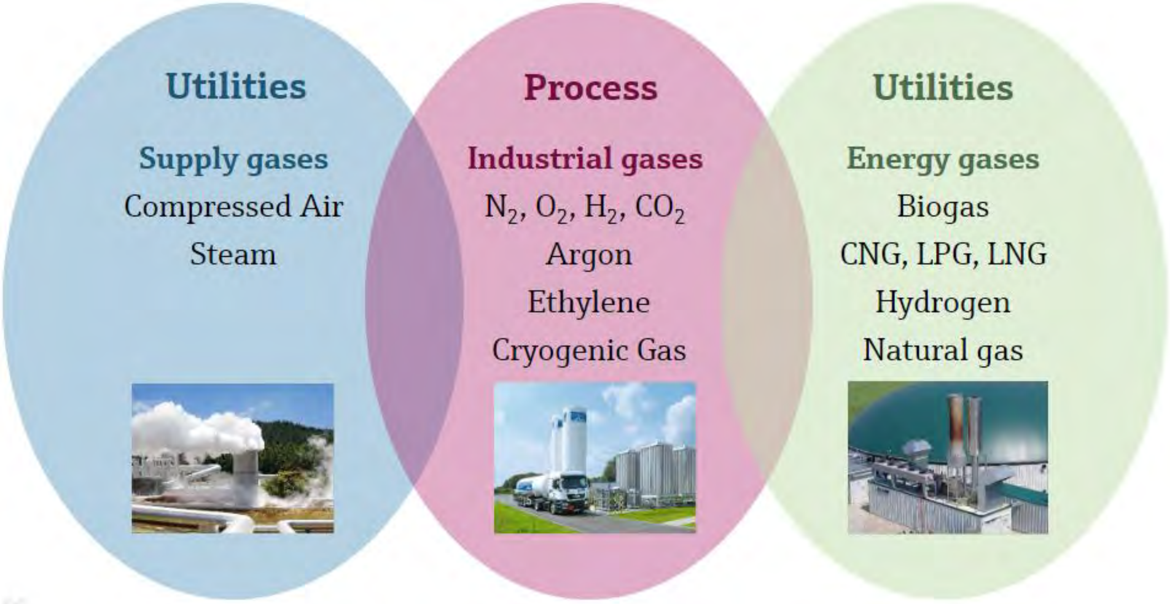
- Background in Chemical Engineering
- 13 years employment at Endress+Hauser Canada
- 7 years field service and metrology focus
- 6 years of flow product and application focus

Why do we measure gas?

- We measure gas out of a necessity….
- All types of gases are measured to be used at the inlet, in process, as a by product, boilers/furnaces.
- Some mote the more talked about gases include: Natural Gas, RNG, oxygen, fuel gases (multi component), CO2, Hydrogen etc….



Application examples in natural gas

Wellhead gas measurement

For high reliability measurement and high robustness under wet gas fluctuating process conditions.

Separator gas outlet

Perfect solution under fluctuating flow, wet gas conditions with high turndown ratio and high pressure.

Gas processing facility

Raw Natural gas measurement for dehydration, sweetening, filtering and fractionation processes.

Application examples in process gases

Process gas measurement

For continuous process gas control in the chemical / petrochemical industries. For example in ethylene production or in the production of polymers with high level of accuracy and safety.

Gas generation systems

For accurate and repeatable gas flow measurement in the gas generation processes.

i.e. Nitrogen generation.

Power & Energy

Natural gas boiler inlet measurement for efficiency monitoring and Wobbe index control.

