KROHNE

New Developments in High Performance Flow Measurement

4th International EMATEM – Summer School

EMATEM

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achieve more

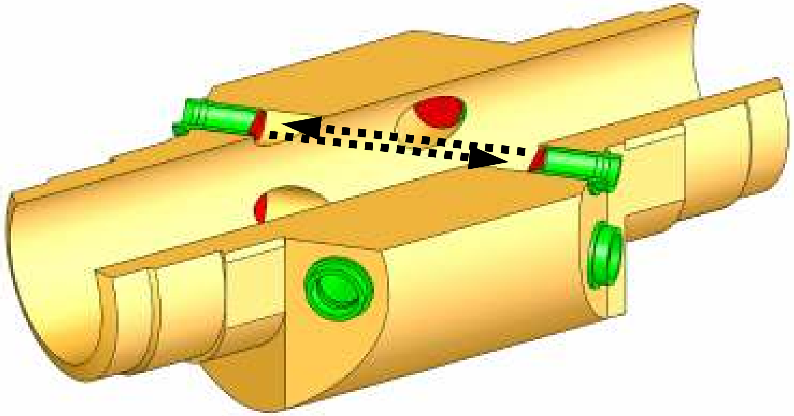
KROHNE

TOPICS

1.	Topics
▶	Performance Flow Measurement
3.	Ultrasonic Flowmeters for Process Applications
4.	High Performance Flow Measurement
5.	New Developments in High Performance Flow Measurement of
5.1	Highly Viscous Oils
5.2	High Temperatures Liquids
5.3	Cryogenic Liquids
6.	Conclusions

Transit Time Measurement: Simple?

Electronics & Signal Processing!



An Example:

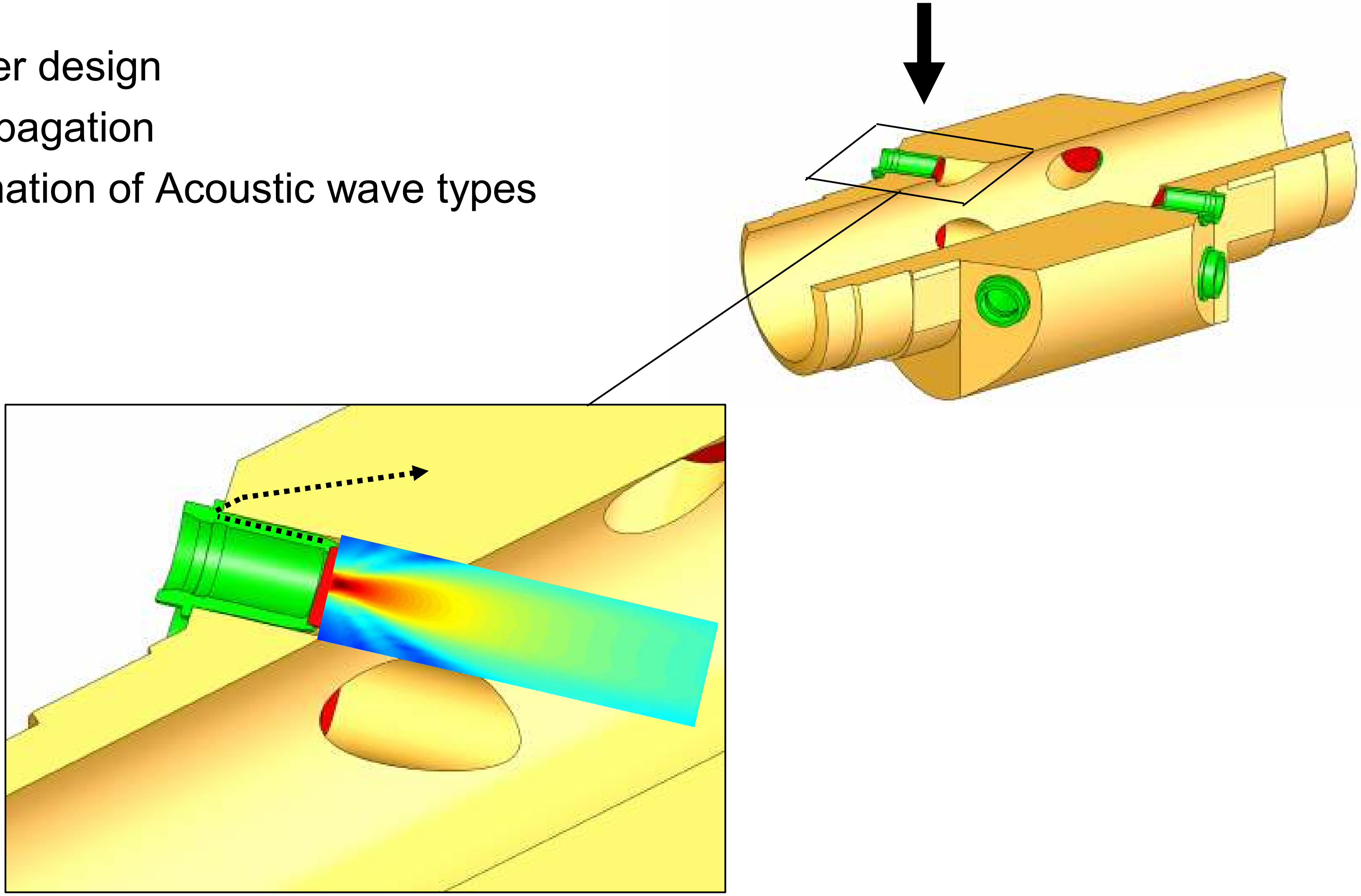
Pipe diameter		100 mm
Medium		Water
Flow velocity		0.1 m/s
Velocity of sound		1480 m/s
Transit time - downstream	$T_{A \rightarrow B}$	9.54949 µs
Transit time - upstream	$T_{B \rightarrow A}$	9.55862 µs
Transit time - difference	ΔT	9.13 nano sec. (= 10^{-9})
0.1% resolution		9.1 pico sec. (= 10^{-12})

So transit time measurement must be very accurate!!

