Multipath Clamp-On Acoustic Flow Meter

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- Signal Coupling
- Path Angle / Wall Thickness
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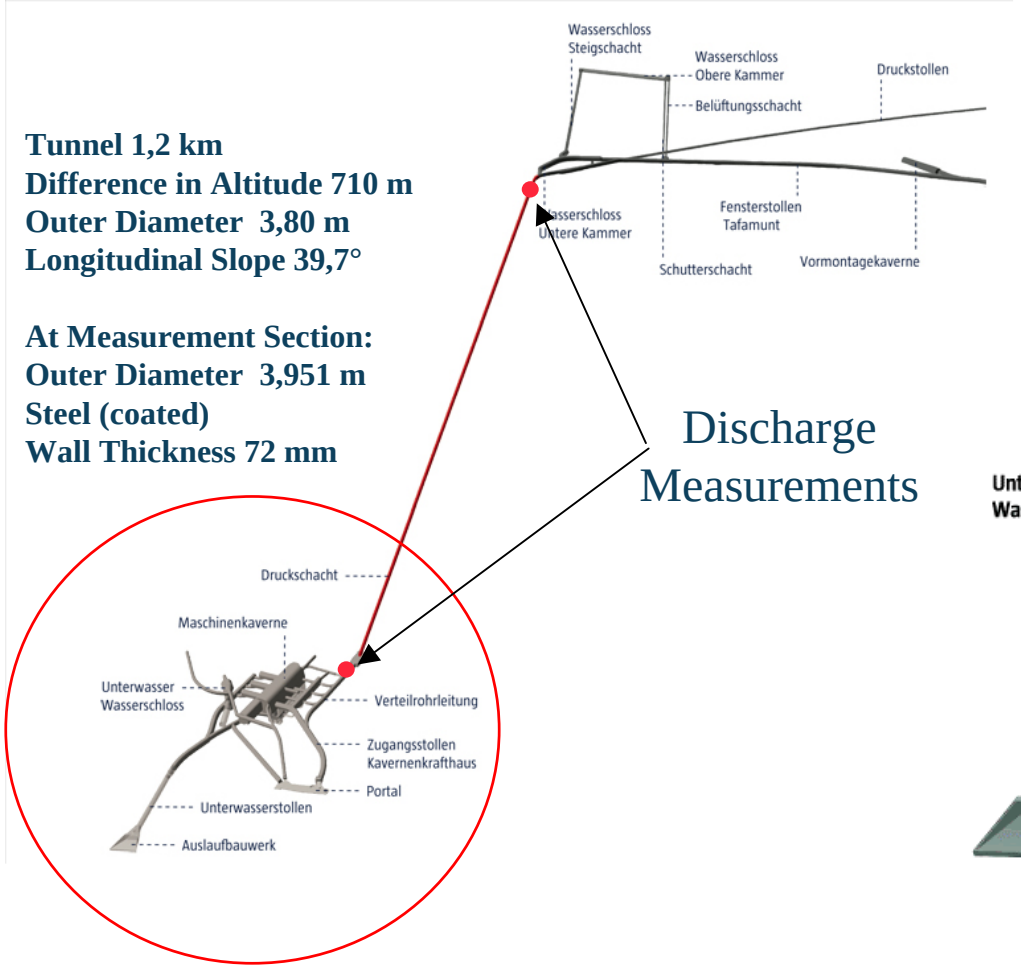
Kopswerk II / Austria

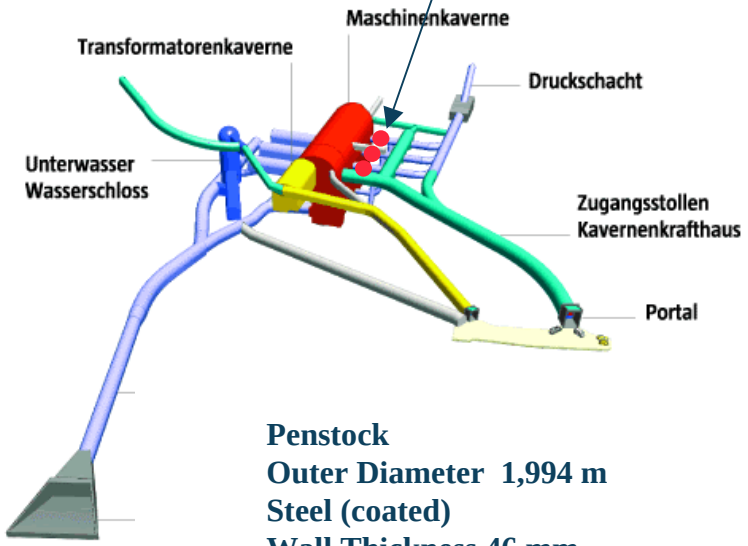
Tunnel 1,2 km
Difference in Altitude 710 m
Outer Diameter 3,80 m
Longitudinal Slope 39,7°

At Measurement Section:
Outer Diameter 3,951 m
Steel (coated)
Wall Thickness 72 mm