Application examples in process gases

Hydrogen

Production

Loading

Blending in to Natural Gas

Biogas & RNG

Digester raw gas flow

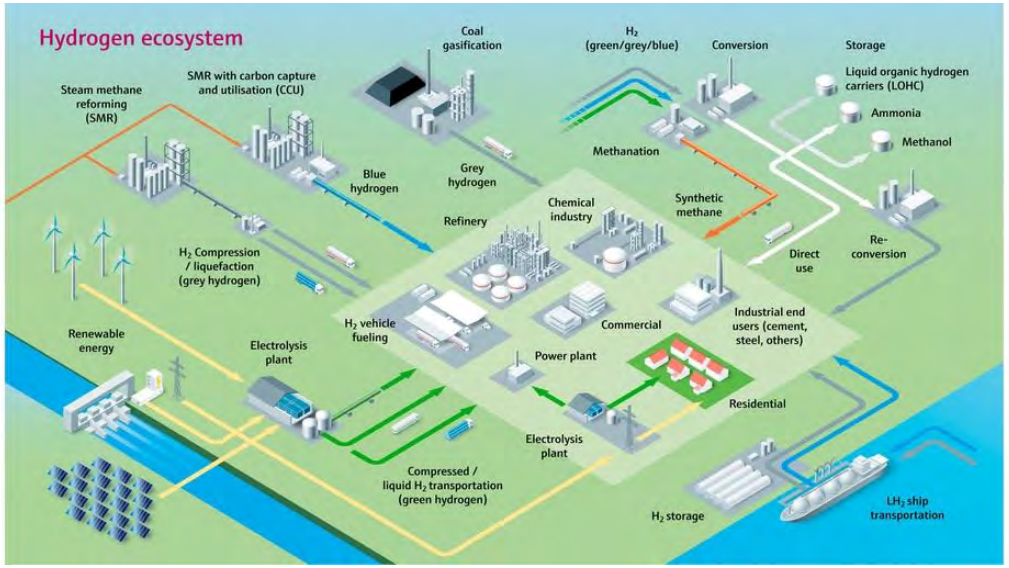
Flare

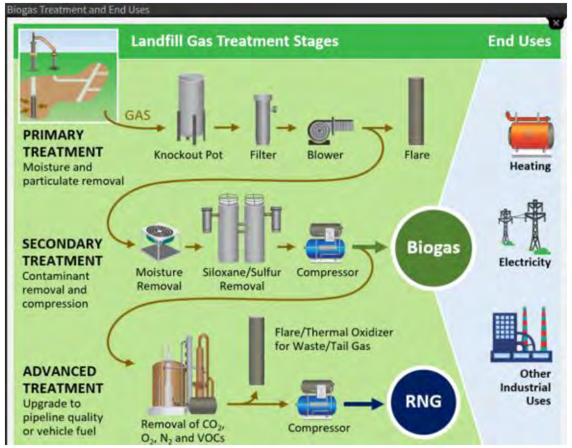
CO2 removal

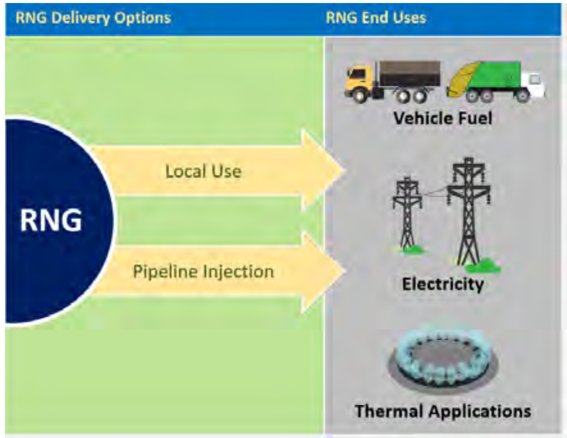
Compression

Truck loading

Pipeline injection

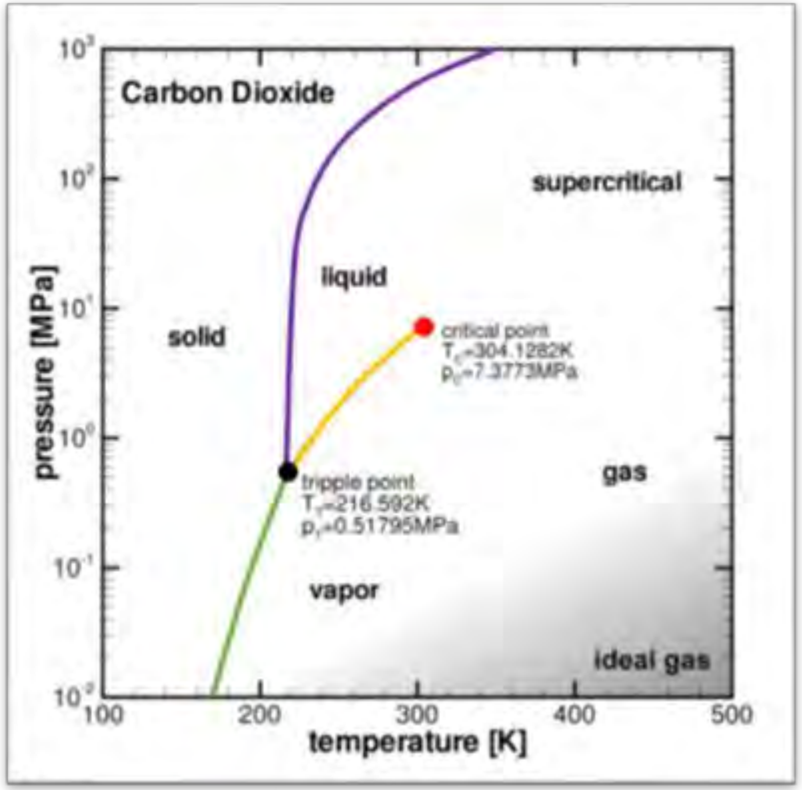






What are the challenges?

- Accurate measurement of gas has proven to be more difficult than measuring liquids due to regulation and the complex physical properties of gas.
  - Clean vs. non-clean
  - Moisture (even in dry systems)
  - Measurement Compliance
  - Less measurement technologies vs liquids
  - Opex – maintenance to ensure highest accuracies possible
- Physical properties of a gas:
  - Compressibility
  - Temperature compensation
  - Pressure compensation
  - Density
  - Changing composition
  - Changing state



Common Technologies for Gas Measurement

- Turbine
- Orifice Plate + dP Transmitters
- Vortex
- Thermal mass/dispersion
- Ultrasonic
- Coriolis
- …

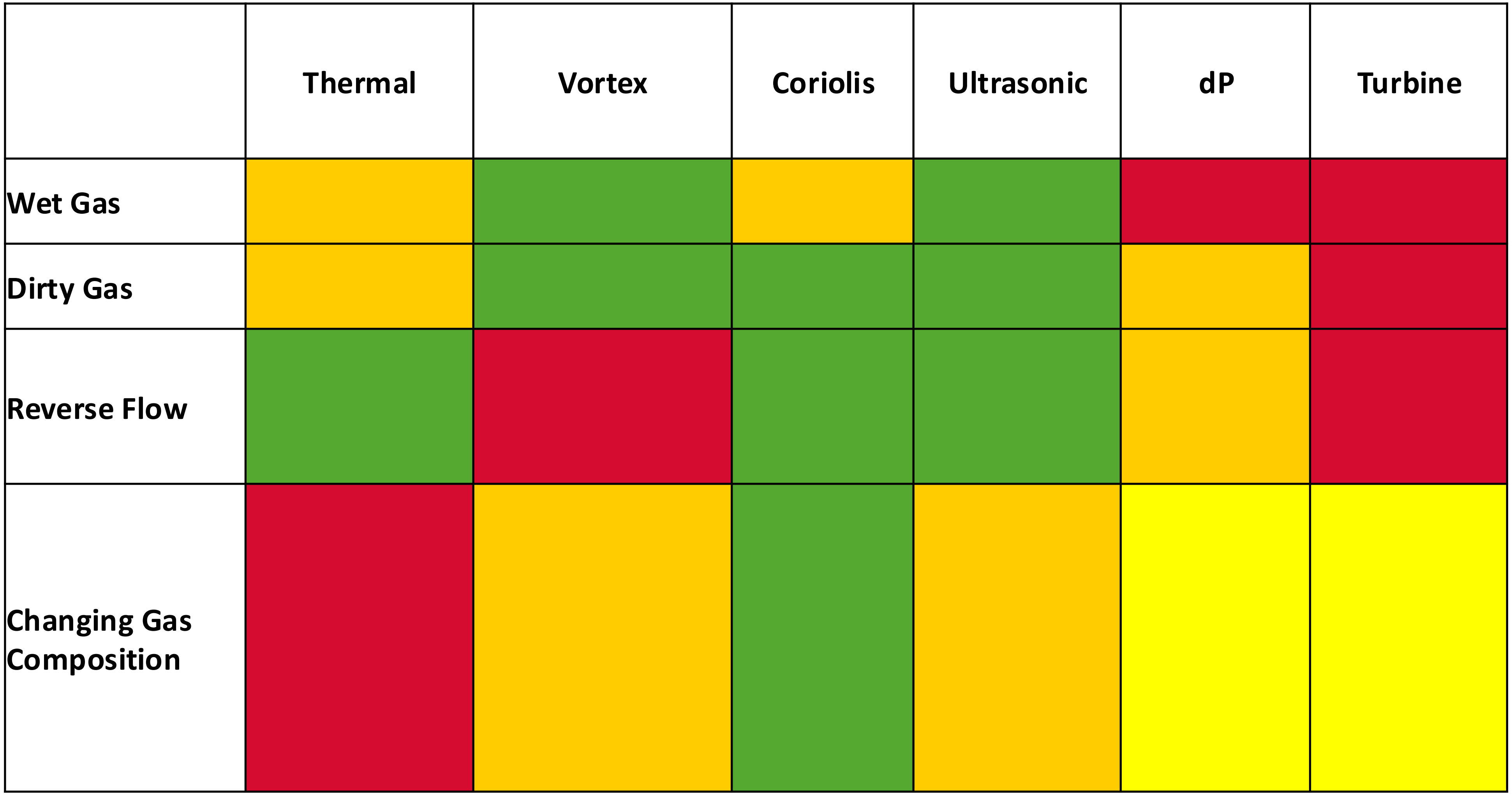
Review of existing Gas Measuring systems

Let’s take a look at the pro’s and cons for each technology with regards to gas measurement!

