EXPERIMENTING WITH A NEW CALIBRATION METHOD FOR CURRENT METERS

Erica Camnasio, Enrico Orsi
D.I.I.A.R. - Politecnico di Milano

erica.camnasio@polimi.it – enrico.orsi@polimi.it

ABSTRACT

The necessity of a simple way to control the reliability of laboratory's current meters brought to develop a method that allows to calibrate the instruments in their usual working conditions, as it happens, for example, in a river or in a sewer, using an equipment simpler than the traditional method: the current meter is still, hung by a support, and the propeller is put in rotation by flow through totally submerged outflows, exploiting the main characteristic of these outflows, that is a uniform velocity profile on all the cross-section.

Since current meter is a local velocity gauger, the influence of current meter's position, respect to the outflow, on velocity measurements reliability, has been investigated. In fact, the current must be linear to obtain satisfying discharge measurements.

Two different kinds of submerged outflows has been analyzed: a flow nozzle and an orifice plate. The problem about the orifice plate is to localize with accuracy where the contracted section A_c is located, that is to say where current is linear, and which is the contraction ratio C_c. Usually, the contracted section is considered to be $D_{OP}/2$ far from the outflow.

On the contrary, the flow nozzle doesn't cause a contracted section, because of its well-connected entrance; nevertheless, there is a lot of turbulence around it, because of liquid jet expansion, but, near the outflow, current may be considered linear, assuming, as reference piezometric line, that of the axial flow pattern.

To confirm the hypothesis at the basis of the method, that is a uniform velocity distribution on all the cross section, velocity profiles along two directions, horizontal and vertical, have been studied, showing results matching with theory.

A calibration method consists in putting into relationship the number of propeller's rates in a fixed time interval with current velocity, determining instrument's characteristic calibration curve; in this case, two reference current velocities have been adopted for calibration: the one is the ratio between discharge (indicated by an electromagnetic flow meter) circulating in the system and outflow's area; the other is obtained by the Torricelli's formula, measuring the difference between upstream and downstream reservoirs' levels. In particular, the propellers of two current meters, different in dimension and typtology, have been calibrated by the new method.

In the end, since a measurement is complete only if associated to its uncertainty, the uncertainty of measurements carried out has been calculated, in particular about Torricelli's velocity.

1. Experimental equipment

Calibration's operations have been carried out in G. Fantoli hydraulic laboratory in Politecnico of Milano. This laboratory is endowed with a pumping system that feeds a series of constant level reservoirs from which some pipes start; one of these conduits feeds a channel that brings water into the current meters calibration tank.

Then, the water goes out from the tank through a rectangular weir and it is gathered and recirculated in the system.

The flow is regulated by a valve at the end of the pressurized conduit, and it is measured by an electromagnetic flowmeter.

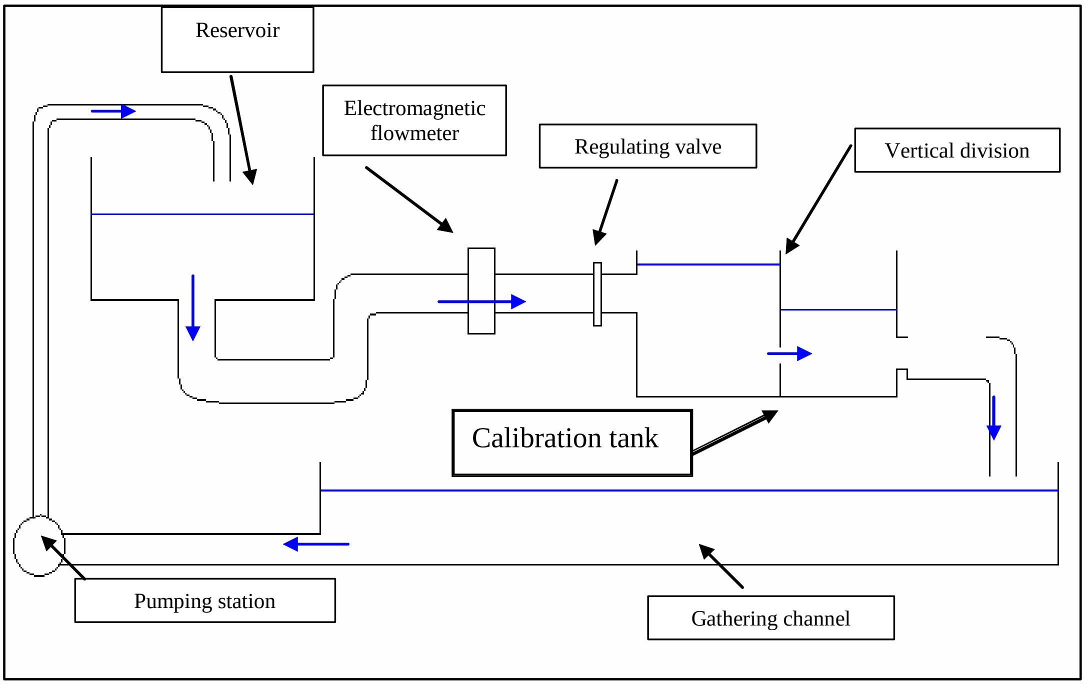

Figure 1 – The calibration hydraulic system

The calibration tank is divided in two parts by a vertical division endowed with 2 outflows: a flow nozzle D_{FN} = 105 *mm* and an orifice plate D_{OP} = 247 *mm*, having the centre at the same height over tank's bottom.