DSP & FPGA technology

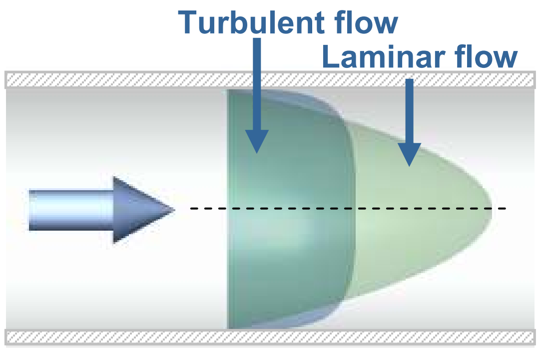
Acoustics

- Transducer design
- Wave propagation
- Transformation of Acoustic wave types

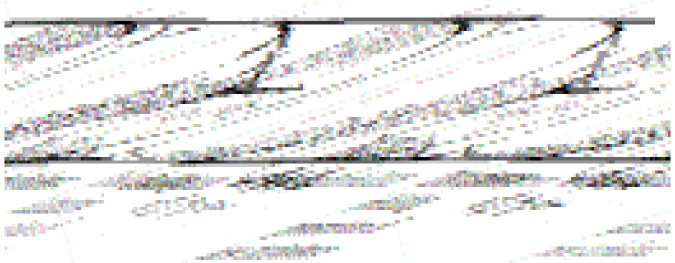


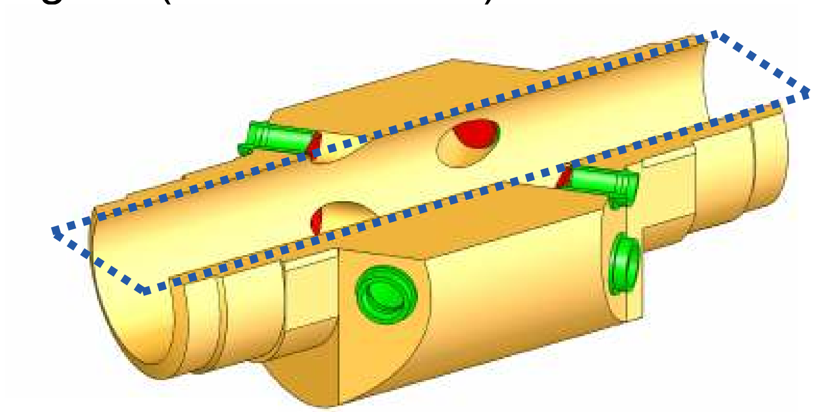
Fluid Mechanics

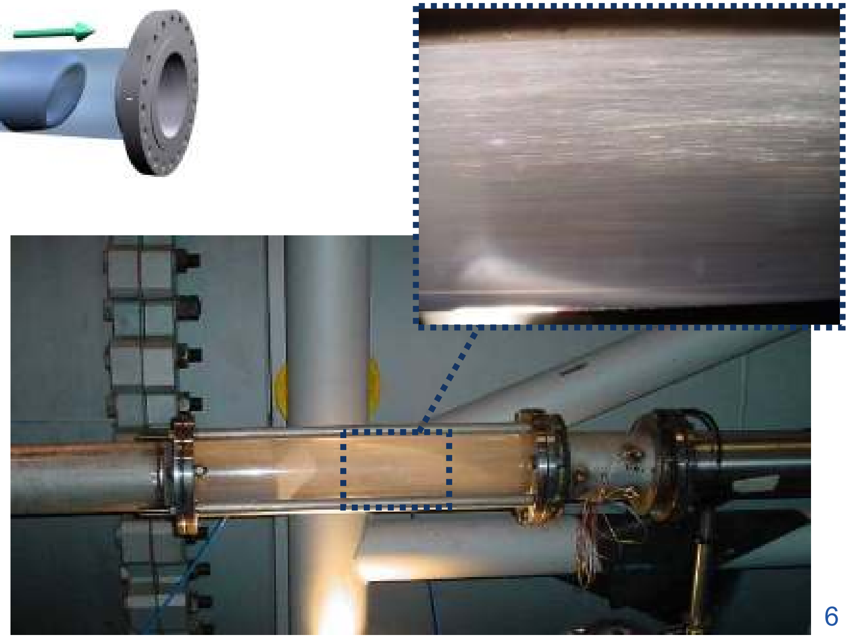
- Laminar, Transitional and Turbulent Flow Regime ($10^2 < Re < 10^7$)
- Transducer Pockets
- Stability of the Flow
- Sensitivity to Flow Profile shape
- 'Two phase' flow



Transitional flow
(Turbulent Plugs)

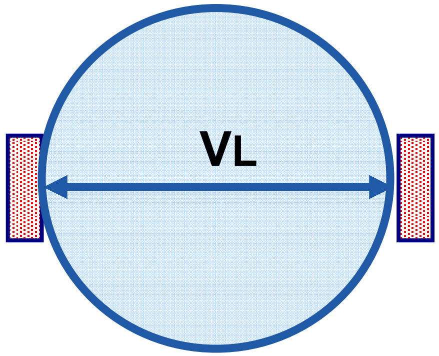


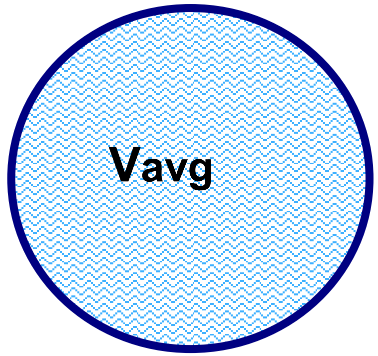




Average Flow
Velocity over a Pipe

What is measured? | **What is required?**





VL = Average velocity over the acoustic path L

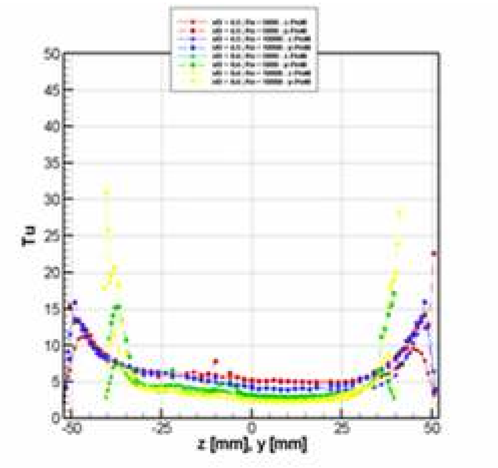
Vavg = Average velocity over the total cross section

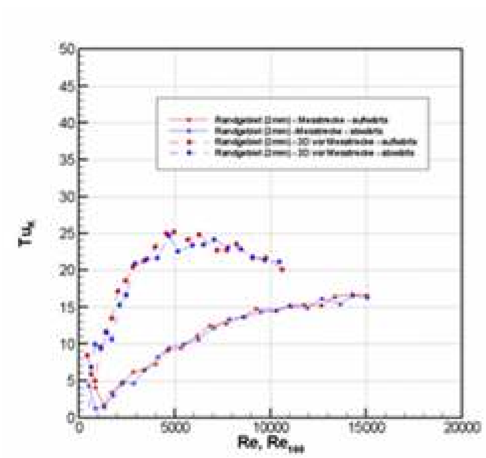
Fluid mechanics:

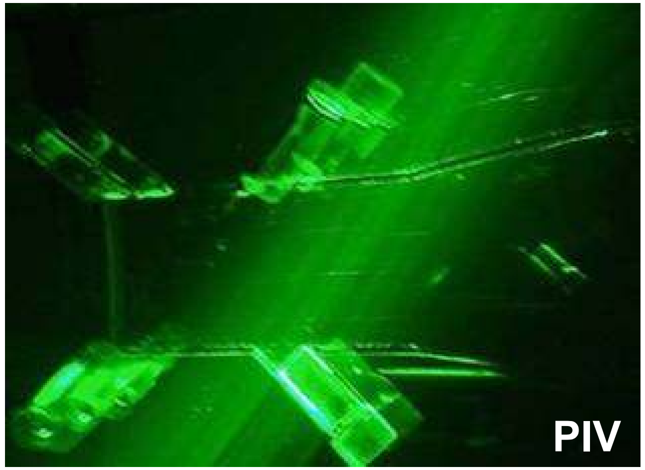
- Stability of flow (PIV, LDA)
- Velocity profile (LDA)
- Turbulence distribution (LDA)
- Turbulence development (LDA)

