
to Jose Peña pro memoriam

Discharge measurement by means of the pressure-time and the 8-path acoustic method in Niedzica HPP pressure tunnels

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Niedzica Complex of Hydropower Plants Co.

Discharge measurement by means of the pressure-time and the 8-path acoustic method in Niedzica HPP pressure tunnels

1. Background:
   Polish Green Certificate System and Niedzica Hydropower Plant
2. The RISONIC 2000 acoustic flow measurement system
3. Installation work and commissioning tests in Niedzica HPP
4. Check tests (pressure-time flow measurement method)
5. Discussion of results
6. Further experience
7. Conclusion

Hydropower potential of Poland, GWh/annum

Hydro power potential	theoretical	technical
Vistula with tributaries	16457	9270
Vistula	9305	6177
Left-bank tributaries	892	513
Right-bank tributaries	4914	2580
Oder with tributaries	5966	2400
Oder	2802	1273
Left-bank tributaries	1615	619
Right-bank tributaries	1540	507
Baltic coast rivers	582	280
Total	**23005**	**11950**

***annual generation* (normalised):**
2300 GWh
(natural inflow only)

Dunajec river downstream Niedzica HPP

Polish large hydro (>10 MW)

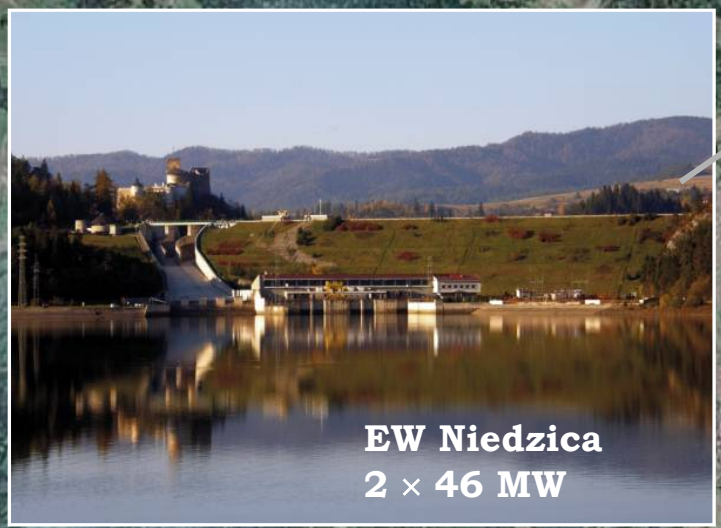
No.	Power plant	Type	Power MW	Production GWh/year	Operator/Owner
1	**Żarnowiec**	Pumped storage	716	991	ESP SA
2	**Żar Porąbka**		500	636	ESP SA
3	**Żydowo**		152	184	Energa
4	**Solina**	Pumped storage with natural inflow	200	131	ESP SA
5	**Niedzica**		**92**	**78**	**ZEW Niedzica**
6	**Dychów**		79	27	ESP S.A.
7	**Włocławek**	Reservoir/ run-off-river	162	770	Energa
8	**Rożnów**		56	138	ZEW Rożnów-Czchów
9	**Koronowo**		25	38	Energa
10	**Tresna**		21	35	ESP SA
11	**Dębe**		20	87	ZE Warszawa-Teren
12	**Porąbka**		13	28	ESP SA
13	**Wały Śląskie**		10	44	Energia Pro

Polish Green Certificate System

Green Energy Production

$$E_{\mathrm{RES}} = E_{\mathrm{tot}} \left(1 - V_{\mathrm{pump}}/V_{\mathrm{turbine}}\right)$$

NIEDZICA Hydropower Plant



1 mi
2 km

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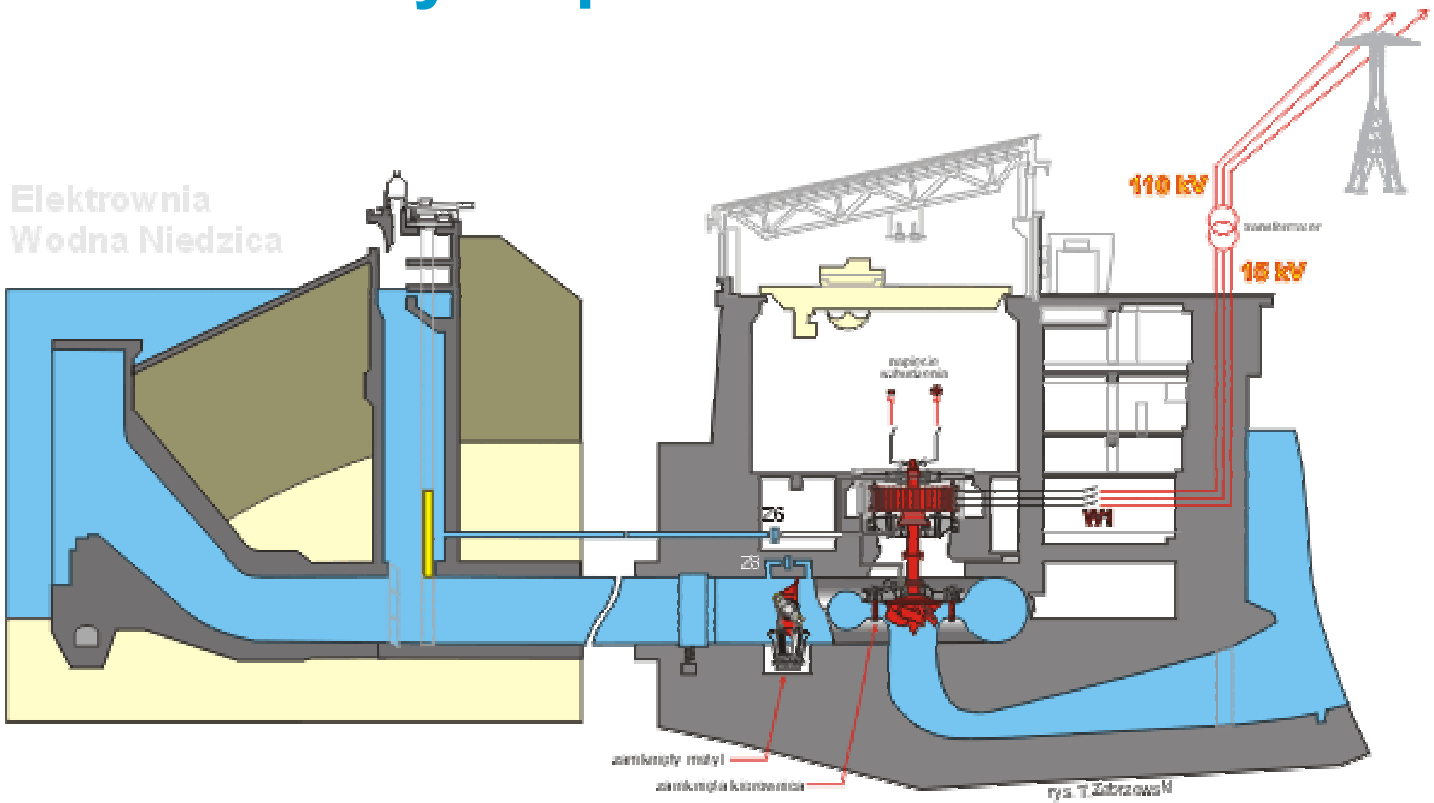
NIEDZICA Hydropower Plant



mode of operation	turbine	pump
installed discharge, m^3/s	130	114
installed power, MW	46.375	44.500
head range, m	21 ÷ 49	22 ÷ 46