Figure 2– Flow nozzle and orifice plate from upstream to downstream

Tank	Length	2,00 *m*
	Depth	1,20 *m*
	Width	1,80 *m*
Flow nozzle	Diameter	0,105 *m*
	Area	0,00866 m^2
Orifice plate	Diameter	0,247 *m*
	Area	0,048 m^2

Table 1 – Geometrical characteristics of experimental equipment

Figure 3 – Calibration tank – from upstream to downstream

At the end of the channel that feeds the tank there is a thin grid to dissipate the cynetic energy of incoming water current, while, to reduce turbulences in the downstream part of the reservoir, a flow conveyor towards the weir has been realized.

Moreover, supports for staff gauges and for current meter have been placed, in the way that current meter can be placed and fixed in the right position.

2. Calibration curves

Current meters, on which the calibration method has been experimented, already had an assigned calibration curve, but wear and passing of time modify the calibrations curve: so, a periodical verification and recalibration of the instrument is necessary to guarantee measurement's accuracy.

The aim of the experience has been to verify the validity of the pre-existing calibration curves, and, if necessary, to bring them modifications, using the new calibration method. The velocity provided by the pre existing calibration curve of which the instrument was endowed has been compared with two experimental velocities: one obtained from the electro magnetic flow meter, the other from the application of Torricelli's formula to the water levels readings in the two parts of the reservoir.

As known, the calibration of a current meter consists in the experimental determination of the relationship between propeller's angular rotation velocity ω, and current velocity v, obtaining the calibration curve, that is usually a straight line:

$v = a + b*w$

Different values for different fields of w are assigned to constants a and b, as it appears in calibration curves of the first column of Table on page 14, referred to the current meters used in this experience. In particular, a constant is the minimum velocity necessary to win hydraulic and mechanic frictions, while b constant is, for horizontal-axis current meters, very near to propeller pitch. In fact, a propeller not subjected to any kind of friction, put in a perfect fluid in motion, would show a rotation depending on propeller's pitch length.

3. Calibration's operations

Velocity measurements in laboratory have been carried out following these operations, for every calibration point:

- After pumps starting, the tank is filled till the outflow through the nozzle, or the orifice plate, is totally submerged;
- The discharge is regulated by a valve till the wanted value, indicated by the electromagnetic flow meter placed upstream of the calibration tank (Promag 30, D_{EM} = 300 *mm*, uncertainty ± 0.5 % of instant value);
- Once the system has reached the steady state, the levels in the two parts of the tank are measured;
- The chronometer starts and some relevations of number of rates in the fixed time interval are done;
- Since water levels in the two parts of the tank are known, it is possible to calculate Torricelli's velocity v_{torr} (assuming equal to 1 the velocity coefficient):

  $$v_{torr} = \sqrt{2g(H-h)}$$

  Where:
  - H = level in the upstream part of the tank;
  - h = level in the downstream part of the tank.
- On the basis of electromagnetic discharge indication, velocity is determined as $v_{magn} = Q/A_{FN}$, o $Q = Q/Ac_{OP}$;
- The average rates number per second is calculated and experimental points, which link current velocity to propeller's angular velocity of rotation ω [*rps*], are represented on a graph.

In particular, for every propeller two new lines interpolating experimental data can be traced: one interpolating v_{magn} points, one interpolating v_{torr} points. Experimental results show that pre-existing calibration curves (v) reflect quite well experimental data, so they can be considered till valid, confirming, on the other hand, the validity of implemented calibration method (in par.10 the discrepancy between the new calibration curves and the pre-existing is presented).

The new interpolating curves (v_{magn} and v_{torr}) present an high coefficient of linear correlation R^2 of experimental data (Table on page 14) and, in first approximation, it has been chosen not to subdivide interpolating curves in multiple branches, because a singular straight line reflect acceptably experimental points distribution.

It must be noted that the new curves, obtained for mini-current meter's propeller number 3 present a coefficient $a<0$, giustified by the fact that this equation has been obtained only for values of $\omega>2,6$. The same consideration is valid for the river current meter, whose calibration curve has been determined for $\omega>0,4$.

Figure 6 shows the graph about n°601485 current meter calibration, similar to the graphs obtained for every of the other propellers studied, while in Table on page 14, the characteristic propellers' equations are showed.

4. Calibrated current meters

Mini-current meter n° 11347

Figure 4 – Mini – current meter n°11347

Figure 5– Propeller n° 2.2, 2.3, 3

The mini-current meter n°11347 is endowed with a series of propellers, with different identification numbers, characterized by different forms and dimensions, so they can work on different velocity fields. As you can notice in Table on page 14, the pre-existing calibration curves, have a precise field of validity according to propeller's rotation frequency ω: they are formed by segments having different slopes.

A sample of 3 propellers has been calibrated:

- Propeller 3: it is the biggest (D_3 = 40 *mm*), and its operating interval is the largest (0,05 *m/s* < v < 2,5 *m/s*). The measurements carried out had never investigated points having $\omega < 3{,}79$, since there are some limits about discharge circulating in the system; on the other hand, measurements have reached the upper limit of propeller's operating field.
- Propeller 2.3: ($D_{2.3}$ = 30 *mm*) for this propeller too, the "upper part" of its operating field (0,08 *m/s* < v < 1 *m/s*) has been investigated. Only a calibration point under $\omega = 1{,}58$ (value that subdivides the calibration curve into two branches) has been taken, because of the limits about circulating discharge.
- Propeller 2.2: it is the propeller with the narrowest operating field (0,13 *m/s* < v < 1 *m/s*) and it is the smallest propeller ($D_{2.2}$= 15 *mm*): for this reason this propeller has been chosen to carry out lengthwise and crosswise velocity profiles, so that measurements can be as precise as possible. Both the branches of the calibration curve have been investigated, carrying out measurements between 0,3 *m/s* and 0,9 *m/s*.

