INSTITUTO DE PESQUISAS TECNOLÓGICAS

FLOMEKO2019

18th International Flow Measurement Conference

Portugal | Lisbon | LNEC | 26-28 june 2019

Pitometry as a validation tool for water flow measurement in large diameter pipelines

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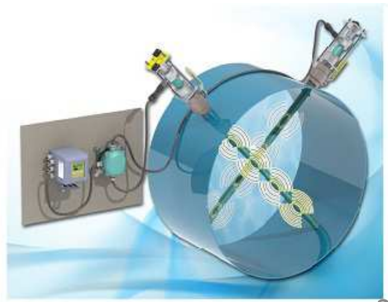
1. Introduction

Due to technical and economic reasons, the accurate measurement of water flow rates in large diameter pipelines is a challenge for water supply companies that everyday need to produce, transport and distribute increasing quantities of water.

It is also an incitement for manufacturers of flowmeters that are requested to offer solutions to this progressively challenging metrological demand.



1. Introduction

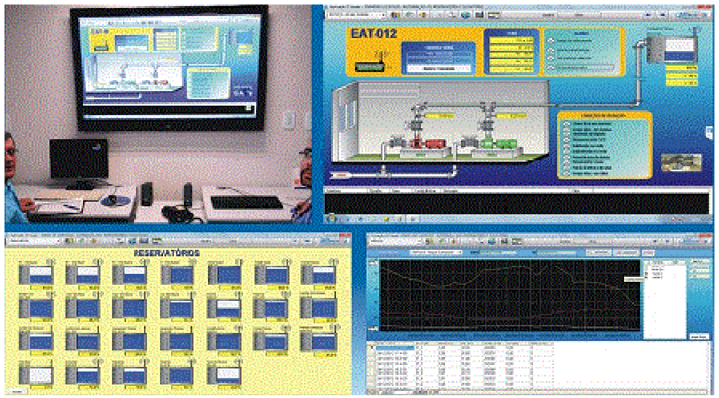
In the last decades, based on the development of sensors, electronic signal processors and software, it has been possible to witness the appearance of new water flow measurement technologies.

Electromagnetic full bore meters

Ultrasonic transit time flowmeters

Electromagnetic and thermal insertion meters

These developments have been induced by the need for automation and control of water flow measurement processes and the requirement for more accurate and reliable flow measurement results.

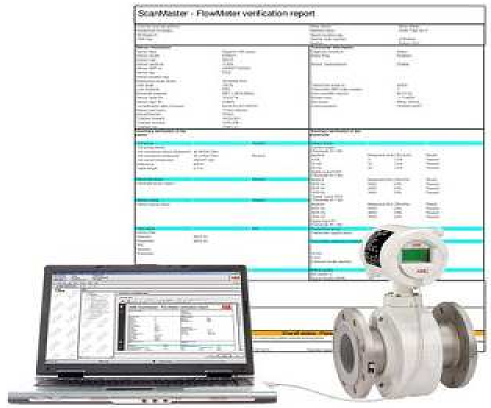


1. Introduction

Despite the natural process of modernization of the flow measurement systems used by the water companies, what we see in practice is a series of issues arising from the application of these new technologies in such situations. Notably, the following topics deserve mention:

- ? the removal of a large full-bore diameter flowmeter from its site of operation in the field and its dispatch to a calibration laboratory is in most cases technically and economically unfeasible. So, the issue of recalibration of the flowmeters within the periodicity established in metrological regulations still remains unsolved.

- ? the signal acquisition and treatment systems in these meters use proprietary electronics and software that are difficult to be audited and validated from the perspective of Legal Metrology, affecting the transparency and reliability of flow measurement results.

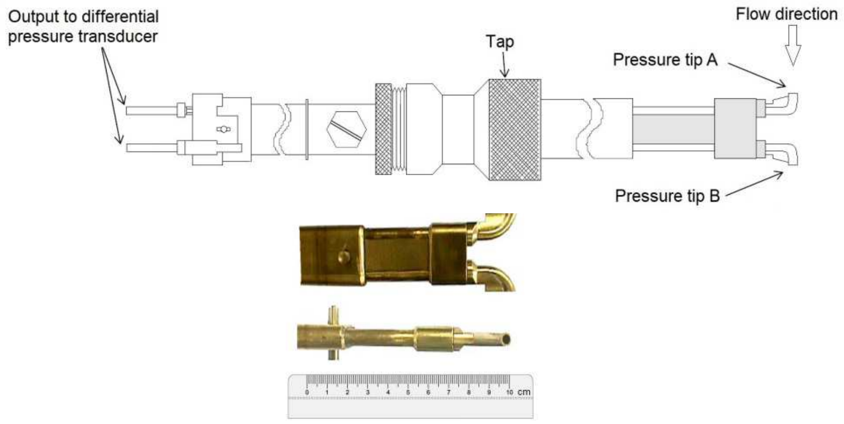


2. Pitometry technique

Considering the worrying issues presented previously, the Fluid Flow Laboratory of IPT-*Instituto de Pesquisas Tecnológicas*, a technological research institute in Brazil, developed a methodology for measuring water flow rate in large conduits based on the fundamental technique of pitometry and using the Cole type Pitot tube for mapping the flow velocity profiles in the pipes.

