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THE USE OF ADCP IN SMALL AND MEDIUM RIVERS

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ABSTRACT

The introduction and operation of a hydrological data net depends on the installation of flow stations net that can generate reliable data obtained from a stage discharge curve, that is produced through a series of flow measurements made in the cross section. Usually, for measurement of those flows, it is used the conventional current meters and other methods. They are well-known and applied plenty methods, however, in the execution they demand time, knowledge and technical abilities, without which can be generated data that are not real.

A way to accelerate the process is the use of methods and automated devices, as it is the case of Acoustic Doppler Current Profiler - ADCP, that measures the flow automatically through Doppler effect. However, its use is restricted to the great rivers.

The present paper makes a review and has the objective of comparing different methods of flow measurement. In this case, the comparison is made between the conventional methods and the acoustic automated method of ADCP. With this study, it intends to verify the reliability of the instrument for flow measurement in small and medium rivers and, according to the case, to develop a methodology for the imposed conditions.

Keywords: *hydraulic measurements, ADCP.*

1. INTRODUCTION

The water resources existent in Brazil are abundant, but distributed in an unequal way, having larger concentration in the Amazon area. However, in the remaining of the country there is a considerable water potential distributed in great basins, formed mainly by small and medium rivers. The preservation of these resources is a necessity, mainly where they are scarcer. The optimum use of the use systems depends on planning, of studies and mainly of the knowledge of the real characteristics of the basins. Thus, it is very important the study of flow stations, through periodic discharge mensurations, for which they are used, generally, conventional methods, that are plenty known and applied, but they need time and technical knowledge for its execution.

The use of methods and automated devices, as the Acoustic Doppler Current Profiler - ADCP, that measures the discharge automatically by means of the Doppler effect, can be very useful, activating this process. This bibliographical revision has the objective of comparing the conventional methods and the acoustic automated method of ADCP, with the intention of verifying the reliability of ADCP for use in small and medium rivers.

2. THE ADCP

The Acoustic Doppler Current Profiler is an instrument used to measure the discharge of rivers through the Doppler effect. It can also be used to measure its movement with relationship to the bottom of the river and the distribution of the suspended sediments in the cross section.

2.1 The Doppler Effect

The Doppler effect is the apparent change in the frequency of sound due to relative motion between the source and the observer. The frequency of the sound emitted by a moving object appears to a stationary observer to increase as the object approaches him and to decrease as it recedes from him. The Doppler effect is used to distinguish between stationary and moving objects and to provide information concerning their velocity, by measuring the frequency shift between the emitted and the reflected sound.

2.2 Operational Principles

The instrument transmits sound waves through the water. The particles transported by the current of water reflect the turn sound for the instrument that notices the echo through sensor, doing with that it recognizes the different depths and the velocities of the respective current lines through the Doppler effect. As the suspended material moves in the same velocity of the current of water, the magnitude of the Doppler effect is directly proportional to the velocity of the currents. Being measured the frequency of the echoes that come back of the suspended material and comparing it with the frequency of the emitted sound, ADCP determines the speed of the particle, that is the same of the current of the water (figure 2). The ADCP can use different frequencies to emit the sound, such as: 75, 150, 300, 600, 1.200 and 2.400 kHz, depending on the model.

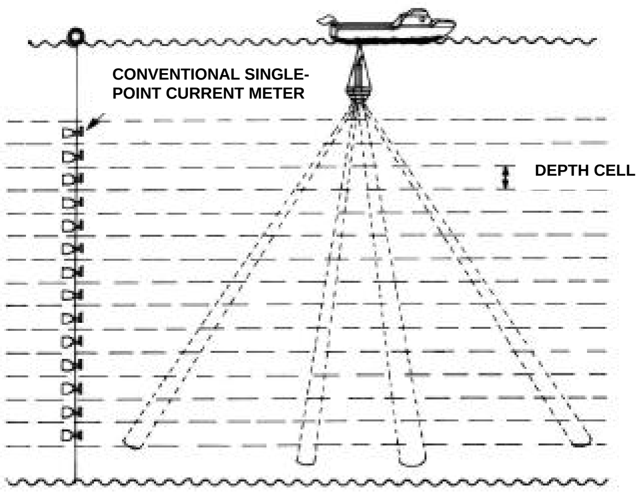

Figure 1. A typical ADCP profiling technique.