The n°11347 current meter is linked to a mechanic rates counter, manually set in motion at the same time of a chronometer. At the end of the fixed time interval, the computation of rates and time is stopped. The counter can also emit a sound to check propeller's rotation regularity.

Every tested propeller has been placed at the outlet of the flow nozzle, in the way that the flow is still undisturbed. Five or six calibration points, in correspondence of different discharges, have been carried out, and for each of them 4 readings of velocity have been taken at least, using time intervals of 1 minute.

River current meter n° 601485

This current meter, having a propeller with diameter $D_{riv.}$ = 12 *cm* and 25 *cm* pitch, is very sensitive to small current velocities (operating field 0,05 *m/s* < v < 10 *m/s*) and very constant in rotation. For every half rate of the propeller, a magnet incorporated in the propeller activates a contact and a signal is send to an electronic counter that gives the number of propeller's rates in time interval.

For the calibration of this current meter it has been necessary to use the orifice plate, because instrument's size is too large for the flow nozzle. In this case, since the flow passes through the orifice plate, it is necessary to evaluate contracted section's size (in other words, which is the contraction coefficient to apply to the geometric area) and position, in the way to put the propeller in the section where current is linear. To find contracted section's position, lengthwise velocity profile was investigated, moving away from the orifice plate (par. 8); because this study showed a velocity profile quite constant for a sufficient length, for calibration's operations propeller has been located at a distance of $D_{OP}/2$ = 12,5 *cm*, as suggested in literature.

Thirteen calibration points for this propeller have been measured, using 30 *s* time intervals, and discharges up to 70 *l/s*.

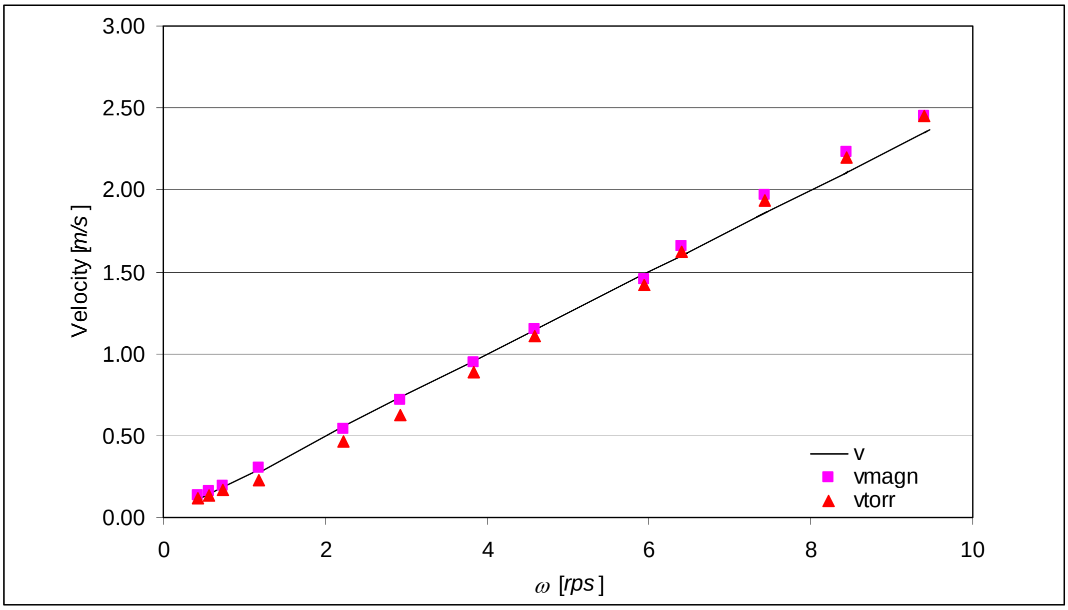

Figure 6 – Calibration graph for river current meter n°601485

5. Experimental equipment's limits

Discharges circulating in the experimental system now available in laboratory, are limited by two factors:

- the inferior limit, about 2 *l/s*, is imposed to guarantee a submerged outflow through the flow nozzle;
- the upper limit is imposed to avoid water overflowing from the upstream tank. This limit corresponds to a discharge of about 70 *l/s* trough the orifice plate, while to a discharge of 21 *l/s* through the flow nozzle.

Since circulating discharges are limited, propellers' velocity fields not always could have been fully investigated, however measurements could spread to a wide velocity range.

6. Lenghtwise velocity profile in front of the flow nozzle

This study has been led to verify how much the distance between current meter and flow nozzle affect the velocities recorded by the instrument. In fact, while next to the outflow current is linear, moving away from the flow nozzle the liquid jet spreads, creating turbulences and velocity decays.

The current meter, located in corrispondence of flow nozzle centre, has been moved away by step, till a distance of 35 *cm*, and for every position current velocity has been recorded. The measurements, done by all the 3 current meter's propellers and using different discharges, have shown that, till a distance of about $2D_{FN}$, recorded velocities are quite constant, while farther velocity shows an evident decrease. So, experimental data well agree with theoric expectations, even if an anomaly has been recorded: at a distance of about $D_{FN}/4$, velocities not in agreement with expected velocity profile have been found in all tests carried out.