2.1 Cole type Pitot tube

The Cole type Pitot tube is a differential pressure probe designed by Edward Cole around 1896 and is composed of two parallel tubes of approximately 6 mm outside diameter, bent at a 90º angle and oppositely oriented at the ends.



The front tip to the flow (tip A) measures the total pressure and the other (tip B) measures the pressure of the wake flow, defining a differential pressure signal measured by pressure transducers and that is proportional to the square of the flow rate of the liquid.

2. Pitometry technique

In the measurement of water flow rates in large pipes it is common to use a modified Cole-type Pitot tube which has a safety pin located in between the tips to protect them from possible damage caused by their impact against the internal wall of the pipe during insertion of the probe.

Modified Cole type Pitot tube with a safety pin in between the tips.

2. Pitometry technique

2.2 Cole type Pitot tube calibration

Tests conducted at IPT using an aerodynamic wind tunnel and a large towing tank showed that Cole type Pitot tubes can be calibrated in air flows and used in water flows, provided that the Reynolds number similarity is respected.

IPT aerodynamic wind tunnel (test section of 0.5 m x 0.5 m)

IPT Towing tank with 280 m long x 6.6 m width x 4.0 m depth

2. Pitometry technique

A conventional L-type Pitot-static tube, calibrated by a LDA, is used as a reference air velocity probe.

Both Pitot tubes are connected to pressure transducers and two rising sequences of points consisting of ten air flow velocities between 5 m/s and 36 m/s are compared.

Based on Reynolds numbers similarity

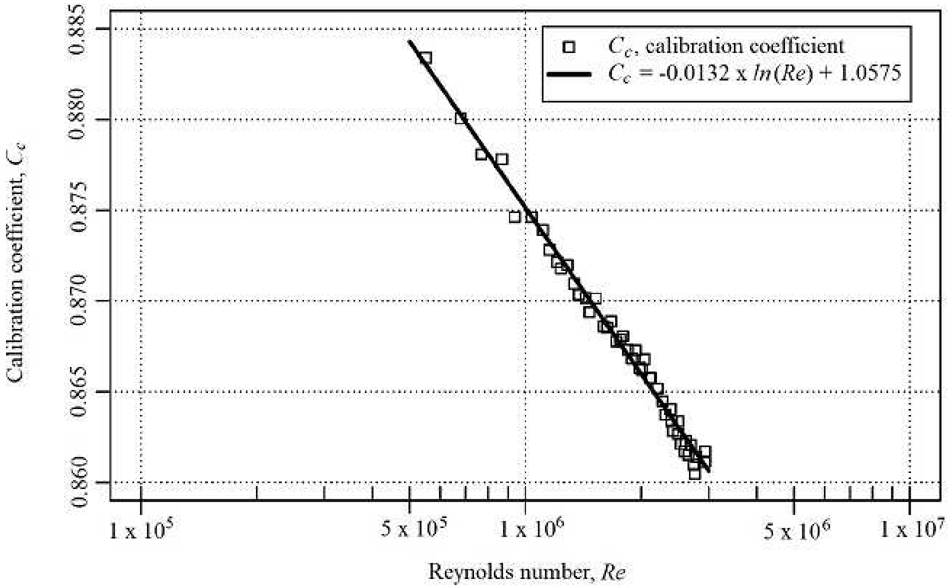
$$Re_{water} = Re_{air} \qquad (1)$$

these air flow velocity limits correspond to water flow velocities of 0.3 m/s and 2.4 m/s, respectively.

2. Pitometry technique

The mean calibration coefficient recommended by the literature for conventional Cole type Pitot tubes, including corrections, is **0.8696**.

However, figure shows the dependence of calibration coefficient (C_c) of the Cole type Pitot tube to the flow Reynolds number.



Reynolds number dependence of calibration coefficient (C_c) of Cole type Pitot tubes

Source: CETESB Sao Paulo *Manual de pitometria*.

Reynolds number is defined as:

$$Re = \frac{V\,L}{\nu} \qquad (2)$$

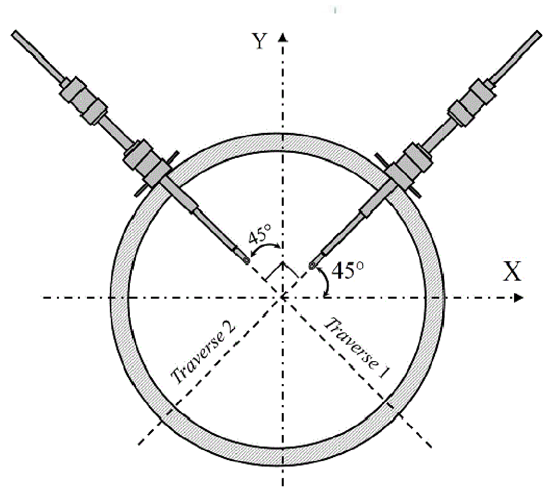
where V is the fluid flow velocity in m/s, L is a characteristic length, here fixed as 1 m, ν = 1.004 x 10^{-6} m/s^2 is the kinematic viscosity of water at 20 °C.

