Flow measurements with current meters at the inlet: reliability of the results and evaluation of the uncertainty.

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Abstract

The measurement of the flow rate at the inlet of a low head machine is certainly not easy. Asymmetries and re-circulations are always possible and often cause erroneous results. The only applicable methodologies are dilution and current meters (scintillation when reliable). The use of current meters in the short intakes is often the subject of perplexity. The IEC-EN 60041 standard, which is twenty years old, and to which WEST is involved in the revision, envisaged the creation of large structures to regulate the flow in the measuring section. These structures were seldom adopted: besides considerable costs, the regularization of the flow determines changes of flow conditions: for low head machines, the results obtained do not correspond to reality.
The aim of this paper is to demonstrate the improvement the measuring capacity of the current meters without modifying the essential characteristics of the plant. The development is on two different directions: improving the instrumental aspect with more and more performing propellers able to measure with extreme precision the only axial component of the speed, without being influenced by the transversal components, and with electronics detecting the direction of flow, able to detect the rotation period and therefore oscillations and fluctuations of the speed, to monitor possible movements and vibrations of the propeller body and the effects due to these phenomena. Digital technologies allow the development of software and procedures for the integration of speed profiles with different methods such as to perform cross checks of congruence, the analysis of results such as to eliminate unreliable measures allowing to identify errors due to each specific cause and its relevance.
This paper describes five test cases, with different test methods in parallel or with reliable verification systems. The error analysis is also shown. The effect of these improvements is clear: the current meters at the entrance of the machine have shown their reliability.

1. Introduction

The propeller current meters represent the most traditional flow measurement; historical data refer to measures dating back to at least two centuries ago, but a detailed analysis of the results of these measures and their reliability began at the end of the 1950s. This very important theoretical and experimental work brings distinguished names such as Alming, Coffin, Chaix, Gerber, Gabaudan, Fisher, Tonini, Zimmerli. The considerable effort was certainly because the current meters were the most established and reliable methodology, in many cases irreplaceable, but also to the experimental finding that those measurements at first sight banal could also present pitfalls and causes of errors.

Based on those fundamental experiences, they set the Codes that are still in force and still give precious hints for thought and critical control on the methods of execution of the tests.

Today the measures with current meters have lost their centrality and other technologically more refined measures are frequently used and preferred for rapidity of use and simplicity of installation, however the current meters still have their importance and often constitute the only alternative to measure in critical conditions. One of these fields of use is represented by the inlet sections which in many cases represent the only measurement area accessible in low-head machines.

WEST has been able to carry out numerous measures of this type, many of which comparing the method of current meters with others recently developed such as tracers and acoustic scintillation. In these comparisons the current meters were used as a reference, but attention must also be paid to the extent of the uncertainty of the measures with current meters themselves.

In this sense, the Codes are not sufficiently up-to-date, proposing impractical solutions such as flow rectifiers and converging mouths, not considering new control devices and analytical tools able to improve the quality of the measurements and to identify with greater clarity the sources of error.

2. Test cases

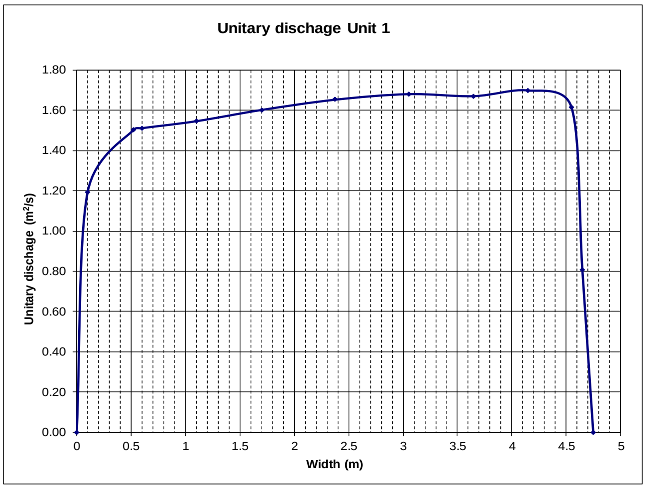
Among the numerous measures, some particularly significant and technically demanding cases were chosen, in which it was possible to carry out a comparative analysis by measuring with other methods, comparing the results with measurements on a scaled physical model, analysing the field of motion with CFD or having in any case a reference with which the deviation margin could be identified.