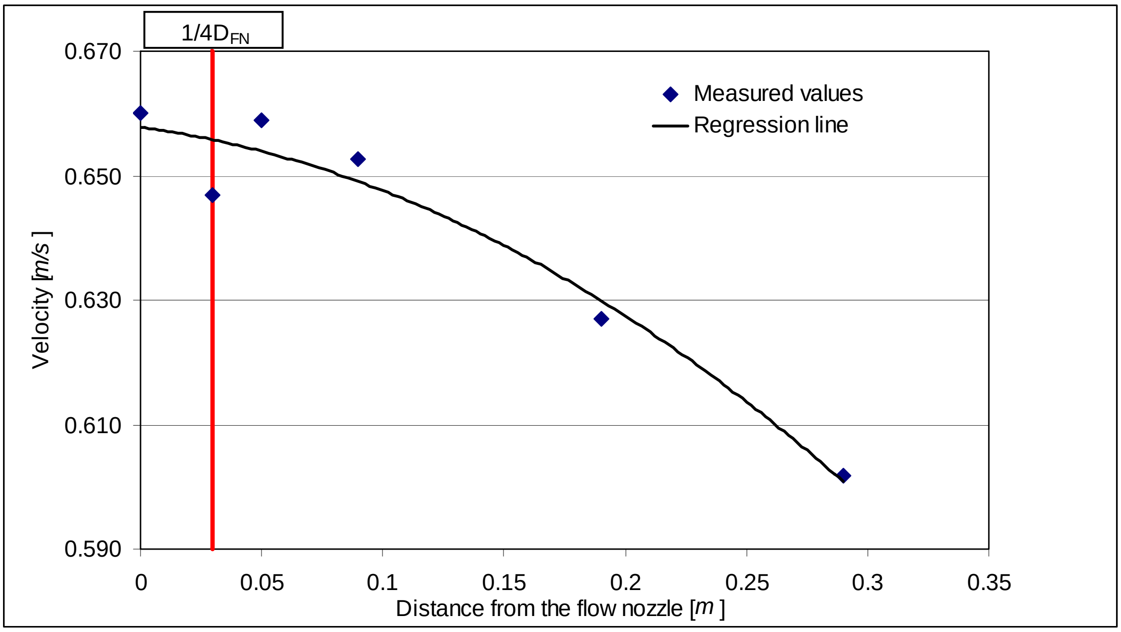

Figure 7– Lengthwise velocity profile (propeller 2.2)

7. Flow nozzle’s crosswise velocity profile

The hypothesis at the basis of the theory about totally submerged outflows is a uniform velocity profile on a section crosswise to current. To confirm this hypotesis, at the basis of calibration method, velocities have been investigated along two diameters of flow nozzle’s cross section, horizontally and vertically.

After placing mini-current meter propeller 2.2 (par. 4) 1 *cm* far from the outflow, in correspondence of flow nozzle’s upper boundary, where no propeller motion has been recorded, propeller has been moved down (by step of 0,5 *cm* near the boundaries, where the velocity gradient is higher, and of 1 *cm* in cross section’s central part), and velocities have been recorded. The same operations have been carried out for the horizontal profile. Graphs in Figure 8 and Figure 9 show a good uniformity of velocity, whose values, nearly nulls at boundaries, increase rapidly towards the centre, till a sufficient uniform value (mean shifting from theoretic expected velocity is about 6%). In particular, velocity on the barycentric axis is only 1% shifted from expected v_{torr}.

It has to be underlined that water at flow nozzle’s boundaries is not necessarily still, but simply its velocity can’t be recorded by the instrument, because of propeller’s inertia: that’s why velocity at flow nozzle’s upper boundary is cosidered to be 0,1946 *m/s*, that is the value of constant *a* for propeller 2.2.

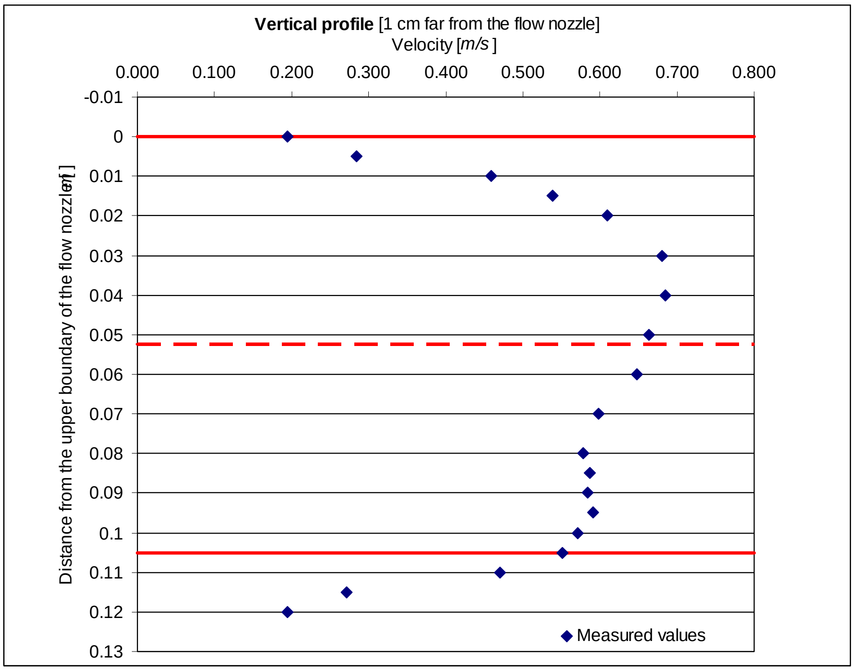

Figure 8–Vertical crosswise velocity profile (1 cm far from the flow nozzle)

