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Hydrometry — Acoustic Doppler profiler — Method and application for measurement of flow in open channels from a moving boat

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 113 *Hydrometry*, Subcommittee SC 1 *Velocity area methods*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The term acoustic Doppler current profilers (ADCP) has been adopted as a generic term for a technology that is manufactured by various companies worldwide. They are also called acoustic Doppler velocity profilers (ADVPs) or acoustic Doppler profilers (ADPs).

To use this document effectively, it is essential that users are familiar with the terminology and functions of their own ADCP equipment. Users should also be familiar with additional requirements.

Hydrometry — Acoustic Doppler profiler — Method and application for measurement of flow in open channels from a moving boat

1 Scope

This document gives guidelines for the use of boat-mounted acoustic Doppler current profilers (ADCPs) for determining flow in open channels. It describes a number of methods of deploying ADCPs to determine flow. Although, in some cases, these measurements are intended to determine the stage-discharge relationship of a gauging station, this document deals only with single determination of discharge.

ADCPs can be used to measure a variety of parameters, such as current or stream flow, water velocity fields, and channel bathymetry. As a potential application, an idea of bedload discharge can be obtained applying the bottom track velocity, while suspended sediment flow can be obtained applying the acoustic backscatter and the sonar equation. This document is generic in form and contains no operational details specific to particular ADCP makes and models.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometry — Vocabulary and symbols*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 772 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
transducer depth
ADCP depth
draft
depth of the ADCP transducers below the water surface during *deployment* (3.6)

Note 1 to entry: The ADCP depth should be measured manually.

3.2
bin
depth cell
truncated cone-shaped volume of water at a known distance and orientation from the transducers

Note 1 to entry: The ADCP determines an estimated velocity for each cell using a centre-weighted averaging scheme, which takes account of the water not only in the bin itself but also in the two adjacent bins.

3.3
blanking distance
blank
distance travelled by the signal when the vibration of the transducer during transmission prevents the transducer from receiving echoes or return signals

Note 1 to entry: This is the distance immediately below the ACDP transducers in which no measurement is taken.

Note 2 to entry: The distance should be the minimum possible. However, care should be taken not to make the distance too short in order to avoid signal contamination by ringing or bias due to flow disturbance.

Note 3 to entry: If software allows it, blanking distance may be set to zero to reduce the blanking distance. During post-processing, user has option to choose to keep or reject this value near ADCP. This is useful when depth is very low.

3.4
bottom tracking
acoustic method used to measure boat speed and direction by computing the Doppler shift of sound reflected from the stream bed relative to the ADCP

Note 1 to entry: With no moving bed, the discharge can be computed with bottom velocity and water velocity data because this is done in ADCP coordinates not earth coordinates. With moving bed, the use of a Global Navigation Satellite System (GNSS) or loop-corrected data using a calibrated compass is required.

3.5
real-time mode
mode in which the ADCP relays information to the operating computer as it gathers it

Note 1 to entry: The ADCP and computer are connected (physically or wireless) throughout the *deployment* (3.6) in this mode.

3.6
deployment
ADCP initialized and activated to collect data while the ADCP is propelled across the section to record data

Note 1 to entry: A deployment typically includes several pairs of *transects* (3.11) or traverses across a river or estuary.

3.7
deployment method
technique used to propel the ADCP across a watercourse

Note 1 to entry: One of three different deployment methods is used: a manned boat; a tethered boat; or a remote-controlled boat.

3.8
ensemble
profile
single measurement of the water column

Note 1 to entry: A column of *bins* (3.2) is equivalent to a vertical in conventional current meter gauging.

3.9
ping
entirety of the sound generated by an ADCP transducer for a single measurement cycle

Note 1 to entry: Sound pulses transmitted by the ADCP for a single measurement.

3.10
self-contained mode
autonomous mode
data retrieval mode in which the ADCP stores the information it gathers within its own memory and then downloaded to a computer after *deployment* (3.6)

Note 1 to entry: This method is generally not used by majority of ADCP practitioners nor recommended by the majority of hydrometric practitioners.