NIEDZICA Hydropower Plant

Pressure and drainage tunnels

Parameter	Unit 1	Unit 2
Length, m	203	224
Diameter, mm	7000	
Slope, %	7	

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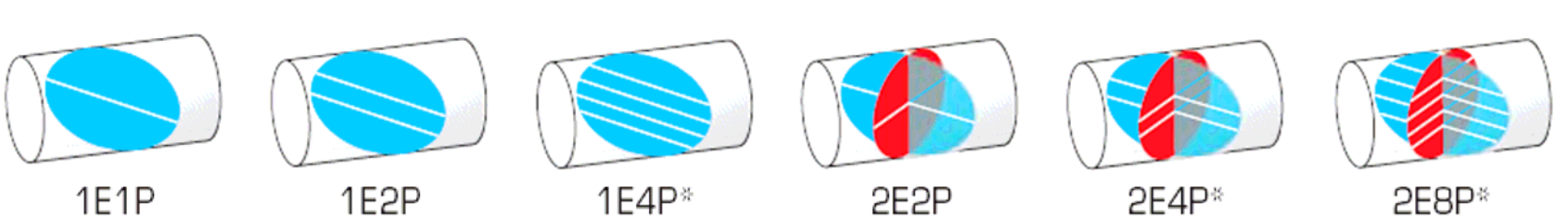
The acoustic flow measurement method



mean velocity
(without cross-sectional components)

$$\overline{v_a} = \frac{L}{2\cos\varphi}\left(\frac{1}{t_d} - \frac{1}{t_u}\right)$$

mean velocity
(with cross-sectional components)

$$\overline{v_a} = -Y\,\overline{v_t}\tan\varphi + \frac{L}{2\cos\varphi}\left(\frac{1}{t_d} - \frac{1}{t_u}\right)$$

discharge

$$Q = k\,\frac{D}{2}\sum_{i=1}^{n} W_i\,\overline{v_{ai}}\,L_{wi}\sin\varphi$$

RISONIC 2000 SYSTEM

- 1 analogue output: 4 - 20 mA
- 4 relays: OK, forward/reverse flow, 2 relays for impulse or limit value
- RS232: Interface for parameterisation by means of PC or Laptop

MFATB2 ultrasonic transducer

Assembled in pipe
Hydrodynamic profile
Oscillating frequency: 1 MHz

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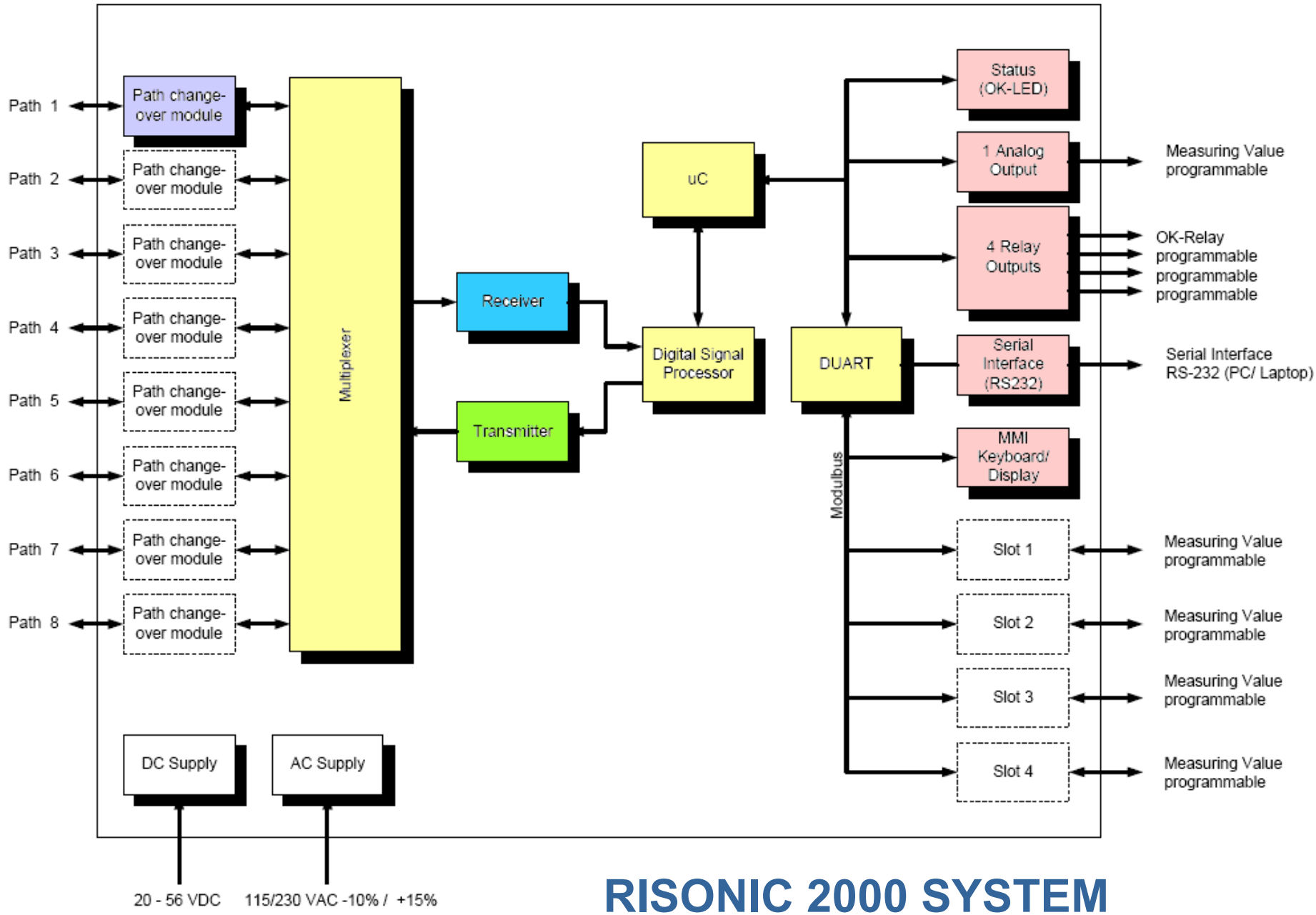
Simple Operation

User-friendly parameterisation and operation:

- Integrated user interface
  - Large illuminated LC display
  - Pull-down menu
  - Alphanumeric keyboard
  - Cursor keys
- RS-232 interface with parameterisation software for PC or Laptop