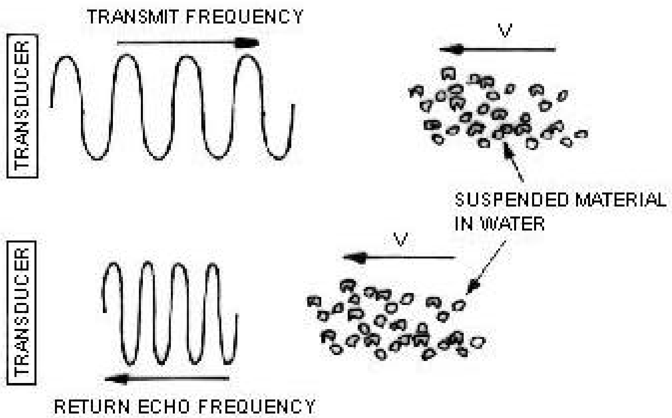

Figure 2. Frequency change caused by Doppler effect.

2.3 Discharge-measurement technique with ADCP

A discharge measurement with the ADCP is accomplished by first choosing an appropriate cross section. This can be done using the depth sounder as a reconnaissance tool. Cross sections with shallow areas are to be avoided. A round-trip transect is needed if there is bottom-sediment movement or such movement is suspected. The measurement is started by positioning the vessel as close to one riverbank as possible. The distance between the vessel and the near shore is determined using an optical rangefinder. The software is started and the vessel is steered across the river (transect). During the transect, the results of each subsection discharge measurement are displayed sequentially on the computer monitor. At the end of the transect, the vessel is positioned as close to the bank as possible. The software is signalled by the operator that the measurement has ended, and the distance to shore is determined. The software then prompts the operator to enter the starting and ending distances to shore, and a discharge-measurement summary is printed on the system printer. If the recording feature has been enabled, all the ADCP velocity data, time tags, and error information are recorded on computer diskette for later playback and analysis. Another discharge measurement can be started immediately, if desired (Simpson, 1993).

3. THEORETICAL ANALYSIS

According to Simpson et al (1993), an algorithm for computing discharge from ADCP water-velocity profile and bottom-track data was developed by K.L. Deines for tests on the Mississippi River in 1982. An advantage of this measurement algorithm was that the vessel did not have to maintain a straight course while traversing a river. The vessel could traverse a river diagonally or along any arbitrary path (bank to bank) and still to collect an accurate discharge measurement.

3.1 Equations

The general equation for determining river discharge through an arbitrary surface ***s*** is

$$Q_t = \int_s \overline{V_f} \cdot \overline{n}\, ds \tag{1}$$

where: Q_t = total river discharge; $\overline{V_f}$ = mean water-velocity vector; $\overline{n}$ = a unit vector normal to *ds* at a general point; and *ds* = differential area.

For moving-boat discharge applications, the area of *s* is defined by the vertical surface beneath the path along which the vessel travels. The dot product of $\overline{V_f} \cdot \overline{n}$ will equal zero when the vessel is moving directly upstream or downstream and will equal $|\overline{V_f}|$ when the vessel is moving normal to $\overline{V_f}$ (both vectors are in the horizontal plane).

Because the ADCP provides both vessel-velocity and water-velocity data in the vessel's coordinate system, it is convenient to recast equation 1 in the following form (Christensen, 1982):

$$Qt = \int_0^T \int_0^d (\overline{V_f} \times \overline{V_b}) \cdot \overline{k}\, dz\, dt \tag{2}$$

where: T = total cross-section traverse time; d = total depth; $\overline{V_b}$ = mean vessel-velocity vector; $\overline{k}$ = a unit vector in the vertical direction; dz = vertical differential depth, and dt = differential time.

