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Introduction: Density Measurement

- Additionally to mass flow multi-variable Coriolis mass flow meters also determine temperature and density
- Precise density measurement performance under real world process conditions is complex, but important for :
  - Volumetric custody transfer and meter proving in the Oil & Gas industry
  - High-end concentration measurement in Food & Beverage industry
  - and in general density is a key indicator of the process fluid quality in all industries

Flow Meter - Design

- Coriolis mass flow meter Proline 300 Promass Q
- Four different line sizes from 1” to 4”
- Process temperature range -196°C … 205°C
- Process pressure range 0 bar … 100 bar
- Secondary safety containment

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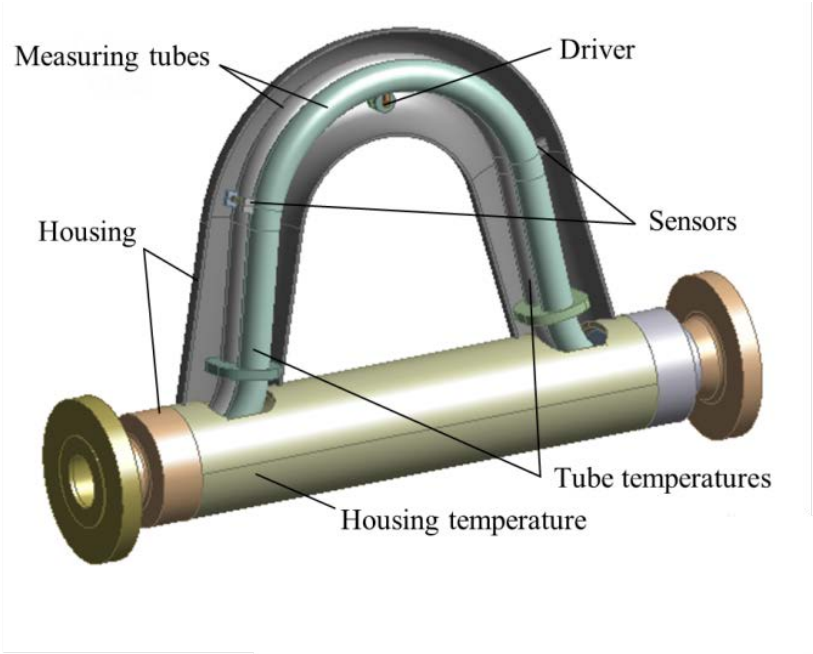
Flow Meter – Internal Structure

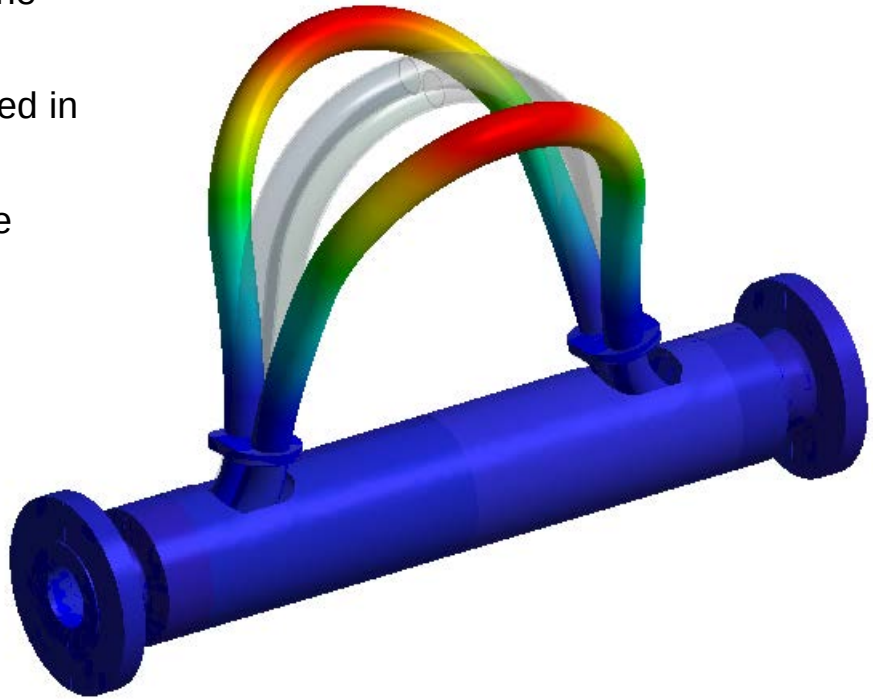
- Two parallel and bent measuring tubes
- Connected via flow splitters to process line
- Coupling elements at inlet and outlet define oscillation length of working mode
- Electro-dynamic driver at the tube center generates harmonic tube vibration at resonance frequency and constant amplitude
- Two electro-dynamic sensors at tube inlet and outlet detect tube vibration
- Temperature sensors at measuring tube and housing