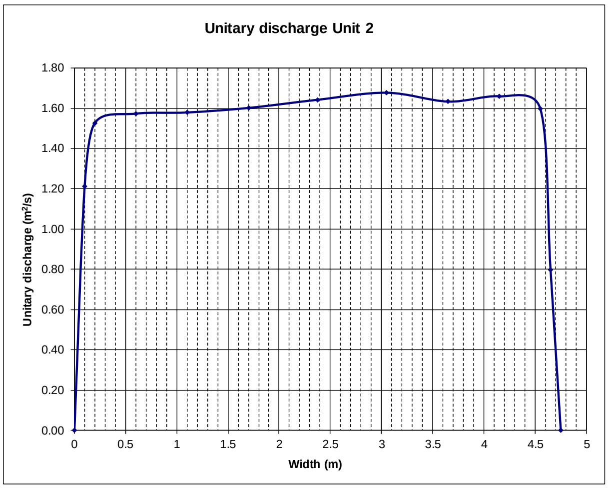
*2.1 **Case 1***

Technical data

- Nr. 2 Kaplan bulb turbines
- Orientation: horizontal axis
- Gross head: 3.45 m
- Maximum nominal flow (project): 12.00 m^3/s
- Maximum mechanical power: 333.00 kW
- Rotation speed: 250.00 rpm

The measurements were made with a mobile trolley with profiled rod on a catwalk made just at the entrance of two units. On the rod 9 propellers were installed and 9 different positions of the trolley were measured in a section of 18 m^2, two current meters positioned on another rod showed the stability of the test conditions.
The measures of the reels are compared to measurements with dye dilution. All current meters used are OTT type A with 125 mm pitch which provide two pulses per revolution and detect the direction of rotation. Measurements had contractual purpose.
Measurements have been carried out on both units, providing results that can be practically overlapped as shown in the graphs of horizontal integration shown hereinafter.





The measurements have not detected re-circulations except for a very modest surface zone on unit 2 (on the left in the direction of flow); in both groups there are no significant turbulences and fluctuations and no dynamic phenomena or mechanical stresses occurred. The differences with the comparison method are less than 0.7%; the comparison method typically measures a lower flow rate.
The calculated uncertainty lays below ±1.5%.

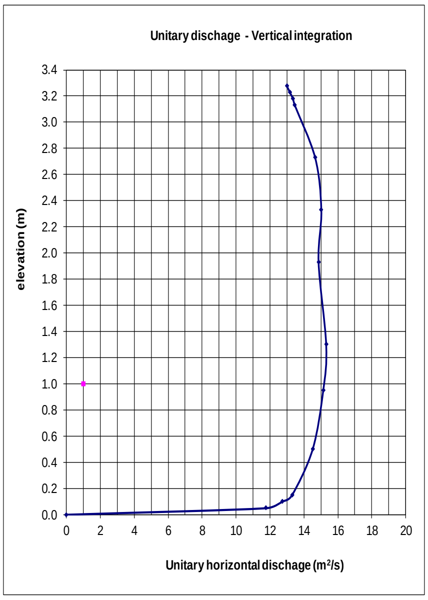
*2.2 **Case 2***

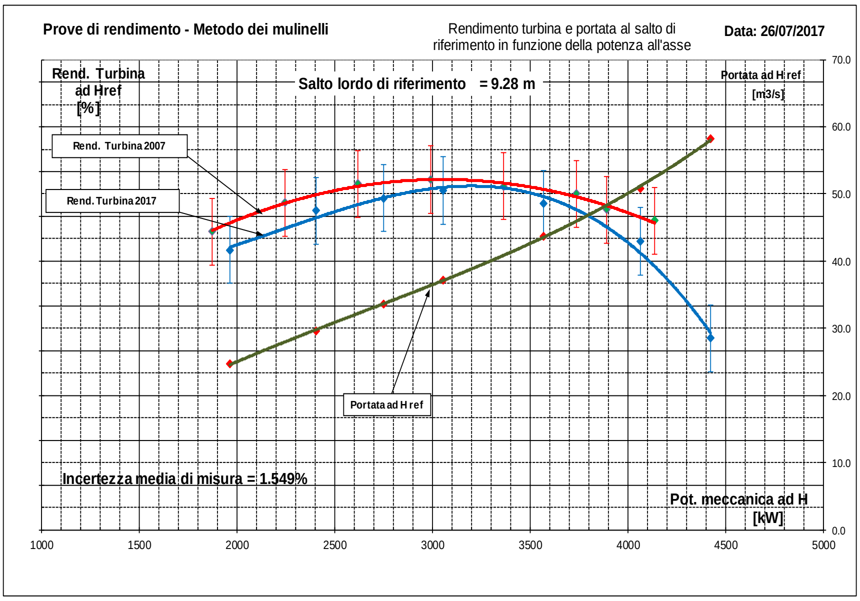
Technical data

- Nr. 1 Kaplan turbine
- Orientation: vertical axis
- Net head: 9.28 m
- Maximum nominal flow (project): 50.00 m^3/s
- Maximum mechanical power: 4115.00 kW
- Rotation speed: 166.67 rpm

The measurements were made by using a structure provided with two profiled horizontal rods to be