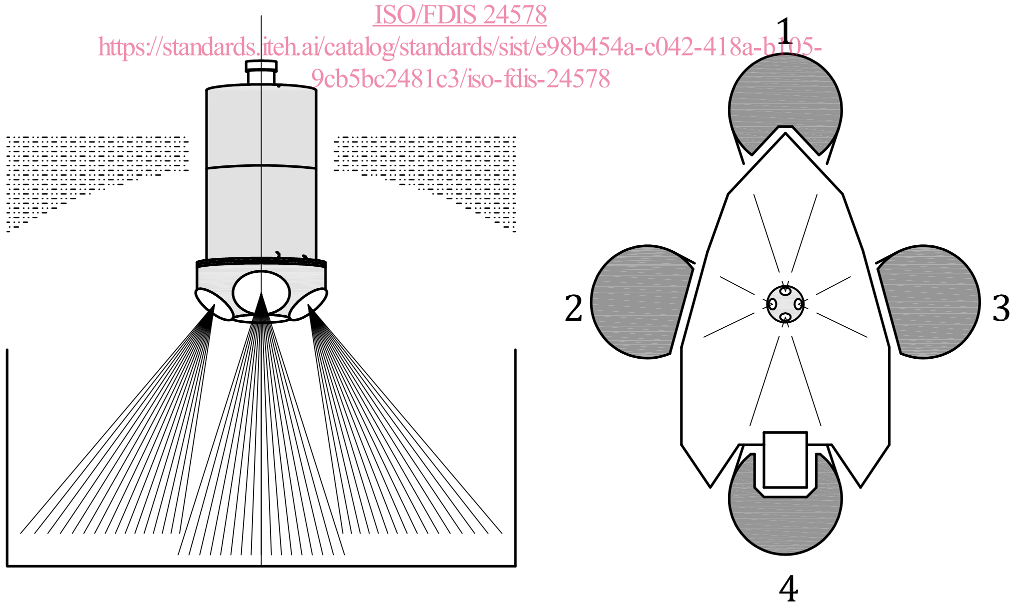
3.11
transect
pass
one sweep across the watercourse during an ADCP *deployment* (3.6)

Note 1 to entry: In the *self-contained mode* (3.10), a deployment can consist of any number of transects.

4 Principles of the boat mounted ADCP method

4.1 General

The ADCP is a device for measuring current velocity and direction, throughout the water column, in an efficient and non-intrusive manner. It can produce an instantaneous velocity profile through the water column while disturbing only the top few decimetres. ADCPs nominally work using the Doppler principle (see 4.2). An ADCP is usually a cylinder with a transducer head on the end (see Figure 1). The transducer head is typically a ring of three or more acoustic transducers with their faces angled to the horizontal and at specified angles to each other. Some ADCPs use phased array transducers, which contain many elements that can form multiple beams at various angles, depending on transducer design. A single phased array transducer can form the three or more beams needed for an ADCP.



Key

1 forward

2 port or left

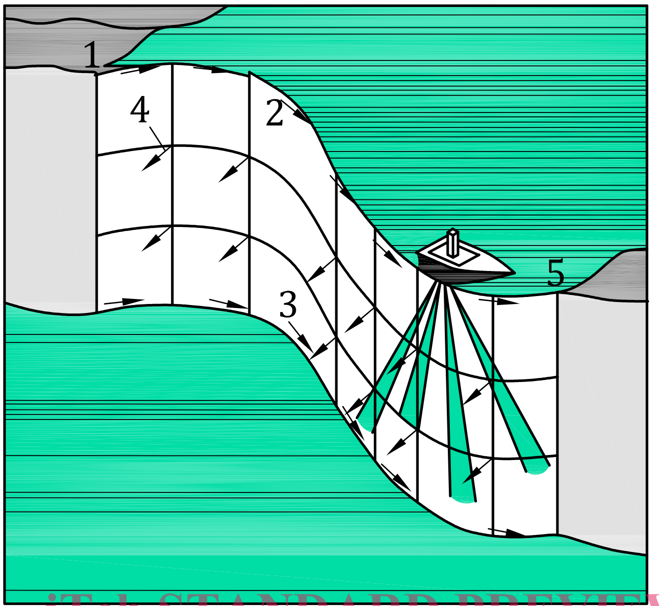
3 starboard or right

4 aft or backward

NOTE ADCP can work in any position or orientation; this figure is an indicative illustration.

Figure 1 — Example sketch illustrating typical ADCP with four transducers

The ADCP, which was originally developed for oceanographic work, has since been developed for use in estuaries and rivers. An ADCP can be mounted on a boat, flotation collar, or raft, and propelled across a river (see Figure 2). The ADCP collects velocity data, direction of flow, depth data, and boat speed, direction, and position. With such information, discharge values are independent of the path; in other words, the route taken does not need to be straight or perpendicular to the bank.