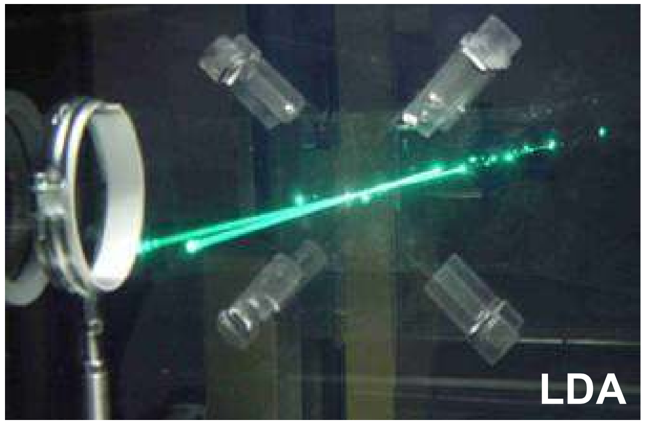
➢ Repeatability

➢ Reproducibility









1. Topics
2. Performance Flow Measurement

Ultrasonic Flowmeters for Process Applications

4. High Performance Flow Measurement
5. New Developments in High Performance Flow Measurement of

5.1 Highly Viscous Oils

5.2 High Temperatures Liquids

5.3 Cryogenic Liquids

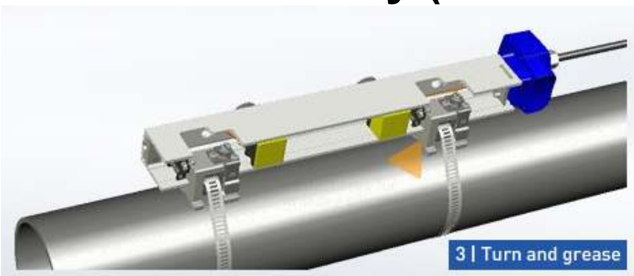
6. Conclusions

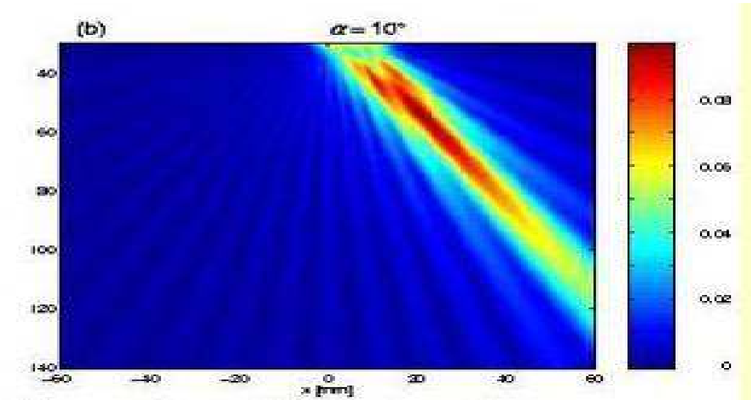
KROHNE offers a complete range of liquid ultrasonic flowmeters

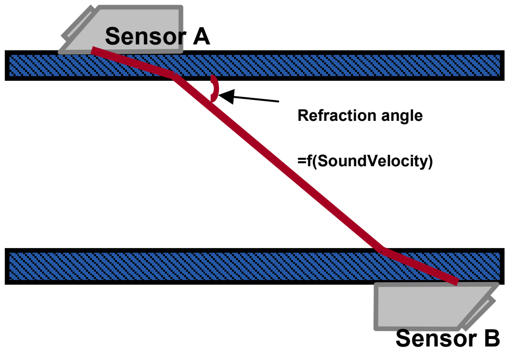
KROHNE offers a complete range of liquid ultrasonic flowmeters

Flow Measurement without Interfering the Tube

- Ultrasonic Clamp-on Flowmeter
- Very easy to install
- Easy to maintain
- Already being used for many years
- Limited accuracy (1% to 3%)







KROHNE offers a complete range of liquid ultrasonic flowmeters

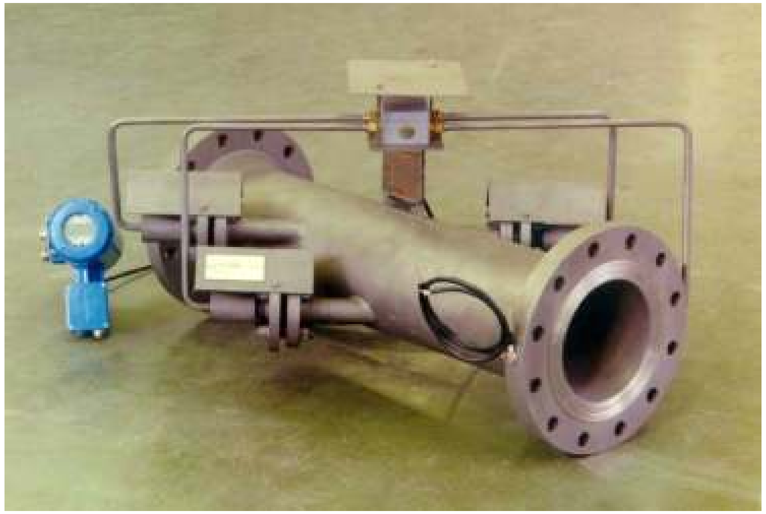
KROHNE

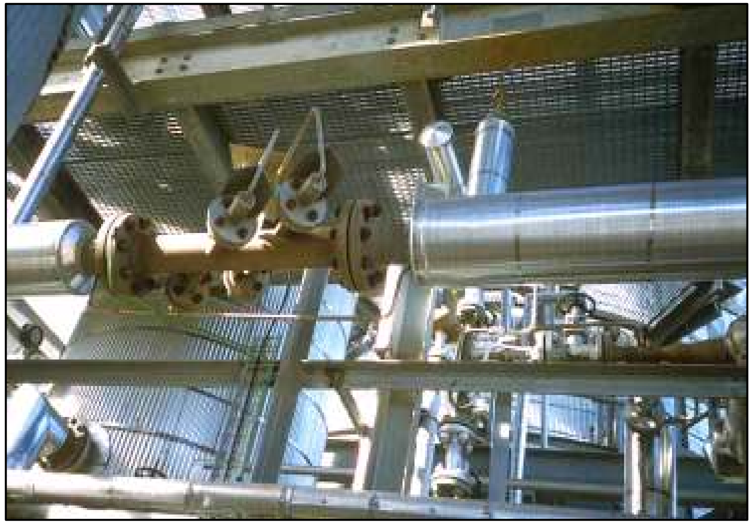
UFM 3030

Flow meter for liquid process and control measurements

- Temp range: - 25 to + 220°C
- DN 25 - 3000 (1”-120”)
- Ex: For haz. areas, zone 1 & 2
- Option: Heating jacket
- Accuracy ± 0.5% of MV
- Repeatability: ± 0.2% of MV

UFM 530 HT & UFM 530 HP





UFM 530 F/HT
for High Temperature

- Temp range: - 200 to + 600°C
- DN 25 - 3000 (1”-120”)
- Ex: For haz. areas, zone 1 & 2
- Option: Heating jacket

Ultrasonic Flowmeters for High Pressure Applications

Goal:

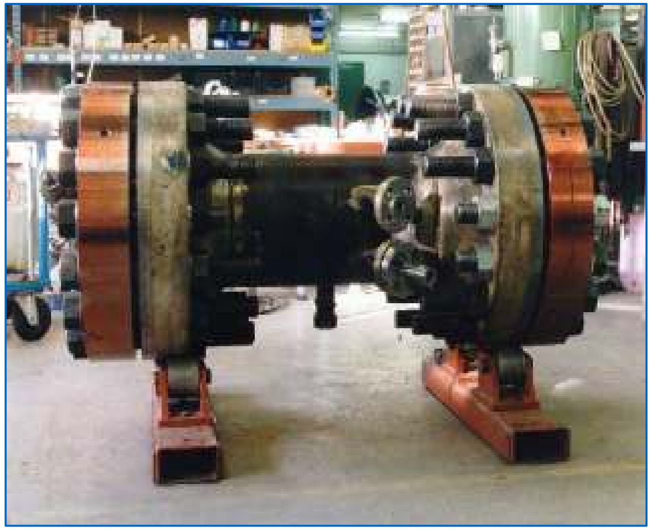
- E.g. Measurement of Re-injection in Oil Wells

Requirements:

- Uncertainty: 1%
- No Pressure Drop
- High Stability
- Reliable & Self Diagnostics
- No Maintenance

Conditions:

- Temperature: 180 ºC
- Pressure: 138 MPa (1380 bar)
- Medium: Sea Water



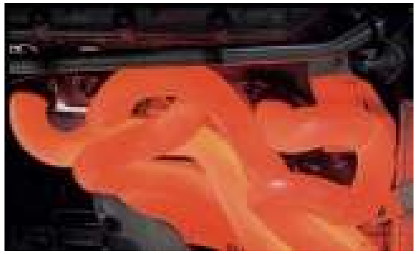
KROHNE offers a complete range of liquid ultrasonic flowmeters

Ultrasonic Gas flow meter

OPTISONIC 7060

- All gases & mixtures except pure hydrogen (H_2) & helium (He)
- Ex version for hazardous areas
- Sensors up to 600^0C
- Measuring error <2% of MV

Ultrasonic Flowmeters for Steam Measurement



Goal:

- Measurement of Mass and Energy Flow of Steam

Requirements:

- Uncertainty: 1%
- No Pressure Drop
- High Stability
- Reliable & Self Diagnostics
- No Maintenance

Conditions:

- Temperature: Up to 600 ºC
- Pressure: 10 MPa
- Medium: Super Heated Steam

KROHNE offers a complete range of liquid ultrasonic flowmeters

Ultrasonic Gas flow meter

ALTOSONIC V6

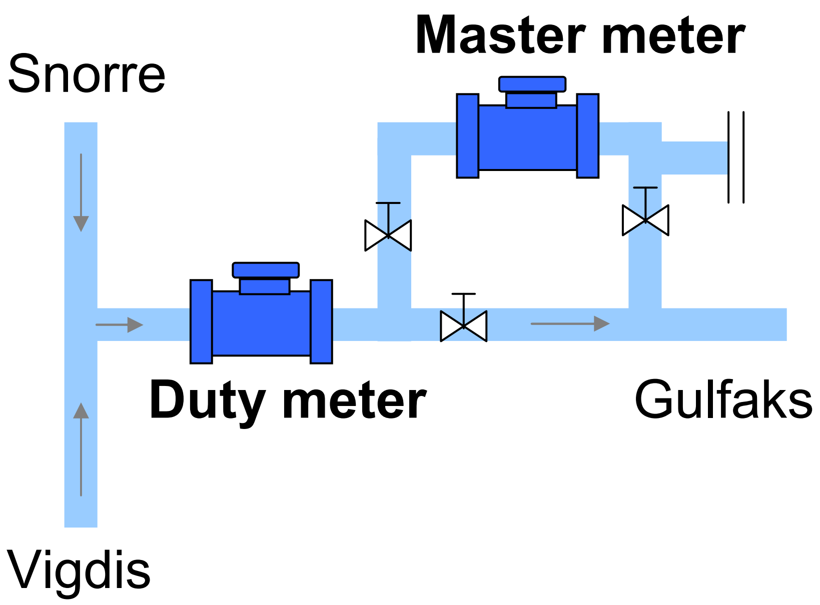
- 6 Beam Ultrasonic Gas Flowmeter
- Separate Diagnostic path
- Allocation measurement of Natural Gas

UFM for Custody Transfer

ALTOSONIC V

Custody Transfer of Single Viscosity Light Liquid Hydrocarbons

- 5 measurement channels
- Accuracy:
  ± 0.15% of MV
- Repeatability:
  ± 0.02% of MV
- No moving parts,
  no wear
- Maintenance-free
- Compliant with
  MI-005, OIML R117, NPD, API,
  ..



- 2 x ALTOSONIC V in master / duty set-up
- Periodically verified against each other (e.g. scaling effects)
- No permanent prover installation and no filters

Results

- “Excellent Experience History”
- Both ALTOSONIC V showed similar linearity curve
- Recent provings by the customer (2007) showed that the k-factor was within 0.02% compared to the first k-factor established in 1997
- No maintenance has been done on these meters since 1997!!

ALTOSONIC V for MERO Solves Clogging Problems

Pipeline Application

- **Mero Pipeline in Czech Republic**
- **ALTOSONIC V 10”, 150 lbs**
- **Crude oil with High grades of Paraffin**
- **Viscosity 4 to 50 cSt**

ALTOSONIC V for MERO, Czech Republic

- Removal of turbine & strainer
- Turbines clogged resulting from paraffin in crudes
- Resulting in high costs for cleaning and recalibration

ALTOSONIC V chosen for its:

- low maintenance costs
- no more frequent re-calibration
- relative small size installation

Transportation & Storage

ALTOSONIC V for Repsol, Zawiya, Lybia

- Crude oil from Murzuq/El Sharara field transported to
- Zawiya terminal
- Operated by Repsol-YPF
- From metering station crude is distributed to refinery and to sea for shipment

- Medium: Crude oil, light (44^{0}API), sweet
- Viscosity: 4,5 cP
- Flow range: 710 to 7100 m^3/hr

ALTOSONIC V for Repsol, Zawiya, Lybia

Old situation:

- 10 PD meters
- High maintenance costs & expensive replacements of parts
- Cost of proving

New: ALTOSONIC V

- 20”
- In operation since Sept 2002

In-situ verification with Small Volume Provers

Compact prover/Flowmeter:

- Large flowmeter (10”), small Calibron prover (94 liter)
- Calibration time of one pass: < 0.5 [s] !