Flow Meter – Working Principle

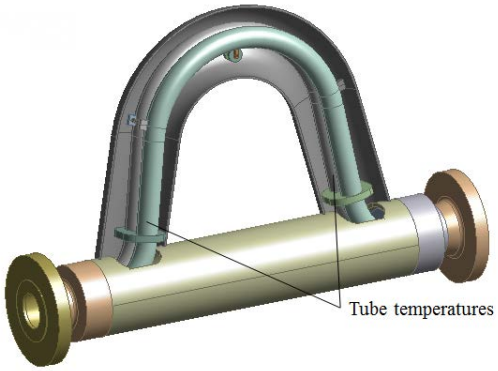
- Both tubes vibrate in opposite directions so the oscillating system is balanced
- Equivalent to a tuning fork energy is conserved in oscillator
- Fluid density ρ is derived from raw resonance frequency f_r

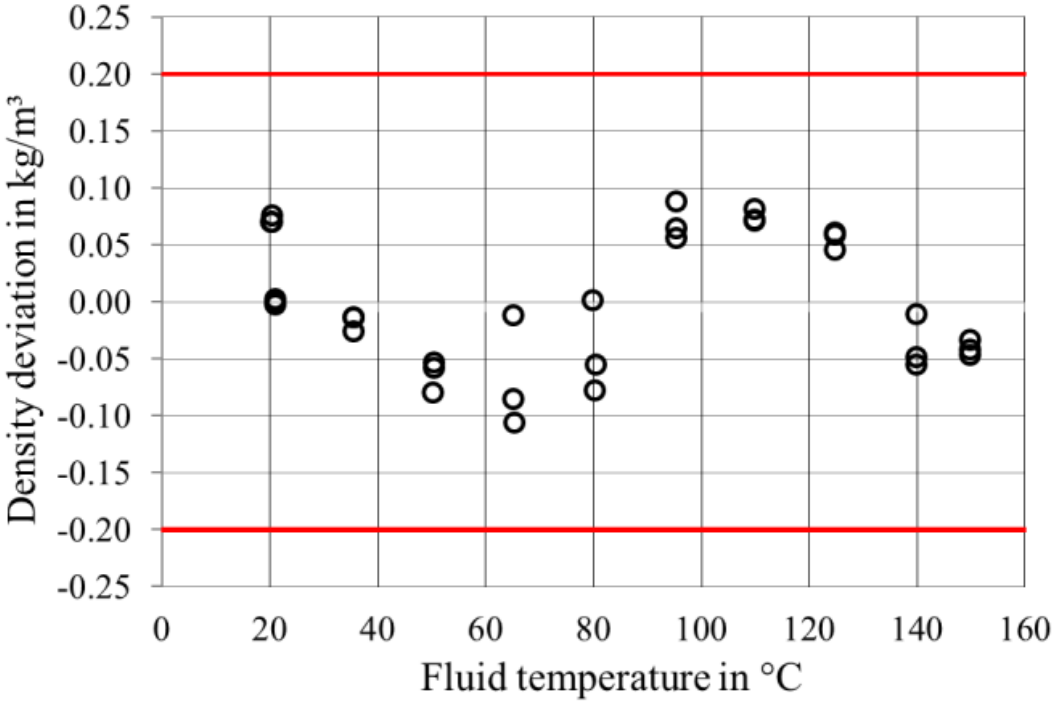
- $f = f_r(p, v, \gamma)$
- $\rho_r = C_0(T_m) + C_1(T_m, T_h)\, f^{-2}$
- $\rho = \rho_r(\eta, c)$