RISONIC 2000 SYSTEM

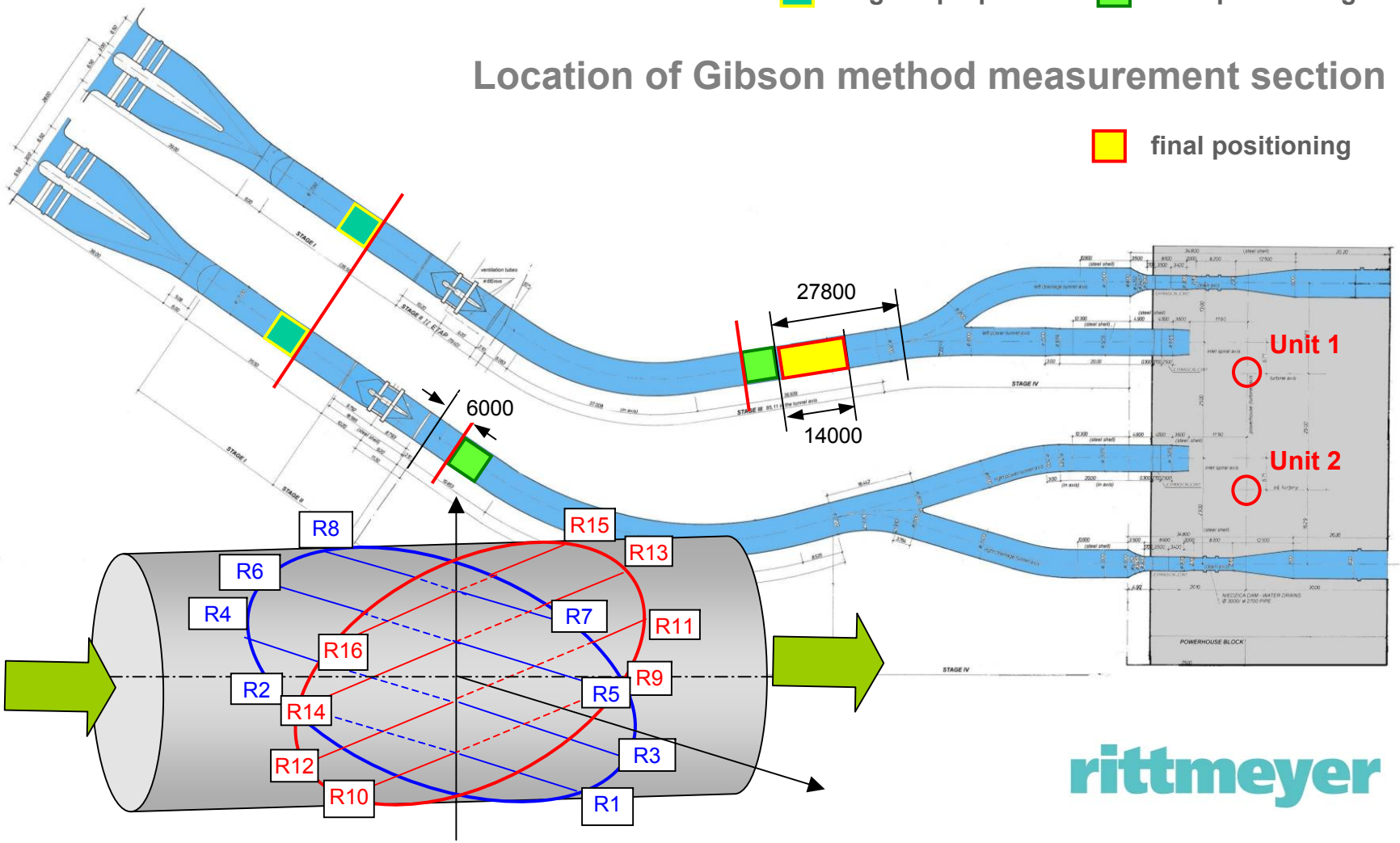
NIEDZICA Hydropower Plant

Location of ultrasonic measurement sections

original proposal final positioning

Location of Gibson method measurement section

final positioning



RISONIC 2000 installation procedure

No	Item		1	2	3	4	5	6	7	8
1	Installation of protecting tubing upstream the measurement section		➡							
2	Determining penstock geometry (5 sections; 40 points per section)									
3	Positioning of ultrasonic transducers									
4	Preliminary installation of transducer mounting plates									
5	Preliminary installation of transducers									
6	Mutual positioning of transducers (laser technique)									
7	Temporary dismantling of transducers									
8	Installation of protecting tubing within the measurement section									
9	Pressure test of the tubing									
10	Pulling the signal conduits up to the mounting plates									
11	Final mounting and mutual orienting of the transducers									
12	Hermetic closing of the tubing									
13	Connecting conduits to the RISONIC 2000 processing unit									
14	Flooding of the tunnel									
15	Loading of the software									
16	Commissioning tests									

HYDRO-NUR

HYDROENERGO
Władysław Kiełbasa

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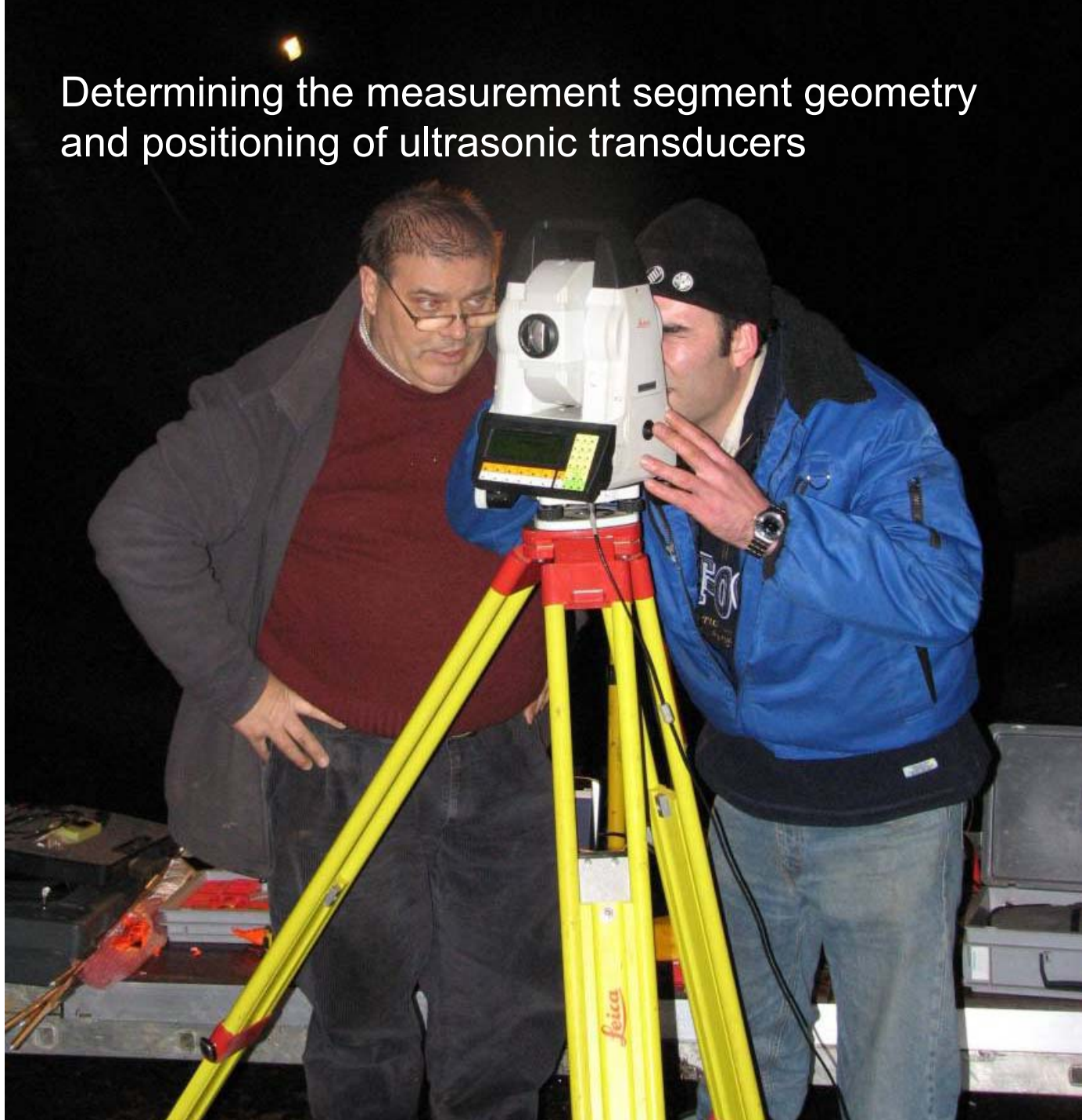
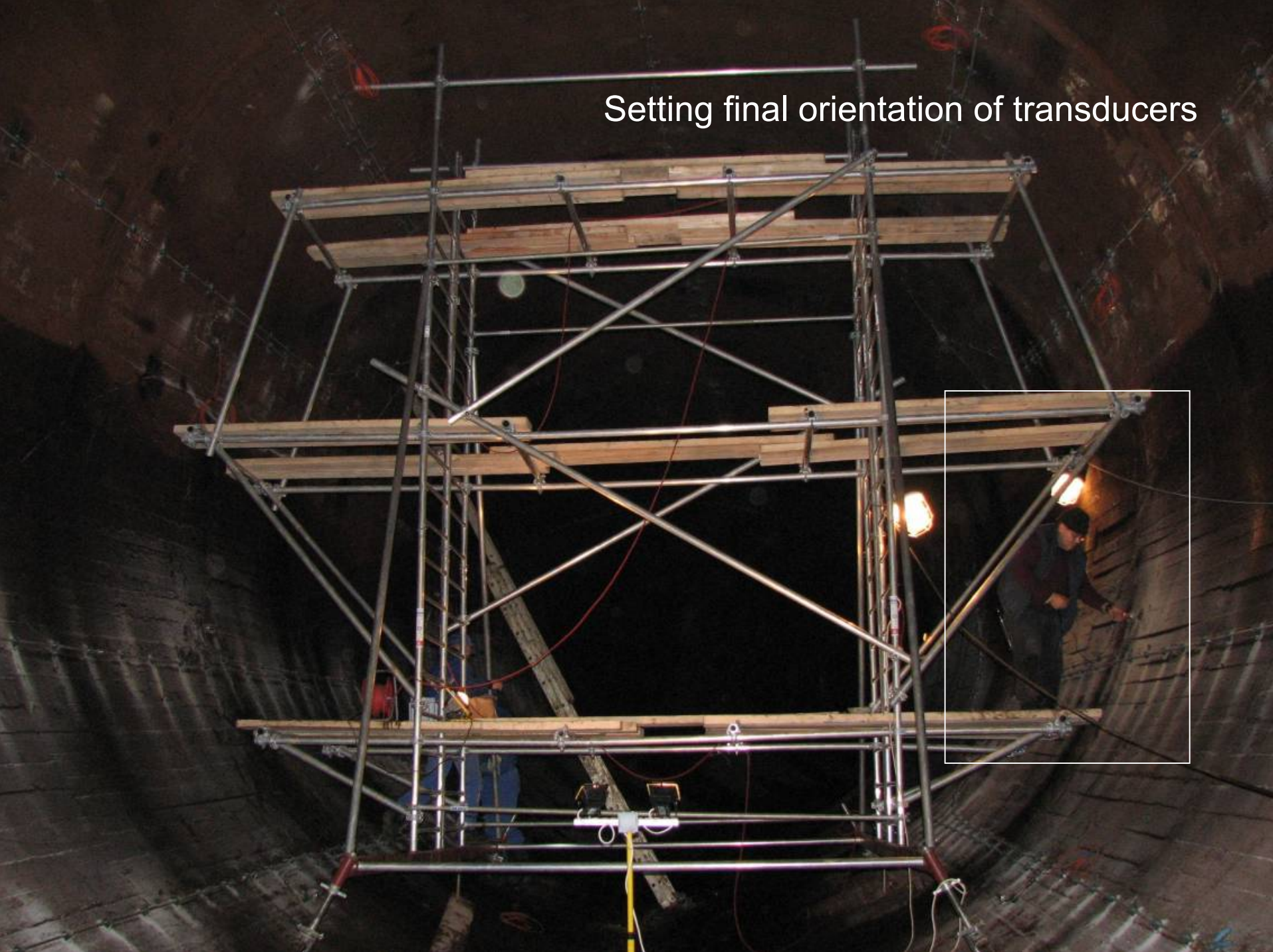
Determining the measurement segment geometry and positioning of ultrasonic transducers