Key

1 start

2 path of boat

3 path of boat on river bottom

4 flow velocity vectors

5 finish

Figure 2 — Sketch illustrating moving — Boat ADCP deployment principles

4.2 Doppler principle applied to moving objects

The ADCP uses ultrasound to measure water velocity using a principle of physics discovered by Christian Doppler. The reflection of sound waves from a moving particle causes a change in frequency to the reflected sound wave. The difference in frequency between the transmitted and reflected sound wave is known as the Doppler shift (see Figure 3).

It should be noted that only components of velocity parallel to the direction of the sound wave produce a Doppler shift. Thus, particles moving at right angles to the direction of the sound waves (i.e. with no velocity components in the direction of the sound wave) will not produce a Doppler shift.

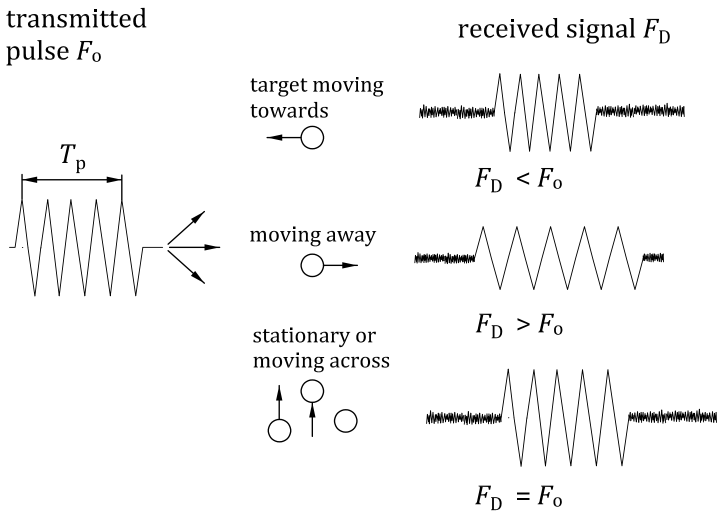


Figure 3 — Reflection of sound — Waves by a moving particle results in an apparent change in the frequency of those sound waves

Doppler's principle relates the change in frequency to the relative velocities of the source (reflector) and the observer. In the case of most ADCPs, the transmitted sound is reflected off particulates or air bubbles in the water column and reflected back to the transducer. It is assumed that the particulates move at the same velocity as the water and, from this, the frequency shift can be translated to a velocity magnitude and direction. The particulates in the river are generally suspended sediments (SS). Too low SS concentration results in no data because of no back signal, while too high SS disrupt the signal, and also results in no data. Therefore, ADCP frequency shall be chosen according to these criteria. The more suspended sediment that are in water, the lower the ADCP operating frequency should be. In addition to that, it should also be noted that excessive air bubbles can cause distortion in, or loss of, the returned signal. Furthermore, air bubbles naturally rise and therefore are likely not to be travelling in a representative magnitude and direction.

4.3 Acoustic Doppler current profiler techniques

4.3.1 General

There are three general types of ping configuration and processing algorithms used in ADCPs:

— pulse incoherent (including narrowband) — Doppler shift long pulse,

— pulse-to-pulse coherent — Doppler shift short pulse, and

— broad band (spread spectrum) — phase shift on two short pulses.

Reference should be made to the ADCP manual to determine the type being used.

4.3.2 Pulse incoherent

An incoherent ADCP transmits a single, relatively long, pulse of sound and measures the Doppler shift, which is used to calculate the velocity of the particles along the path of the acoustic beam. The velocity measurements made using incoherent processing are very robust over a large velocity range, although they have a relatively high short-term (single ping) uncertainty. To reduce the uncertainty, multiple pulses are transmitted over a short time period; these are then averaged before reporting a velocity. "Narrowband" is used in the industry to describe a pulse-to-pulse incoherent ADCP. In a narrowband ADCP, only one pulse is transmitted into the water per beam per measurement (ping), and the resolution of the Doppler shift shall take place during the duration of the received pulse. The narrowband acoustic pulse is a simple monochromatic wave and can be processed quickly.