Sensitivity and accuracy: Process influences - Fluid temperature T_m

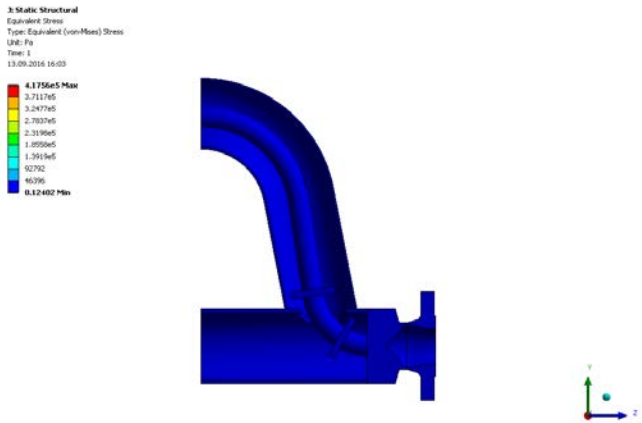
- Compensate Young's Modulus
- Two PT1000 at inlet and outlet
  - Over a 100 000 CFD simulations for optimally placed sensors
  - Very low gradient… ± 0.015 kg/m3
  - To provide redundancy

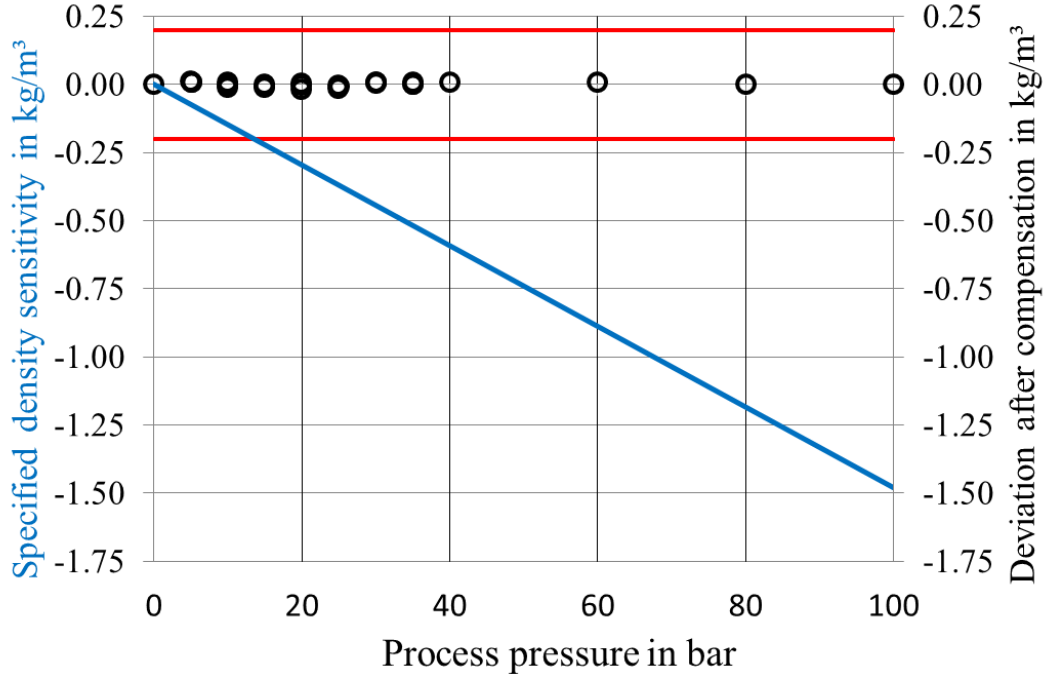




Sensitivity and accuracy: Process influences - Process pressure p

- Optimized tube shape and braces
- Hydro formed tubes
- Small residuum -0.015 kg/m³/bar
- Repeatable and linear sensitivity
- Structural simulation:





