Use of total station theodolite for the installation of ultrasonic flow-meters in large diameter penstocks

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In the field of Ultrasonic Flow Measurement, the required accuracy for an eight path system is generally 0.5% or even better. In order to reach such a high accuracy, all sources of uncertainties such as travelling times, protrusion effect, influence of the flow and geometrical uncertainties have to be minimized. The installation of transducers on site for penstocks with diameters larger than 2 m also requires a very accurate installation procedure.

Also, because the pipe has to be dewatered during the installation, down time electric power generation may be costly. For a reduction of such costs, the survey procedure should be realized in the shortest possible time. Using the adequate installation procedure as described in this article, the duration for a complete installation procedure can be reduced to 2 or 3 days if planned properly.

In order to perform such accurate installations, the use of a theodolite system is certainly the most accurate and efficient way. It allows installation of the transducers with optical devices eliminating measuring tapes or other inaccurate devices. The presented new theodolite system allows to measure not only the path-angles but also the distances with an accuracy of ± 0.75 mm with distances up to 150 m. The total station allows the installer to measure targets on the surface of the pipe while reconstructing the complete pipe geometry with the sensor locations in a mathematical space.

Based on the measured points, an extrapolated geometrical shape can be calculated using a least square method. The second step is to calculate the location of the transducers in the mathematical space created for the shape approximation. These coordinates are given to the motorized theodolite and pointed on the pipe surface using a laser pointer. This allows precise location of the transducers. The last step consists of the measurement of all characteristic dimensions, the path lenghts Li, the angels φi and the relative distances from the pipe axis di after the installation of the transducers.

This article also presents an application of this installation procedure. Ultrasonic flow-meters with eight paths have been installed in the Brazilian power-plant Salto Caxias on the Iguau River as well as in the Iceland power-plant Sultarthangi. The application of this methodology in large (11 m and 6 m) diameter penstocks allowed us to reach a very high accuracy even under difficult conditions. For instance, considering the angular location of the ultrasonic path, the angle installation uncertainty did not exceed 0.2°.

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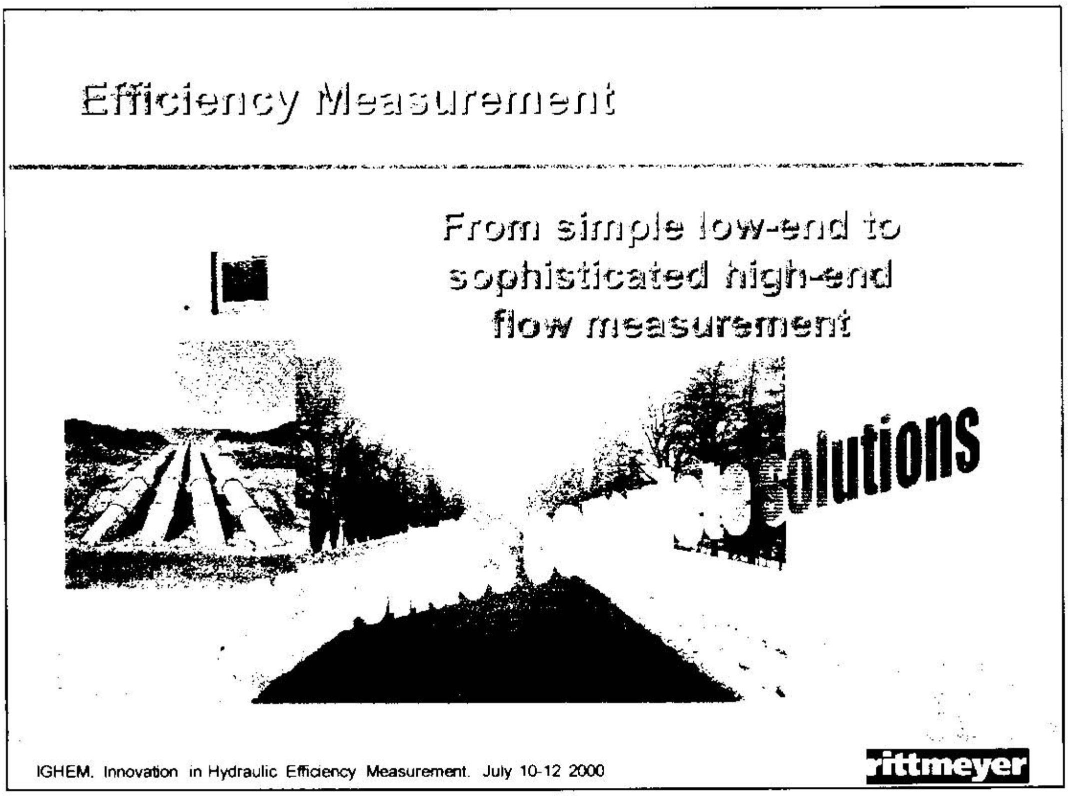
Kempten, July 10-12, 2000