Goal satisfy API table:

- ±0.027% uncertainty

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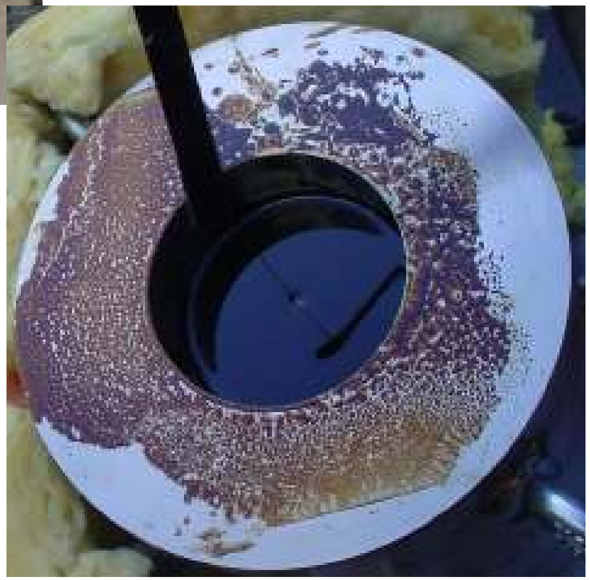


ALTOSONIC V

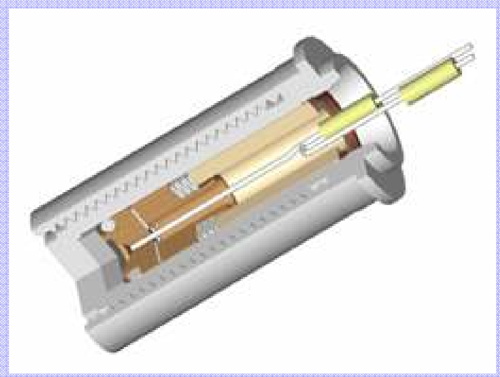
Custody Transfer of High Viscosity Hydrocarbons

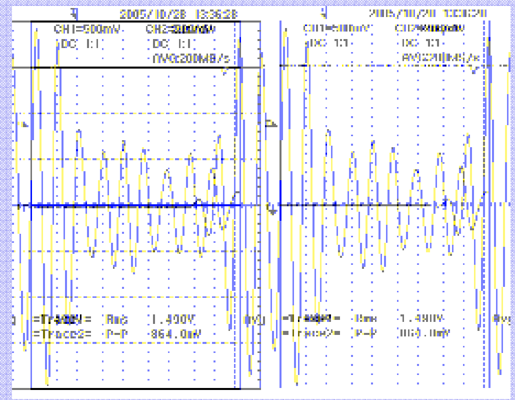
e.g. from Oil Sands, new High Viscosity Oil field

- 5 Measurement Channels
- Accuracy:
  ± 0.20% of MV
- Repeatability:
  ± 0.06% of MV
- Certified up to 400 cSt
- Viscosities up to 1500 cSt
- Compliant with MI-005, OIML R117, NPD, API

Acoustically decoupled transducers:

- Improve signal quality
- Larger band width
- Optimum SNR
  - Accuracy
  - Improved stability (temperature, ..)





Calibration at SPSE France:

- ALTOSONIC V
- DN600
- Max. available viscosity > 400 cSt
- Witnessed and approved by NMi

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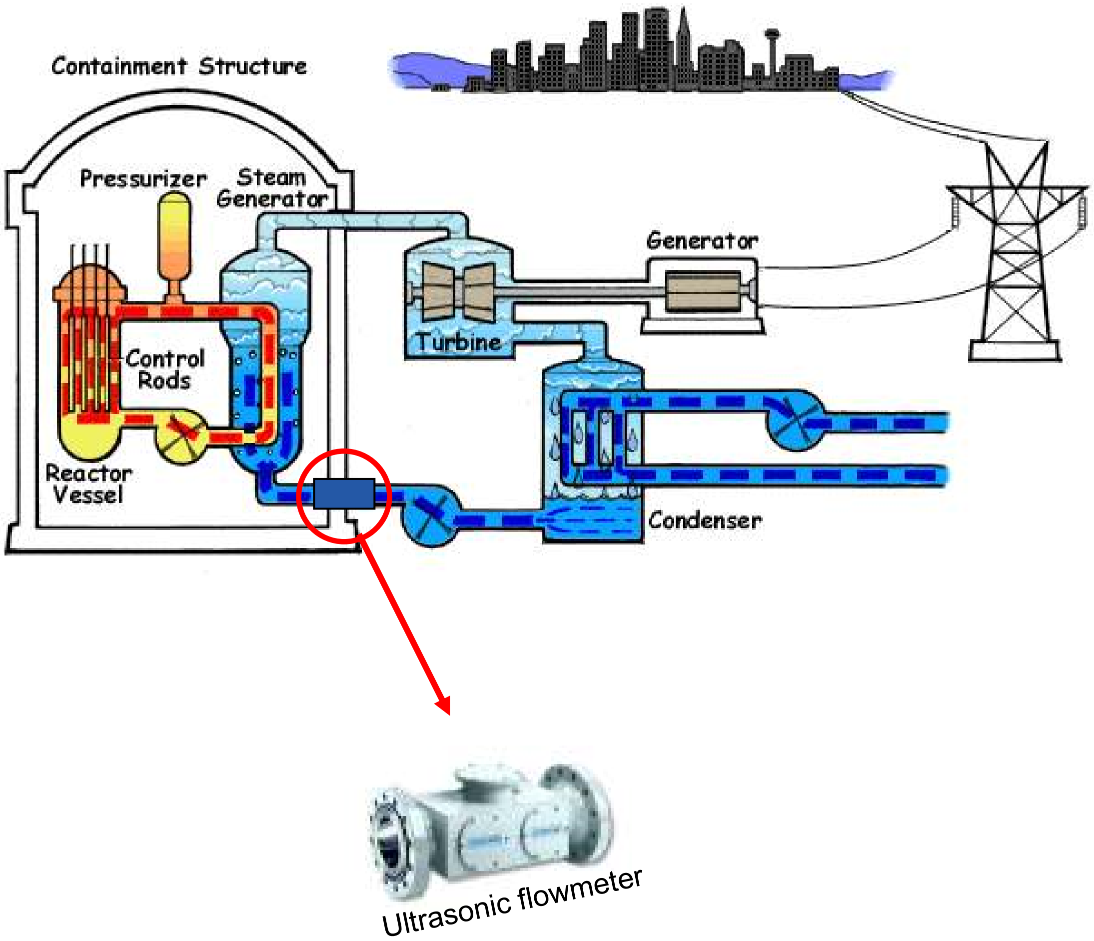
Application of Ultrasonic Flowmeter in Power Plants



Feed water flow measurement

- **Measures actual energy output of power plant**
- **Typically orifice plates are used**
- **Redundant system (safety)**
- **Uncertainty 2%**

- **Process conditions**

  water @ 250 ˚C / 70 Bar

- **Ultrasonic flowmeter as replacement for orifice**
  - **Reliability**
  - **Improved uncertainty**
  - **Diagnostics / verification**

Calibration with Focus on Application in Nuclear Power Plants

- 10 years of experience in feed water make-up water flow measurements with ultrasonic flowmeters

- No calibration facility available on water at 230ºC (ν=0.14x10^{-6} [m^2/s])

- Calibration procedure:

  Transfer calibration at ambient conditions to application at operating condition

- Phenomena that play a role:
  - Uncertainty Calibration Rig
  - Linearity/Reproducibility of ALTOSONIC V
  - Extrapolation in Reynolds Number Range
  - Thermal expansion
  - Effect of flow profile disturbances

Calibration: calibration facilities KROHNE

- Calibration rig: 45 meters high
- Max. flow rate: 30.000 m3/hr (almost ½ million liters of water within 1 minute)
- Flow meter sizes from 2.5 mm to 3000 mm can be calibrated
- Uncertainty down to 0,013% on Volume (0.04% BMC)

Extrapolation in Reynolds Number Range - KROHNE

- Maximum feasible velocity in ALTOSONIC V at calibration rig: 8 m/s
- Reynolds number calibration tower: Re= v.D/ν = 8x0.45/1.0e-6 =3.6×10^6
- Typical velocity at application : 4.9 m/s
- Reynolds number application: Re= v.D/ν=4.9x0.45/0.14e-6 =1.58×10^7
- Ratio: 1.58×10^7 / 3.6×10^6 = 4.4