Technology Comparison

Technology	Accuracy	Turndown	Max. temperature (°C)	Max. process pressure (psi)	Pressure drop at Qmax	Inlet/outlet run requirements
Thermal	1% o.r.	1000:01:00	180	1450	Negligible	20/5
Vortex	1% o.r.	33:01:00	400	3600	Low	20/5
Coriolis	0.25% o.r.	>100:1	350	5800	High	0/0
Ultrasonic	0.5% o.r.	>100:1	150	1450	Negligible	10/3
dP	1% o.r.	4:01	454	5800	High	15/5
Turbine	0.5% o.r.	10:1	90	1500	Low	5/2

Flow Technology – Heat Map



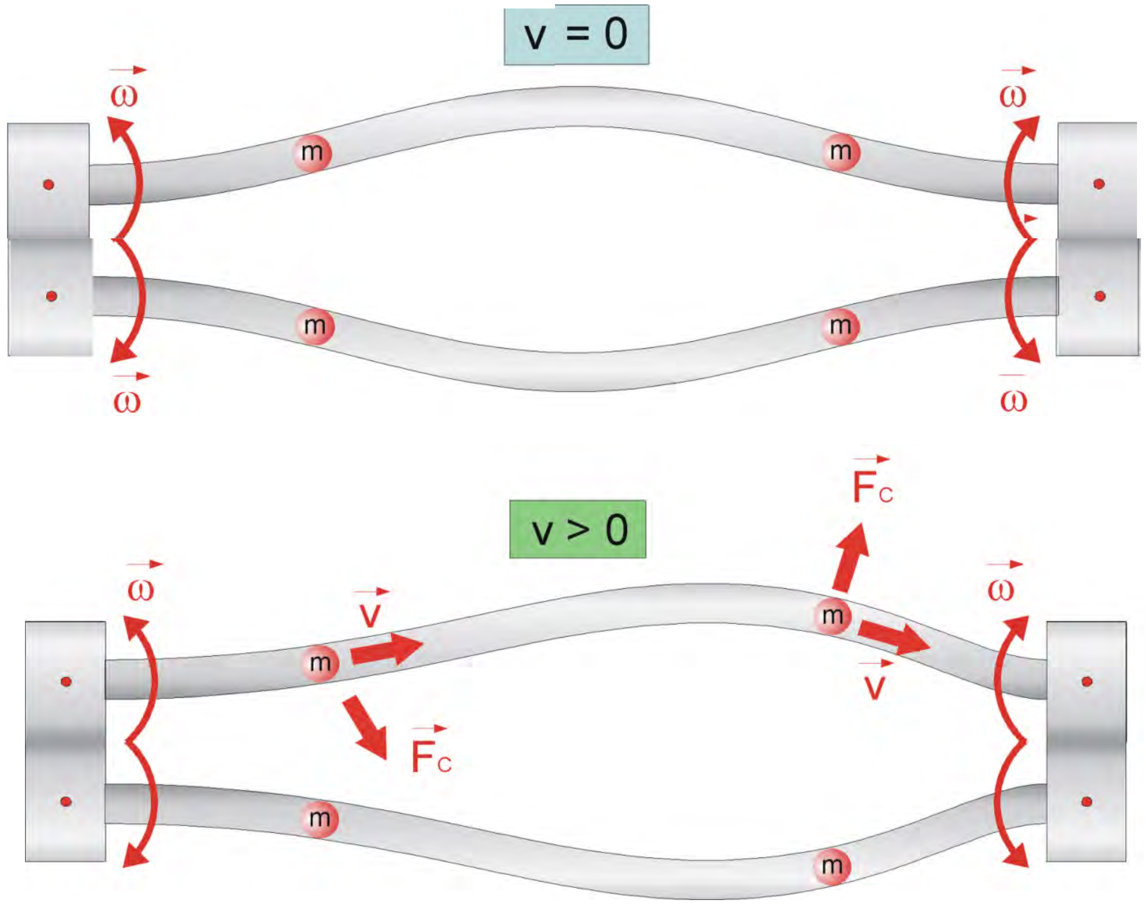
Coriolis

Now that we have seen the heat map on technologies… let's have a closer look at….

What is Mass Flow – How does it work?