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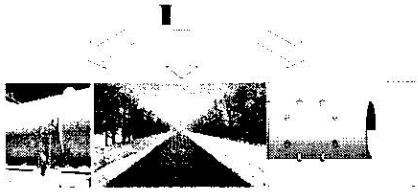
Topics

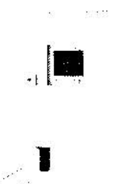
- Principles of Acoustic Flowmetering
- Uncertainties in Acoustic Discharge Measurement
- Total Station for Best Performance in Installing Ultrasonic Flowmeters with 8 Paths
- Applications and Test Measurements

General Applications

- Closed conduits
- Open channels
- Partially filled pipes



Single Path / 8-Path Measurement



- Simple, low-cost single-path system in closed conduits or open channel
- 8 path system in closed conduits according to IEC 41 (ASME PTC 18) as well as open channels

Conditions to Achieve Accurate Flow Measurement:

- **Accurate and reliable flowmeter**
  - Intrinsic accuracy of the flowmeter
  - Sensitive transducers
  - State of the art signal detection
- Knowledge of hydraulic conditions
  - Careful selection of measuring site
  - Appropriate placement of transducers
- **Precise determination of pipe geometry and transducer positions**

Uncertainties in Acoustic Discharge Measurement

Topics

- Integration uncertainties
- Influences of geometric parameters
  - Diameter
  - Angle
  - Out of roundness
- Influences of the flow profile

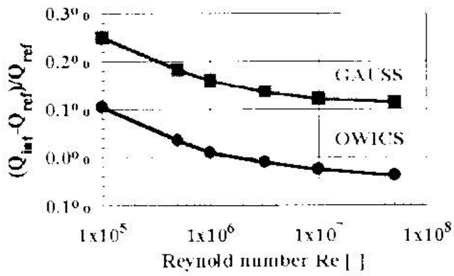
Integration Uncertainties

- Integration method according to Gauss (IEC 41)
  - Fixed weighting factors
  - Misalignment of path positions lead to errors
- Integration method according to OWICS*
  - Weighting factors are not fixed anymore
  - Weighting factors depend on positions of installed transducers
  - Path-misalignment is "allowed": integration errors can be reduced by 0.1 % to 0.2 %

*OWICS: Optimal weighted integration for circular sections

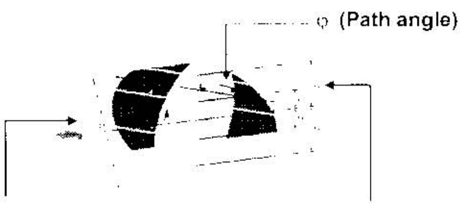
Integration Uncertainties

Comparison: Gauss IEC 41 - OWICS



Influences of Geometric Parameters

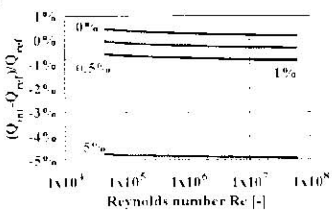
Influences of parameters: $Q = k \cdot \frac{D}{2} \cdot \sum W_i v_i L_{wi} \sin\varphi$



Influence of "Out of Roundness (elliptic)"

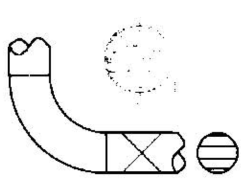
Out of roundness of cross-sections leads to integration uncertainties

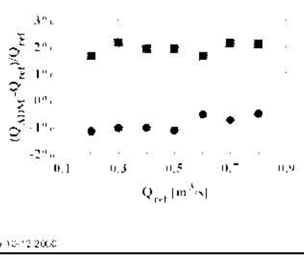
- Simulation on elliptic sections
- Acceptable: up to 1 % difference of the 2 semi-axis a and b
- For a 5% difference of axis a and b, errors can reach up to 5%



Influences of the Flow Profile

Laboratory tests: 90° elbow



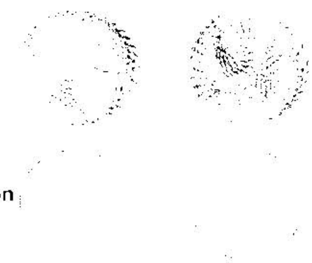


Results of the Flow Simulations

- Presence of secondary flows
- Asymmetrical flow profile

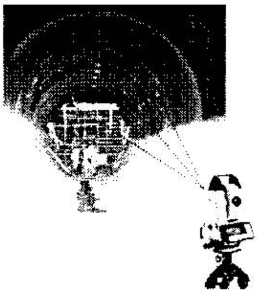
→ Find optimal orientation of the acoustic paths