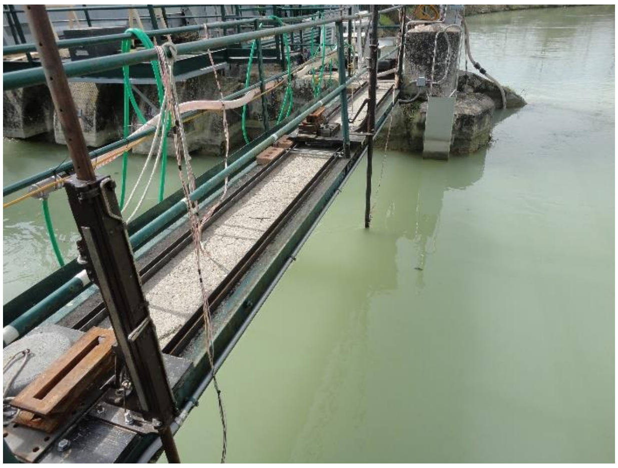
lowered to different elevations in the gate tracks in the inlet channel. On each horizontal rod there were 13 current meters so that a total number 26 current meters were used; 4 different sinking of the structure provided an adequate mapping of the velocity profiles in a section of 25 m^2, the stability of the test conditions was verified through differential pressure measurements on the Winter Kennedy taps.
The current meters used are OTT type A either with a 125 mm pitch (near the side walls) or with a 250 mm pitch; they provide two pulses per revolution and detect the sense of rotation.
The measures aimed to detect the degradation of the unit over time and were compared with the previously calibrated Winter Kennedy measures and with the original measurements supported by tests on the homologous model.





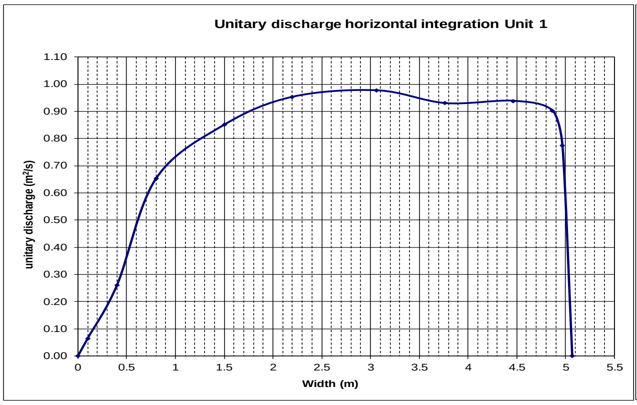
As highlighted in the above graphs, the measurements did not detect re-circulations, but rather significant turbulences and fluctuations that led to dynamic phenomena and mechanical stresses.
The trend of the velocity profiles is regular without significant anomalies. The congruence with the previous measures is excellent and it is noted that in the top conditions the efficiency is substantially identical, while there are elements of deterioration both at low loads and at full load confirmed by subsequent investigations that showed an increase in impeller clearance and zones of superficial roughness probably related to cavitation. As can be seen, the uncertainty bands (calculated in approx.. ± 1.55%) do not show a statistically significant difference between the current and previous tests, but there is however a systematic nature that makes the difference between the measurements appreciable.

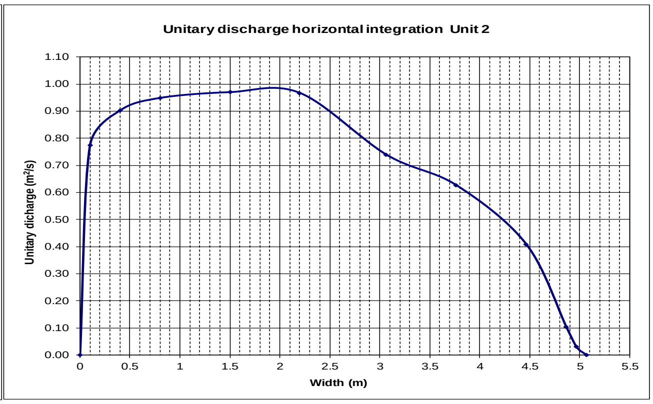
*2.3 **Case 3***

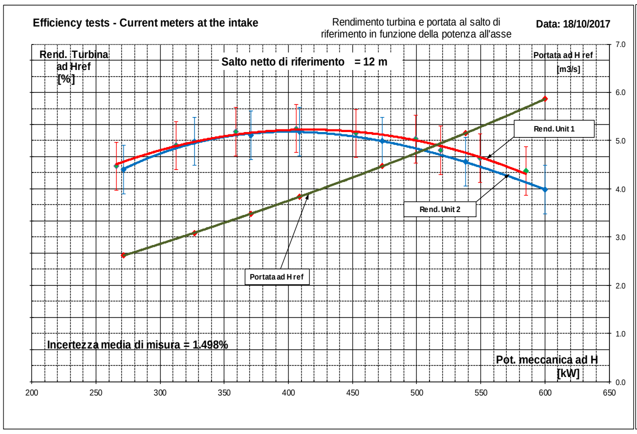


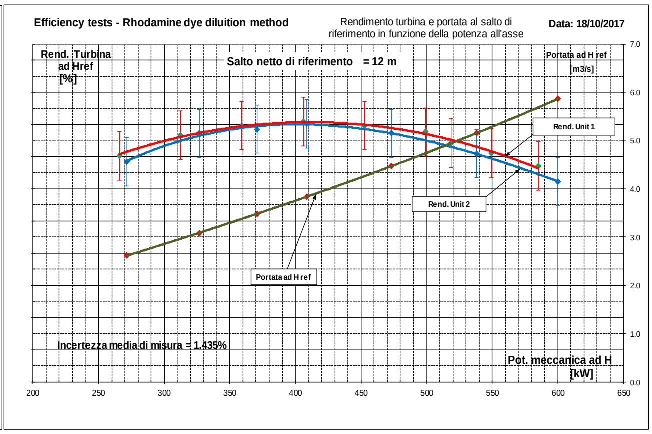
Technical data
• Nr. 2 Kaplan turbines
• Orientation: vertical axis
• Net head: 12 m
• Maximum nominal flow (project): 6.00 m^3/s
• Maximum mechanical power: 550.00 kW
• Rotation speed: 300.00 rpm