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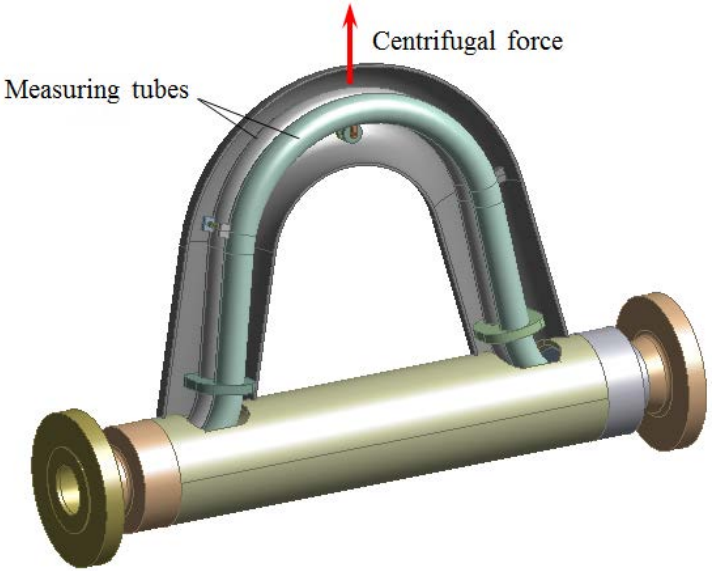
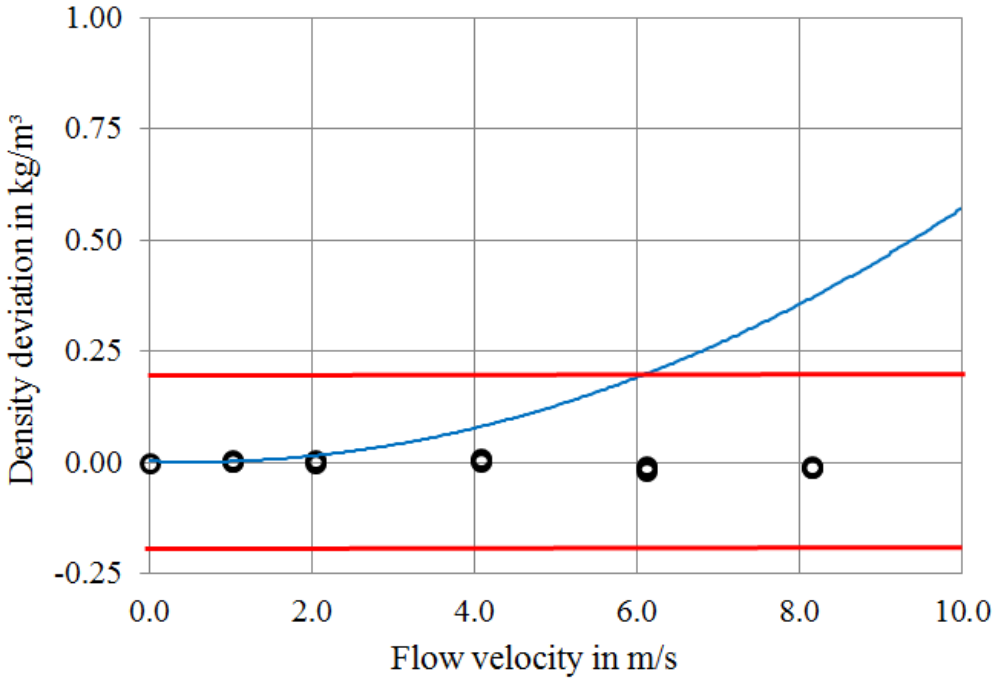
Sensitivity and accuracy: Process influences - Flow velocity v

- Flow velocity v generates centrifugal force
- Stiffening effect of tube is compensated





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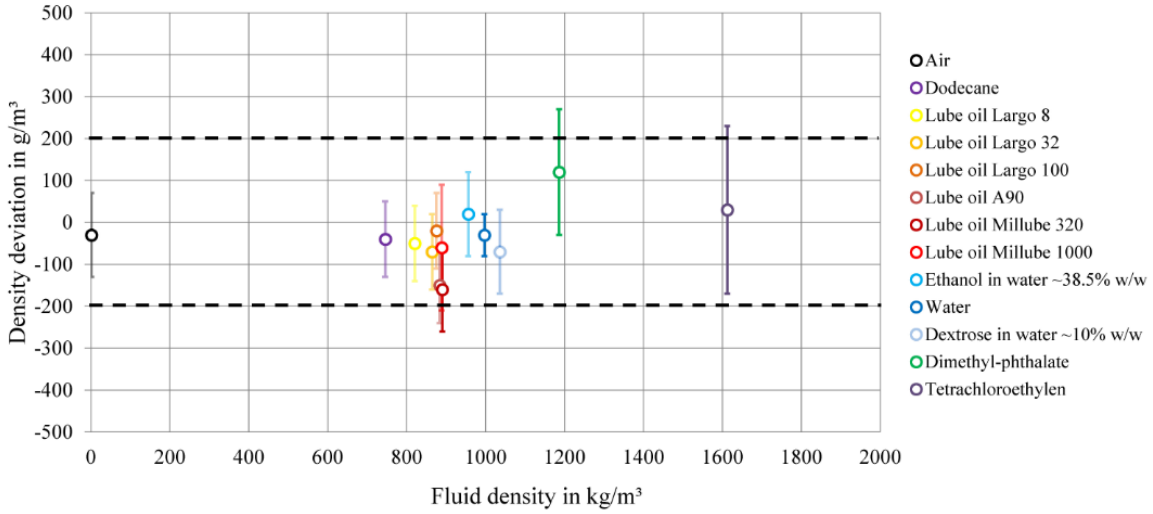
Sensitivity and accuracy: Fluid properties - Fluid density ρ