Turbine 2 Turbine 1



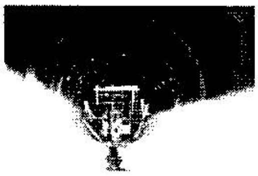
Total Station for Best Performance in Installing Ultrasonic Flowmeters with 8 Paths

Installation Services



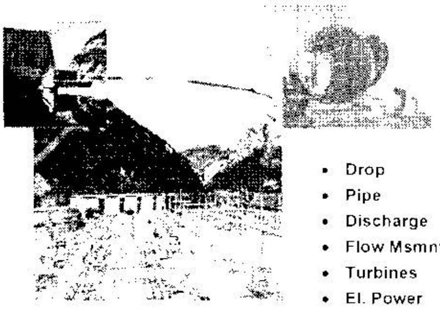
- Determination of pipe cross-section
  - Measurement Tools: Theodolite with integrated interferometer for distance measurement and laser pointer accessory
- Installation of transducers
- Determination of final positions of installed transducers (data is used in flow computation to improve measurement accuracy)
- Configuration of flowmeter

Installation of Transducers



Applications and Test Measurements

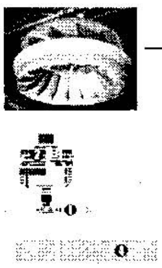
Hydropower Station Zervreila (CH)



- Drop 673 m
- Pipe Ø 2.5 m
- Discharge 20 m³/s
- Flow Msmnt. 8 path
- Turbines 6 Pelton
- El. Power 160 MW

Basics of Turbine Efficiency Measurement

Definition: $\eta_R = \frac{P_{mechanic}}{P_{hydraulic}}$



$P_{mechanic}$ + $P_{hydraulic}$ ← Q, H, ρ, g

P_e, η_e

↓

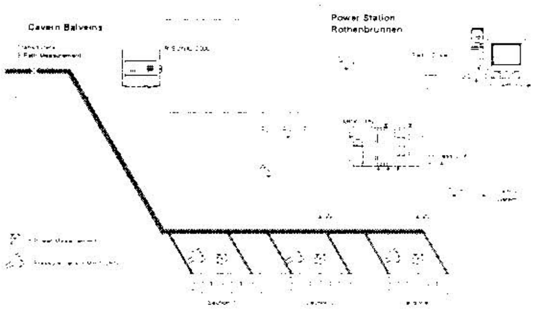
η_R

$P_{hydraulic} = Q \cdot H_n \cdot \rho \cdot g$

H_n: net head height

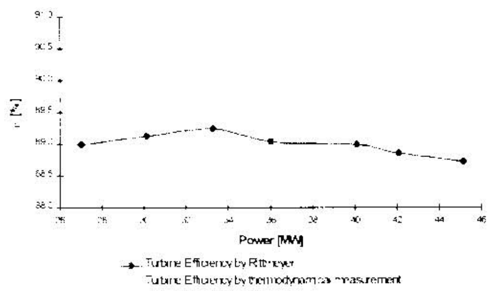
Test Setup

Applications and Test Measurement: Zervreila (CH)

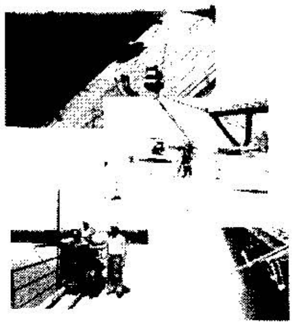


Efficiency Measurement

Applications and Test Measurement: Zervreila (CH)



Hydropower Zevio / Verona (IT)



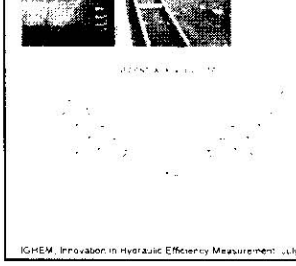
- Open channel:
  - Bottom width 11.2 m
  - Channel height 8 m
- Measurement arrangement:
  - Reference measurement
    - Current meters
  - Acoustic flowmeter
    - 4 paths
    - 1 plane
- Installation
  - High precision installation using a theodolite

Measurement Results

Applications and Test Measurement: Zevio (IT)

Q Current Meter	Q RISONIC	Error
[m3/s]	[m3/s]	[%]
89.2	90.7	1.68%
129.16	128.8	-0.28%
148.2	148.4	0.13%

Hydropower Castelletto, Treviso (IT)



- Open channel:
  - Top width 9.6 m
  - Channel height 3.7 m
- Measurement arrangement:
  - Reference measurement
    - Current meters
  - Acoustic flowmeter
    - 8 paths
    - 2 planes crossed
    - 1 MHz transducers
- Installation
  - High precision installation using a theodolite

Measurement Results

Applications and Test Measurement: Castelletto (IT)