Mounting an ultrasonic transducer
in Niedzica pressure tunnel


Setting final orientation of transducers


An MFATB2 ultrasonic transducer
in its final position and orientation
Risonic Sensor
Type: MFATB2.001
Art.Nr.: 0066635.001
Date: 24.10.2006
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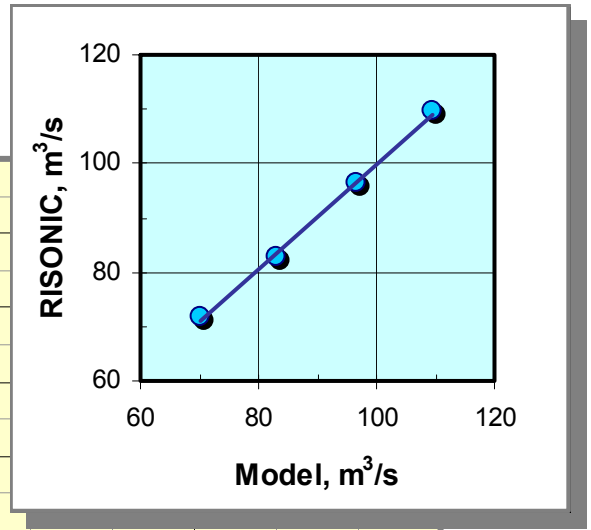
Unit 2 commissioning tests



Q_M	Q_R
m³/s	m³/s
109,37	109,53
96,61	96,37
82,93	82,82
70,28	71,76

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Handover Protocol of RISONIC-System
including the Site Acceptance Test (SAT) results

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– The flow meter has been tested of its plausibility in the configuration 2E8P in the following conditions (pumping and turbining mode). The hydraulic unit discharge characteristics following from the RISONIC measurements has been compared with the characteristics based on the pump-turbine model tests.

H	P	$Q_{RISONIC}$	$Q_{Model\ Test}$
m	MW	m^3/s	m^3/s
Turbining mode			
42,28	2,0	13,90	
42,37	5,0	21,80	
42,15	10,0	33,70	
41,94	15,0	46,25	
41,77	20,0	59,00	
41,61	25,0	71,85	72,01
41,41	30,0	85,35	86,02
41,19	35,0	99,30	100,24
40,93	40,0	114,75	114,71
Pumping mode			
40,86	43,20	89,91	95,36