Discharge Measurements

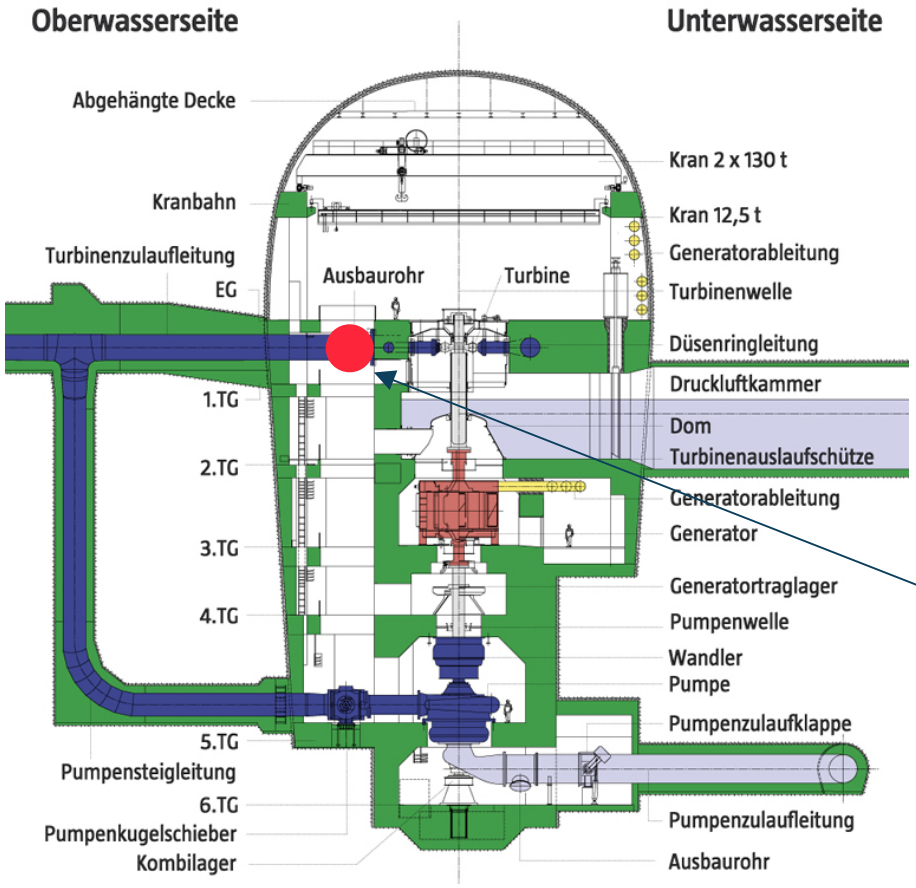
Discharge Measurements



Penstock
Outer Diameter 1,994 m
Steel (coated)
Wall Thickness 46 mm

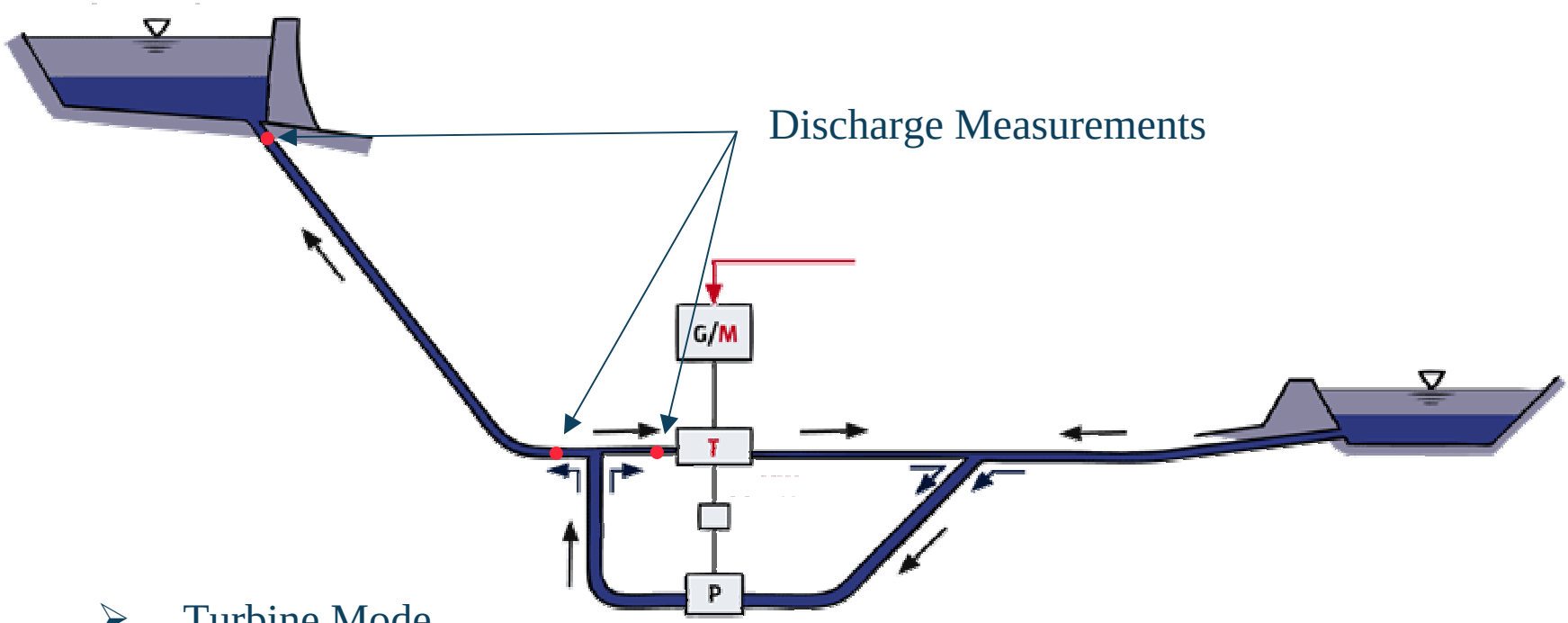
Source: Illwerke AG

Kopswerk II / Austria



Source: Illwerke AG

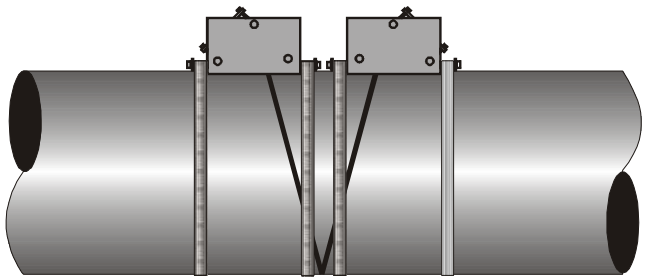
Kopswerk II / Austria

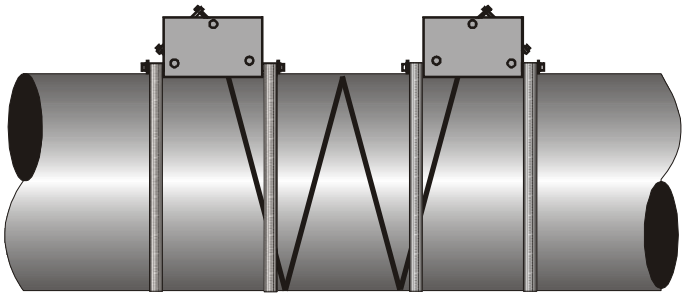


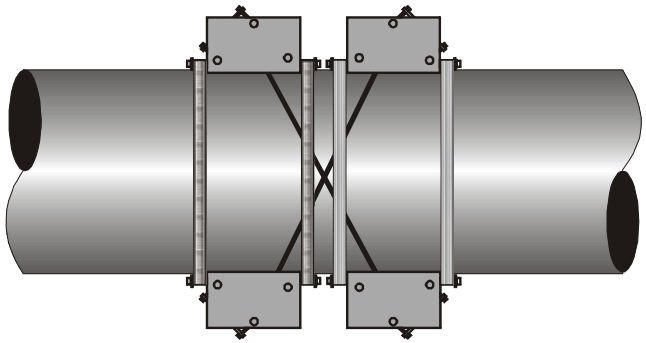
- Turbine Mode
- Pump Mode
- Hydraulic “Short-Circuiting”