2. Pitometry technique

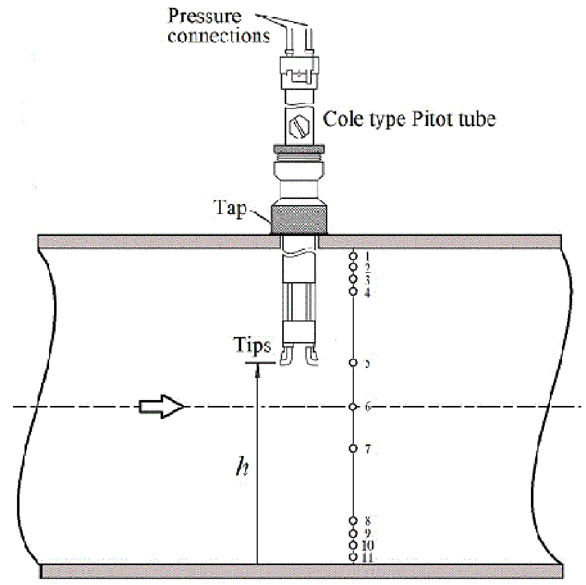
2.3 Flow velocity profile

For the determination of the water flow rate, the guidelines of the technical standard **ISO 3966** are followed for the calculation of the mean flow velocity in the cross section of the pipe using Cole-type Pitot tube and the log-linear method for the mapping of the flow velocities at eleven points distributed along the conduit measuring diameter.

The measurement positions along the measuring diameter with respect to the reference dimension h.



Position of the taps for mapping the flow velocity profile along two diameters arranged perpendicularly to each other.



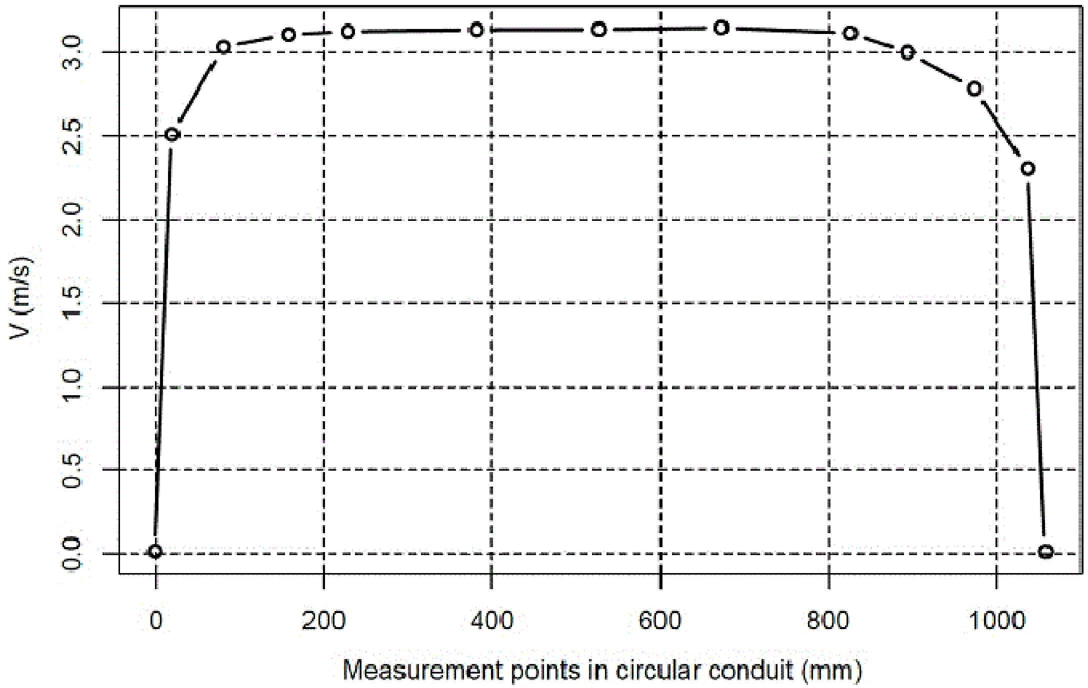
Positions of velocity measurement points along the traverse.

ISO 3966:2008 *Measurement of fluid flow in closed conduits - Velocity area method using Pitot static tubes*, reviewed and confirmed in 2012.

2. Pitometry technique

2.3 Flow velocity profile

Example of water flow velocity profile depicted from the velocity measurement points.



Water flow velocity profile determined by mapping the flow velocities at points along the conduit measuring diameter.