Extrapolation in Reynolds Number Range – Calibration at NMIJ

- **Feasible velocity in ALTOSONIC V at calibration rig(DN600): 12 m/s**
- **Temperature at NMIJ calibration facility: 70ºC → ν=0.41 cSt**
- **Reynolds number calibration NMIJ: Re= v.D/ν = 12x0.45/0.41e-6 =1.3x10^{7}**
- **Typical velocity at application: 4.9 m/s**
- **Reynolds number application: Re= v.D/ν=4.9x0.45/0.14e-6 =1.58x10^{7}**
- **Ratio: 1.58x10^{7} / 1.3x10^{7} = 1.2**

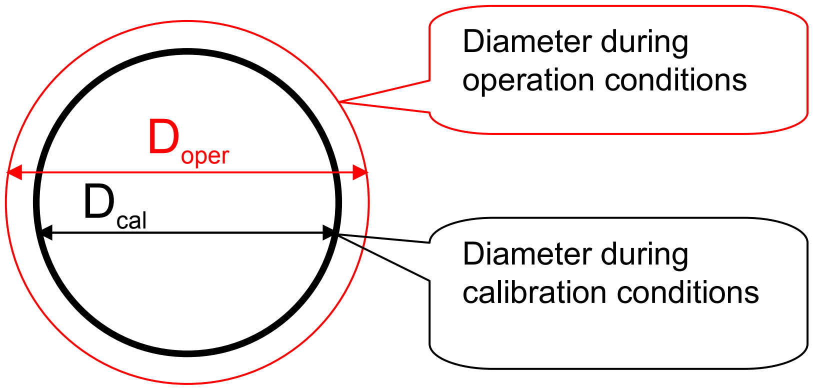
- **Almost complete coverage of Reynolds number range at application (80%)**

Thermal expansion

Flow = A (Area) x V (Flow velocity)

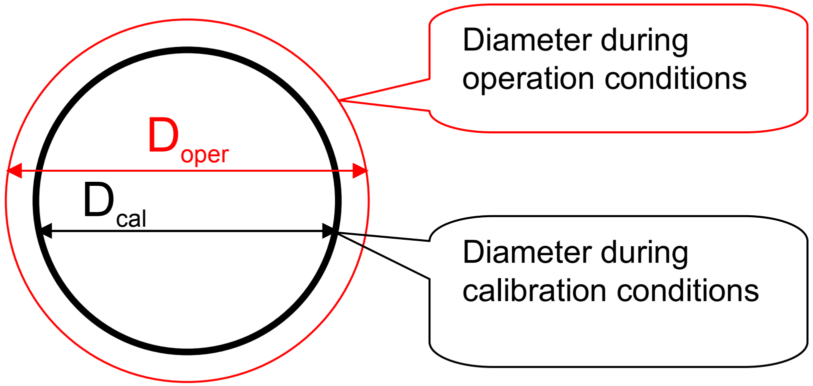
$$= \frac{\pi D^3}{4 \sin (2\alpha)} \times \frac{T_{B\rightarrow A} - T_{A\rightarrow B}}{T_{B\rightarrow A} \cdot T_{A\rightarrow B}}$$

Pipe diameter is assumed to be constant, but is not…



… so we need a compensation for the changing pipe diameter

Thermal expansion



$$D_{oper} = D_{cal} * (1+ \alpha\Delta T)$$ with

α =	lin. Exp. Coeff. Of pipewall mat.
ΔT =	temp. Diff. Between operating and calibration conditions

Using the meterfactor (MF) as a function of D^3 gives

$$MF_{oper} = MF_{cal} * (1+3\alpha\Delta T)$$

Thermal expansion

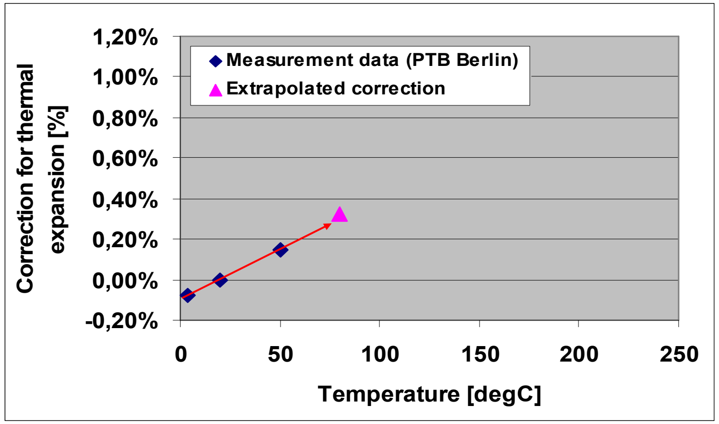
- **Practical example Nuclear Power Industry**
  - **Calibration at 20 °C and operation at 230 °C**
  - **α= 16 ppm; ΔT=210 °C**
  - **$\alpha\Delta T = 3.47 \times 10^{-3}$**
  - **Gives MF change (3* $\alpha\Delta T$) of 1.04 %**

  - **…so operating MF is 1.04 % larger than the calibration MF**

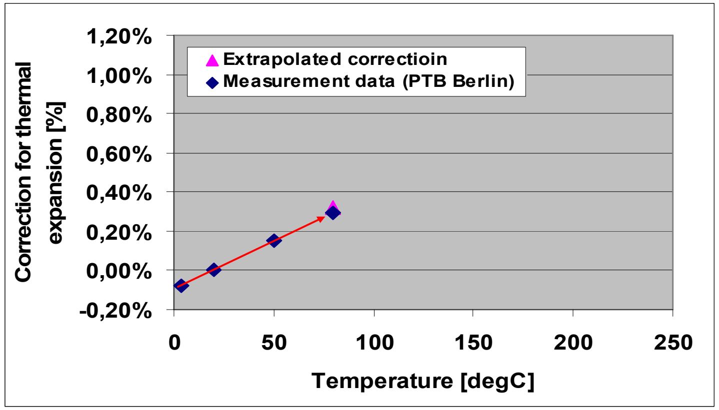
- **<u>Every</u> flowmeter principle (Venturi, Orifice, Clamp-on, ..) is facing this phenomenon!**

Procedure:

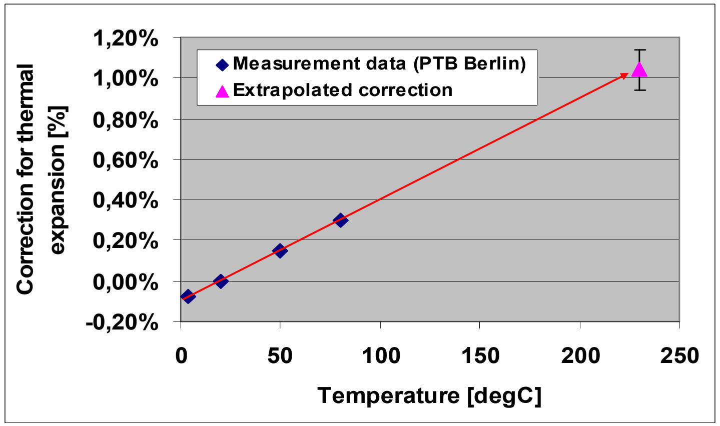
- **Step 1:**
  - **Measurement at 4ºC, 20ºC and 50ºC**
  - **Estimate correction at 80ºC (1+3αΔT)**