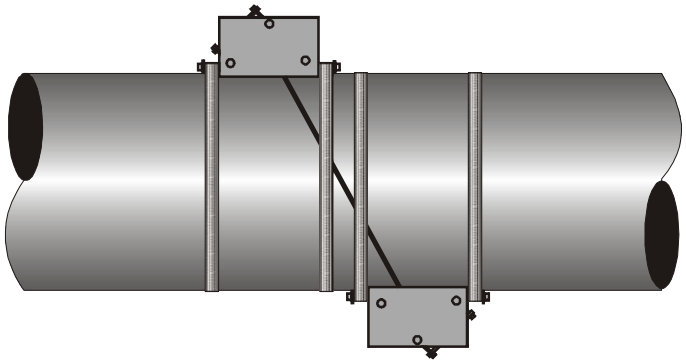
Source: Illwerke AG

Clamp-On / Path Arrangement

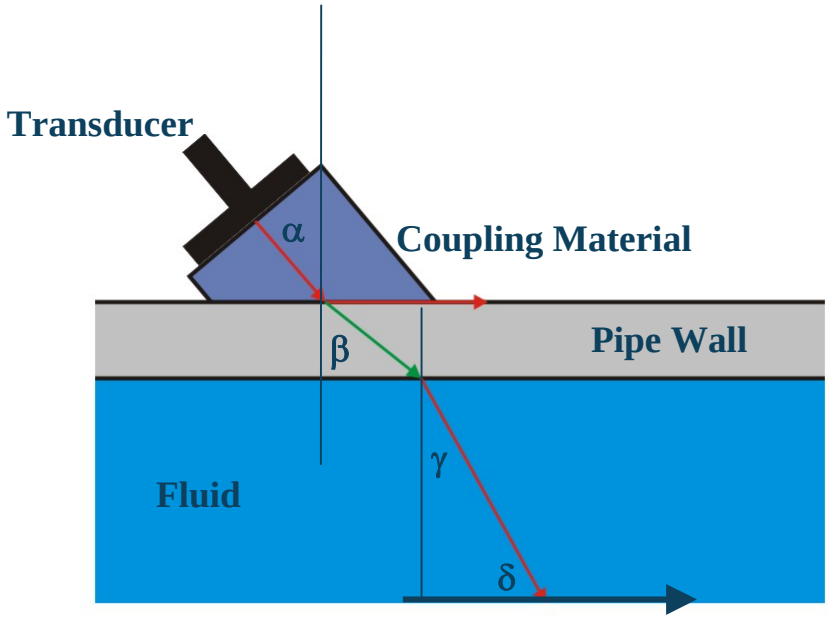


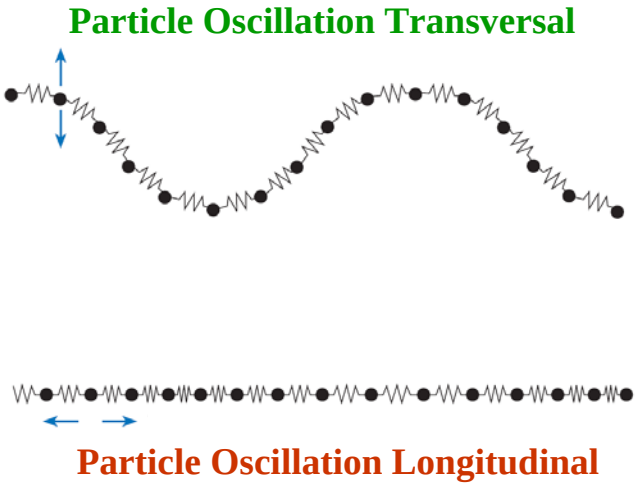






Signal Coupling / Adjusted Refraction



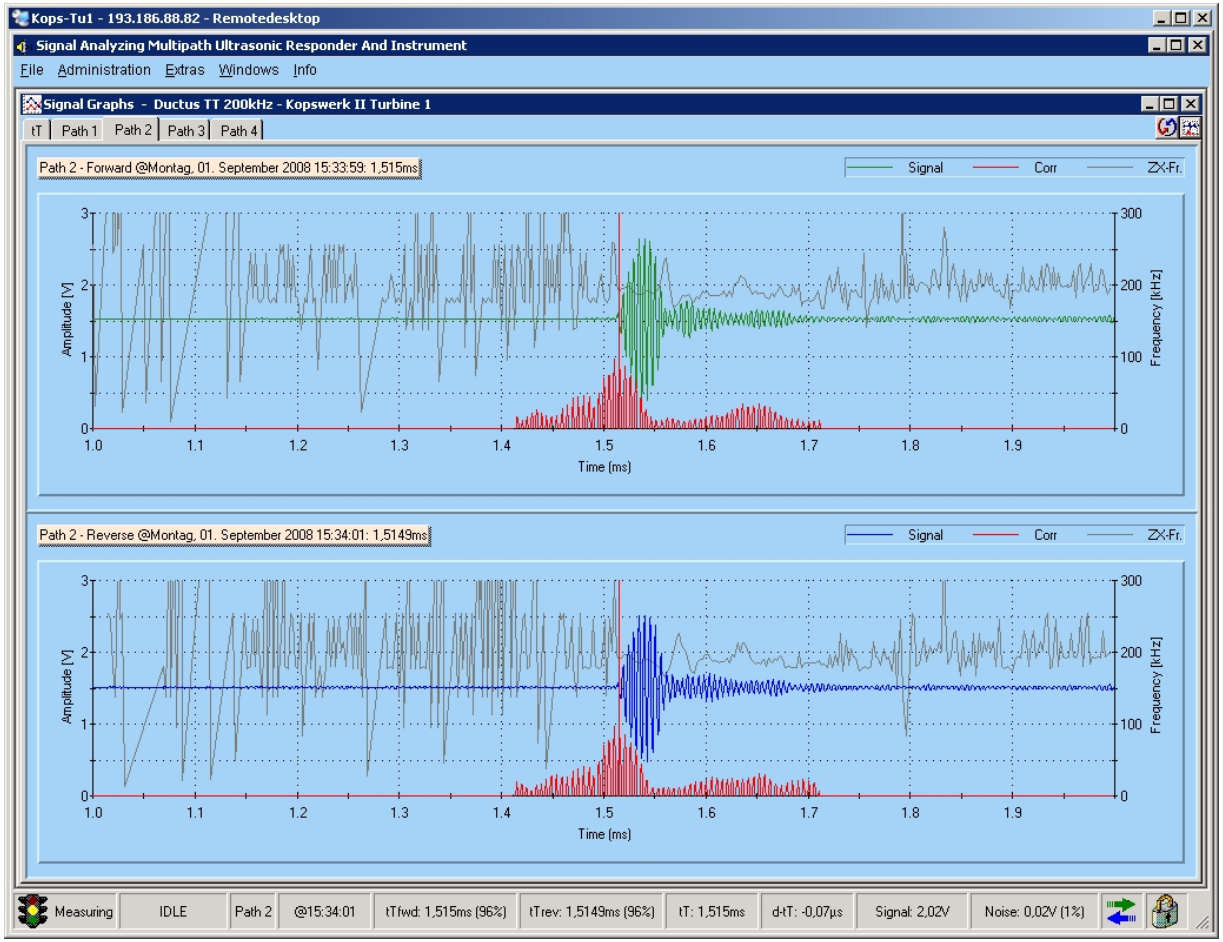


Snell's Law

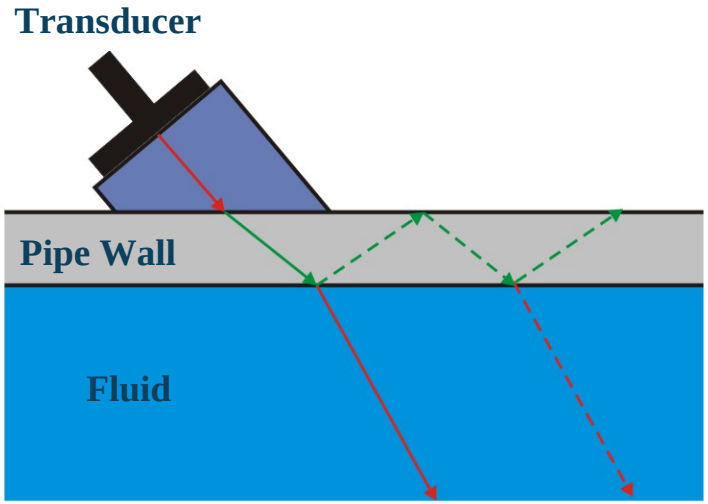