2. Pitometry technique

2.4 Volumetric flow rate calculation

The volumetric flow rate of water (Q) in the conduit is calculated as a function of the average flow velocity ($\overline{V}$) in the measuring section and the internal cross-sectional area (S) of the measurement location.

$$Q = \overline{V} \cdot S \qquad (4)$$

where:

$$\overline{V} = C_c \cdot \frac{\sum_{i=1}^{n} \sqrt{\frac{2 \cdot \Delta P_i}{\rho_o}}}{n} \qquad (5)$$

and:

C_c calibration coefficient of the Cole type Pitot tube

ΔP_i differential pressure at each point i ($i = 1,\ldots, n$) of the velocity mapping

ρ_0 water density under measurement conditions

2. Pitometry technique

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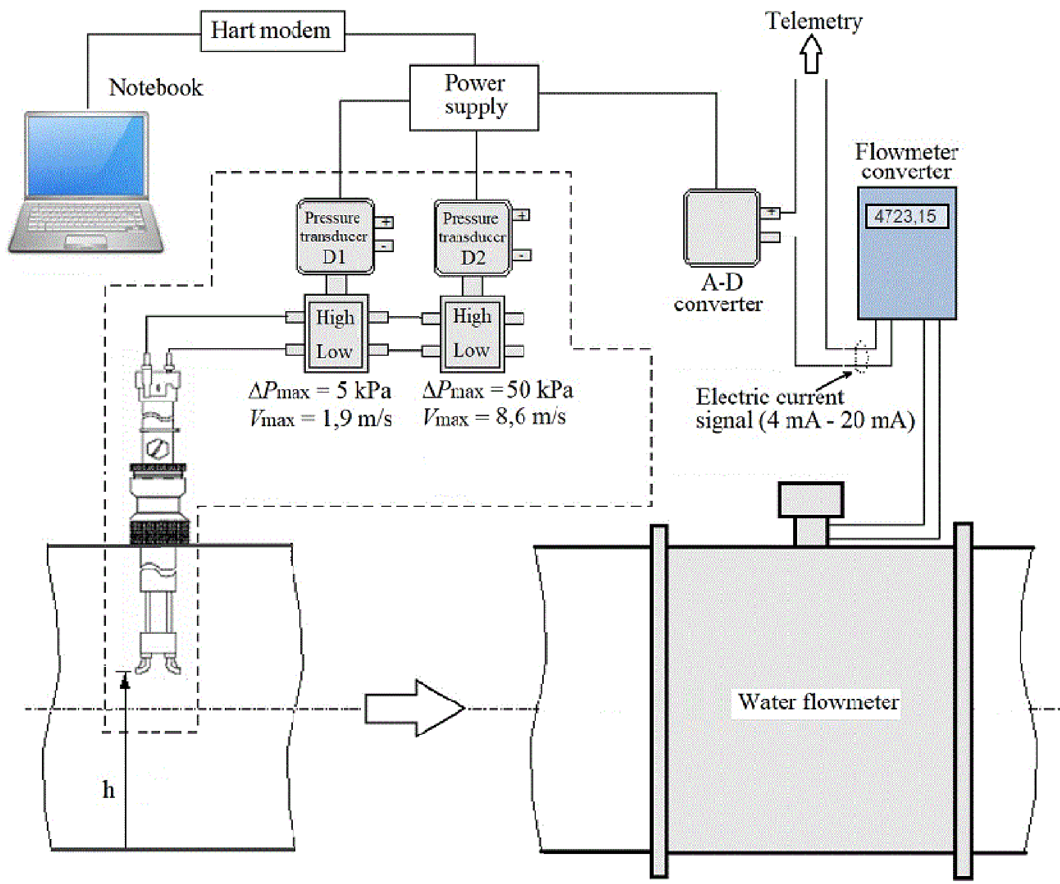
2.5 Instrumentation scheme

The methodology developed and applied by IPT allows the monitoring of the signal of a flow meter present in series in the same pipeline during the process of mapping the velocity profile.

A data logger collects the electrical output signal of the flow meter making it possible to simultaneously perform the calibration of the flowmeter and correct for possible flow fluctuations that may occur during measurements.



Scheme of the instrumentation used for the mapping of flow velocity profiles using the pitometry technique.