- **Step 2:**
  - **Measurement at 80ºC**
  - **Compare measured and estimated value**
  - **Calculate deviation**

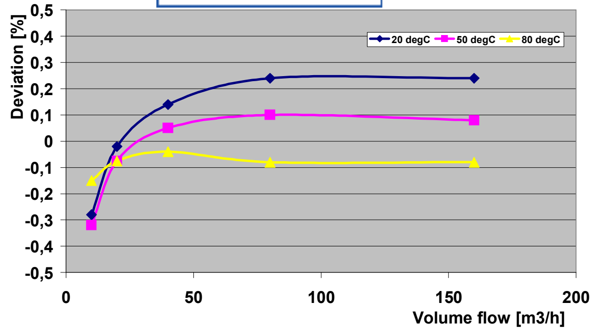


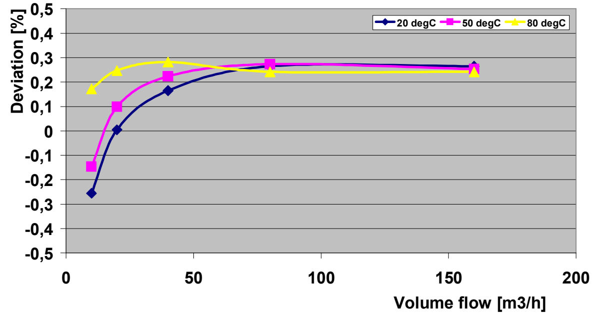
- **Step 3:**
  - **Estimate correction at 230ºC**
  - **Take into account the result obtained in step 2**

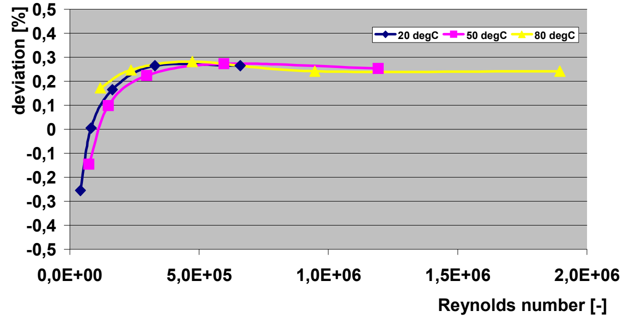


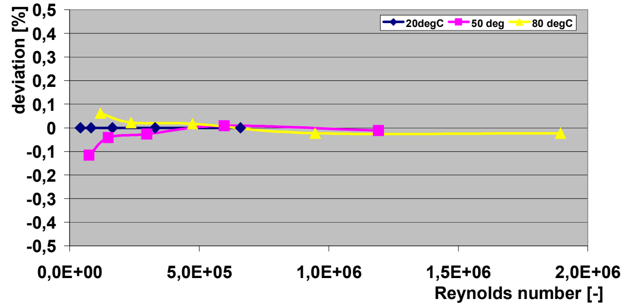
Example of tests at PTB Berlin with ALTOSONIC III

- **Figure 1:**
  - **Deviation as Function of Volume Flow**
  - **Uncorrected Results**
  - **20ºC, 50ºC and 80ºC**
- **Figure 2:**
  - **Deviation as function of Volume Flow**
  - **Corrected for thermal expansion (1+3αΔT)**
- **Figure 3:**
  - **Deviation as function of Reynolds number**
  - **Corrected for thermal expansion (1+3αΔT)**
- **Figure 4:**
  - **Deviation as function of Reynolds number**
  - **Corrected for thermal expansion (1+3αΔT)**
  - **Linearized with 20ºC curve**









Transducer Design – Piezo Crystal

Piezo Crystal Tests:

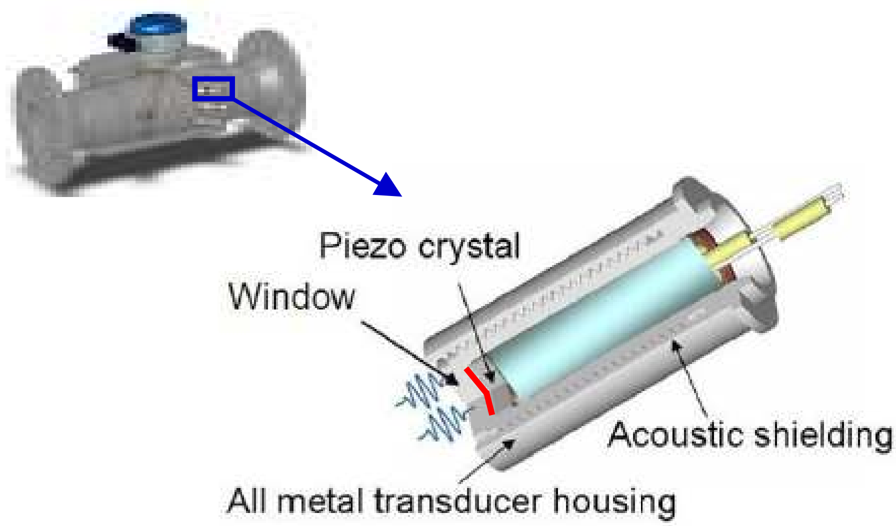
- **Piezo is basis of Ultrasonic Flowmeter**
- **Piezo material selection for application at 270 ºC**
- **Investigation focused on:**
  - **Electric properties**
  - **Acoustic properties**
  - **Mechanic properties**

- **Very good performance of Piezo Crystal**

Transducer Design

Transducer performance at 270 ºC:

- **Acoustical coupling between piezo and acoustic window is essential**
- **Considerable geometrical changes due to thermal expansion**
- **Choosing the wrong construction and material shall lead to failing transducer**



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Development on LNG Measurement

- **Last years and coming years: Construction of many new LNG Terminals**

- **Current method of measuring quantity: Mainly tank gauging**

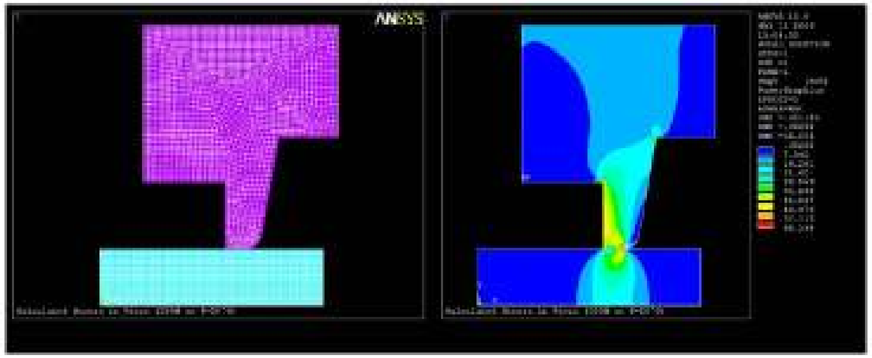
- **Disadvantages:**
  - **Semi static measurement**
  - **Limited accuracy**

- **Increasing demand for measuring Actual Flow of LNG with <u>Fiscal Accuracy (0.25%)</u>**

Transducer Tests

Transducer design:

- **New coupling technique**
- **Finite Element Modeling of entire design**
- **Focusing on:**
  - **Thermal expansion**
  - **Performance**
  - **Robustness**
  - **Reliability**
- **Guaranteed contact between piezo and window**

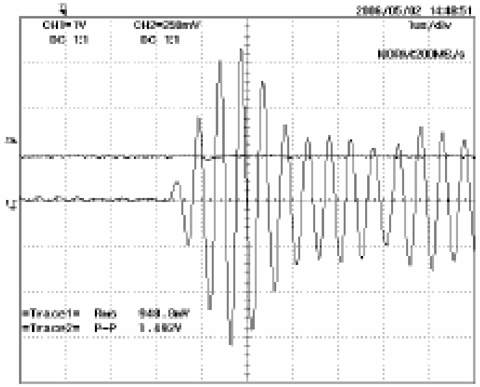


Transducer Tests

Transducer tests:

- **Transducer submerged in Liquefied N_2**
- **In laboratory of Linde, The Netherlands**
- **Signal is monitored**
- **Temperature shock tests**

- **Result: Stable behaviour and a good performance**



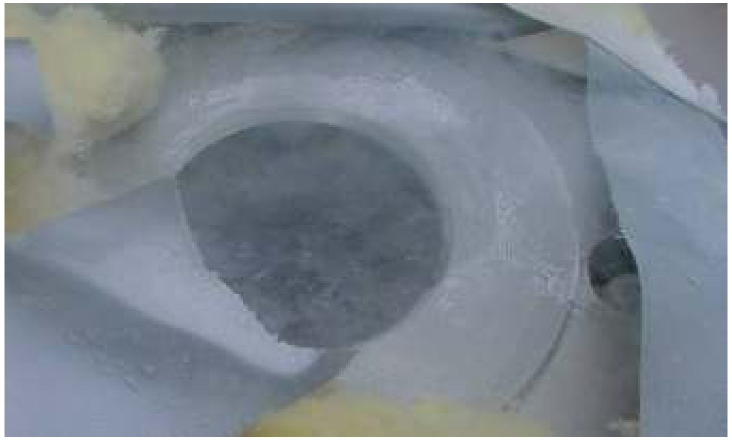
Liquefied Nitrogen @ -196 degC

Flowmeter Design and Static Tests

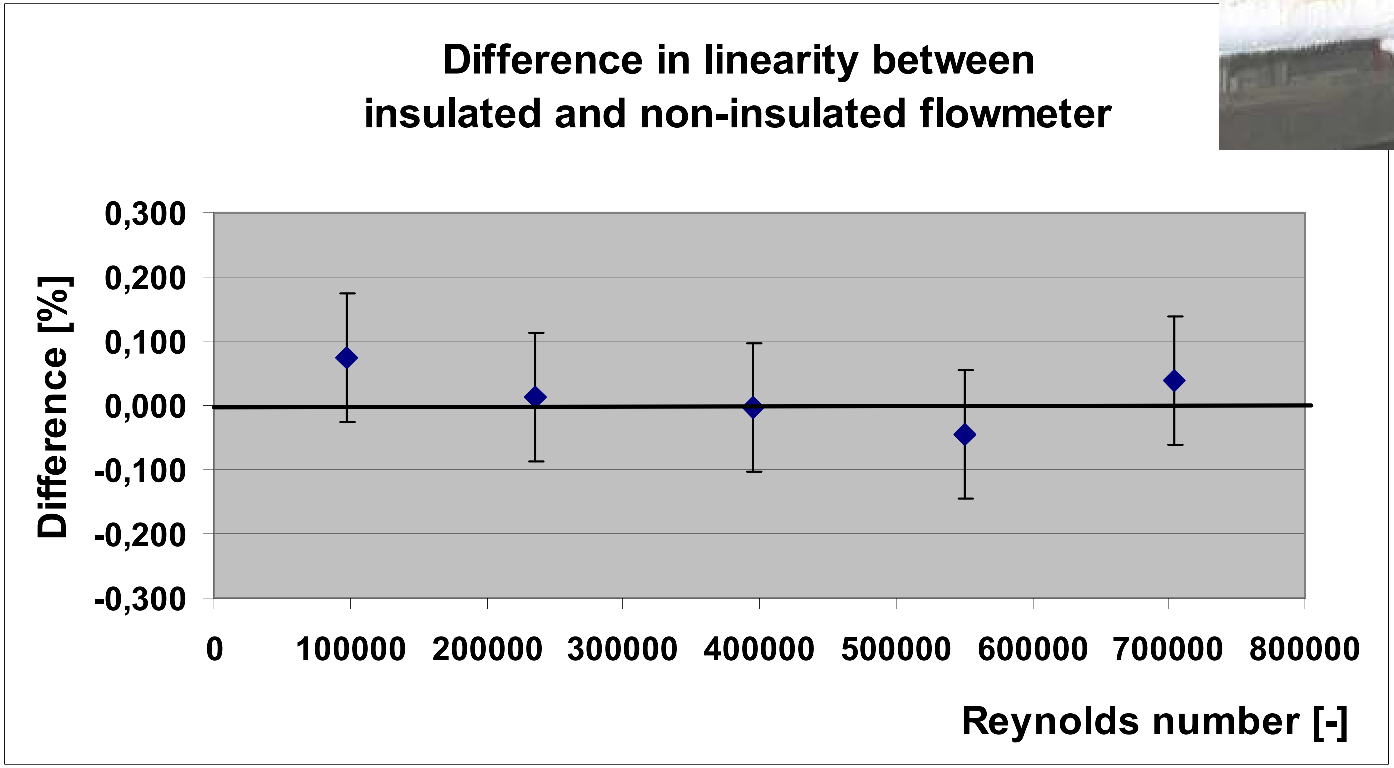
Flowmeter tests:

- **Static Tests with complete Flowmeter**
- **Filled with LN_2 (-196 ºC)**

- **Very good and stable performance**
- **Design meets all requirements like:**
  - **Strong acoustic signal**
  - **Large acoustic bandwidth**
  - **Good SNR (> 50 dB)**
  - **Stable performance during cooling down**
  - **No effect of thermal cycles**



- **Effect of thermal insulation:**
  - **Vacuum insulation jacket**
  - **Measurements done with and without jacket**
  - **No significant effect on linearity (LN2)**
  - **Slight improvement on repeatability at very low flow rates**



1. Topics
2. Performance Flow Measurement
3. Ultrasonic Flowmeters for Process Applications
4. High Performance Flow Measurement
5. New Developments in High Performance Flow Measurement of
5.1 Highly Viscous Oils
5.2 High Temperatures Liquids
5.3 Cryogenic Liquids

Conclusions

Conclusions:

- **Ultrasonic Flowmeters in Process Industry**
  - **Over 30 years of experience**
  - **well accepted, widely used**
  - **reliable, robust**
  - **More and more a commodity product for standard applications**
  - **Applications at extreme conditions**

- **Ultrasonic Flowmeters for High Performance Measurement**
  - **Over 10 years of experience in Custody Transfer applications**
  - **Well accepted**
  - **Reliable, robust, lots of diagnostic information**
  - **Expanding application range to:**
    - **difficult applications (High Viscosities, High Temperatures, Cryogenic conditions, ..)**
    - **applications where extreme high stability, accuracy and reliability is required (Feed water flow measurements, environments with radiation, ..)**

Thank you for your attention

achieve more