$$\frac{\sin\alpha}{\sin\beta}=\frac{c_\alpha}{c_\beta} \qquad \frac{\sin\beta}{\sin\gamma}=\frac{c_\beta}{c_\gamma}$$

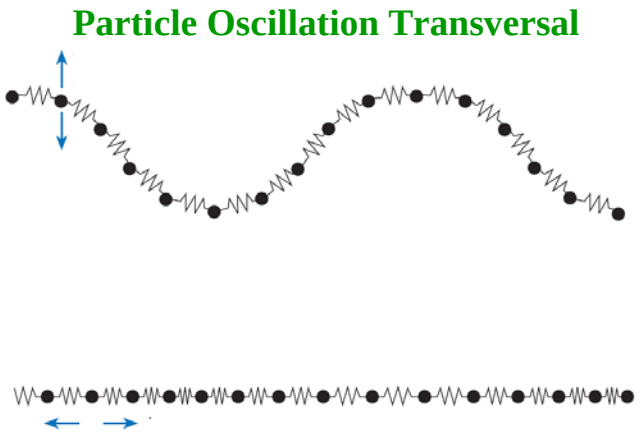
c_α = Velocity of Sound Coupling Material
c_β = Velocity of Sound Pipe
c_γ = Velocity of Sound Fluid

Signal Quality / Adjusted Refraction



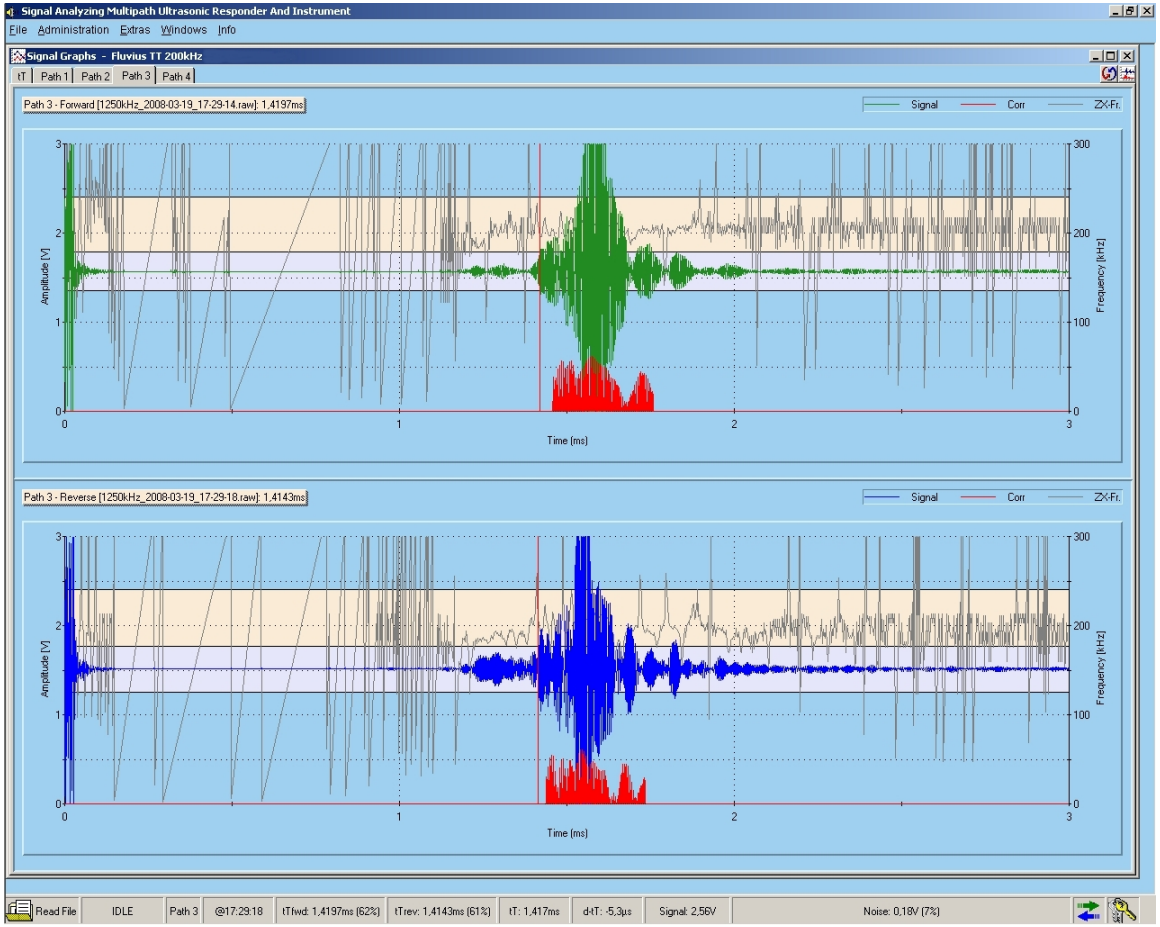
Signal Coupling / Non Adjusted Refraction