The measurements were made by using two mobile mini carts equipped with profiled rod on a catwalk made just at the entrance of two units. On the rod 8 propellers were installed and 4 different positions of each cart were measured (i.e. 8 positions in total) in a section of 11 m^2, two current meters positioned on different rods showed the stability of the test conditions.
The measures of the current meters are compared to measurements with dye dilution. All current meters used are OTT type A with 125 mm pitch which provide two pulses per revolution and detect the direction of rotation. Measurements had contractual purpose.
Measurements were carried out on both units, providing very different results as velocity profiles. The geometric adduction configuration determined in Unit 2 a zone with particularly marked transversal components and turbulences. In both groups there is a markedly asymmetrical velocity profile, indicatively specular in the two units.
Even with these differences in measurements, the efficiency curves of unit 1 and unit 2 are completely overlapping. Likewise, measurements with the dye dilution method confirm with good approximation the measurements obtained with current meters.







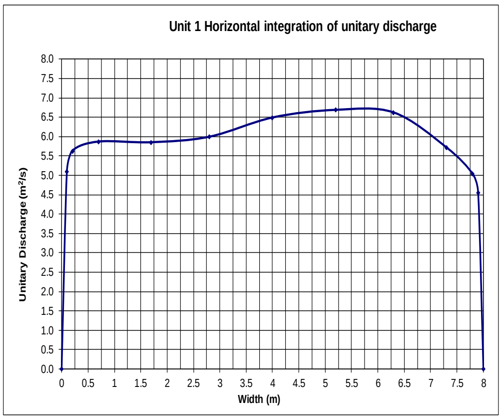


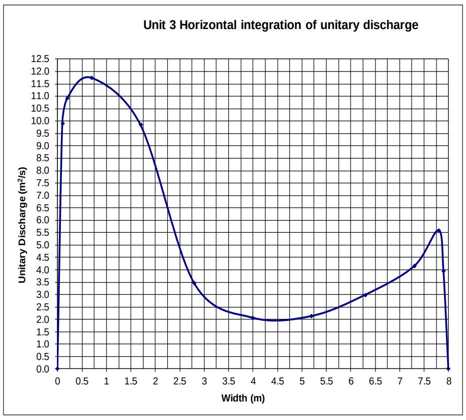
2.4 *Case 4*

Technical data

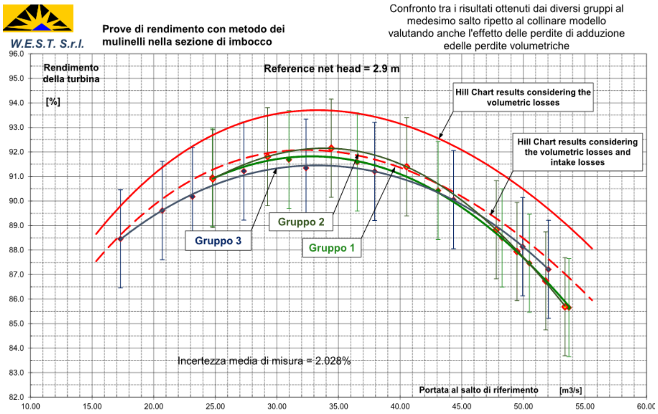
- Nr. 3 Kaplan bulb turbines
- Orientation: horizontal axis
- Net head: 3.9 m
- Maximum nominal flow (project): 50.00 m^3/s
- Maximum mechanical power: 1750.00 kW
- Rotation speed: 115.00 rpm

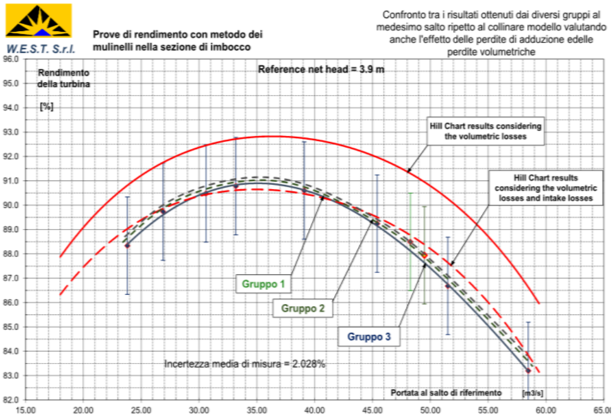
The measurements were made with a mobile vertical rod on a trolley with horizontal translation positioned 3 meters before the grids and 4 meters downstream of the intake. On the rod there were 7 current meters with two sinks (14 vertical positions) and 10 different vertical positions were measured in a 40 m^2 section, the stability of the test conditions was verified through differential pressure measurements on the Winter Kennedy taps.
All current meters used are OTT type A with 125 mm pitch which provide two pulses per revolution and detect the direction of rotation. Measurements were carried out on all three units, providing very different results as velocity profiles. The intake conditions of each group are substantially different. The power house is located on the left bank with respect to the barrier of the channel: while unit 3 is facing the channel, unit 1 is facing a large basin. A submerged wall that separates the power house from the barrier causes a very marked turbulence at the entrance of unit 3 while