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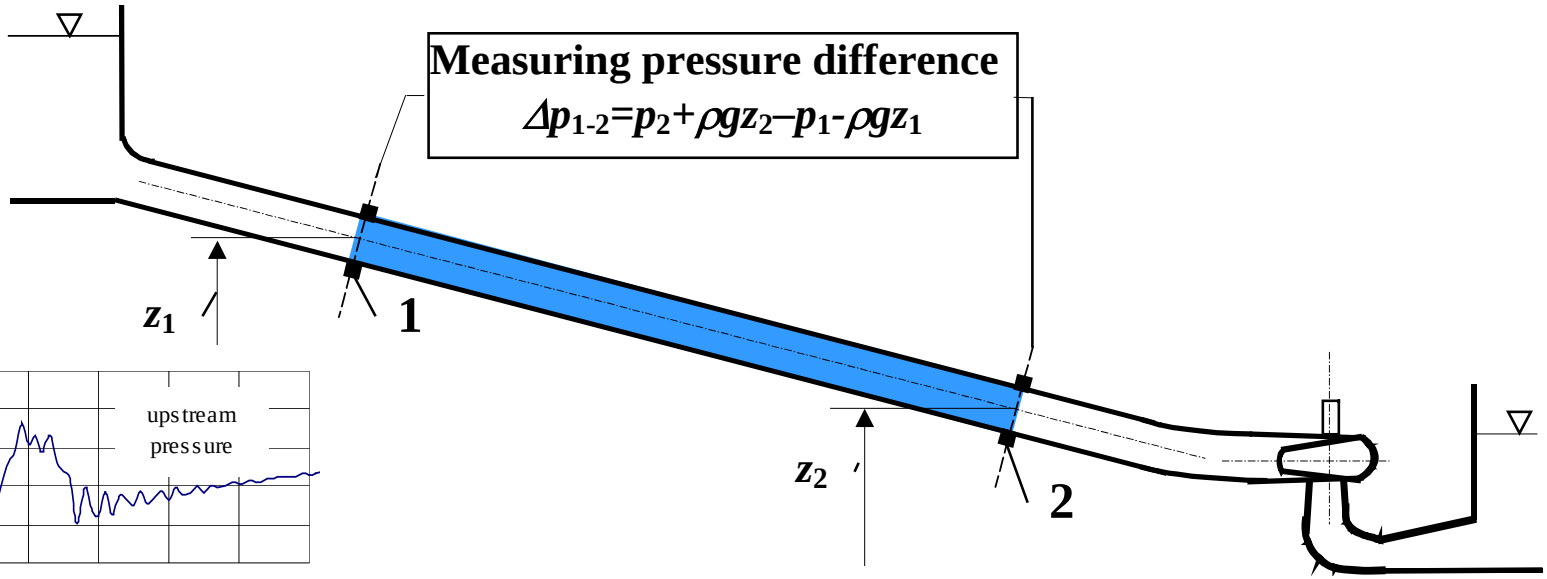
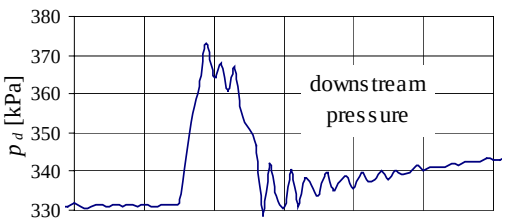
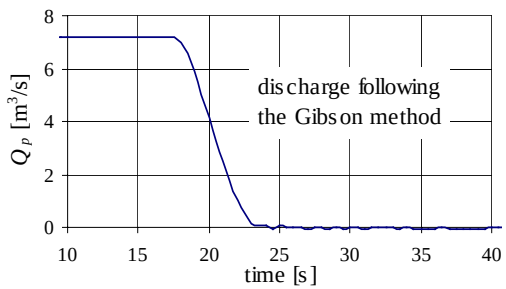
The flow meter passed the test.

GIBSON METHOD PRINCIPLE





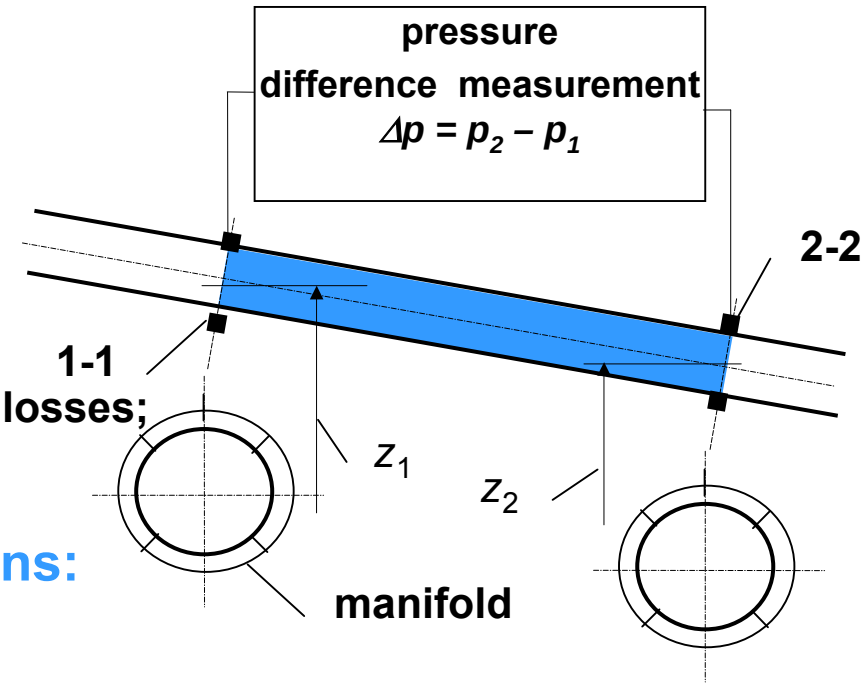


Gibson method utilizes the effect of water hammer phenomenon in a pipeline when water flow is stopped using a cut-off device. The flow rate is determined by integrating the measured pressure difference change caused by the water hammer (inertia effect).

THEORETICAL BASIS

Equation of motion

$$p_1 + \rho g z_1 = p_2 + \rho g z_2 + P_f + \frac{\rho L}{A} \cdot \frac{dQ}{dt}$$



p_1, p_2 – **mean static pressures;**

z_1, z_2 – **hydrometric section weight center elevations;**

P_f – **pressure drop caused by friction losses;**

ρ – **water density**

Discharge value in the initial conditions:

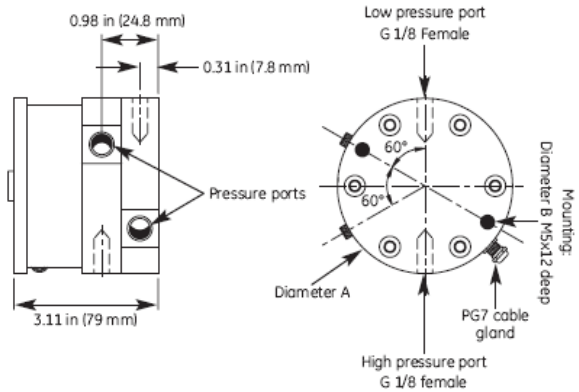
$$Q_0 = \frac{A}{\rho L} \int_{t_0}^{t_k} [\Delta p(t) + P_f(t)] dt + Q_k$$

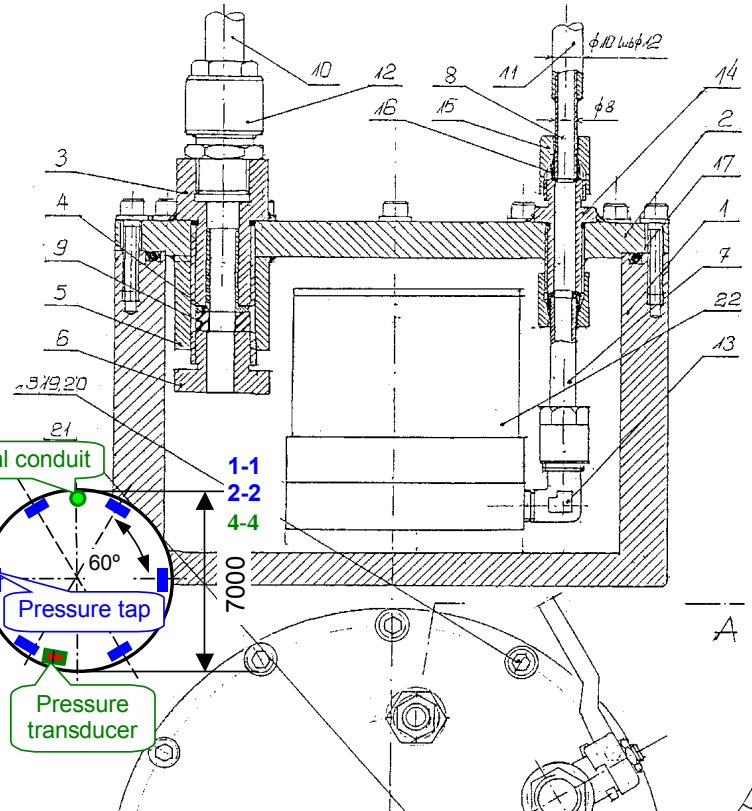
$\Delta p = p_2 + \rho g z_2 - p_1 - \rho g z_1$ – **static pressure difference ,**