3. Case study

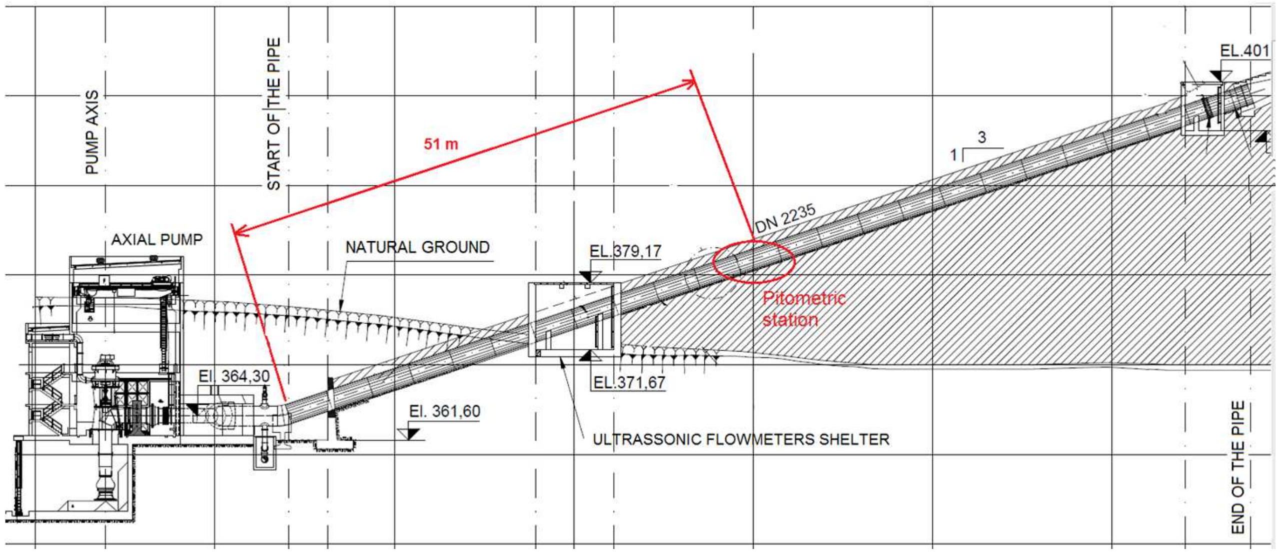
3.1 Description of the installation

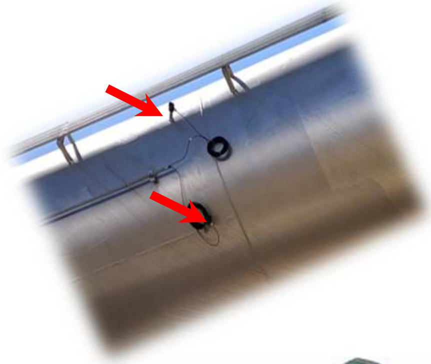
A water pumping station which operates with two axial hydraulic pumps of same size in parallel. In the discharge pipeline of 2232 mm internal diameter, made in steel, there is installed a dual path transit time ultrasonic flowmeter with two pairs of transducers which needed to have its metrological performance evaluated.

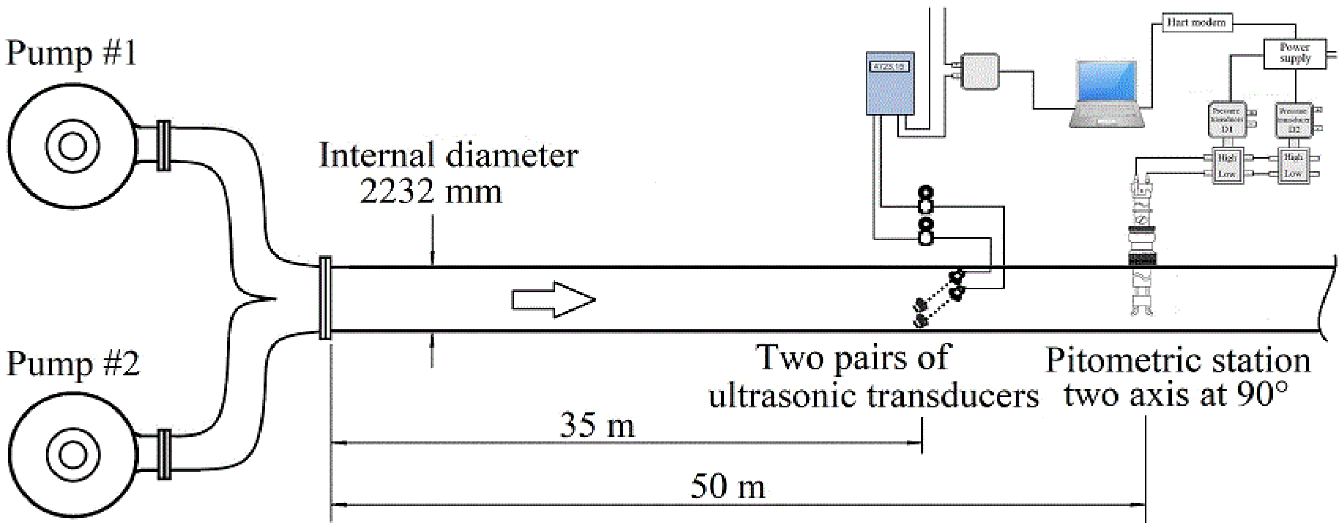




3. Case study


PUMP AXIS
START OF THE PIPE
51 m
AXIAL PUMP
NATURAL GROUND
EL.379,17
DN 2235
Pitometric
station
EL.401
EL.371,67
El. 364,30
El. 361,60
ULTRASSONIC FLOWMETERS SHELTER
END OF THE PIPE