the trend is much quieter in the unit 1, unit 2 presents an intermediate trend. Such indication is clearly visible in the graphs of horizontal integration.
Re-circulations, turbulences, dynamical phenomena, asymmetries and non-axial flow components were very heavy on unit 3 so as to make the realization of the measurements critical. However, the grids; very narrow, operated as a flow straightener so that (apart from the considerable load losses of the grids themselves) they made the downstream patterns very stable and smooth.
Measurements had contractual purpose and a homologous model was tested in an accredited hydraulic laboratory
Taking into account the real head downstream of the grids and adequately assessing the volumetric losses (wheel casing, balancing, etc.) the results obtained on the three groups during the field tests are congruent with the tests on the reduced scale homologous model. This comparison, combined with the superimposition of the power vs opening curves and the progress of the Winter Kennedy results, suggests that even in such extreme conditions the measure of the flow rate realized with current meters is correct.



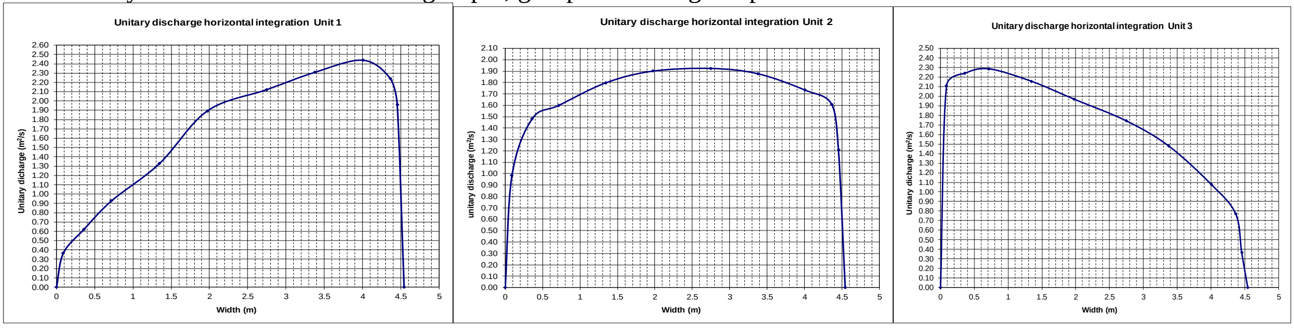


2.5 *Case 5*

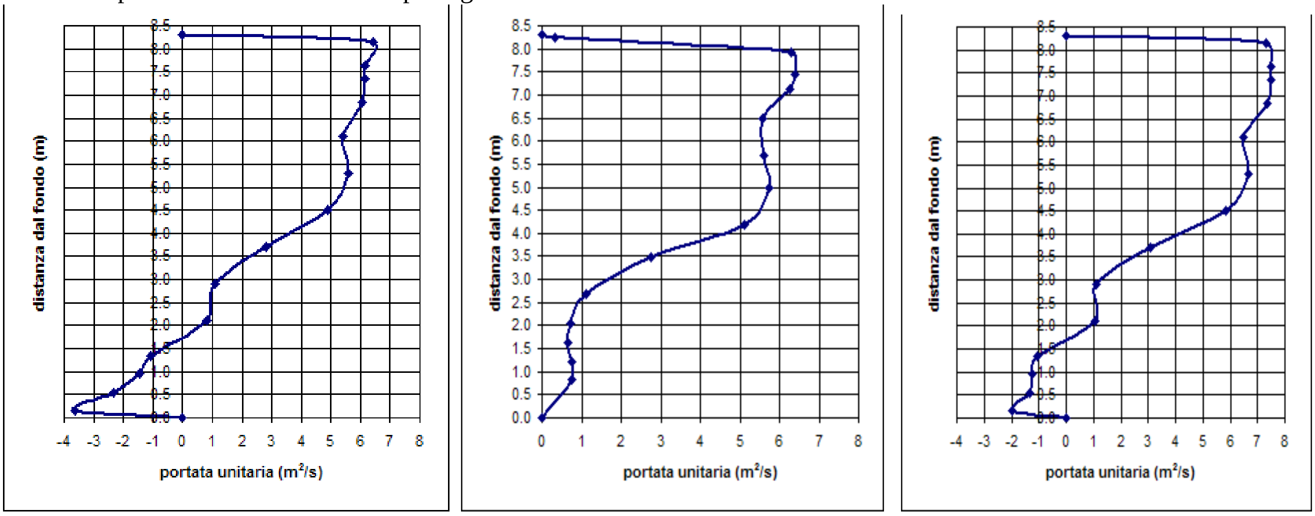
Technical data

- Nr. 3 Kaplan turbines
- Orientation: vertical axis
- Net head: 8.8 m
- Maximum nominal flow (project): 83.50 m^3/s
- Maximum mechanical power: 6750.00 kW
- Rotation speed: 103.45 rpm