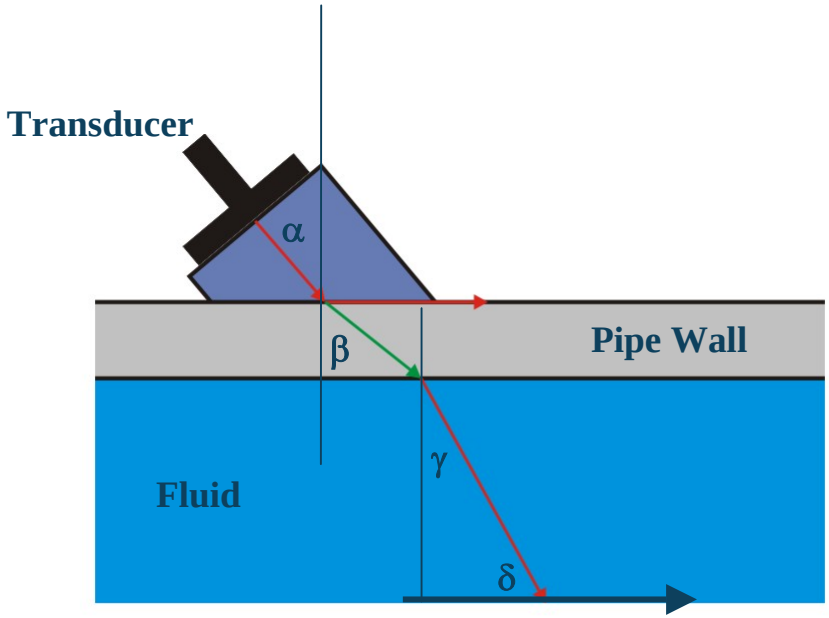


Multiple beams due to reflections in pipe wall
Superposition of the signal

Signal Quality / Non Adjusted Refraction



Path Angle



Material pipe: steel
Fluid: water
Path angle: typical 67°

Very sensible geometrical parameter for Q
Error of 0.1° in path angle / 0,9% in discharge
Error of 0.5° in path angle / 5% in discharge

Temperature Dependency
Velocity of sound of material and velocity of sound of fluid depending on temperature. Angle of refraction depends on temperature too. Path angle (and path length) are influenced by the temperature as well.

Wall Thickness

w [m]	D [m]	ΔL_{PW}	ΔL_{FS}	ΔA	ΔQ
0,015	1,010 (-1,00%)	+33,33%	-1,00%	-2,00%	-1,45%
0,016	1,008 (-0,80%)	+25,00%	-0,80%	-1,60%	-1,16%
0,017	1,006 (-0,60%	+17,65%	-0,60%	-1,20%	-0,87%
0,018	1,004 (-0,40%)	+11,11%	-0,40%	-0,80%	-0,58%
0,019	1,002 (-0,20%)	+5,26%	-0,20%	-0,40%	-0,29%
0,02	1,00	0	0	0	0
0,021	0,998 (+0,20%)	-4,76%	+0,20%	+0,40%	+0,29%
0,022	0,996 (+0,40%)	-9,09%	+0,40%	+0,80%	+0,59%
0,023	0,994 (+0,60%)	-13,04%	+0,60%	+1,20%	+0,88%
0,024	0,992 (+0,80%)	-16,67%	+0,80%	+1,60%	+1,18%
0,025	0,990 (+1,00%)	-20,00%	+1,00%	+2,00%	+1,48%

w = Wall Thickness

D = Diameter

ΔL_{PW} = Change of Path Length in Pipe Wall

ΔL_{FS} = Change of Path Length in Flow Section

A = Cross Section

Q = Discharge

v = 1,00 m/s

Measuring Wall Thickness

Optical 3D-System / Determination of Positions

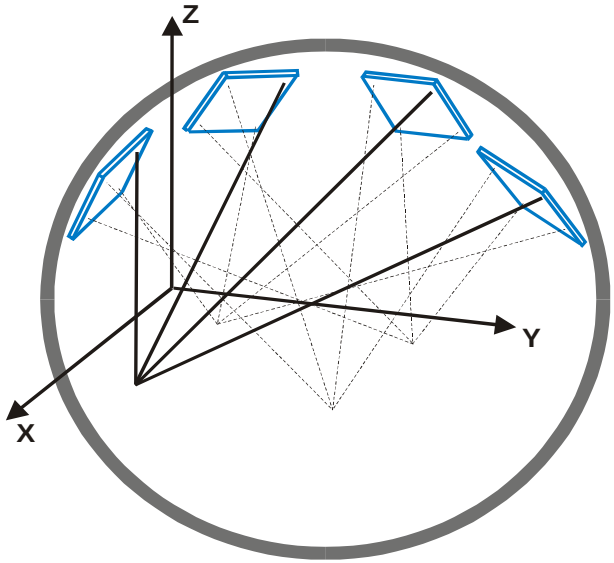
Measuring Principle

- Digital Photogrammetry Analysis (DPA)
  (Spatial Triangulation of Pictures)