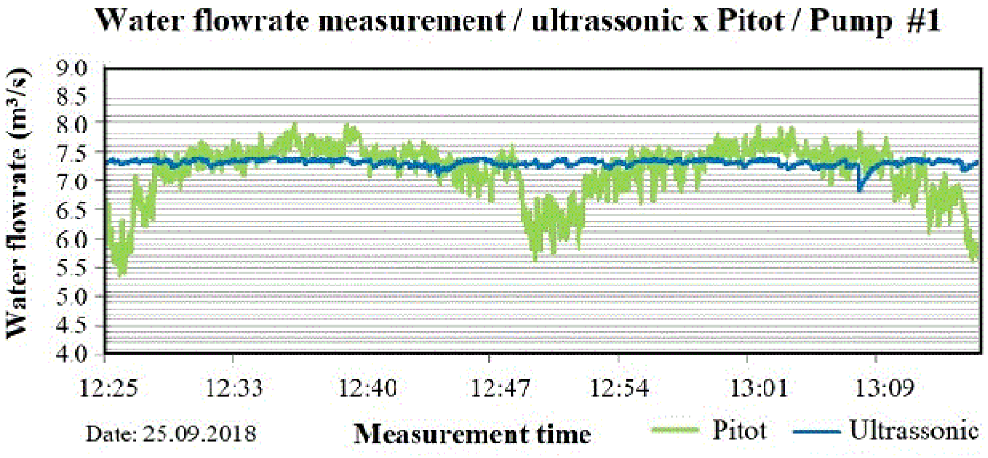



Pump #1
Pump #2
Internal diameter
2232 mm
Two pairs of
ultrasonic transducers
Pitometric station
two axis at 90°
35 m
50 m
Hart modem
Power
supply

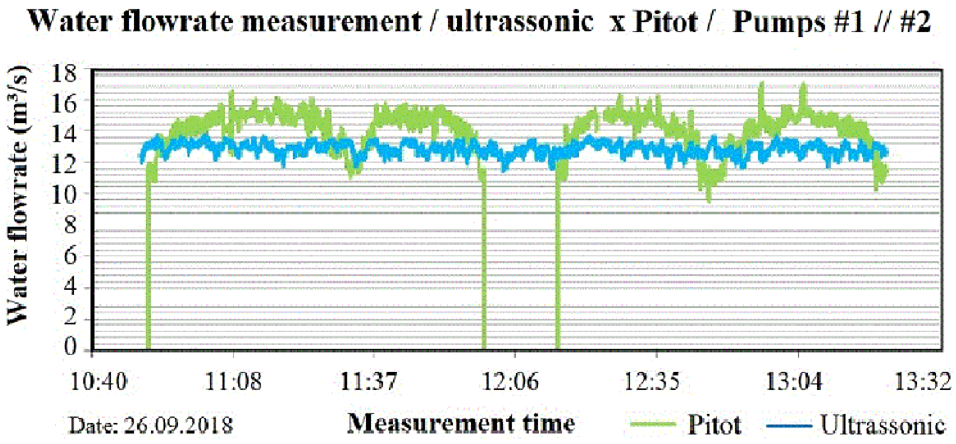
3. Case study

3.2 Results of flow velocity profiles mapping

Water flow rates measured by the ultrasonic meter versus pitometry, only with the pump #1 in operation.



Water flow rates measured by the ultrasonic meter versus pitometry, with pumps #1 and #2 operating in parallel.



3. Case study

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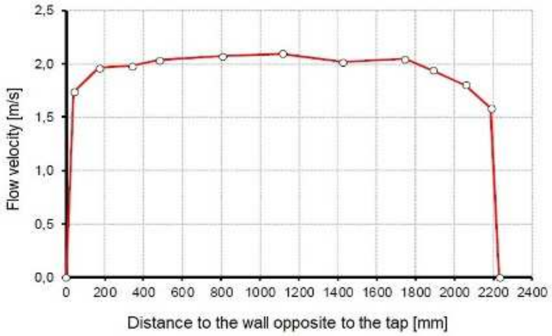
Worksheet for Pitometric Mapping

Local:	EBV-4 - Pump #1	**Nominal diameter of the pipe:**	2300 mm	**Cross sectional area:**	3,9127 m²
Date:	25.Sept.2018	**Measured vertical internal diameter:**	2230 mm	**Equivalent diameter:**	2232 mm
Technicians:	Leonardo / Kazuto / Valmir	**Measured horizontal internal diameter:**	2234 mm	**Tip diameter:**	6,00 mm