The measurements were made by using three structures provided with two profiled horizontal rods to be lowered to different elevations in the gate tracks in the intake.
As there are three separate mouths in each mouth a different structure has been lowered. On each horizontal rod of each structure 10 current meters were positioned for a total of 20 current meters in each structure and therefore 60 in total. 7 different sinking were carried out in a section of 38 m^2 for each mouth, the stability of the test conditions was verified through differential pressure measurements on the Winter Kennedy outlets.
The reels used are of the Ott type both with 125 mm pitch propeller A (near the side walls) and with R propellers with 250 mm pitch; they provide two pulses per revolution and detect the sense of rotation. The measures carried out on the three groups were intended for contractual verification.
The entry conditions of each group are substantially different. The power plant positioned on the right bank with respect to the barrier on the canal has an axis inclined with respect to the water course; the deviation of water to enter group 3 is considerably more marked than that of group 1, group 2 has a regular pattern.



Vertical trends show not only turbulence but also recirculation and negative flow in the two side groups with particularly tormented profiles and considerable speed gradients.



The uncertainty on the efficiency calculated on Unit 2 is around 1.48%, while it has an average value of 2.12% in Unit 1 and 1.94% in Unit 3. The difference in efficiency measured between the three groups is much lower, remaining on average lower. 1%. The congruence of the measurements is confirmed by the Winter Kennedy measures and the shape of the efficiency curve obtained confirms that of the model tests. With respect to the guaranteed values, Unit 2 showed a deficit of 0.32%, much lower than the value calculated of uncertainties.

3. Uncertainty analysis

The systematic uncertainty introduced in the measure of the flow rate using the method of current meters in a free surface channel can be the result of many factors that can be subdivided into errors due to the determination of local speeds and errors due to the integration of the mentioned speeds for the calculation of the flow rate. Hereinafter the schematic procedure used in the evaluation of the discharge error in the tests described.

3.1 *Random errors in the determination of the local speeds*

- *Error due to the number of counts and the duration of the measurements.*

The measuring system detects two pulses per revolution and, in the case of low speeds, determines the period between the different pulses; the time is measured with the accuracy of the tenth of a second and is determined individually by the occurrence of the first pulse until the last pulse occurs.

Based on the times taken and the number of pulses measured for each measured speed, the single uncertainty is:

$$f(V_{Ni}) = \pm \frac{1}{T \cdot n} \qquad \text{then globally} \qquad f(V_N) = \pm \frac{V_i \sum_i f(V_{Ni})}{V_{med}} = \pm 0.05\%$$

- *Error due to speed oscillations.*

In unstable conditions an error linked to the possibility to acquire the completeness of the dynamic phenomenon shall be considered. In the case of low frequencies, it is related to the ratio between the period of the oscillations (t) with respect to the acquisition period (T). When, as in the present case, T> 10 t and the velocity oscillation ΔV is less than 10% of the average velocity for each measured velocity, therefore it is:

$$f(V_{Oi}) = \pm 0.1 \cdot \frac{t}{T} \cdot \frac{\Delta V}{V_{med}} \qquad \text{then globally} \qquad f(V_O) = \pm \frac{V_i \sum_i f(V_{Oi})}{V_{med}} = \pm 0.10\%$$

3.2 Systematic errors in the determination of the local speeds

- *Error related to the calibration of the current meter*

The uncertainty due to the calibration of the current meter is defined in the calibration certificates issued by the official calibrating institution and depends on the measurement systems adopted by the certification laboratories.

In the case of the laboratory of the University of Padua each current meter has an error *f (Vci) = ± 0.25%*, if the speed detected is greater than the minimum number of rotations per second r0 which corresponds to the lower calibration limit. This error includes both the intrinsic error of the calibration values and the interpolation error of the points measured with a linear equation of the type.

V = k · r + v0

where:

k: is the real pitch of the whirlpool propeller

r: is the number of rotations per second (n / T)

v0: it is an experimental constant that represents the inertia for friction and / or the losses of the reel

If some measurement points, relative to tests at lower or higher loads, are outside of the calibration limit speed; within reasonable limits the equation can be extrapolated considering that a greater error is associated with the measurement carried out

$$f(V_{Ci}) = \pm 0.25 \cdot | r - r_0 | \cdot \frac{v_0}{V_i} \quad \text{then globally} \quad f(V_C) = \pm \frac{V_i \sum_i f(V_{Ci})}{V_{med}}$$

- *Error due to turbulence and fluctuations in speed.*

Experimental measurements and laboratory analysis have shown that the effects of dynamic phenomena on the measures of the reels can be analysed by decomposing the vector velocity over time into a constant component and a variable component describable as a sum of sinusoids at different frequencies (Fourier). The current meters by its nature is not symmetrical with respect to the direction of the fluid, the efficiency of the propeller is in fact lower with negative flows and therefore the negative component of the flow rate is generally underestimated. A not negligible role also has the inertia of the whirlwind that is linked to the mass of the helix in a simple oscillatory function.