https://www.youtube.com/watch?v=XIIViaNITIw

Coriolis force - Rotation and Translation



m = arbitrary body of mass

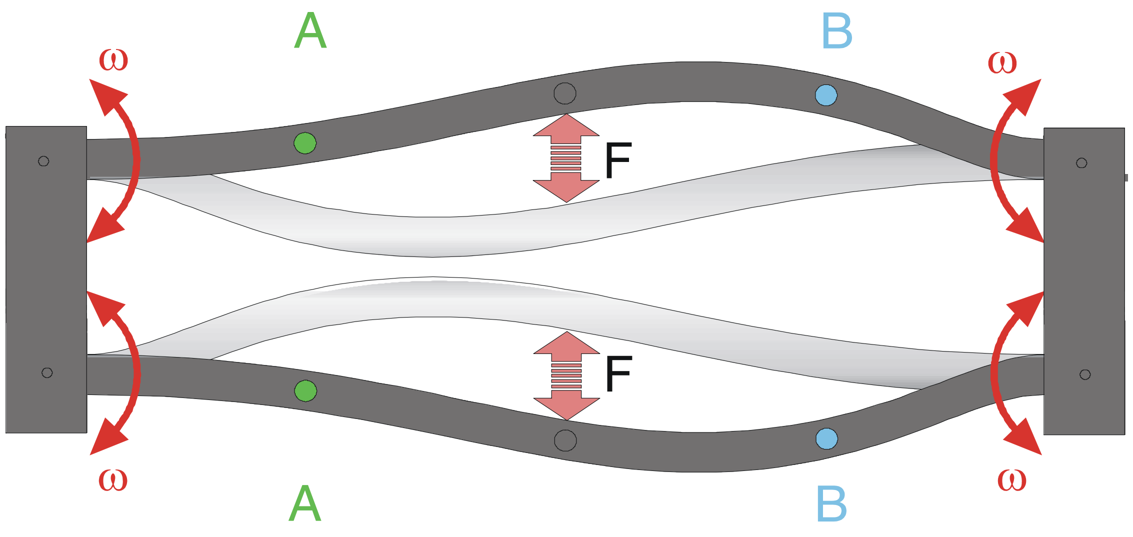
$\vec{\omega}$ = angular velocity

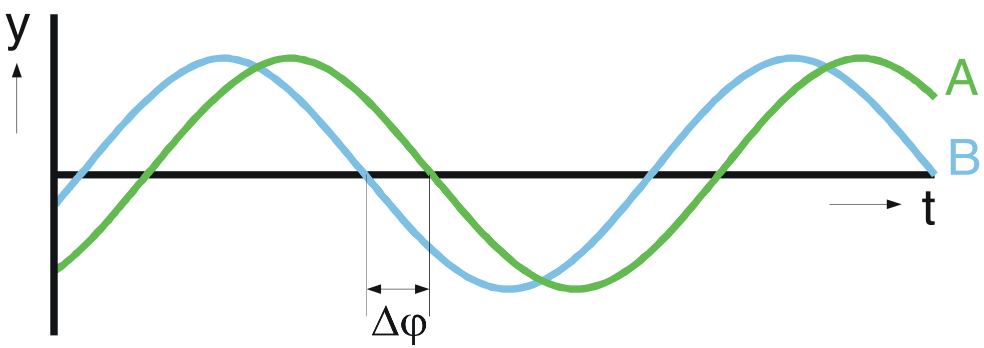
$\vec{v}$ = fluid velocity

$\vec{F}_C$ = Coriolis force

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

Direct mass flow measurement - Measuring principle





ω = Angular velocity

F_c = Coriolis force

Δφ = Phase shift

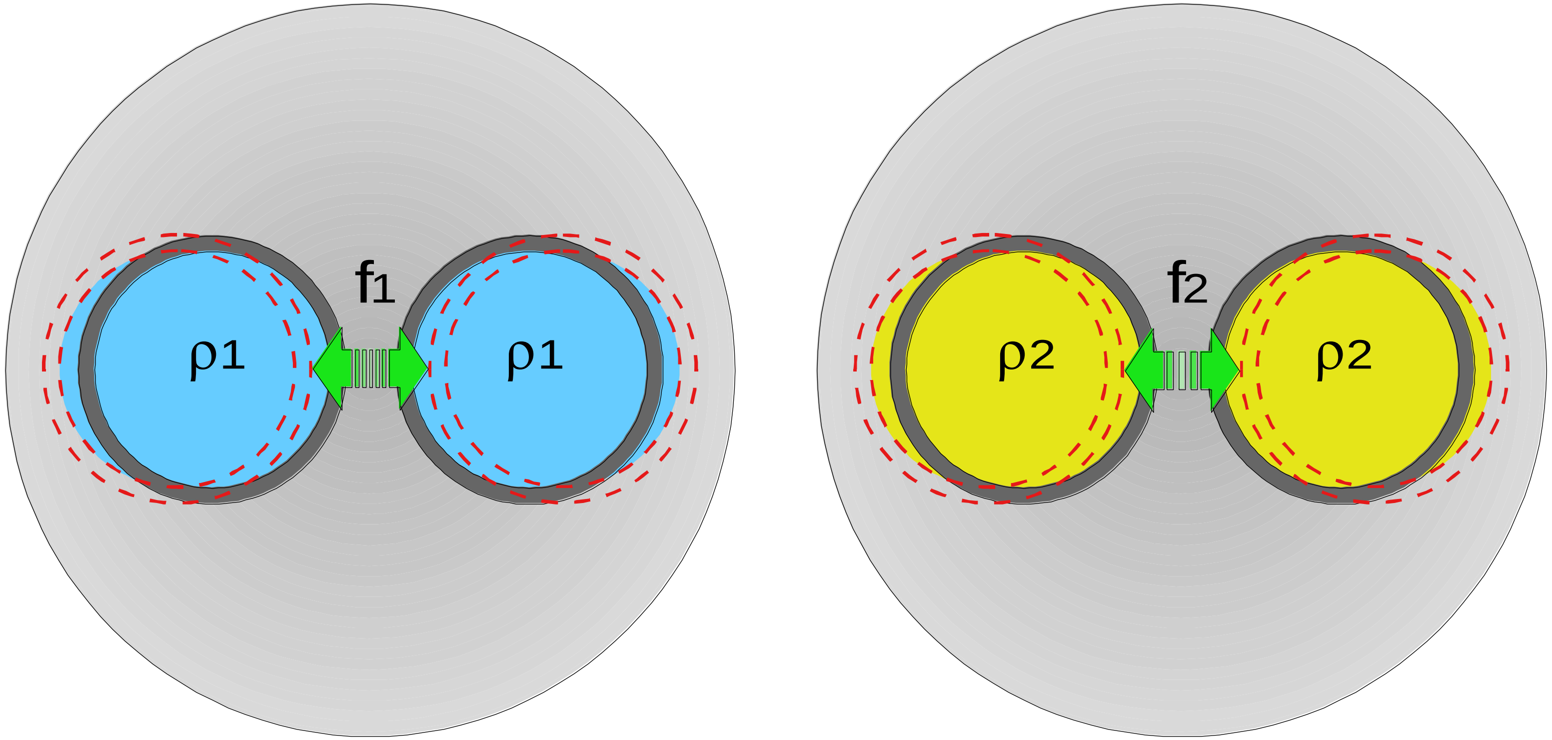
A,B = Pick-ups

y = Amplitude

t = Time

$$\Delta\varphi \sim F_c \sim \dot{m}$$

Density Measurement Principle



Volume:

$V_1 = V_2$

Density:

$\rho 1 \neq \rho 2$

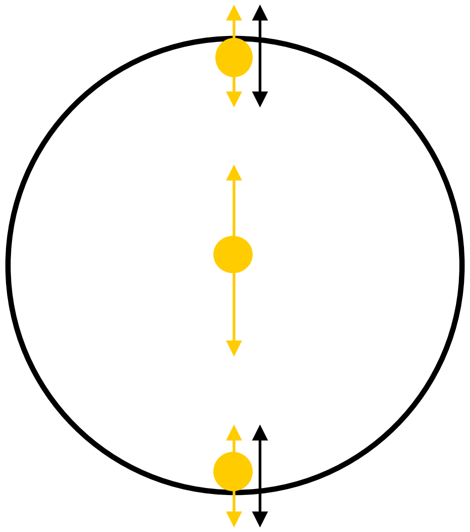
Resonant Frequency:

$f_1 \neq f_2$

Density of gas hard to measure since it is lighter than liquid…. Unless its **compress**!

$f \sim \rho$

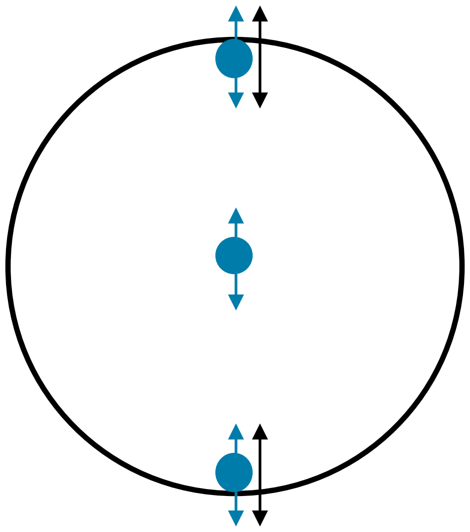
Behavior of gas molecules in an oscillating pipe system



Gas molecule

Gas molecule in the middle vibrates at higher amplitude compared to gas molecule close to the pipe

Overreading, if not compensated



Liquid molecule

Liquid molecule in the middle vibrates at the same amplitude compared to liquid molecule close to the pipe

No over- or underreading

Coriolis mass flow measurement with Promass

Direct mass flow measurement for liquids and gases

- Multivariable measurement – simultaneous measuring of mass flow, density (concentration), temperature and viscosity
- Very high measuring accuracy
- Measuring principle independent of the physical fluid properties and the flow profile
- No inlet/outlet runs necessary
- Liquid + Gas Measurement

Liquids

- typically: ±0.1% o.r.
- optionally: ±0.05% o.r. (PremiumCal)
- 0.1 kg/m3 (density)