Converting $(\overline{V_f} \times \overline{V_b}) \cdot \overline{k}$ into rectangular coordinates yields

$$\overline{V_f} = a_1 \overline{i} + a_2 \overline{j}\ ; \quad \overline{V_b} = b_1 \overline{i} + b_2 \overline{j},$$

and then

$$(\overline{V_f} \times \overline{V_b}) \cdot \overline{k} = a_1 b_2 - a_2 b_1, \tag{3}$$

where: a_1 = cross component of the mean water-velocity vector; a_2 = fore/aft component of the mean water-velocity vector; b_1 = cross component of the mean vessel-velocity vector, b_2 = fore/aft component of the mean vessel-velocity vector; $\overline{i}$ = unit vector in the cross-component direction; and $\overline{j}$ = unit vector in the fore/aft component direction.

For brevity, let $f = a_1 b_2 - a_2 b_1$.

The ADCP provides velocity data both in vessel-related coordinates and in earth-related coordinates. The coordinates system can also be used to compute discharge as long as both water and vessel velocities are described in the same system. In practice, the discharge integral is approximated by a summation of many sections of measured discharge. The equation takes the form

$$Q_m = \sum_{i=1}^{N_s} [\int_0^{d_i} f_i \, dz] \, t_i \qquad (4)$$

where: Q_m = measured channel discharge (does not include the unmeasured near-shore discharge); N_s = number of measured discharge subsections; i = index for a subsection; d_i = depth of the subsection; f_i = integrated f value for subsection i, dz = differential vertical depth of subsection i; and t_i = elapsed traveltime between the ends of subsections i and i -1.

4. OBTAINED RESULTS FOR OTHER AUTHORS

4.1 Results

According to Santos et al (1997) and, Gomes et al (1999), in simultaneous discharge mensurations accomplished with ADCP and the conventional method in several stations (figure 1), in the ones which the obtained data were submitted to some statistical tests as: for the average of the relative differences (deviations), for the linear regression between the deviations and some characteristic of the mensuration and for the linear regression among the measured discharges for the two methods, with the objective of verifying if the relationship among them can be represented by a straight line for 45° going by the origin, indicating the same values of discharge for the two methods in study; the results demonstrated that the tested hypothesis were accepted at the 0.05 level of significance (tolerated error), as shown in figure 3. In comparison between the discharge measurements and the stage discharge curves, the same tests were accomplished, being obtained similar results. Exception done to the test for the medium depth and the percentage of the measured discharge in relation to the total discharge, where the tested hypothesis was rejected at the 0.05 level of significance, suggesting that as larger the medium depth and the percentage of the measured discharge for ADCP in relation to the total, smaller the deviations.

However, it was verified that the differences observed among the measured discharges by the two methods cannot be explained by the analysis in group of the accomplished measurements. Consequently, it was proceeded to a detailed analysis of the simultaneous measurements, trying to analyse the measurements that presented the largest deviations among the conventional and acoustic methods (table 1), through two factors: the distribution of velocities (figures 4 and 5), and the geometric representation of the cross section (figures 6 and 7), being reached the conclusion that the negative relative differences, where the discharge for the acoustic method is smaller than the discharge for the conventional method, partly they can be explained by the distribution of velocities in the cross section and the differences of the areas are in the same sense of the differences presented by the discharge and, in spite of they be smaller, they can explain the differences of the discharge (table 2).

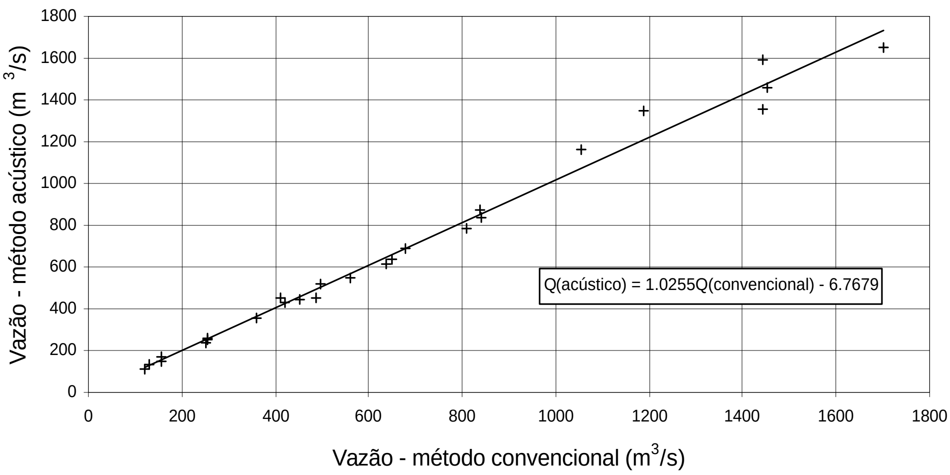

Figure 3. Comparison among the values of measured discharge for the conventional method and for ADCP.