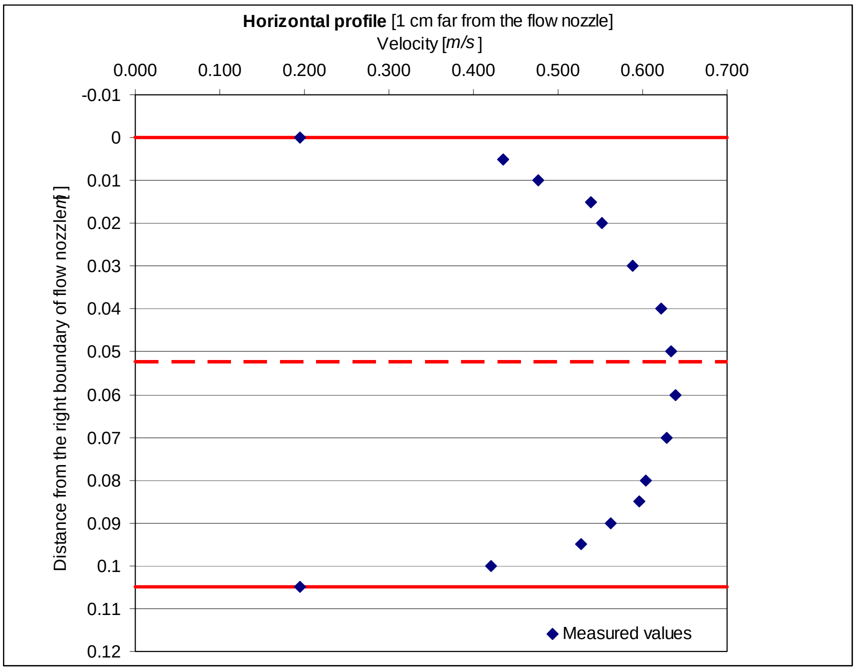

Figure 9– Horizontal crosswise velocity profile (1 cm far from the flow nozzle)

In Figure 8, it is also noticeable that propeller still records velocities under the lower flow nozzle's boundary: it is index of the turbolence existing into the downstream reservoir. This turbolence also creates some irregularity in vertical velocity profile, in the lower part of the flow nozzle.

8. Lenghtwise velocity profile in front of the orifice plate

This profile has been recorded twice, before calibration's operations, using two different discharges (8,8 *l/s* and 45 *l/s*) to localize contracted section's position: in both cases, experimental data show that, between 2-3 *cm* and 20 *cm* of distance from the orifice plate, velocity is quite constant and near to theoric value, with shiftings from it less than 1% for Q = 45 *l/s* and of about 2% for Q = 8,8 *l/s*. Farther, velocity decrease rapidly because of dissipations. During calibration, currrent meter has been placed at a distance of $D_{OP}/2$, position where contracted section is considered to be, according to literature.