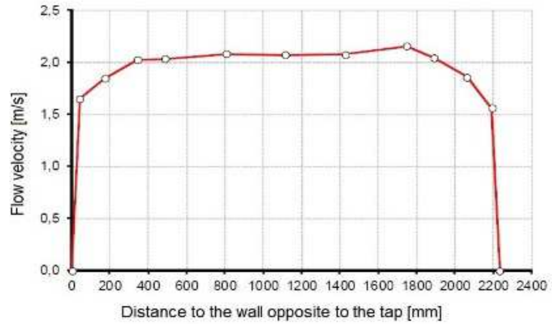
Vertical Traverse

Point h	Position (y/D)	Corrected distance (mm)	Distance from lower wall y (mm)	Velocity (m/s)	Corrected velocity (m/s)	Corrected velocity Pitot (m/s)
0	1	2224	2230	0,00	0,00	0,00
1	0,981	2182	2188	1,59	1,59	1,59
2	0,923	2052	2058	1,80	1,80	1,80
3	0,847	1883	1889	1,94	1,94	1,94
4	0,783	1740	1746	2,05	2,05	2,05
5	0,639	1419	1425	2,02	2,02	2,02
6	**0,500**	**1109**	**1115**	**2,10**	**2,10**	**2,10**
7	0,361	799	805	2,08	2,07	2,07
8	0,217	478	484	2,04	2,04	2,04
9	0,153	335	341	1,99	1,98	1,98
10	0,077	166	172	1,97	1,96	1,96
11	0,019	36	42	1,75	1,74	1,74
12	0,000	-6	0	0,00	0,00	0,00



Horizontal Traverse

Point h	Position (y/D)	Corrected distance (mm)	Distance from lower wall y (mm)	Velocity (m/s)	Corrected velocity (m/s)	Corrected velocity Pitot (m/s)
0	1	2228	2234	0,00	0,00	0,00
1	0,981	2186	2192	1,56	1,56	1,56
2	0,923	2056	2062	1,86	1,86	1,86
3	0,847	1886	1892	2,04	2,04	2,04
4	0,783	1743	1749	2,15	2,15	2,15
5	0,639	1422	1428	2,08	2,07	2,07
6	**0,500**	**1111**	**1117**	**2,07**	**2,07**	**2,07**
7	0,361	800	806	2,08	2,08	2,08
8	0,217	479	485	2,04	2,03	2,03
9	0,153	336	342	2,03	2,02	2,02
10	0,077	166	172	1,85	1,84	1,84
11	0,019	36	42	1,66	1,65	1,65
12	0,000	-6	0	0,00	0,00	0,00



Measured flowrate (m³/s)			US indicated flowrate (m³/s)		
Value	Expanded uncertainty		Value	Measurement error	
7,53	**0,147**	**2,0 %**	**7,28**	**-0,25**	**-3,3 %**

Pitometric data and flow velocity profiles in the discharge pipeline of the pumping station operating only with pump #1.

3. Case study

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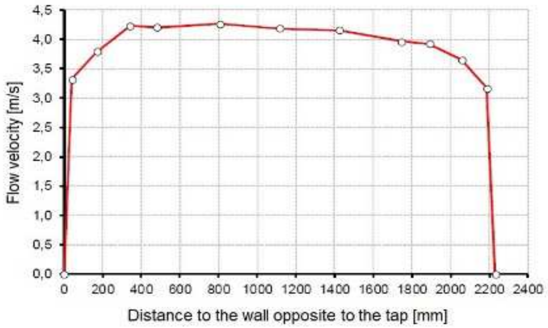
Worksheet for Pitometric Mapping

Local:	EBV-4 - Pump #1 + Pump #2	**Nominal diameter of the pipe:**	2300 mm	**Cross sectional area:**	3,9127 m²
Date:	26.Sept.2018	**Measured vertical internal diameter:**	2230 mm	**Equivalent diameter:**	2232 mm
Technicians:	Leonardo / Kazuto / Valmir	**Measured horizontal internal diameter:**	2234 mm	**Tip diameter:**	6,00 mm

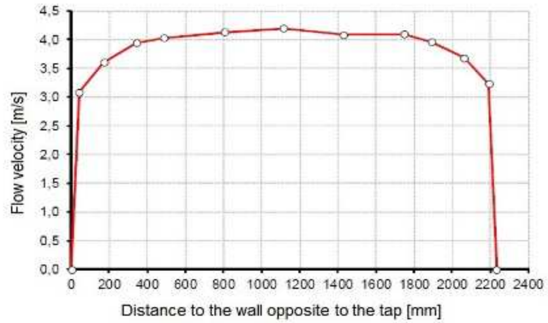
Vertical Traverse

Point h	Position (y/D)	Corrected distance (mm)	Distance from lower wall y (mm)	Velocity (m/s)	Corrected velocity (m/s)	Corrected velocity Pitot (m/s)
0	1	2224	2230	0,00	0,00	0,00
1	0,981	2182	2188	3,17	3,17	3,17
2	0,923	2052	2058	3,65	3,65	3,65
3	0,847	1883	1889	3,93	3,93	3,93
4	0,783	1740	1746	3,97	3,96	3,96
5	0,639	1419	1425	4,17	4,16	4,16
6	**0,500**	**1109**	**1115**	**4,20**	**4,19**	**4,19**
7	0,361	799	805	4,28	4,26	4,26
8	0,217	478	484	4,22	4,20	4,20
9	0,153	335	341	4,25	4,23	4,23
10	0,077	166	172	3,80	3,79	3,79
11	0,019	36	42	3,34	3,32	3,32
12	0,000	-6	0	0,00	0,00	0,00