Table 1 – Comparative of the mensurations used in the detailed analysis of the simultaneous mensurations by the conventional and acoustic methods.

Code of the station	Station	Date	Discharge (m³/s) (conventional method)	Discharge (m³/s) (ADCP)	Difference (%)
64685000	Porto Paraíso do Norte	16/10/96	1189	1337	12,45
65035000	Porto Amazonas	04/09/96	120	111	-7,50

Table 2 – Comparative of the areas of the analysed mensurations

Code of the station	Station	Area of the section (m²) (conventional method)	Area of the section (m²) (ADCP)	Area difference (%)	Discharge difference (%)
64685000	Porto Paraíso do Norte	935.84	984.48	5.20	12,45
65035000	Porto Amazonas	169.85	164.98	-2.86	-7,50

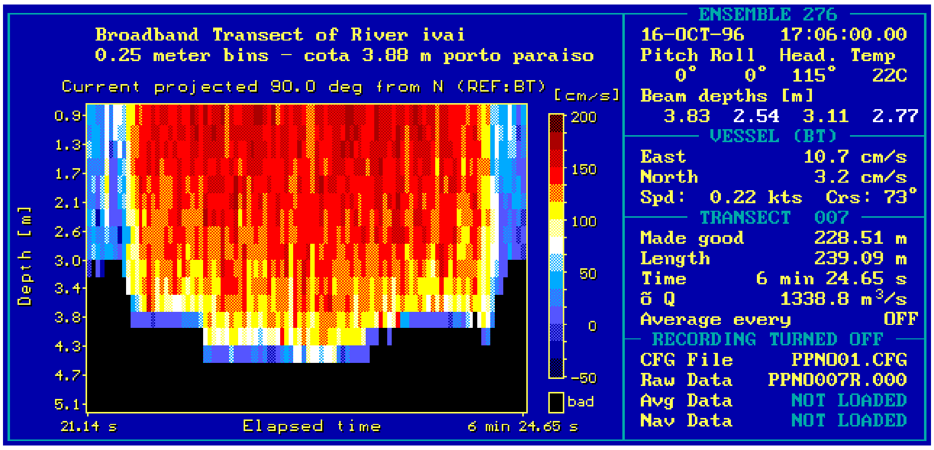

Figure 4 – Distribution of velocities of the acoustic measurement in Porto Paraíso do Norte.

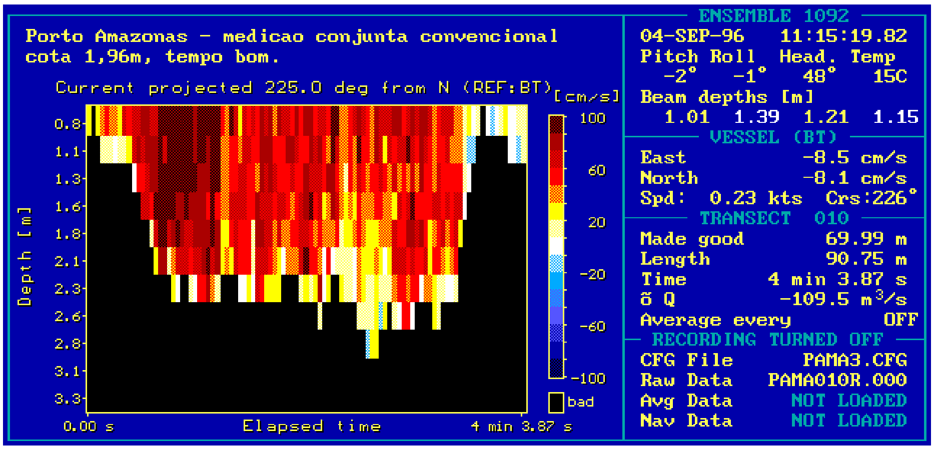

Figure 5 – Distribution of the velocities of the acoustic measurement in Porto Amazonas.