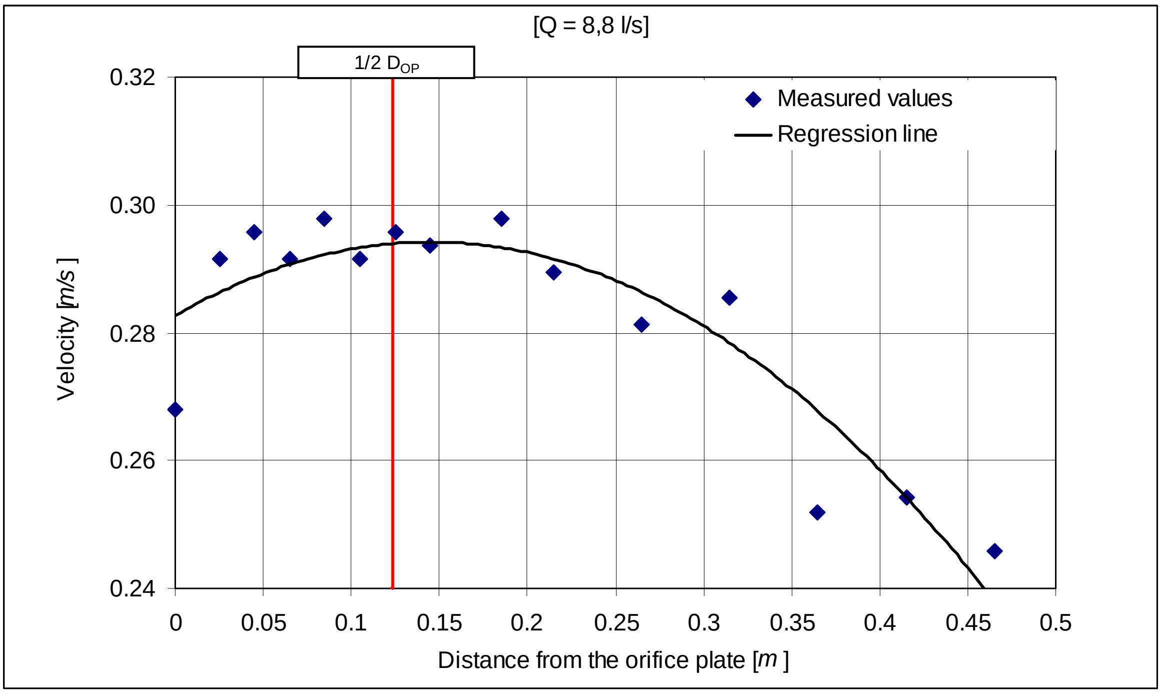

Figure 10 – Lenghtwise velocity profile in front of the orifice plate

9. Orifice plate's crosswise velocity profile

Velocities have been recorded on a section 12,5 *cm* far from the orifice plate, that is where contracted section is considered to be. The propeller has been moved by step of 1 *cm* near orifice plate's boundaries, of 2 *cm* in the central zone. Seventeen calibration points has been recorded for each direction, horizontal and vertical. Experimental data show a good uniformity of velocity; contracted section's existence and size is well shown in Figure 11 and Figure 12; in fact the propeller doesn't rotate even if it is placed inside geometrical orifice plate area, till a distance of 2-3 *cm* from boundaries. It means that in those points water is still or, more precisely, it has a velocity smaller than 0,1946 *m/s*, limit value for propeller recording. Then, there is a quick increase of velocity, that reaches a quite constant value, even if with oscillations of about 2% from the expected value: the propeller is inside the contracted section.

Contracted section diameter is considered to be D_{Ac} = 19,7 *cm* and, comparing contracted section area to the geometrical one, a contraction coefficient Cc = 0,6 is calculated, according to literature.

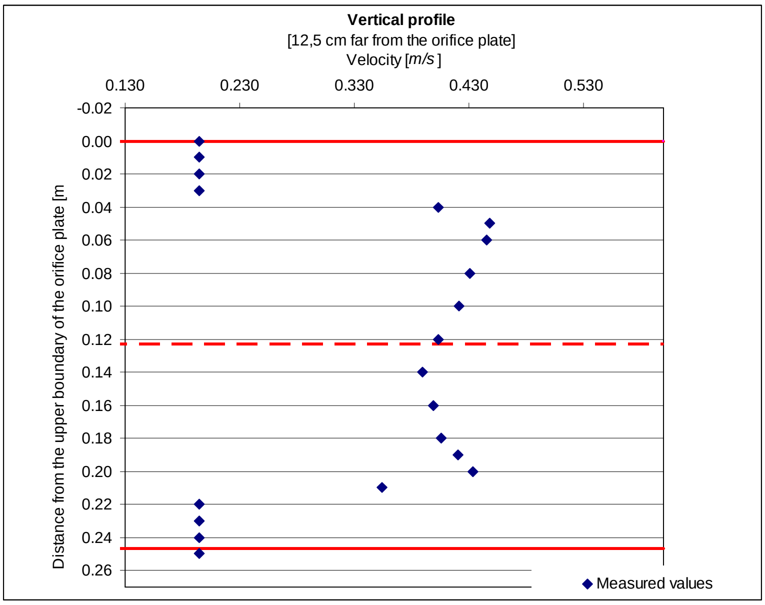

Figure 11 – Vertical crosswise velocity profile (12,5 cm far from the orifice plate)

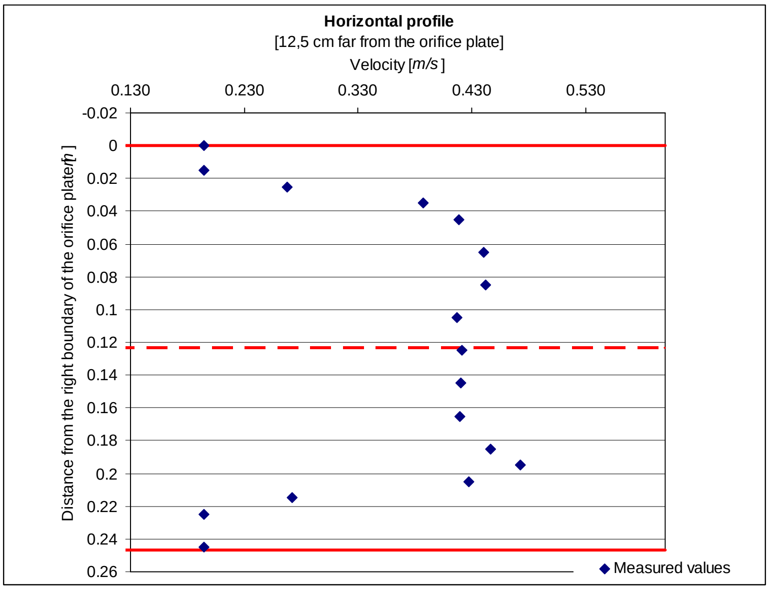

Figure 12– Horizontal crosswise velocity profile (12,5 cm far from the orifice plate)

10. Experimental data interpolation and shifting between interpolating curves

It has been already said that experimental data have been linearly interpolated, obtaining new calibration curves. The choice of a linear interpolation is giustified by:

- the usual current meters calibration practise;
- the physics of the problem: it can be asserted that there is a direct proportionality between current velocity, force on propeller's blades and number of rates;
- in this specific case, linear approximation is well supported by the high linear correlation coefficient R^2, near to unity, that characterizes experimental data (Table on page 14).

Then, percent fractional shiftings $\frac{|v - v_{torr/magn}|}{v} \cdot 100$ have been calculated for every calibration point, between current velocity obtained by the new interpolating lines (v_{torr} line and v_{magn} line both) and current velocity obtained by the pre-existing calibration line (v). Results are showed in Table 2.