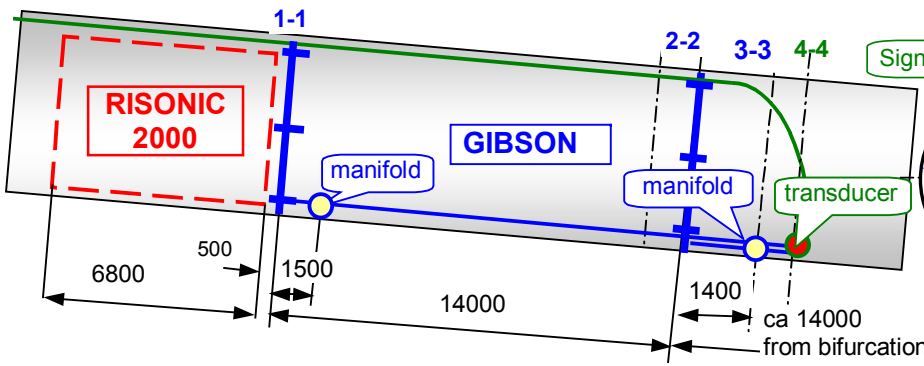
Q_k – **discharge under final conditions,**

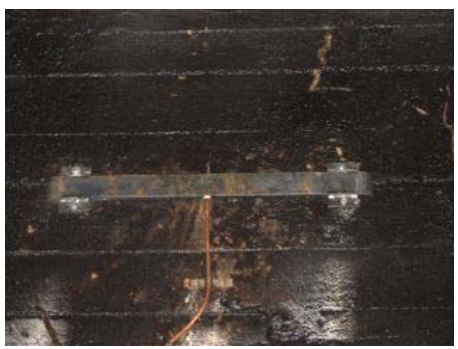
(t_0, t_k) – **time interval**

GIBSON METHOD INSTRUMENTATION

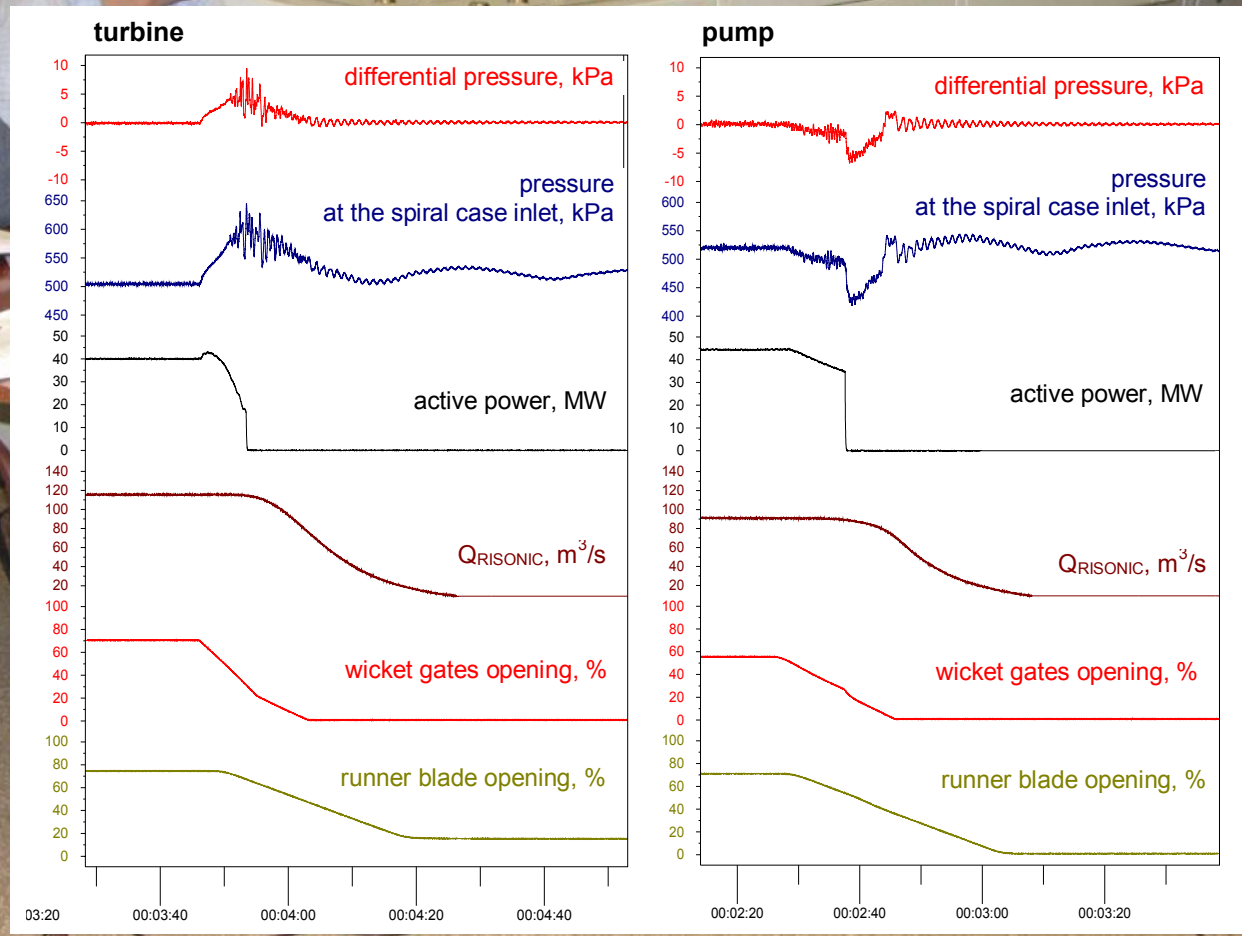




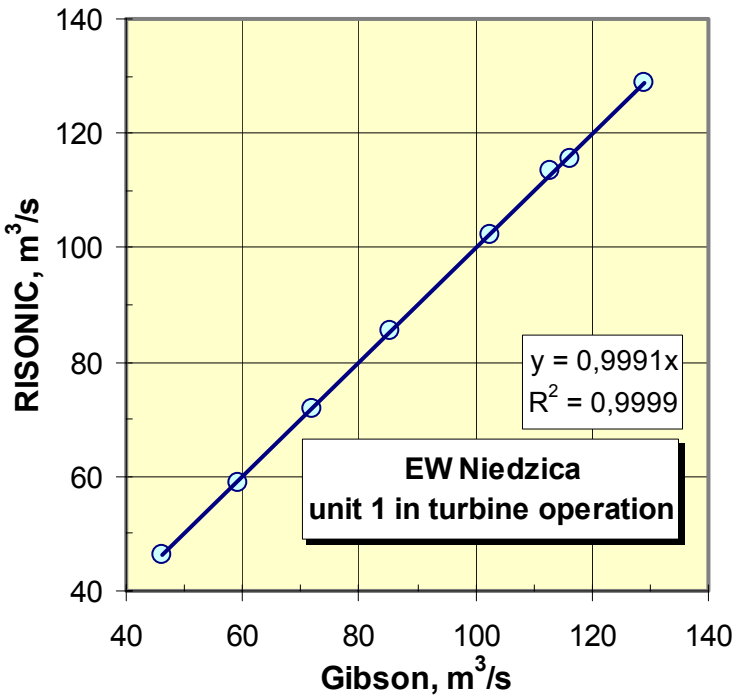


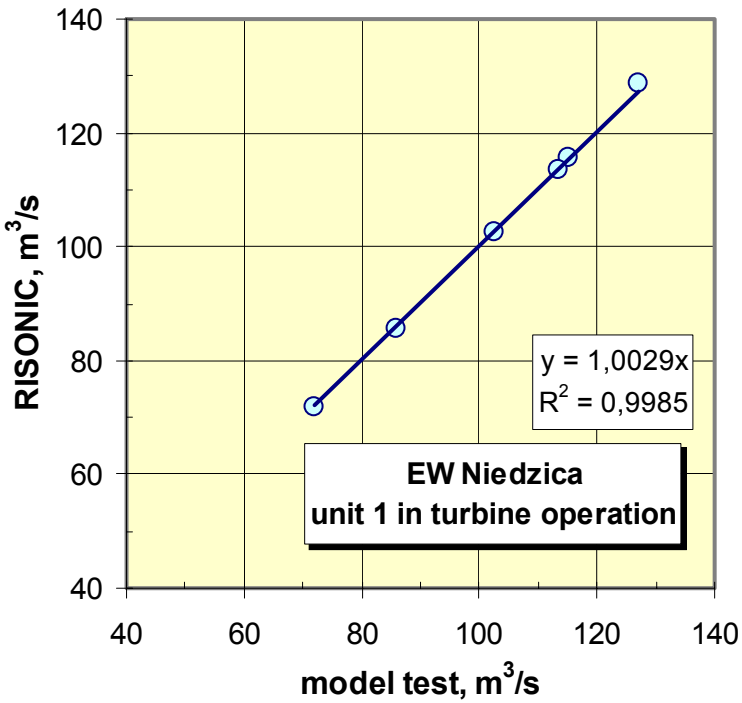


Data acquisition



Unit 1 discharge in the turbine mode of operation as measured using