On the basis of laboratory measurements, the negative speed component determines a number of revolutions of the helix, which is from 15% to 22% lower than a positive component of the same size. This phenomenon shall be taken into account in the calculation phase, however, from the point of view of the measurement error, when the amplitude of the variable component (sinusoidal) is $\boldsymbol{\Delta v}_s$

$$f(V_{Ti}) = \pm 0.22 \cdot \frac{\Delta v_{si}}{2} \quad \text{then globally} \quad f(V_T) = \pm \frac{V_i \sum_i f(V_{Ti})}{V_{med}}$$

- *Error due to speed gradient.*

In the presence of a high velocity gradient the different points of the helix are invested by different velocities that change cyclically at each turn of the helix which determine the dynamic stresses and also, since not all the points of the helix have the same conformation, at acceleration and deceleration of the rotation speed, similarly to what described in the previous point. This effect is normally negligible and is globally proportional to the ratio d / D where d is the diameter of the propeller and D is the equivalent hydraulic diameter. Identified with $\boldsymbol{\Delta v_d}$ the variation of speed that is determined inside the diameter d of the helix occurs:

$$f(V_{Gi}) = \pm 0.22 \cdot \frac{\Delta v_{di}}{2} \quad \text{then globally} \quad f(V_G) = \pm \frac{dV_i \sum_i f(V_{Gi})}{DV_{med}}$$

- *Error due to the inclination of the flow with respect to the axis of the current meter*

There are three main models of current meters in relation to the ability to measure only the axial component even in the presence of an oblique flow:

Model C / E OTT Types 1 ÷ 4 compensation up to angle $\alpha = \pm 5°$

Model F OTT Type R compensation up to angle $\alpha = \pm 25°$

Model G OTT Type A compensation up to an angle $\alpha = \pm 45°$

The axial component follows the cosine law of the velocity vector and normally the current meter provide a lower axial component than the real value. This negative deviation is less than -0.35% when the angle between the axis the current meter and the local instantaneous flow is within the so-called compensation angle different for each type of reel, as indicated above. The used reels are OTT Type A (normally called as self-component reels) that allow the compensation of the axial component up to angles between ± 45 °; if therefore the angle between the axis of the reel and the flow is less than or equal to that of compensation the value of the uncertainty due to the inclination of the flow with respect to the axis of the reels is less than or equal to Af (VI) = ± 0.35%

In general, $$f(V_{Ii}) = -0.4 \cdot \cos\left(\frac{\pi\varphi}{180}\right) \cdot \frac{\pi\alpha}{180} \cdot \tan\left(\frac{\pi\varphi}{180}\right)$$

then globally $f(V_I) = \pm \frac{dV_i \sum_i f(V_{Ii})}{DV_{med}}$

3.3 Determination of the overall errors for local speed.

According to the codes, the various sources of random and systematic error contribute to the determination of the global error as the square root of the sum of the squares of the individual error components. Although a specific error is associated with each individual measurement point, the global error is assumed. Therefore, with regard to the random error of the determination of local speed we will have:

$$f(V_A) = \pm \left(\sum f(V_{VA})^2 \right)^{0.5} = \pm \cdot \sqrt{f(V_N)^2 + f(V_O)^2}$$

Regarding the random error of the determination of the local speed we will have instead:

$$f(V_S) = \pm \left(\sum f(V_{VS})^2 \right)^{0.5} = \pm \cdot \sqrt{f(V_C)^2 + f(V_T)^2 + f(V_G)^2 + f(V_I)^2}$$

It should be noted that, despite having treated the errors as equitable-probabilistic, the error due to the inclination is instead always unidirectional (only negative).

3.4 Random errors in the integration of the flow rate

- *Random error in determining the local speed*

The random error in the measure of speed as previously defined obviously contributes to the determination of the random error of the flow rate.

$$f(Q_{AV}) = f(V_A) = \pm \left(\sum f(V_{VA})^2 \right)^{0.5} = \pm \cdot \sqrt{f(V_N)^2 + f(V_O)^2}$$

Random error in the determination of the wall coefficient

The wall coefficient **m** is determined by the adjacent measurements closest to the walls (or the free surface) so the error in its determination is essentially random. Its effect on the global error is related to the extension of the section close to the wall Ap with respect to the measurement section A and to the random component of the near-wall velocity measurements.

$$f(Q_{Am}) = \pm \cdot 2 f(V_A) . \frac{A_P}{m.A}$$

- *Error on positioning the current meters*

The positioning error due to the misalignment of the trolley or structure with respect to the theoretical foreseen position may be assumed of the order of ± 10 mm.

The calculation of this error was obtained by simulating the difference in flow rate ΔQ which would have caused the position of the rod(s) when moved of a predetermined value (Δl = 50 mm). Considering then the real mean Δlx deflection of the rods at each vertical **x** we obtain:

$$f(Q_{AP}) = \pm \left(\sum_X \left(\frac{\Delta l_X \Delta Q}{\Delta l} \right)^2 \right)^{0.5}$$

- *Error in determining the height of the free surface from the bottom*

This error component is predominantly random and is linked to the uncertainty of the measurement of the level sensors and in the survey of the channel bottom.