- Linearity across fluid density
- 11 different fluids at 25°C tested
- Densities of air and liquids from 745 kg/m³ to 1612 kg/m³
- UKAS certificate issued by H&D Fitzgerald Ltd.



CERTIFICATE OF CALIBRATION

ISSUED BY H & D FITZGERALD LTD.

DATE OF ISSUE **25 February 2016** CERTIFICATE NUMBER **15215**

UKAS CALIBRATION 0291

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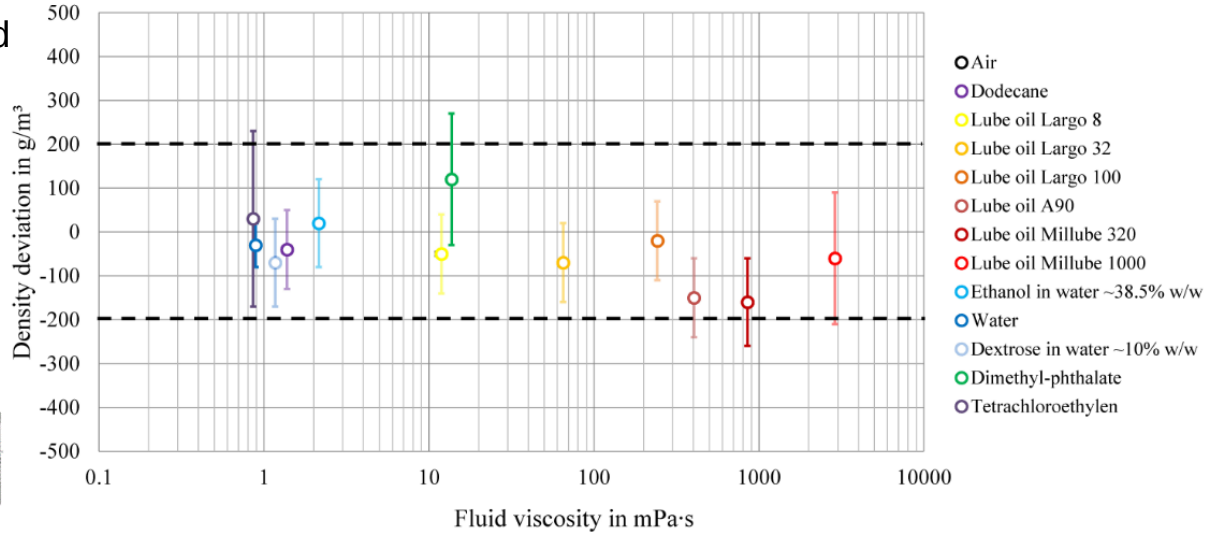
Approved signatory E Webster — H. Fitzgerald, I. Edge, E. Webster

Sensitivity and accuracy: Fluid properties - Fluid viscosity η

- Compensated viscosity effect
- 11 different fluids at 25°C tested
- Viscosities up to 2885 mPa·s
- UKAS certificate issued by H&D Fitzgerald Ltd.