		$\frac{\lvert v - v_{torr} \rvert}{v} \cdot 100$ Average value	σ	$\frac{\lvert v - v_{magn} \rvert}{v} \cdot 100$ Average value	σ
MINI-CURRENT METER N°11347	**2.2**	(14.3%) 9.1%	(4.9%) 2%	(20%) 12.7%	(7.2%) 3%
	2.3	6.7%	3.4%	(13.8%) 5.2%	(13.9%) 4.3%
	3	4.5%	2.9%	4.6%	2.0%
RIVER CURRENT METER N°601485		(13.5%) 1.8%	(0.7%) 1.0%	(3.7%) 3.3%	(0.2%) 0.4%

Table 2 – Per cent shiftings (average of measurements and respective standard deviation) between the new interpolating lines and the pre-exixting one

About river current meter n°601485 and propeller 2.2, values in brackets in Table 2 refers to all calibration points carried out, while, if only calibration points with velocities > 0,6 *m/s* are considered, shiftings between v_{torr} interpolating line and the pre-existing one are much lower. (values not in brackets).

For propeller 2.3 values in brackets in Table 2 refers to all calibration points carried out, while values not in brackets are obtained excluding from the sample two calibration points which have anomalous shiftings of 20% and 40% and correspond to the lowest discharges.

In conclusion, measurements carried out by river current meter are the most reliables, referring to velocities > 0,6 *m/s*; for the other propellers, shiftings from pre-existing curves are higher, in particular for propeller 2.2 and 2.3, probably because all velocities measured are quite low, < 1 *m/s*. On the other hand, for these propellers there is a good agreement between v_{torr} and v_{magn}, and this fact could suggest that it's the pre-existing calibration curve that can't be considered valid anymore.

From these considerations, the method seems to give good results for velocities not too small, at least > 0,6 *m/s*; however these assumptions would require to be supported by a greater number of measurements, in the way to identify and eliminate from the sample, possible anomalous data.

11. Uncertainty evaluation about v_{torr}

Since a measurement is complete only if associated to its uncertainty, uncertainty about experimental results has been evaluated, in particular about v_{torr} values.

The uncertainties (*u*) taken into account are those about measurement of propeller's rotation frequency and of reservoirs' level.

- Since level measurements have been carried out using staff gauges, there is an uncertainty caused by the reading approximation to deci-millimeter:

$$u_{reading}[m] = \frac{0{,}0001}{\sqrt{12}}$$

Moreover, there is the own staff gauge uncertainty, expressible as:

$$u_{staffgauge}[m] = \frac{3 + 2 * z[mm] + 10[\mu m]}{1000000}$$

where *z* is the value read on staff gauge.

Every water level reading is affected with these two uncertainties, which are combined in this way:

$$u(z)[m] = \sqrt{u_{reading}{}^2 + u_{staffgauge}{}^2}$$

Then, it must be considered that the water level determination in the upstream and in the downstream part of the tank is obtained as difference between two readings:

$$h_{upstream}[m] = z_{upstream} - z_{0\,upstream} \qquad h_{downstream}[m] = z_{dowmstream} - z_{0\,downstream}$$

So, uncertainties have to be combined again as following:

$$u(h_{upstream})[m] = \sqrt{u(z_{upstream})^2 + u(z_{0upstream})^2}$$

$$u(h_{downstream})[m] = \sqrt{u(z_{downstream})^2 + u(z_{0downstream})^2}$$

Considering that water levels and velocities are linked together by Torricelli's formula, there is a functional uncertainty $u_{functional}$, that allows to transform water level reading uncertainty into velocity uncertainty:

$$u_{functional}\left[\frac{m}{s}\right] = \sqrt{\left(\frac{g}{\sqrt{2 * g * \Delta h}}\right)^2 * u(h_{upstream})^2 + \left(-\frac{g}{\sqrt{2 * g * \Delta h}}\right)^2 * u(h_{downstream})^2}$$

The constants multiplying *u(h)* are called sensibility factors, and they are the partial derivatives $\frac{\partial v_{torr}}{\partial h_{upstream}}, \frac{\partial v_{torr}}{\partial h_{downstream}}$. It is noticeable that this uncertainty grows when the difference between upstream and downstream water levels decrease.

- About rotation's frequency uncertainty (u_ω), assuming that experimental data belong to a normal distribution, for every calibration point, sample standard deviation can be calculated:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - x_m)^2}{N - 1}}$$

where x_i is one of the *N* readings, and the average x_m is the best estimate of rotation's frequency for the calibration point.

The σ is linked to the singular sample but it is useful to define the standard deviation of the mean $\bar{\sigma}$, that is the real index of population dispersion and that constitutes rotation's frequency uncertainty u_ω:

$$\bar{\sigma} = \frac{\sigma}{\sqrt{N}} = u_\omega$$

In the end, combining rotation's frequency uncertainty with water levels uncertainty, it is obtained:

$$u(v_{torr})\left[\frac{m}{s}\right] = \sqrt{u_{functional}{}^2 + (\vartheta * u_\omega)^2}$$

Adding and substracting the absolute uncertainty $u(v_{torr})$ to the measured value, the field in which there is the "measurement's true value" is defined.

The θ factor allows to transform rotation's frequency uncertainty into a velocity uncertainty and it has been assumed to be the propeller's calibration line slope. In fact, since interpolating line well reflect experimental points distribution, calibration line slope is suited to transfer rotating frequency uncertainty to velocity uncertainty, around the calibration point.

