Using Precise Flow Measurements to Increase Efficiency in Power Plants

„Power Plants – Technology in Dialogue“

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KROHNE Alrometer

achieve more
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Application of Ultrasonic Flowmeter in Power Plants

Feedwater flow measurement

- Measures actual energy output of power plant
- Typically orifice plates are used
- Redundant system (safety)
- Uncertainty 2%
- Process conditions
  - water @ >250 °C / 150 Bar
- Ultrasonic flowmeter as replacement for orifice
  - Reliability
  - Improved uncertainty
  - Diagnostics / verification
Acoustic signals are transmitted and received along a diagonal measuring path.

A sound wave going downstream with the flow travels faster than a sound wave going upstream against the flow.

The difference in transit time is directly proportional to the flow velocity of the liquid.
Calculation of Flow Velocity

Transit time \((T)\) = \(\frac{\text{Distance}}{\text{Speed}}\)

Downstream transducer A to B

\[
T_{A\to B} = \frac{L}{C + V \cdot \cos \alpha}
\]

Upstream transducer B to A

\[
T_{B\to A} = \frac{L}{C - V \cdot \cos \alpha}
\]

Average Flow Velocity \((V)\)

\[
V = \frac{L}{2 \cdot \cos \alpha} \left( \frac{T_{B\to A}}{T_{B\to A}} \cdot \frac{T_{A\to B}}{T_{A\to B}} \right)
\]

- \(D\) = Pipe diameter
- \(L\) = Acoustic path length
- \(V_m\) = Flow velocity medium
- \(C_m\) = Velocity of sound medium
Volumetric Flow Measurement

Flow = A (Area) \times V (Flow velocity)

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

**Meter Factor** (= GK = Calibration constant)

is determined during calibration

Measurement is *independent* of:

- Density
- Temperature
- Viscosity
- Velocity of sound
**Why multiple beams?**

- **Determination of Average flow velocity**
  - Integration over cross section
  - 5 Paths with optimal path position
  - Integral converted to formula:
    \[
    \bar{v} = w_1v_1 + w_2v_2 + w_3v_3 + w_4v_4 + w_5v_5 = \sum_{i=1}^{5} w_i v_i
    \]
  - Optimized for whole Reynolds number range
  - Remaining error is just function of Reynolds
12” ALTOSONIC V: Calibration over more than 3 decades

\[ R_e = \frac{\rho \times \bar{v} \times D}{\eta} \]
• 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!!
Pipeline Application

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
Pipeline Application

ALTOSONIC V for MERO Solves Clogging Problems

- Mero Pipeline in Czech Republic
- ALTOSONIC V 10”, 150 lbs
- Crude oil with High grades of Paraffin
- Viscosity 4 to 50 cSt
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Calibration with Focus on Application in (Nuclear) Power Plants

- No calibration facility available at feed water conditions (water at ~ 230ºC)
- Calibration procedure:
  
  Transfer calibration at ambient conditions to application at operating condition

- Phenomena that play a role:
  
  - Uncertainty Calibration Rig
  - Linearity of flow device
  - Extrapolation in Reynolds Number Range
  - Thermal expansion
  - Influence of installation conditions
Calibration: calibration facilities

- 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 (0.03% BMC)
Linearity of Flow Device:
Example of Calibration of 12” ALTOSONIC V at Water

- Result of Corrected Error as Function of Reynolds Number
- Correction on Basis of Reynolds Number (Re=v.D/ν) with ν=f(T)
- Uncertainty: 0.03%

\[ V_{av} = \sum_{i=1}^{5} w_i \cdot v_i + \varepsilon(Re) \]
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High Temperature

Instrument
• Double Beam Ultrasonics
• Diameter DN 4”
• Process temp. approx. 480°C
Thermal expansion

\[ \text{Flow} = A \text{ (Area)} \times V \text{ (Flow velocity)} \]

\[ = \frac{\pi D^3}{4 \sin (2 \alpha)} \times \frac{T_B \rightarrow A - T_A \rightarrow B}{T_B \rightarrow A \cdot T_A \rightarrow B} \]

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

… so we need a compensation for the changing pipe diameter
Thermal expansion

\[ D_{\text{oper}} = D_{\text{cal}} \times (1 + \alpha \Delta T) \]

with \( \alpha \) = lin. Exp. Coeff. Of pipewall mat.
\( \Delta T \) = temp. Diff. Between operating and calibration conditions

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

\[ MF_{\text{oper}} = MF_{\text{cal}} \times (1+3\alpha \Delta T) \quad (MF_{\text{oper}} > MF_{\text{cal}} \text{ at high temperature applications}) \]
Thermal expansion

- Practical example Power Plant

- Calibration at 20 °C and operation at 230 °C
- $\alpha = 12$ ppm; $\Delta T = 210$ °C
- $\alpha \Delta T = 2.52 \times 10^{-3}$
- Gives MF change ($3^* \alpha \Delta T$) of 0.76 %!

- ...so operating MF is 0.76 % larger than the calibration MF
Example of tests at PTB Berlin with an Ultrasonic Flowmeter

- **Figure 1:**
  - Deviation as Function of Volume Flow
  - Uncorrected Results
  - 20°C, 50°C and 80°C

- **Figure 2:**
  - Deviation as function of Reynolds number
  - Corrected for thermal expansion (3αΔT)

- **Figure 3:**
  - Deviation as function of Reynolds number
  - Corrected for thermal expansion (3αΔT)
  - Linearized with 20°C curve
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Test with Disturbances

- Reference: Calibration Tower
- Flowmeter:
  - ALTOSONIC V
  - 10D inlet with tube bundle straightener
- Disturbance types:
  - 180° Bend at 0D, 3D and 6D

- Header at 0D

- With straightener the error is < 0.05% at 10D
- Without straightener < 0.1% at 10D
Test Results as Function of Distance of Disturbance

- After about 10D upstream of the inlet piece: deviation < 0.05%
- Without straightener the error is 0.1% at maximum at 10D
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Total Uncertainty

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Total Uncertainty:

- Uncertainty due to:
  - Calibration Rig: 0.03%
  - Non-linearity in ALTOSONIC V on Water: 0.03%
  - Extrapolation in Reynolds Range: 0.07%
  - Extrapolation w.r.t. Thermal Expansion: 0.11%
  - Upstream Disturbances: 0.1%

- Total Uncertainty: \( (0.03^2 + 0.03^2 + 0.07^2 + 0.11^2 + 0.1^2)^{0.5} = 0.17\% \)

- This Uncertainty can be Controlled by taking e.g. upstream disturbances into account during calibration
Calibration of EMF, DN900

- In-situ calibration of upstream piping configuration
- Application in Neurath
- KROHNE Altometer, ca. 1987
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**Summary & Developments**
Japanese initiative to reduce CO$_2$ emissions
Increased plant efficiency, through lower uncertainty
No On-Site Calibrations

- Diagnostics
  - Alarming on deposits via Velocity of Sound Profile, and VOS deviation
  - Alarming on Transducer / Transducer cable break down
  - Alarming on Gas / Flashing
  - Alarming on Communication errors
  - Flow Profile instability
Ultrasonic flowmeters

- Strong & growing interest from the (nuclear) power industry
- Use more than 20 years of experience that exists in the oil & gas industry
- Ultrasonic flowmeters have the potential of being very accurate and stable in their measurement performance…

...measure much more than just flow, ultrasonic flowmeters have very powerful diagnostic capabilities.
Thank you for your attention