Advantages

- Analysis of the real position at the site
- High flexibility at limited space

Optical 3D-System



Measuring principle
The portable 3D measuring device consists of a high resolution digital camera as acquisition device. The object is captured from different viewing directions to get a complete coverage of any kind of object. These images were processed with a powerful software on a standard notebook to calculate the 3D coordinates of all relevant geometry points. The calculation is based on the principle of spatial image triangulation and is processes fully automatically. No pre-calibration is necessary due to an integrated simultaneous calibration procedure.

Marking
The object to be measured is marked at all geometry relevant points with targets. A large variety of adapters allows the marking of almost every point, even hidden points, points in holes, points at bottom sides of parts etc.

Optical 3D-System / Determination of Positions

System Components

- Digital Camera (NIKON D2xs (12.4 MP) with Nikkor 24mm)
- Notebook with DPA-Software Package (OS: Windows XP)
- Coded marks

Accuracy

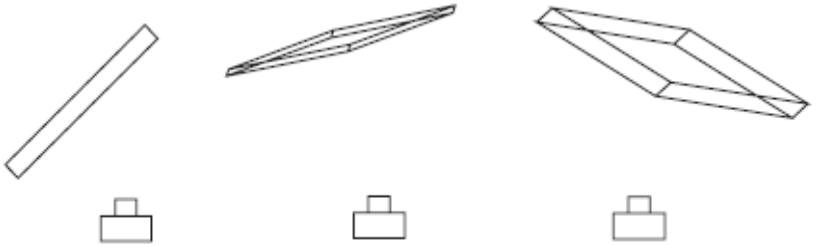
- +/- 0,015 mm/m

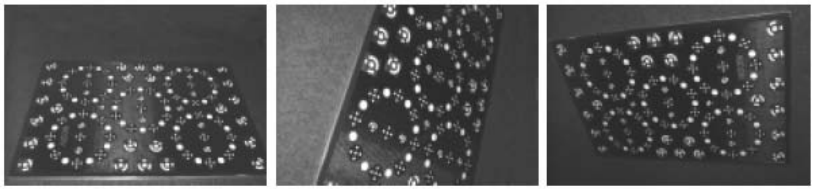
Optical 3D-System / Determination of Position

Step by Step

- Calibration of the optical system

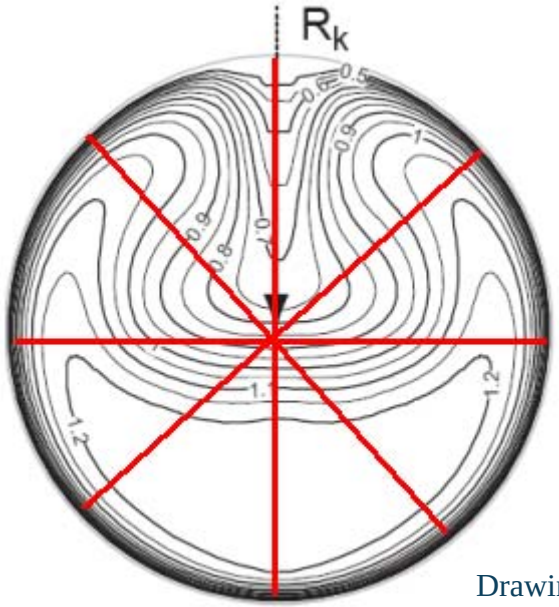
Coded Plate
ISO (80 marks, 5 rings)





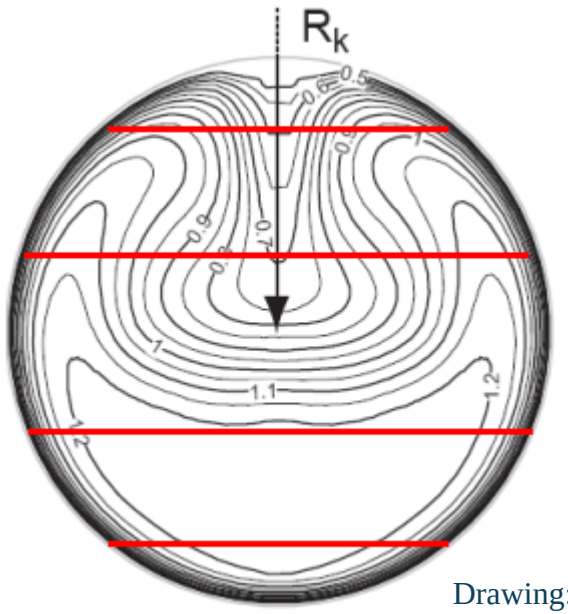
- Setting marks
- Pictures of the object from different directions
- Online or offline evaluation of the 3D Co-ordinates (software)

Discharge Calculation / Path Orientation



Drawing: Voser

Clamp-On (axial planes)



Drawing: Voser

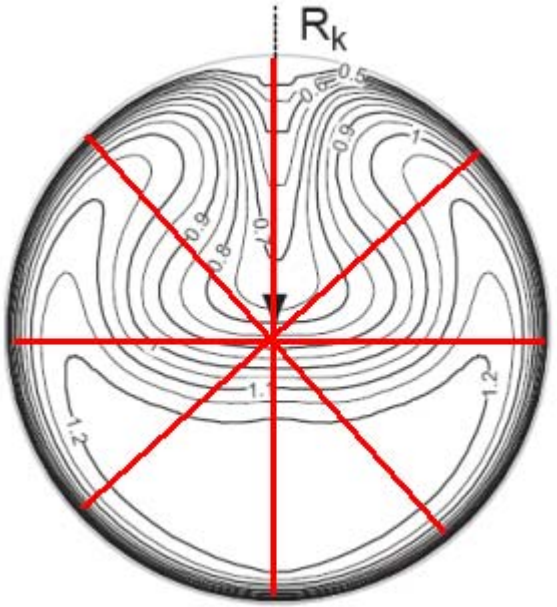
„Wetted“ transducers (parallel planes)