Horizontal Traverse

Point h	Position (y/D)	Corrected distance (mm)	Distance from lower wall y (mm)	Velocity (m/s)	Corrected velocity (m/s)	Corrected velocity Pitot (m/s)
0	1	2228	2234	0,00	0,00	0,00
1	0,981	2186	2192	3,23	3,23	3,23
2	0,923	2056	2062	3,68	3,68	3,68
3	0,847	1886	1892	3,96	3,96	3,96
4	0,783	1743	1749	4,10	4,10	4,10
5	0,639	1422	1428	4,10	4,09	4,09
6	**0,500**	**1111**	**1117**	**4,21**	**4,20**	**4,20**
7	0,361	800	806	4,15	4,13	4,13
8	0,217	479	485	4,05	4,03	4,03
9	0,153	336	342	3,96	3,94	3,94
10	0,077	166	172	3,62	3,60	3,60
11	0,019	36	42	3,11	3,09	3,09
12	0,000	-6	0	0,00	0,00	0,00

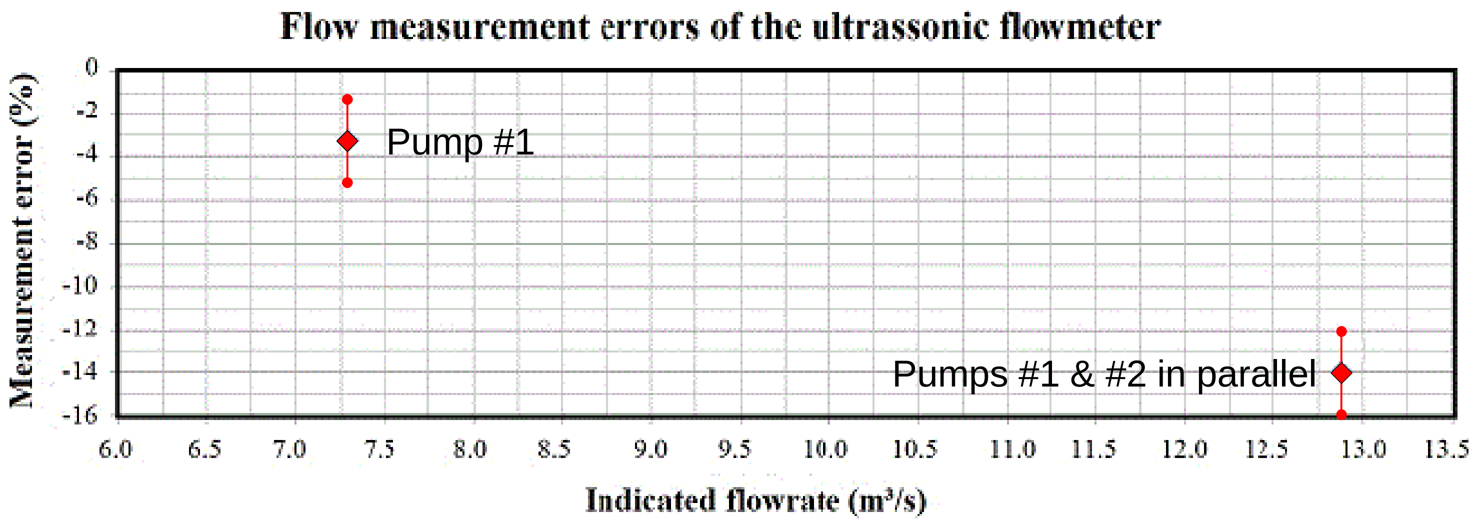


Measured flowrate (m³/s)			US indicated flowrate (m³/s)		
Value	Expanded uncertainty		Value	Measurement error	
14,97	**0,286**	**1,9 %**	**12,88**	**-2,09**	**-14,0 %**

Pitometric data and flow velocity profiles in the discharge pipeline of the pumping station operating with pumps #1 and #2 in parallel.

3. Case study

Measurement errors determined in the calibration of the ultrasonic flow meter at the pump station operating flow rates.



Uncertainties associated with the measured values were of the order of 2.0 %.

4. Conclusions

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- ✓ The good results obtained in a large number of measurements in the field show that the fundamental technique of pitometry is a quite appropriate tool for validation of water flow rate measurement in large diameter pipelines.

- ✓ The pitometry technique allows recalibration of the flow meters within the periodicity established in the metrological regulations without the need to removal of the flow meter from its local of operation in the field.

- ✓ In addition, it is not necessary to know and dominate the acquisition and signal processing technology used by these meters since the end result of the measurement system as a whole is validated to ensure the reliability and metrological traceability of flow measurement results.

- ✓ Although the uncertainties are greater when compared to those obtained in calibrations in a laboratory test bench, they can be improved with the technical standardization of the shape and dimensions of the Cole type Pitot tubes, by improvement of the calibration methods of the probes and by using techniques of mathematical modelling of the flow.

Thank you

for your attention!