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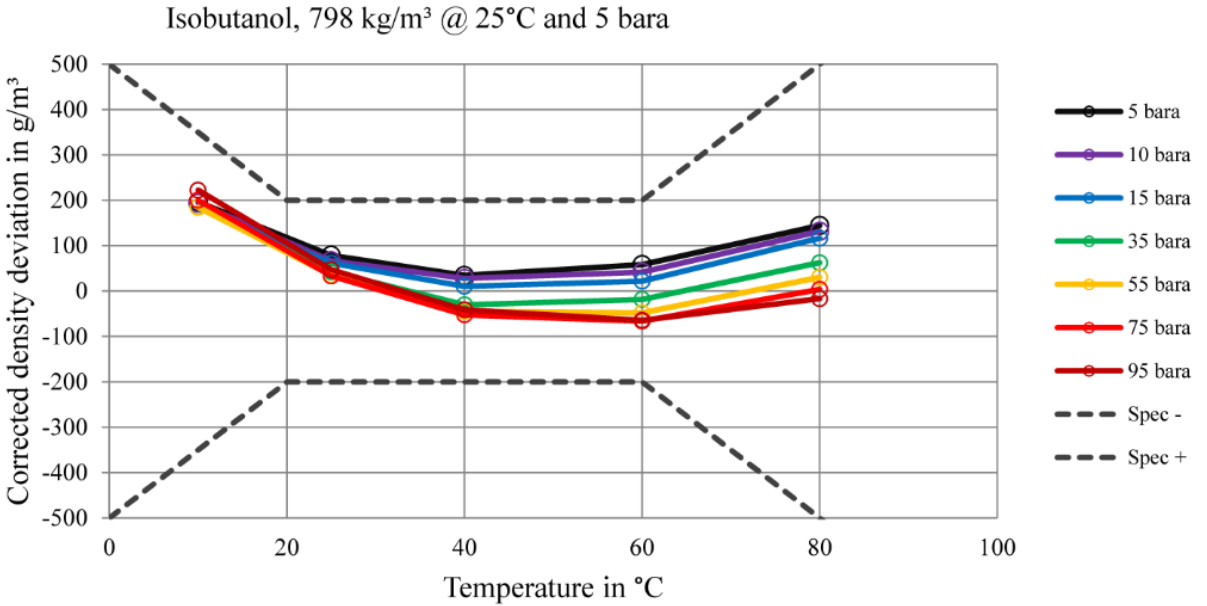
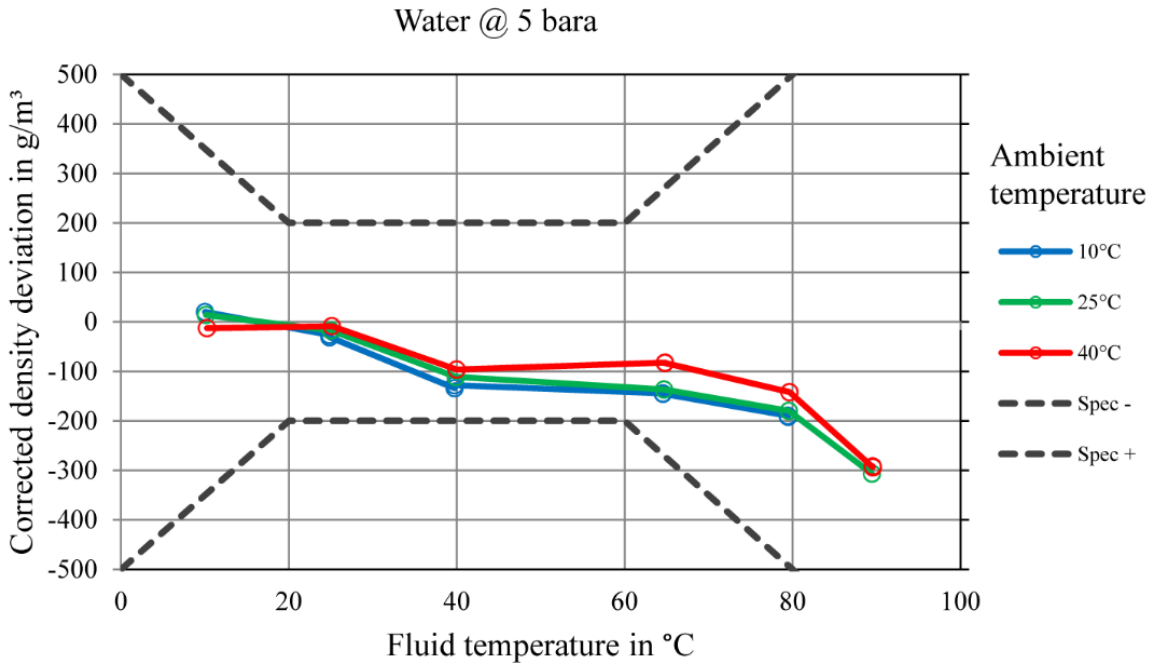
Corrected density across varying fluid temperature and pressure