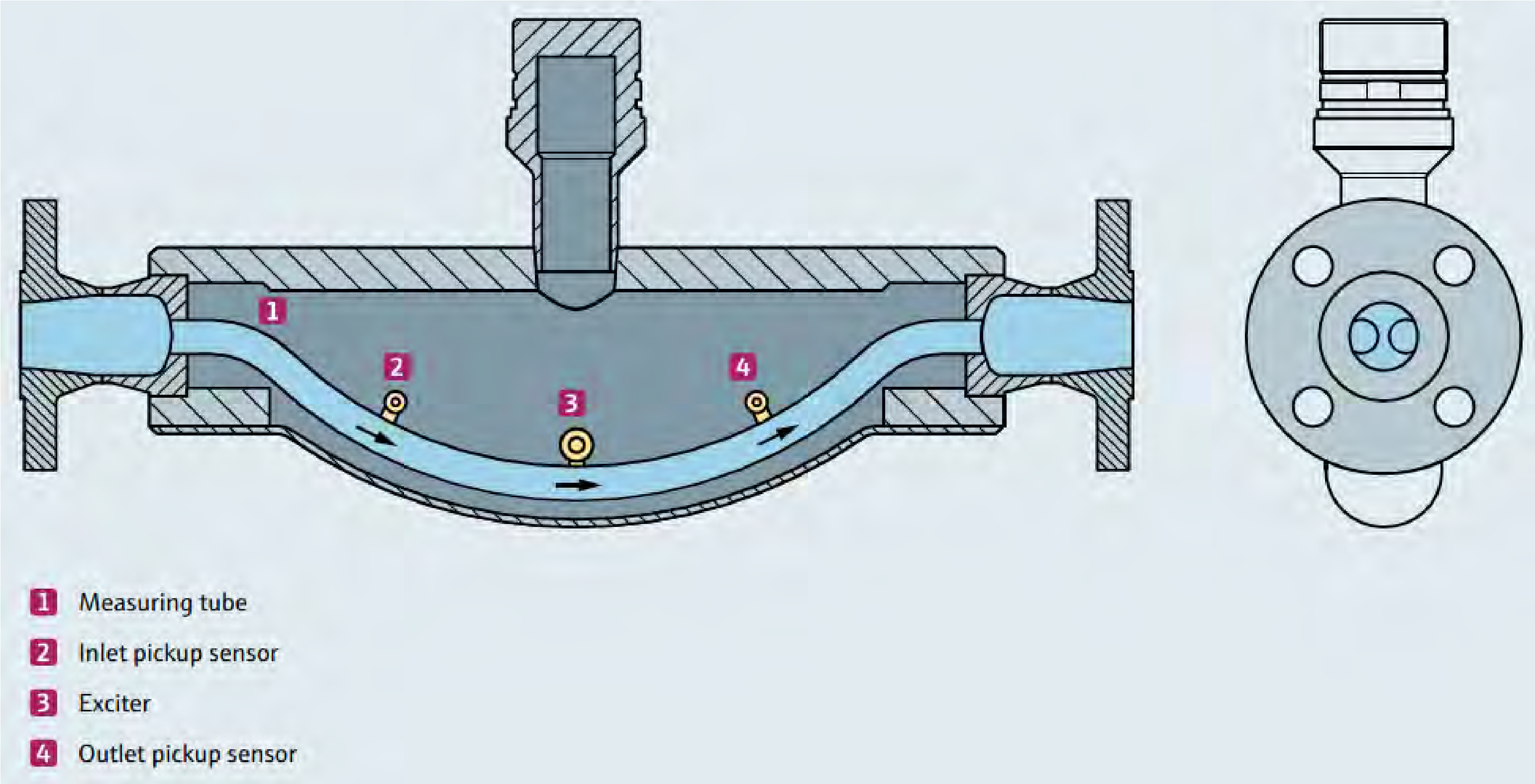
Gas

Mass flow (gas): ±0.25 %

Click here to watch the full movie

Sensor design

Promass F has a fully welded, dual tube design with slightly curved tubes. Due to the slight curves, dimensions are small and the weight is low, allowing installation without pipe support and full drain ability in vertical installations.



Large range of DN

With line sizes from DN 8 to 250 (3/8" to 10") and a large turndown scale up is easy.

Measuring ranges for liquids

DN		Measuring range full scale values $\dot{m}_{min(F)}$ to $\dot{m}_{max(F)}$	
[mm]	[in]	[kg/h]	[lb/min]
8	⅜	0 to 2 000	0 to 73.50
15	½	0 to 6 500	0 to 238.9
25	1	0 to 18 000	0 to 661.5
40	1½	0 to 45 000	0 to 1 654
50	2	0 to 70 000	0 to 2 573
80	3	0 to 180 000	0 to 6 615
100	4	0 to 350 000	0 to 12 860
150	6	0 to 800 000	0 to 29 400
250	10	0 to 2 200 000	0 to 80 850

Gas Approvals

AG-0647 – Endress+Hauser Promass F Gas Approval

- Promass F 300
  - 8F3B08
  - 8F3B15
  - 8F3B25
  - 8F3B40
  - 8F3B50
  - 8F3B80
  - 8F3B1H
  - 8F3B1F
  - 8F3B2F
- Promass F 500
  - 8F5B08
  - 8F5B15
  - 8F5B25
  - 8F5B40
  - 8F5B50
  - 8F5B80
  - 8F5B1H
  - 8F5B1F
  - 8F5B2F
- Gas Application
- Bi-directional
- Pressure Effect Compensation

Custody transfer

Custody transfer, sometimes called fiscal metering, occurs when fluids or gases are exchanged between parties. Payment is usually made as a function of the amount of fluid or gas transferred, so accuracy is paramount as even a small error in measurement can add up fast, leading to financial exposure in custody transfer transactions.

CT offering for Promass F 300/500

MC: liquids other than water, Gas,

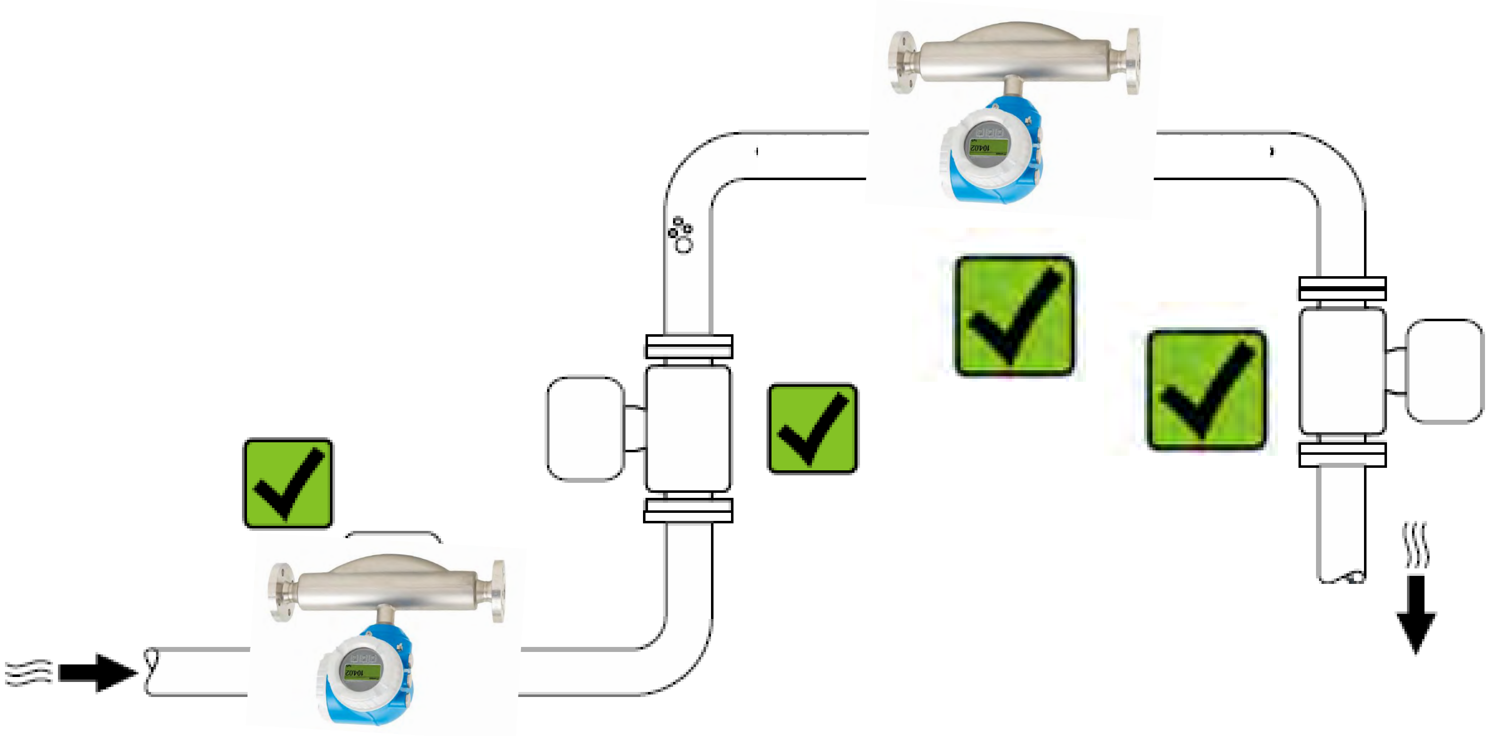
Correct installation position for gas applications