Discharge Calculation

Multipath Path Clamp-On / Disturbed Velocity Profile

Mean value of measured path velocities

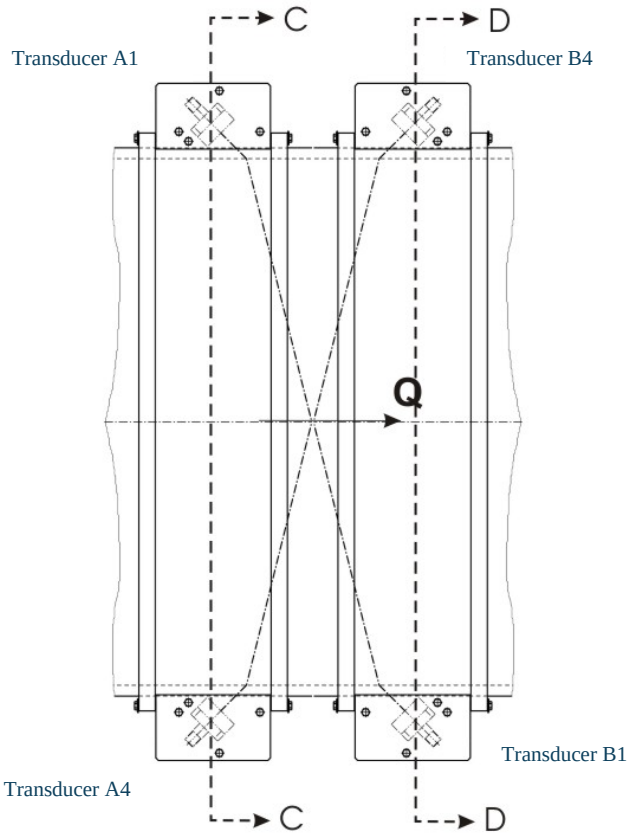
Numerical method
On-line approximation of the 3D velocity profile
Input: mean path velocity
Boundary condition: velocity at the wall is 0,
velocity in pipe axis must be the same for all paths.