- Corrected density variation for Iso-Butanol across varying fluid temperature and pressure within specification ± 0.2 kg/m3
- Fluid: Iso-Butanol (751…816 kg/m3)
- Pressures from 5 to 95 bara
- Fluid temp. 10…80 °C
- Measuring data by TUV NEL density test facility



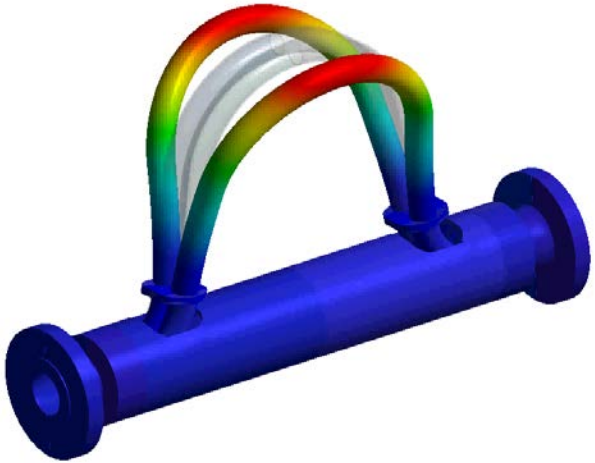
Corrected density across varying fluid and ambient temperature

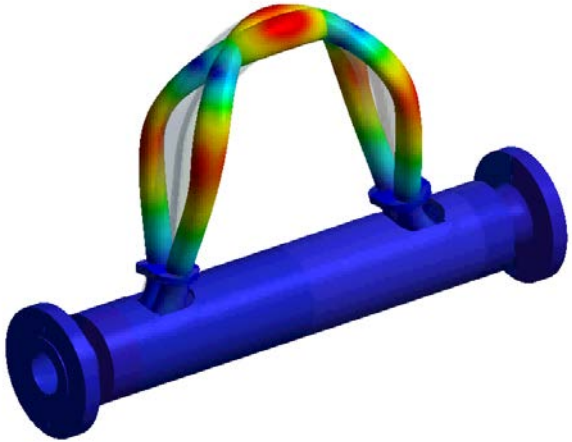
- Corrected density variation for Water across varying fluid temperature and ambient temperatures within specification ± 0.2 kg/m3
- Fluid: Water (972…1004 kg/m3)
- Ambient temp. from 10 to 40 °C
- Fluid temp. 10…80 °C
- Measuring data by TUV NEL density test facility



Sensitivity and accuracy: Fluid properties – Entrained gas

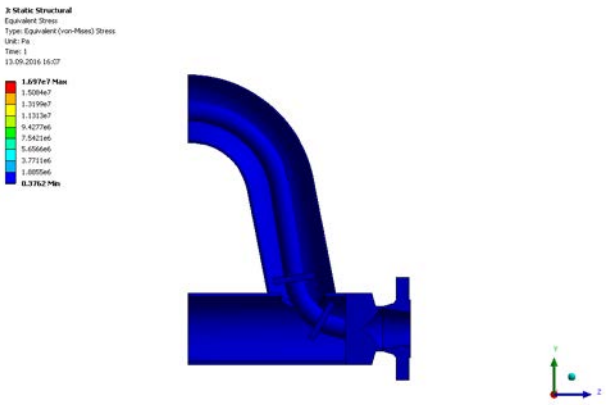
- Entrained gas in liquid rises compressibility of the mixture significantly
- Higher compressibility increases mixture amplitude and thus causes positive density deviation
- Using simultaneously driven higher order mode, error compensation called Multi Frequency technology (MFT) is implemented