In the measurements the sensors were placed in still pipes and the number of measurements performed was able to have very low random errors, therefore the level measurement can have an average uncertainty of

$$f(Q_{SL}) = \pm \cdot 2 \cdot \sum \frac{2 \cdot \sigma}{Y_m}$$

3.5 Systematic errors in the integration of the flow rate

- *Systematic error in determining local speed*

The systematic error in the velocity measurement as previously defined obviously contributes to the determination of the global flow error.

$$f(Q_{SV}) = f(V_S) = \pm \left(\sum f(V_{VS})^2 \right)^{0.5} = \pm \cdot \sqrt{f(V_C)^2 + f(V_T)^2 + f(V_G)^2 + f(V_I)^2}$$

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- *Error in determining geometric parameters*

The uncertainty due to the determination of the geometric parameters, ie the width of the measurement section, obtained from field surveys and supported by the construction drawings, is normally $f(Q_{SA}) = \pm 0.15\%$.

- *Error related to the method of integrating the speed solid*

The uncertainty due to integration may be very modest when the profiles appear well aligned and congruent with each other. Three different integration methodologies are adopted: the so called numerical methods of Coffin, Spielbaur and a three dimensional integration whose results should not differ from each other on average more than ± 0.5%
When bigger values are obtained a deeper investigation is required and other integration techniques are involved.
In particular to reduce errors in some cases looks effective the use of the three dimensional integration with respect to the theoretical pattern of the velocity profile.
The final integration uncertainty in the mentioned cases has been in the order of $f(Qs_I) = \pm 0.45\%$.

- *Integration errors related to the number of measurement points*

Further external causes of error can result from an insufficient mapping of the velocity profile, based on the type of profile and the measured data we can consider $f(Q_{SP}) = \pm 0.2\%$ and the uncertainty deriving from the choice of the speed correction due to back-flow coefficient $f(Qc) = \pm 0.25\%$.

3.6 Determination of the overall errors for the flow rate.

According to the codes, the various sources of random and systematic error contribute to the determination of the global error as the square root of the sum of the squares of the individual error components. Although a specific error is associated with each individual measurement point, the global error is assumed. Therefore with regard to the random error of the determination of the flow rate we will have:

$$f(Q_A) = \pm\left(\sum f(Q_{iA})^2\right)^{0.5} = \pm \cdot \sqrt{f(Q_{AV})^2 + f(Q_{Am})^2 + f(Q_{AP})^2 + f(Q_{AL})^2}$$

Regarding the random error of the determination of the flow rate we will have instead:

$$f(Q_S) = \pm\left(\sum f(Q_{iS})^2\right)^{0.5} = \pm \cdot \sqrt{f(Q_{SV})^2 + f(Q_{SI})^2 + f(Q_{SP})^2 + f(Q_{SL})^2}$$

4. Conclusion

The different cases presented show that in short-intakes, even in situations that can be defined as extreme, the current meters are able to provide reliable results with sufficiently limited margins of uncertainty.
These positive results, however, are the consequence of several determining factors: the use of appropriately adjusted and individually calibrated propellers auto-component type, the use of current meters able to measure the reverse rotation, the vibration detection and oscillations of the support system, the subsequent analysis of the temporal trend of the impulses with oscillation analysis of the period and of the frequencies. The use of comparative methods for the integration of the speed solid is another particularly delicate and important point.
Only an analysis of the sources of detailed and realistic error allows to precisely define the reliability of the measures obtained and their suitability for the purpose for which they were made. The methodology proposed here, which is undergoing constant refinement, has made it possible to identify the measures that were reliable, despite the difficulties presented.
The new revision of the IEC 60041 code should clearly define, also for current meter tests, the uncertainty calculation procedure and the solutions to be adopted in the aim of reducing them.

References

[1] IEC EN 60041 – ed. 1997.
[2] CHAIX B.: Essais en campagne et en laboratoire relatifs a l'influence de la turbulence sur différents moulinets hydrometriques. I.C.M.G., Rap. n. 9-1962.
[3] ZIMMERLI M.: Vergleichsmessungen mit vier verschiedenen Flügeltypen. I.C.M.G., Rap. n. 35, 1965.
[4] FISCHER M.: Versuche über dem Einfluss der turbulenten Strömung auf hydrometrische Flügel durch Nachahmung der Turbulenz im Schlepptank. I.C.M.G., Rap. n. 19, 1966.
[5] COFFIN J„ MOREL H.: Methode d'integration entierement numerique des courbes de repartition des vitesses. - I.C.M.G., Rap. n. 20, 1966. ·.
[6] TONINI M.: L' influenza nelle misure forma e peso dell'elica portata con molinelli, L'Energia Elettrica n.5 1972
[7] ALMING K.: Measurements on current meters in skew and rotating flow , I.C.M.G., Rap. n. 37, 1965
[8] VINNOGG L.: Current meter measurement in intake structure with uneven and unstable velocity distributions and oblique flow to the current meters I.C.M.G., Rap. n. 127, 1987.