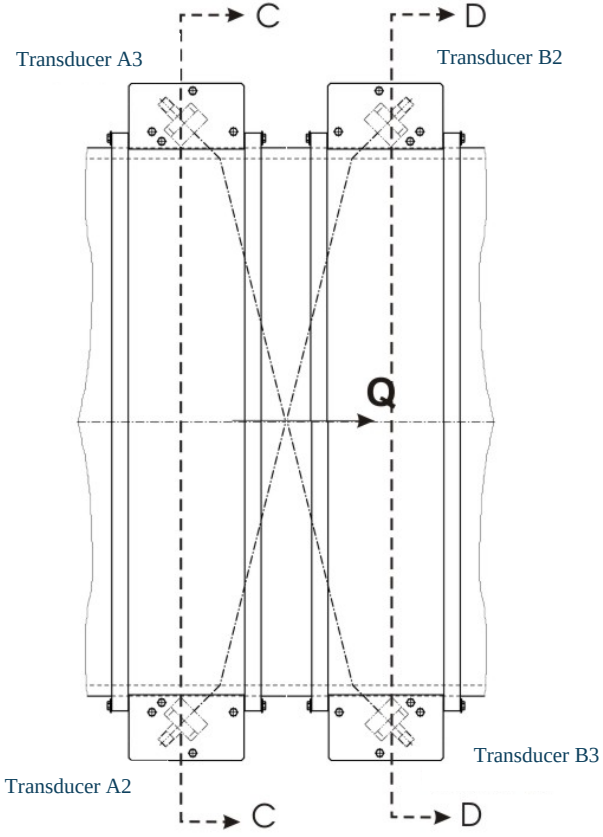
Drawing: Voser

Transducer Arrangement / Kopswerk II

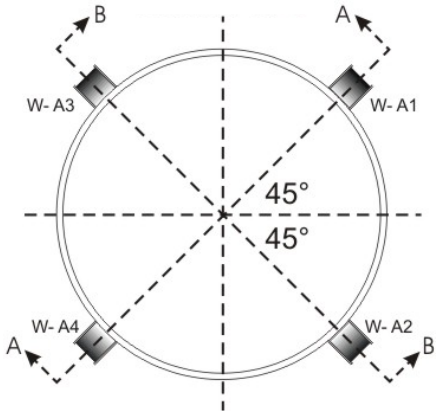
Section A:A



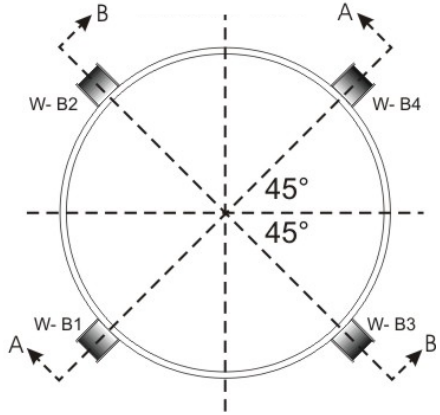
Section B:B



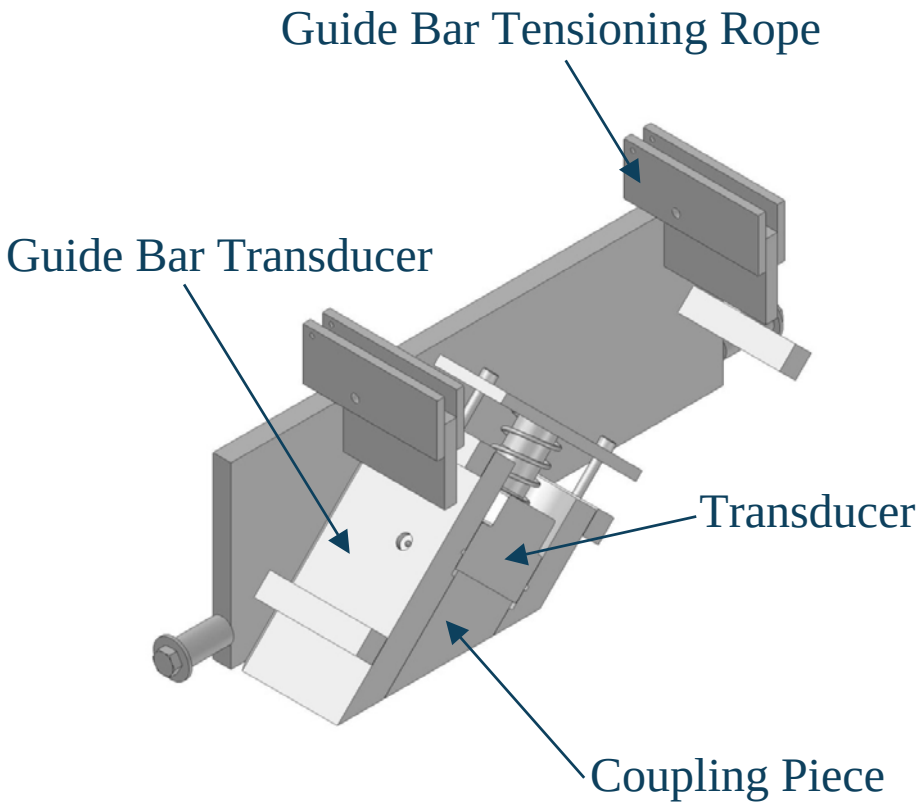
Section C:C

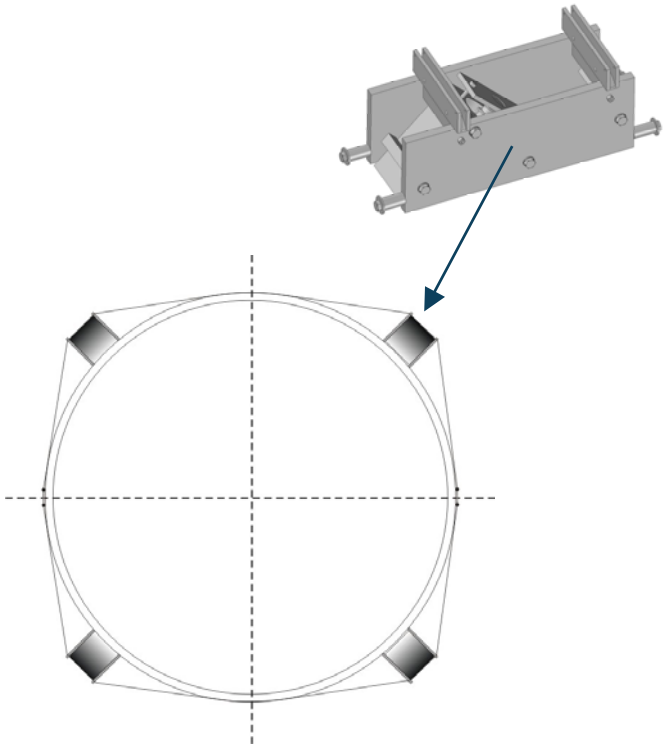


Section D:D



Clamp-On Assembly

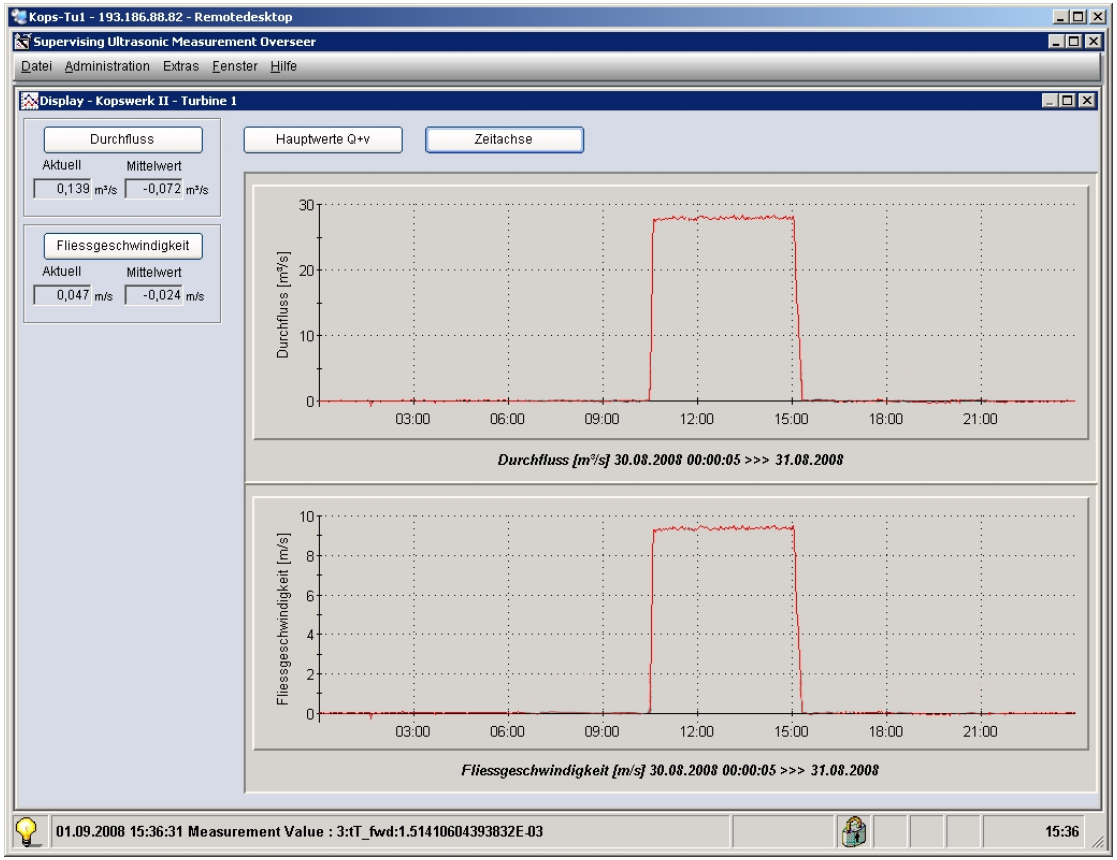




Clamping Fixture

Turbine 3 / Kopswerk II

Measurement Result



Turbine 1 / Kopswerk II

Thank You !