the Gibson and ultrasonic methods, and determined basing on the model test results





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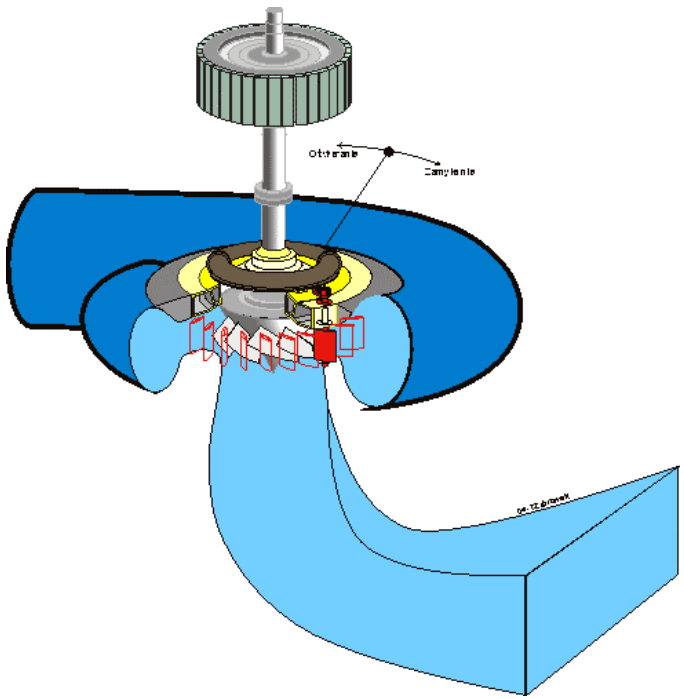
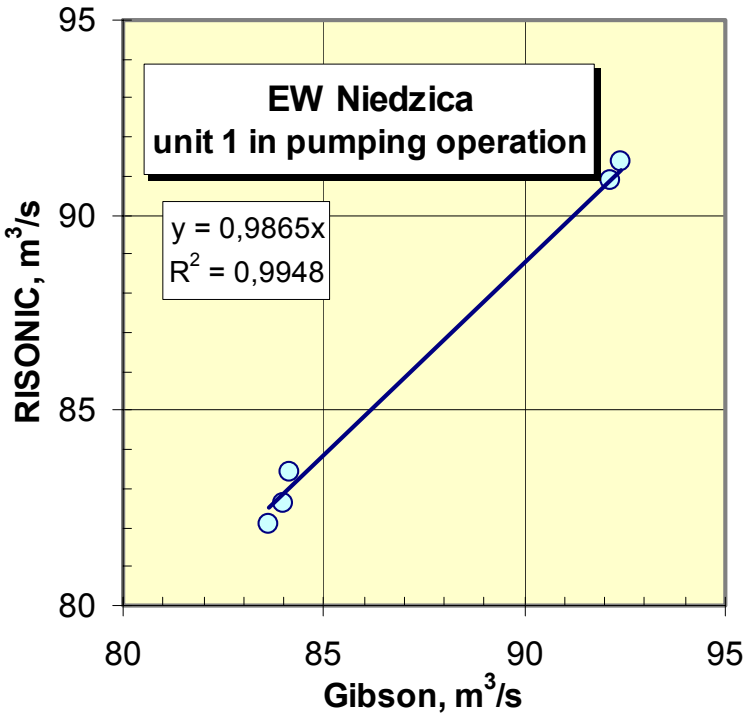
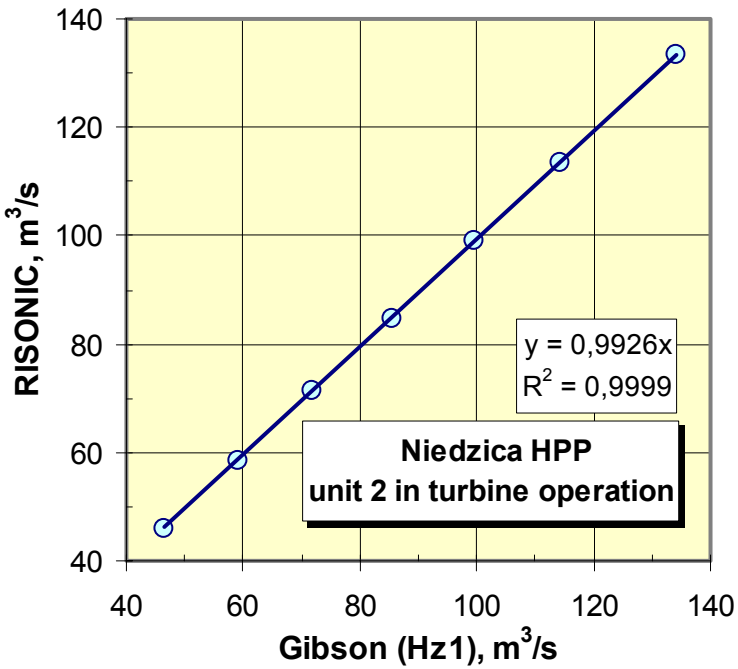
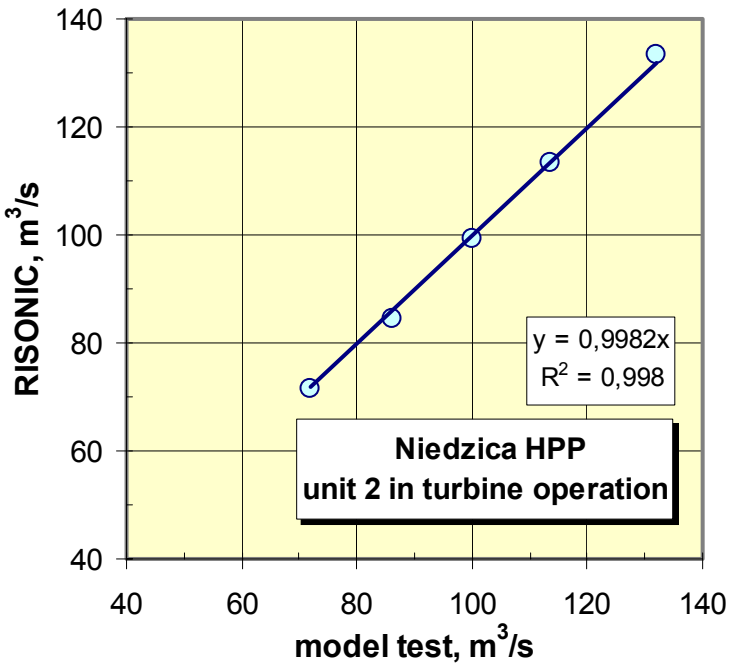
Unit 1 discharge in the pumping mode of operation as measured using the Gibson and ultrasonic methods