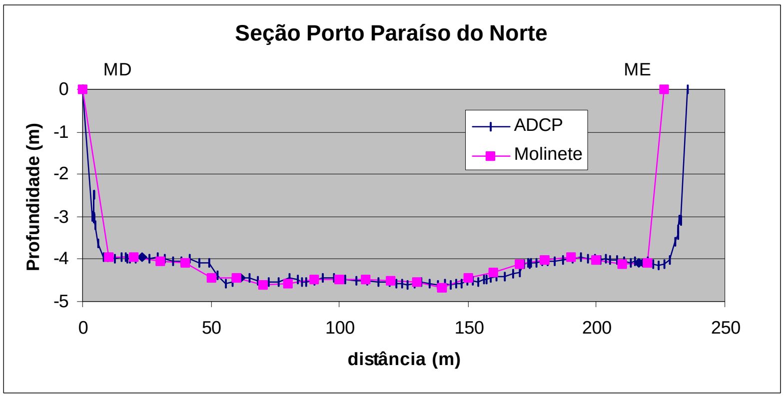

Figure 6 – Cross section determined in the acoustics and conventional measurements in Porto Paraíso do Norte.

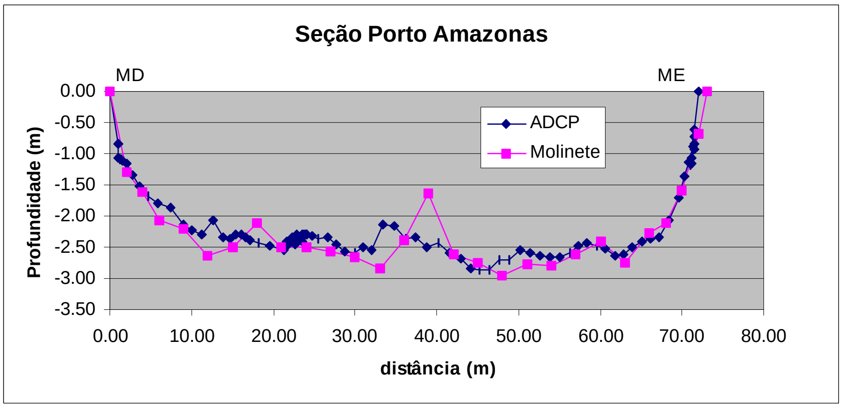

Figure 7 – Cross section determined in the acoustics and conventional measurements in Porto Amazonas.

According to Simpson et al (1993), numerous measurements were made with the ADCP on the Sacramento River near Freeport, California and compared with data provided by an ultrasonic velocity meter located at that site.

The ADCP was used at the Freeport site to collect measurement data sets under various dicharge-measurement techniques. During data-collection transects, vessel traverse speeds were varied. Different ADCP averaging periods were tried; diagonal, s-curve, and figure-eight vessel traverse paths were used. The transducer mounting also was rotated through 360º during several data-collection transects.

Vessel traverse speed and different averaging periods had a significant effect on the accuracy of discharge measurements because they indirectly determine the number of subsection measurements collected during the cross-section traverse. Vessel traverse path had little effect (less than 2 percent) on the accuracy of the discharge measurement. Transducer rotation also had little effect on the accuracy of the discharge measurement. However, the sign (±) of the subsection discharge values changed as the transducer was rotated through 180º.

Discharge-comparison results showed that the discharges provided by the ADCP were within 2 percent of the ultrasonic velocity meter measured discharges.

According to González et al (1996), in comparison of approximate two-dimensional open-channel velocity distributions, collected in two data sets with a fixed ADCP at the Chicago Sanitary and Ship Canal (CSSC) at Romeoville, Illinois, with the logarithmic- and power-law velocity distributions, the results indicated that both the laws fit well the measured mean velocity profiles of the two data sets. The coefficients of determination obtained from the nonlinear regression analysis for each theoretical distribution are practically equal. The deviations of the measured mean velocity profile obtained from the first data set (25 velocity profiles), with respect to the theoretical velocity profiles seem to result from the averaging time span. The results of the analysis performed on the second data set indicated that the deviations of estimates of the mean velocity based on 20-sequential profiles are approximately within half a standard deviation from the long-term mean velocity.