Recommended installation position

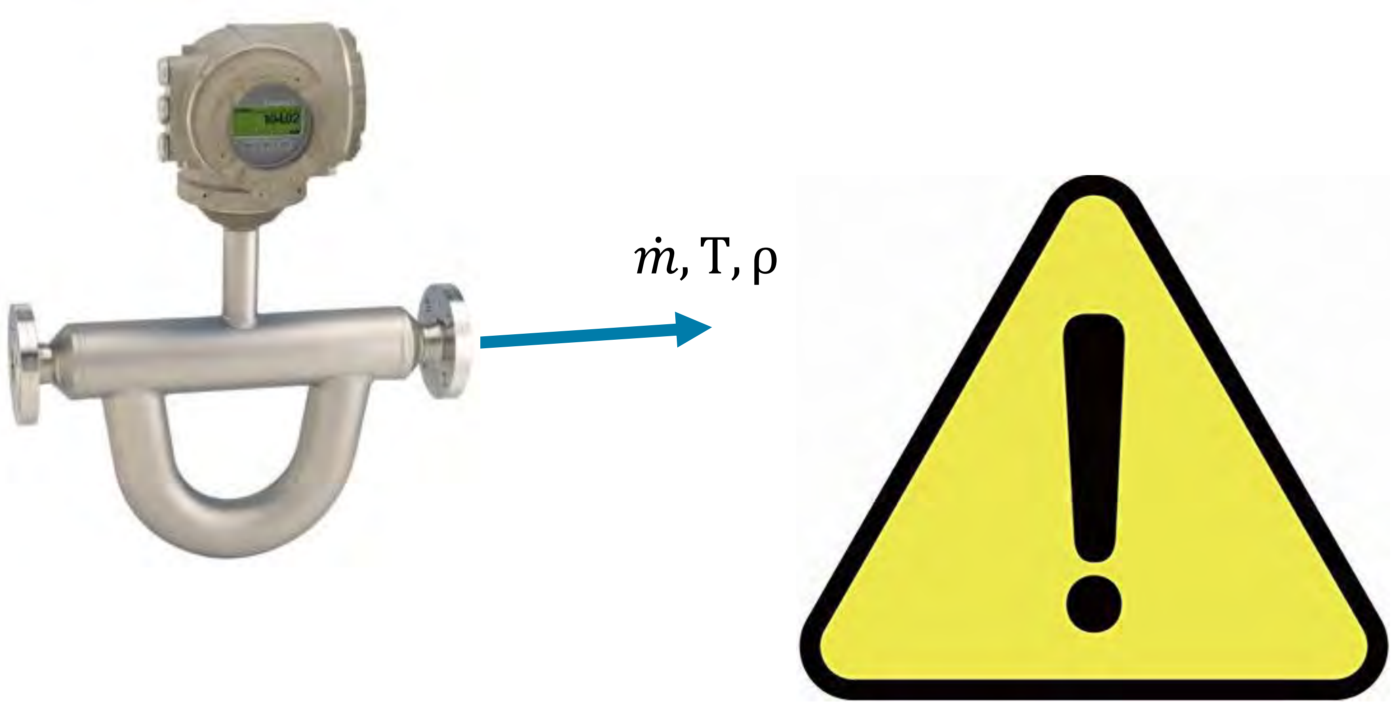
- As a rule, orient the sensor flow tubes in such a way as to minimize the possibility of loading condensate in the vibrating portion of the sensor

Not recommend for gas with condensate or wet/dirty gas

Mounting location for Gas



Coriolis



$\dot{m}$, T, ρ

Coriolis technology vs traditional volume gas flow meters

- Reduced maintenance
- To derive to standard volume from mass you **do not need temperature and pressure correction**
- How to calculate standard volume:

$$Q_{StdVol} = Q_{mass} / \rho_{Std}$$

- Typically, you can use a **smaller Coriolis DN compared to** turbines and orifice plates
- For gas measurement density of the Coriolis is not used typically, because typical % gas density error does not meet customer expectations.
  - Typically, relative density or base density of the gas is entered in flow computer or Proline 300/500 transmitter.
  - Accurate reference density is derived from sampling methods or online-gas analysis

How to derive to the gas standard volume?

$$\frac{\text{Mass}}{\text{Std. density}} = \text{Std. Volume}$$

$$\frac{\text{Mass}}{\text{Reference Density}} = \text{Corrected volume flow}$$

Conversion of Mass to Volume at standard conditions

- Coriolis meters measure mass directly
- This eliminates the need to quantify gas volumetrically at **flowing** conditions
  - There is no need to measure flowing pressure and temperature to calculate the Std. Volume
  - There is no need to calculate compressibility (Z)
- You simply need to know the gas density at base conditions

$$\frac{\text{Mass}}{\text{Std. density}} = \text{Std. Volume}$$

Coriolis does not need pressure and temperature correction

- Customer is interested in Standard Volume and Mass.