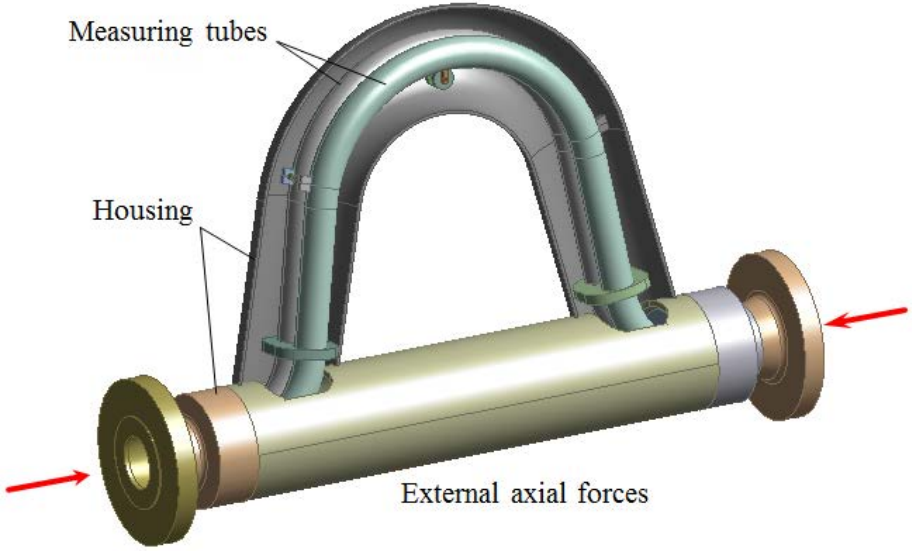




Sensitivity and accuracy: Environmental effects - Forces and vibrations

- Tube shape and housing stiffness optimized
- Overall meter size and weight still compact and light
- Moderate working frequency offers immunity against the influence of external vibrations which are typically at low frequencies
- Structural simulation:





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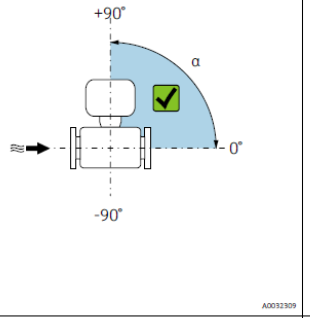
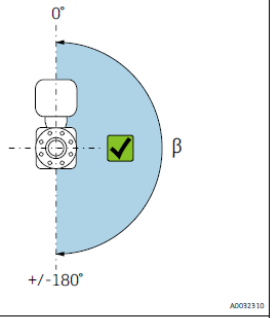
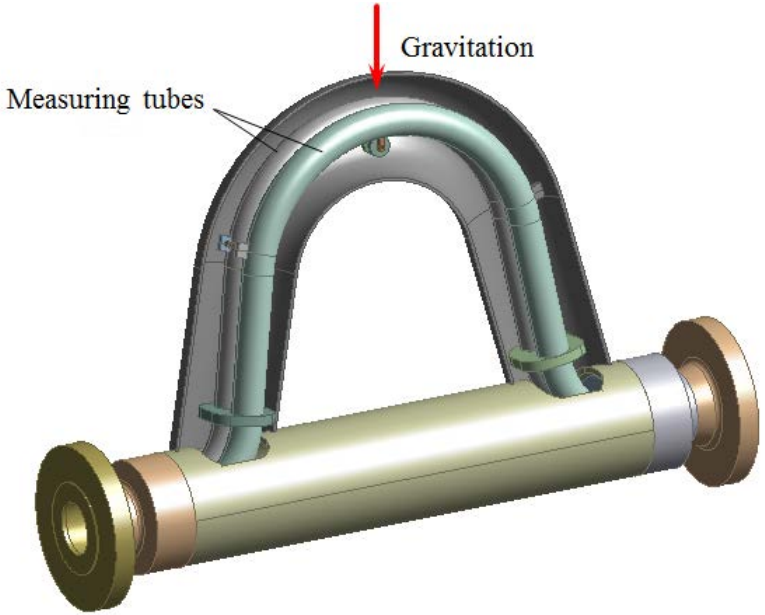
Sensitivity and accuracy: Environmental effects - Meter orientation

- Effect depending on meter orientation with respect to the earth's gravity
- Tube mass give rise to tension or compression along straight measuring tube segments
- Changing resonance frequency and density reading
- Automatic compensation by giving installation angle

Pitch angle	Roll angle
	
The adjustable pitch angle is the blue marked area of angle **α**.	The adjustable roll angle is the blue marked area of angle **β**.



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Conclusion

- A new type of Coriolis mass flow meter has been presented
- Among other highlights it brings precise fluid temperature and density measurement which is desirable for many applications in the hydrocarbon processing industry
- During the development process FEM and CFD simulation in combination with an experimental approach have been used and the design were optimized to ensure robust temperature and density performance in the field
- The meter was third part tested at H&D Fitzgerald Ltd. and NEL - TUV SUD Ltd. to independently confirm the temperature and density specifications of ±0.1°C and ±0.2 kg/m³ respectively across a broad range of process parameters, fluid properties as well as environmental and installation conditions
- Test results collected under widely differing conditions provide confidence in the meter designs' ability to provide adequate density measurement performance for key applications found in industry

Thanks for your Attention