Based on these results and assuming that the coefficient of variation of the first data set is transferable to the second one, deviations of approximately ± 3.5 cm/s should be expected.

The shear velocity and Nikuradse's equivalent sand roghness were estimated by fitting the data to the logarithmic law. The values of the Nikuradse's equivalent sand roughness independently estimated from each data set were very similar.

The estimated exponents of the power law for the two sets of data are very close to 1/6, wich links the power law with Manning's equation for uniform flow in wide channels.

4.2 Found Accuracy

According to Simpson et al (1993), the vessel traverse speed and different averaging periods had a significant effect on the accuracy of discharge measurements. Transducer rotation and vessel traverse path had little effect (less than 2 percent) on the accuracy. The results showed that the discharges provided by the ADCP were within 2 percent of the ultrasonic velocity meter measured discharges.

According to González et al (1996), the accuracy of the ADCP to measure velocities at locations closer to the side walls where the flow departs from 2D behavior has yet to be studied.

5. RESEARCH

For the validation of the methodology of discharge mensuration in small and medium rivers with the use of ADCP, it intends to install a platform of tests in a channel of a small hydro power plant, item 1 of the figure 7, with section of 4,0 x 3,5 m, where discharges can be measured of up to 8 m^3/s. The obtained results from the acoustic method will be compared with the results supplied by the classic method of the propeller flowmeter, installed in the same channel, item 2 of the figure 7, with the results supplied by the weir, built in the tailrace, item 4 of the figure 7, and with the results measured with an ultrasonic velocity meter, installed in the penstock of the plant, item 3 of the figure 7. A station on the downstream of the dam will also be used to mensurations with the ADCP and the flowmeter.

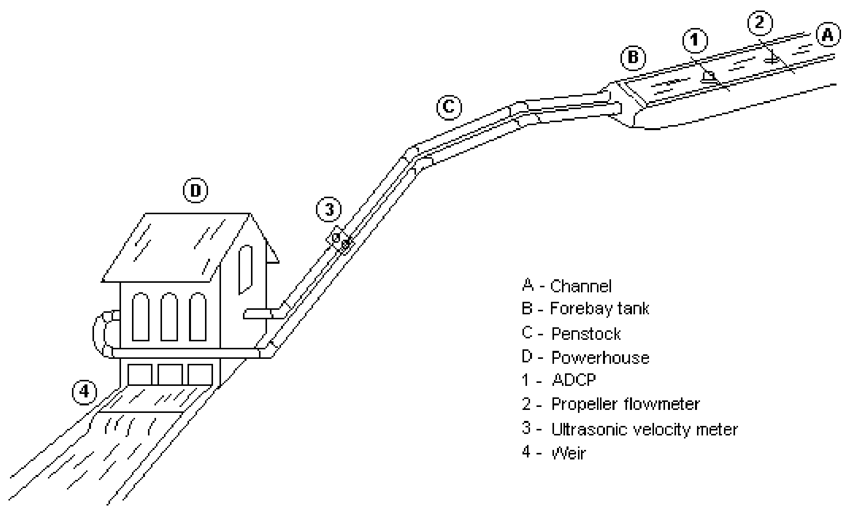

Figure 7 - Platform for tests of ADCP in a channel.

6. CONCLUSIONS

The ADCP is particularly useful for flow conditions that cannot be adequately measured with conventional current meters. The acoustic method presents technical and operational advantages in relation to the conventional for a wide band of conditions, having eliminated some serious limitations of the propeller flowmeter, as the non identification of the direction of the velocities. Two of the most relevant advantages of applying the ADCP is relative to traditional current meters are that ADCP measurements can be made in much less time, and that they provide three-dimensional velocity information.

According to Santos et al (1997) and, Gomes and Santos (1999), for small depths, there is a decrease of the discharge percentage directly measured by ADCP in relation to the total discharge.

However, at present, despite the experience with ADCP for discharge measurement in streams and channels, especially for small and medium rivers, the reliability and accuracy of ADCP measurements have not been rigorously tested in the field. It is waited, through new studies, to obtain favorable results to the use of ADCP in small and medium rivers.

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