Gas volume meters	Coriolis
Requires line density	Requires density at reference conditions
Constant composition gases: Requires additional P+T devices	Constant composition gases: **No** P+T devices required for Coriolis
Changing composition gases: Requires Gas chromatograph + P + T devices	Changing composition gases: Requires Gas chromatograph or specific gravity meter. **No** P+T devices required for Coriolis

$$Q_{StdVol} = Q_{mass} / \rho_{Std}$$

Advantages of Promass vs traditional gas flow meters (Turbine, PD)

CAPEX

- Typical capital expenditures that **are reduced or eliminated** are as follows
  - **Gas flow calibration of sensor** - Factory water flow calibration transfers to natural gas measurement
  - **Specialty upstream and downstream piping and/or flow conditioning** – Not required
  - **Pressure measurement** - Typically not required for flow measurement and if required, a high accuracy transmitter is not necessary
  - **Temperature measurement** - Integral to Coriolis sensor design
  - Installation and startup

Advantages of Promass vs traditional gas flow meters (Turbine, PD)

OPEX

- Typical operating expenditures that are reduced or eliminated are as follows.
  - Pressure calibration – Although pressure measurement, if used, will require periodic verification its recalibration with a precision reference is typically not required.
- Temperature measurement – Although temperature measurement will require periodic verification its recalibration with a precision reference is typically not required
- **Inspection and cleaning of specialty upstream and downstream piping and/or flow conditioning**
- **Validation of flow factor - Coriolis meters can be validated with water flow references**, which are typically **more economical than that of their natural gas counterparts**. Some Coriolis designs **incorporate structural integrity diagnostics** that verify the sensor's flow factor or identify the requirement for recalibration. Structural diagnostics eliminate unnecessary flow validations or recalibrations. → **Heartbeat**

Comparison to traditional gas flow meters

	Promass	Turbine	Orifice
Reduced maintenance	No moving parts		
Capital Costs	Consider also all the other factors (e.g. installation, building, filter)		
Flow profile sensitivity	No need of straight inlet/outlet runs		
Requires gas calibration			
Pressure loss	Consider the entire system (e.g. filter). Coriolis **system** might have lower pressure drop.		
Additional Pressure + Temperature	Not needed to calculate Standard Volume		

Heartbeat Technology – Taking the pulse of your measurement

Improve your plant performance while reducing operative expenses

What Heartbeat Technology can do for you

Increase your plant performance and ...

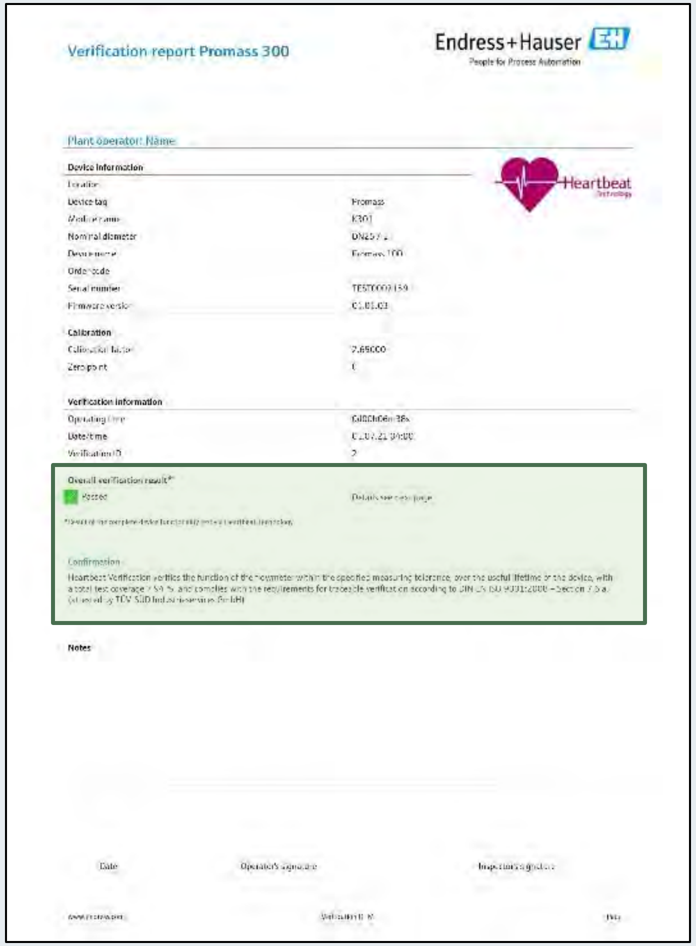
... boost reliability as well as safety levels	... reduce your verification efforts	... improve your process insights

Heartbeat Technology

for diagnostics	for verification	for monitoring

Permanent process and device diagnostics	Documented device functionality without process interruption	Information for process optimization and predictive maintenance

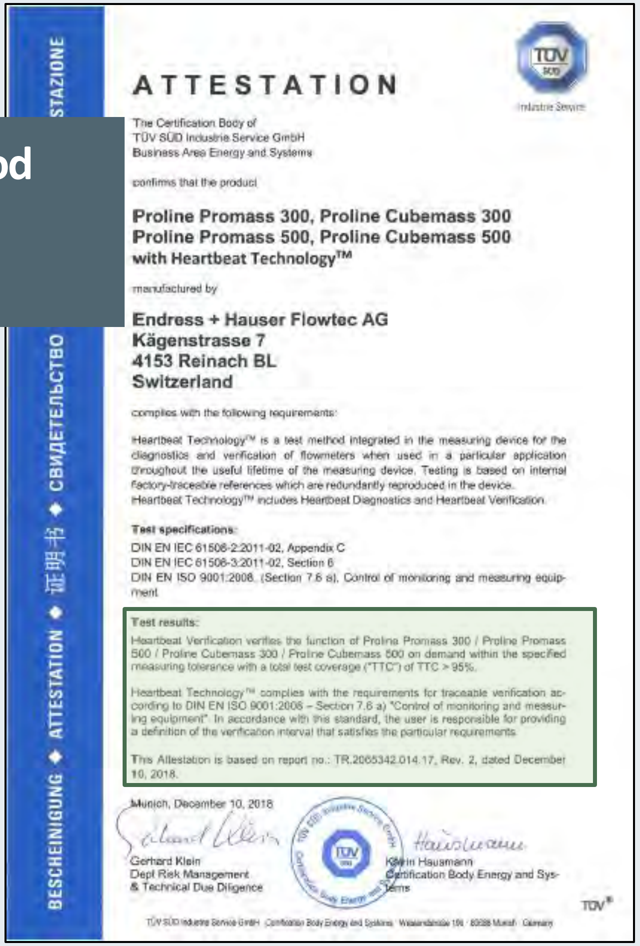
Heartbeat Verification – Documented and certified reliability



Traceable verification method according to ISO 9001 – Third-party attested

Verification result ✓ Passed

Heartbeat Verification verifies the function of the flowmeter within the specified measuring tolerance with confirmed total test coverage (TTC) over the useful lifetime of the device and complies with the requirements for measurement traceability according to ISO 9001.



ATTESTATION

The Certification Body of
TÜV SÜD Industrie Service GmbH
Business Area Energy and Systems

confirms that the product

Proline Promass 300, Proline Cubemass 300
Proline Promass 500, Proline Cubemass 500
with Heartbeat Technology™

manufactured by

Endress + Hauser Flowtec AG
Kägenstrasse 7
4153 Reinach BL
Switzerland

complies with the following requirements:

Heartbeat Technology™ is a test method integrated in the measuring device for the diagnostics and verification of flowmeters when used in a particular application throughout the useful lifetime of the measuring device. Testing is based on internal factory-traceable references which are redundantly reproduced in the device. Heartbeat Technology™ includes Heartbeat Diagnostics and Heartbeat Verification.