To define a 95% confidence limit, $u(v_{torr})$ has been multiplied for the factor $k = 2$, obtaining in this way the “extensive measurement uncertainty” (as required by *EA* – European Acrreditation). This factor assumes that sample is normal; this hypothesis, even if it would require a larger number of measurements, in any way is reasonable, as already said; however, the aim of this paper is only to outline a logic procedure, leaving to future measurements the task to reach more completeness.

The Table at page 14 shows the fractional uncertainties calculated for current meters that were calibrated in this experience. In particular, the uncertainty’s average value about calibration points carried out, and its standard deviation, are indicated.

12. Conclusions

On the whole, experimental results obtained by the new calibration method are satisfying: in fact, they show a good correspondence beetween the two calibration curves obtained by interpolation of experimental data v_{torr} e v_{magn}, and they also agree with propellers’ pre-existing calibration curves (Table on page 14).

Investigations about outflow’s velocity profiles have given good results: lenghtwise profiles show that velocity, moving away from the outflow, is quite constant for a lenght sufficient to current meter positioning; crosswise profiles confirm the hypotesis at the basis of this calibration method, that is a unifrom velocity distribution along outflow’s cross section.

For these reasons, the proposed calibration method can be considered valid; by this method, current meters’ propellers have been calibrated with an uncertainty, about $v_{torr,}$ of the order of ± 1-2% (Table on page 14). Linear approximation for experimental data is appropriate, on the basis of high R^2 values of new interpolating lines, for v_{torr} and v_{magn} both.

Authors are aware of the necessity to collect a larger sample of measurements to give more validity to considerations exposed in this paper, however the work carried out has defined the logic procedure at the basis of the calibration method, validating the hypotesis on which it is based and analyzing factors that can influence a correct calibration. For example, about the experimental equipment, it is noticeable that an enlargement of downstrem reservoir would led to reduce turbolence and boundary effects near the outflows, guaranteeing better measurements. By the way, an improvement of accuracy and reliability of the calibration method is postponed to future developments of the method and to extension of experimental data.

		PRE-EXISTING CALIBRATION CURVES	NEW CALIBRATION CURVES		FRACTIONAL EXTENSIVE UNCERTAINTY	
	PROPELLER	v	v_{torr}	v_{magn}	AVERAGE VALUE $\overline{\frac{u(v_{torr})}{v_{torr}}}$	σ
MINI-MULINELLO N°11347	2.2	$\omega < 3{,}39 \quad v = 0{,}0929 \cdot \omega + 0{,}114$ $\omega > 3{,}39 \quad v = 0{,}105 \cdot \omega + 0{,}073$	$v_{torr} = 0{,}0979 \cdot \omega + 0{,}1946$ R^2=0.987	$Q/A_{bocc.} = 0{,}0942 \cdot \omega + 0{,}2485$ R^2=0.996	± 1 %	± 0.3 %
	2.3	$\omega < 1{,}58 \quad v = 0{,}0875 \cdot \omega + 0{,}056$ $\omega > 1{,}58 \quad v = 0{,}104 \cdot \omega + 0{,}03$	$v_{torr} = 0{,}0878 \cdot \omega + 0{,}0685$ R^2=0.969	$Q/A_{bocc.} = 0{,}0815 \cdot \omega + 0{,}1445$ R^2=0.964	± 1.8 %	± 1.1 %
	3	$\omega < 1{,}14 \quad v = 0{,}2297 \cdot \omega + 0{,}034$ $1{,}14 < \omega < 3{,}79 \quad v = 0{,}2481 \cdot \omega + 0.013$ $\omega > 3{,}79 \quad v = 0{,}2510 \cdot \omega + 0{,}002$	$v_{torr} = 0{,}3239 \cdot \omega - 0{,}516$ R^2=0.989	$Q/A_{bocc.} = 0{,}3245 \cdot \omega - 0{,}4883$ R^2=0.985	± 1.2 %	± 0.3 %
MUL. N°601485		$0{,}4 < \omega < 9{,}5 \quad v = 0{,}2501{*}\omega - 0{,}0011$	$v_{torr} = 0{,}2638{*}\omega - 0{,}0706$ R^2=0.995	$Q/A_{diafr.} = 0{,}2611{*}\omega - 0{,}0159$ R^2=0.997	± 2.3 %	± 2.9 %

Bibliography:

- Camnasio E., Ragazzoni D. – Tesi di laurea "Problemi di taratura dei mulinelli idrometrici" (A.A. 2003-2004)
- Citrini D., Noseda G. – Lezioni di idraulica (1987)
- Grego G., Muciaccia F. – "Comparison between self-component and standard propellers in current meter discharge measurement" (IGHEM 2004, Lucerne, Juli 14-16)
- Offredi M. – Tesi di laurea "Analisi e validazione sperimentale delle procedure per la taratura di strumenti misuratori della velocità: mulinelli e tubo di pitot"(A.A.2001-2002)
- Paoletti A. – Sistemi di fognatura. Manuale di progettazione (1997)
- Scimemi E. – Compendio di idraulica (1964)

Rules of reference:

- ISO 748 – Correnti in canali aperti – Metodo area-velocità (1997)
- ISO 2537 – Mulinelli idrometrici (1988)
- ISO 3454 – Equipaggiamenti di sospensione (1983)
- ISO 3455 - Liquid flow measurement in open channels - Calibration of rotating elements current meters in straight open tanks (1976)
- UNI 4546 – Misure e misurazioni - Termini e definizioni fondamentali (1994)
- UNI ENV 14028 – The application of propeller-type current meters and their calibration (2003)

Key words: instrumentation and calibration of testing device – current meters – data analysis and evaluation of measuring uncertainties.