Unit 2 discharge in the turbine mode of operation as measured using the ultrasonic method, and determined basing on the Unit 1 characteristics





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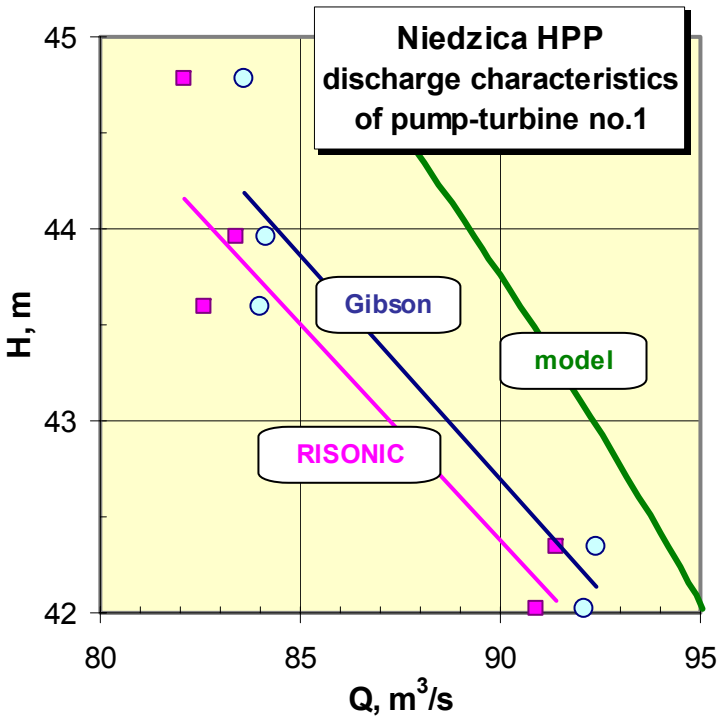
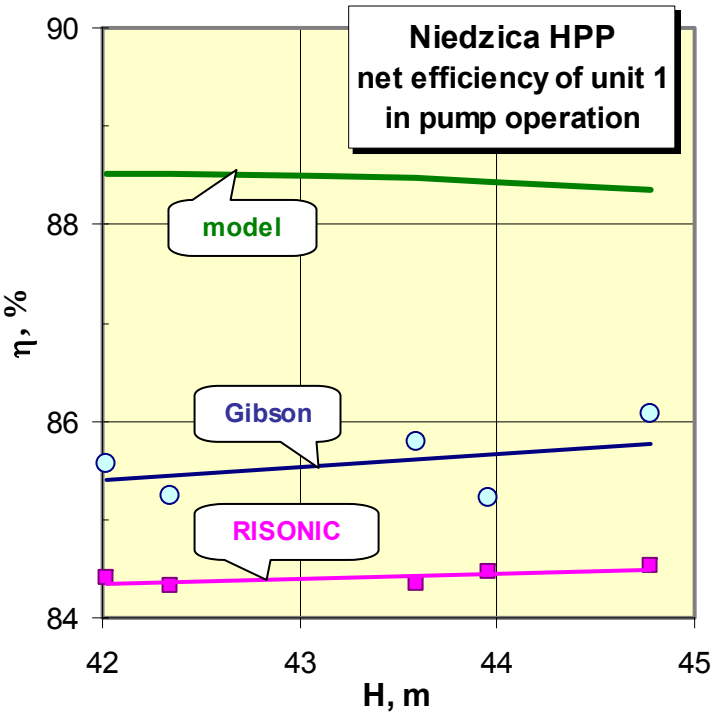
Unit 1 performance in the pumping mode of operation





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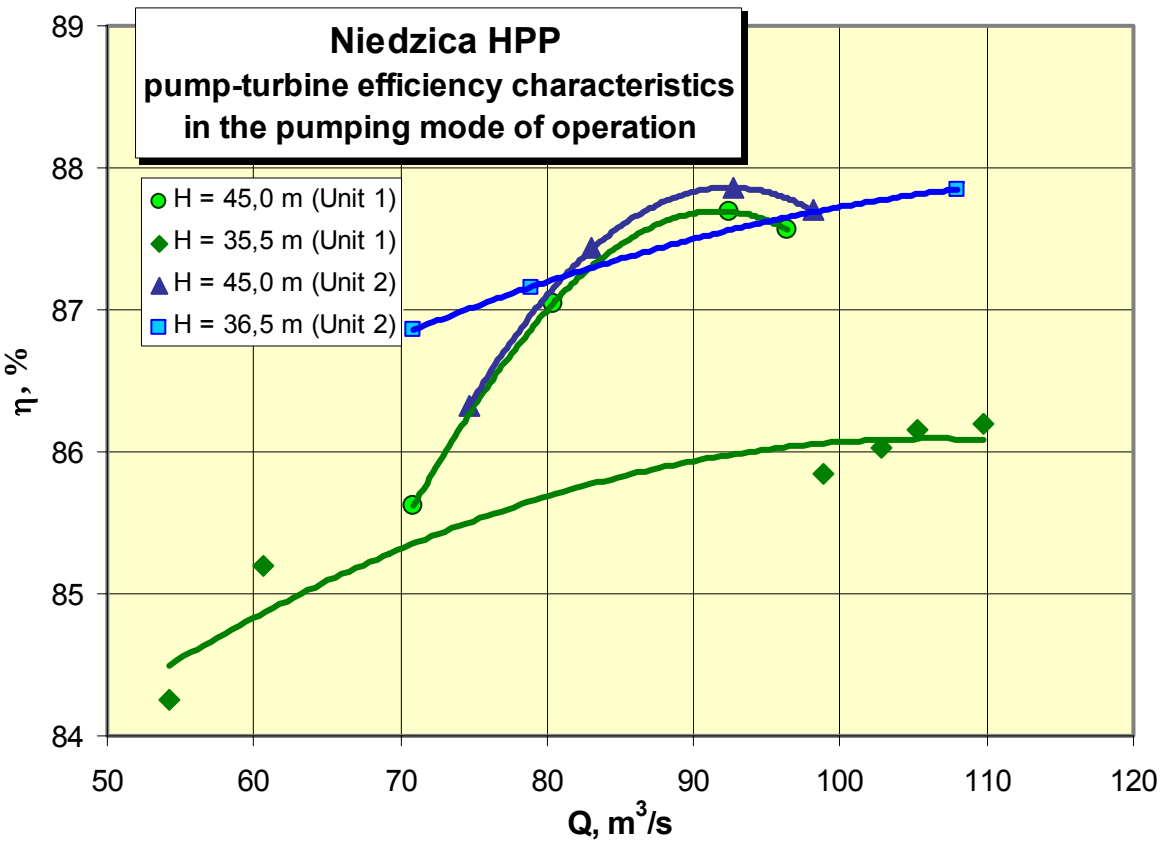
Performance tests:
Efficiency characteristics in the pumping mode of operation



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Conclusion

1. *The ultrasonic discharge measurement instrumentation installed in Niedzica Hydropower Plant is in faultless operation for over 1.5 year, contributing essentially to the local green energy accounting system.*
2. *The accuracy of the installation fulfils expectations in both modes of operation and can be hardly challenged by any other discharge measurement method.*

   In case of reversible hydraulic units, no reasonable alternative system for a permanent discharge measurement can be proposed.
3. *In the pumping regime, the velocity field fluctuations at off–design points of operation (low head) probably affect ultrasonic measurement close to the spiral case outlet.*

Thank you for your attention !