Test specifications:
DIN EN IEC 61508-2:2011-02, Appendix C
DIN EN IEC 61508-3:2011-02, Section 6
DIN EN ISO 9001:2008, (Section 7.6 a), Control of monitoring and measuring equipment

Test results:
Heartbeat Verification verifies the function of Proline Promass 300 / Proline Promass 500 / Proline Cubemass 300 / Proline Cubemass 500 on demand within the specified measuring tolerance with a total test coverage ("TTC") of TTC > 95%.

Heartbeat Technology™ complies with the requirements for traceable verification according to DIN EN ISO 9001:2008 – Section 7.6 a) "Control of monitoring and measuring equipment". In accordance with this standard, the user is responsible for providing a definition of the verification interval that satisfies the particular requirements.

This Attestation is based on report no.: TR.2065342.014.17, Rev. 2, dated December 10, 2018.

Munich, December 10, 2018

Gerhard Klein
Dept Risk Management
& Technical Due Diligence

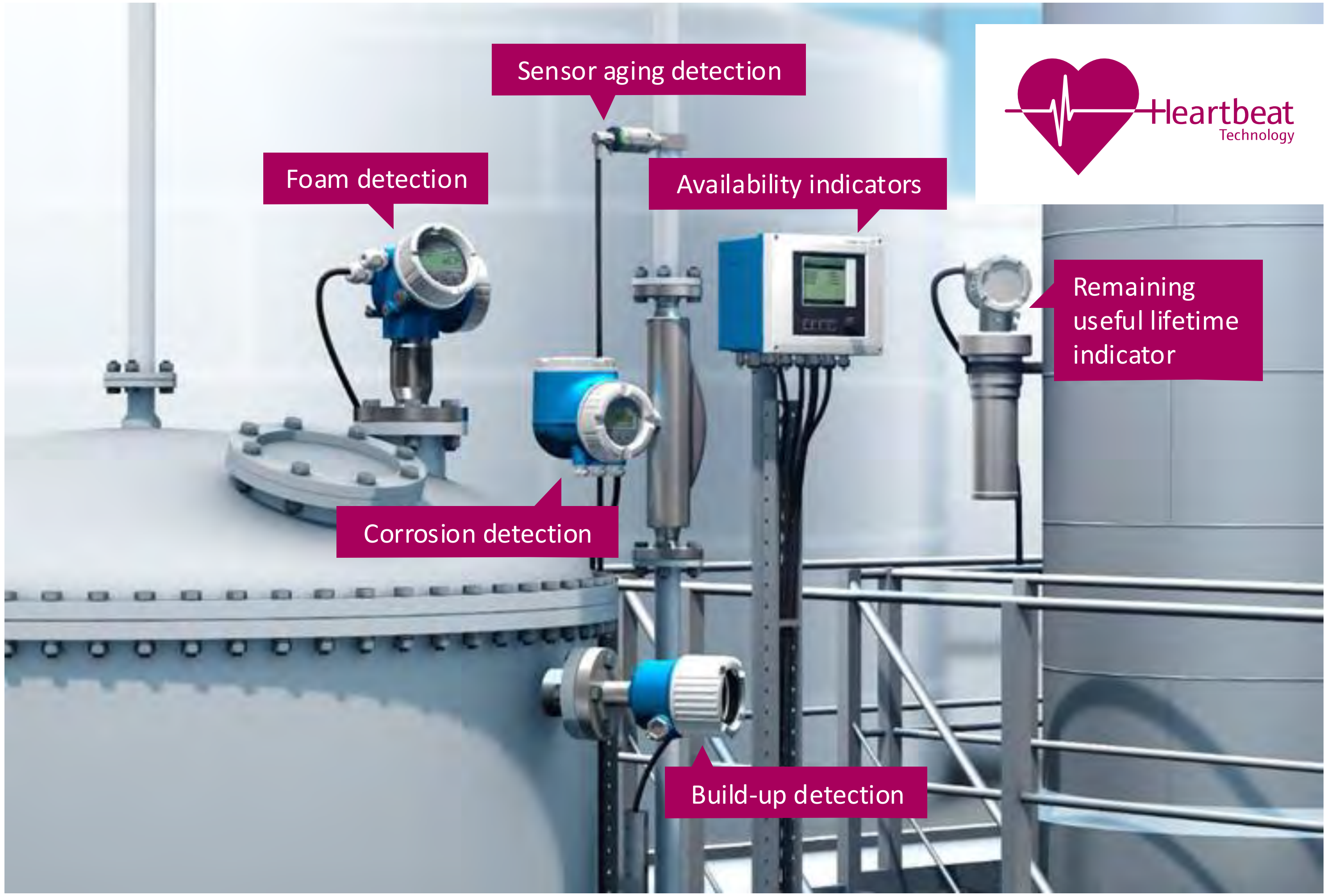
Katrin Hausmann
Certification Body Energy and Systems

Monitoring with Heartbeat Technology

Obtain insights to optimize your processes and predict maintenance needs

- **Informative** – Physical responses from the sensors are converted into easily understandable process and device insights
- **Specific** – Monitor dedicated device parameters to optimize operations by identifying anomalies in the process and predicting maintenance needs
- **Predictive** – Take measures in a timely manner to avoid any potentially unsafe process conditions or device malfunction
- **Reliable** – Increase plant availability by planning maintenance activities exactly when needed and avoiding unplanned shutdowns

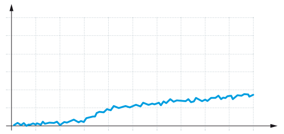
Be efficient and proactive in your operations by having insights into your process and device conditions



Use cases – Device and asset condition monitoring and process optimization

Click/tab to navigate

Condition monitoring enabling predictive maintenance by identifying process conditions that may negatively affect device or asset integrity or process performance



Most often occurring over a longer time period (weeks to years)

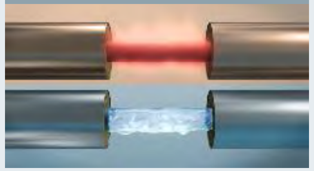
Corrosion

Abrasion

Build-up

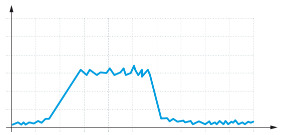
Mechanical stress

Thermal stress



Sensor aging

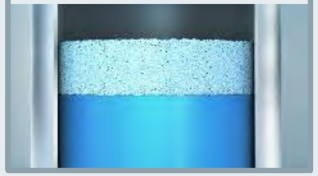
Supporting **process optimization** by identifying process anomalies (not critical to the device integrity, but might affect its performance) and monitoring of the device’s **installation condition** to increase the reliability of the measuring point (or identify any need for corrective actions)



Ranging from transient conditions to more long term effects

Inhomogeneous medium

Foam detection



Availability

Connection and power supply

Conclusion

Conclusion

- Coriolis mass flow technology affords users significant advantages in metering service of gaseous hydrocarbons. Coriolis meters offer valued improvement over mechanical flowmeters.
  - higher accuracy,
  - lower uncertainty,
  - long term stability and extended life in service.
- Broad based acceptance of Coriolis meters exists today as seen with recognition from national and international standards organizations.
- Coriolis mass flowmeters that are gravimetrically calibrated on water have been proven to be capable to satisfy the specifications and requirements of national and international standards for the measurement of natural gas in custody transfer applications.
- Heartbeat Monitoring – Offers process insight if the gas is becoming “wet” via trending of data (oscillation damping/frequencies)

Open Items / Questions