4.3.3 Pulse-to-pulse coherent

Coherent ADCP systems are the most accurate of the three, although they have significant range limitations. Coherent systems transmit one, relatively short pulse, record the return signal, and then transmit a second short pulse when the return from the first pulse is no longer detectable. The ADCP measures the phase difference between the two returns and uses this to calculate the Doppler shift. Velocity measurements made using coherent processing are very precise (low short-term uncertainties), but they have significant limitations. Coherent processing will work only in limited depth ranges and with a significantly limited maximum velocity. If these limitations are exceeded, velocity data from a coherent Doppler system are effectively meaningless.

4.3.4 Broadband (Spread spectrum)

Like coherent systems, broadband ADCP systems transmit two pulses and look at the phase change of the return from successive pulses. However, with broadband systems, both acoustic pulses are within the profiling range at the same time. The broadband acoustic pulse is complex; it has a code superimposed on the waveform. The code is imposed on the wave form by reversing the phase and creating a pseudo-random code within the wave form. This pseudo-random code allows a number of independent samples to be collected from a single ping. Due to the complexity of the pulse, the processing is slower than in a narrowband system; however, multiple independent samples are obtained from each ping.

The short-term uncertainty of velocity measurements using broadband processing is between that of incoherent and coherent systems. Broadband systems are capable of measuring over a wider velocity range than coherent systems; although, if this range is exceeded, the velocity data will be rendered meaningless. The accuracy and maximum velocity range of a broadband system is a function of the precise processing configuration used.

4.4 Measurement of velocity profile

4.4.1 General

ADCPs measure velocity profiles relative to the ADCP. In order to obtain an absolute velocity profile, a combination of relative velocity and boat velocity are necessary.

4.4.2 Measurement of relative velocity

The velocity is measured as a centre-weighted average that spans the cells above and below as described in 4.3 and the result is reported at the depth of the cell centre. With these results and using trigonometric relations, a 3-dimensional water velocity is computed and assigned to a given depth cell in the water column. Although this is analogous to a velocity profile obtained from a point velocity meter, the entire measurable region of the water column is sampled by the ADCP. Acoustic pulse requires to be stabilized, in order to obtain data. The blanking distance exits in order for acoustic pulse to stabilize (see Figure 4).

4.4.3 Measurement of boat velocity

4.4.3.1 Bottom tracking

The ADCP can use the Doppler principle to track their movements across a channel using a technique called “bottom tracking”. Bottom-tracking measurements are similar to water-velocity measurements, but separate pulses are used. Bottom-tracking pings are longer than water pings. These pings are also used to measure the depth of water. The sound pulses are reflected from the stream bed and used to calculate the velocity of the ADCP relative to the bed. ADCPs may also have an on-board compass and can combine this data with bottom-tracking data to determine boat direction and speed assuming the stream bed is stable.

In order to conduct the water and bottom tracking measurements, first, the ADCP sends a pulse to measure the boat velocity which is just the opposite of bottom velocity relative to the ADCP. Second, the ADCP sends a pulse to measure water velocity relative to the ADCP. Third, the ADCP combines these two velocity vectors (water and boat) to compute the absolute water velocity. To do this with accuracy, two conditions shall be met.

a) The stream bed should not move, otherwise the water velocity can be under estimated. In this case, GNSS should be implemented or special treatments shall be taken care as described in 5.3.

b) The boat should not move or rotate between the pulse for bottom velocity and the pulse for water velocity. Otherwise, there is an angle error between the velocity water vector and the boat velocity vector.

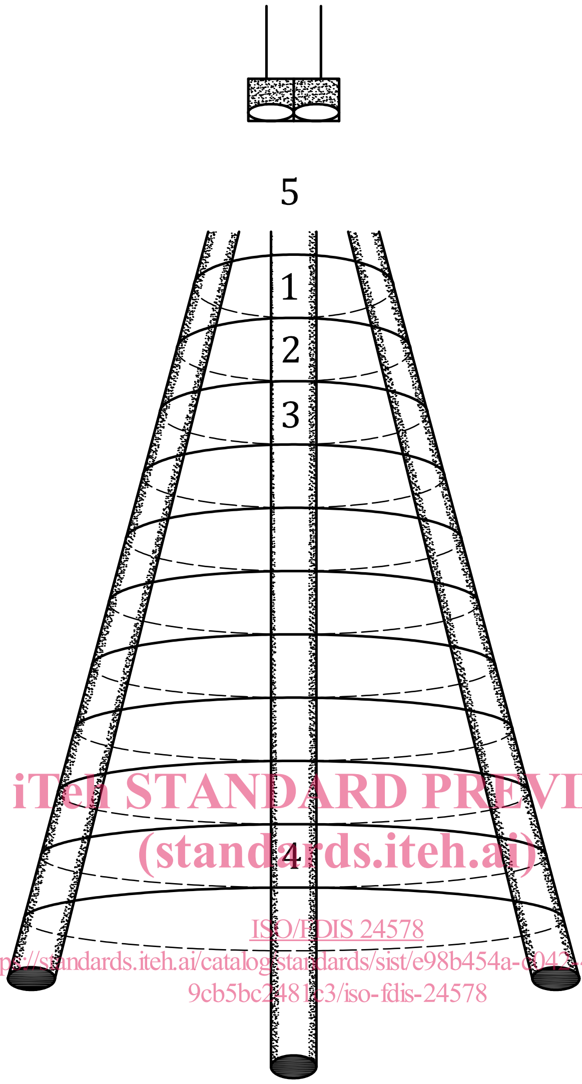
To ensure that these conditions are met:

1) test for a moving stream bed using a stationary method, loop test, or GNSS;

2) deployment of boat has to be smooth and even, and slow relative to the water velocity.

4.4.3.2 Global Navigation Satellite System (GNSS)

A GNSS may be integrated with an ADCP to provide position and boat velocity data. This is used as an alternative to bottom tracking when the bed is unstable due to high bedload discharge or when bottom tracking is unable to accurately determine bed level due, for example, to vegetation growth or heavy suspended sediments. It is important to implement the most accurate GNSS system available to users. The accuracy of the GNSS may be affected by trees or buildings on the river bank on narrow rivers. When GNSS can only sight four or less satellites at one time, the accuracy of the ADCP is reduced considerably. The GNSS system should warn the user when this occurs.



Key

1 cell/ bin 1

2 cell/ bin 2

3 cell/ bin 3

4 cell/ bin n

5 blanking distance

Figure 4 — ADCP depth cells or bins

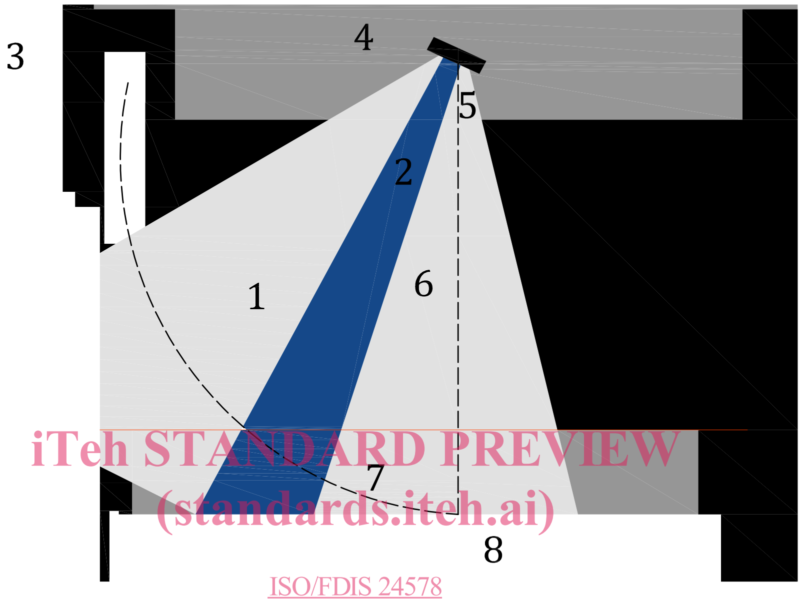
4.4.4 Near boundary data collection

The angle of the ADCP transducers varies depending on the manufacturer and type. It typically ranges between 20° and 30° from the vertical. The ADCP cannot measure all the way to the stream bed. When acoustic transducers produce sound, most of the energy is transmitted in the main beam. However, there are also side lobes that contain less energy that propagate from the transducer as well. These side lobes do not pose a problem in most of the water column because they emit low energy. However, when the side lobe strikes the stream bed, the stream bed is a good reflector of this acoustic energy, and much of the energy is reflected back to the transducer. Due to the slant of the beams, the acoustic energy in the main beam reflects off scatterers in the water column near the bed at the same time that a vertical side lobe reflects from the stream bed. The energy in the main beam reflected from these scatterers in the water column is relatively low compared to the energy in the side lobe returned from the stream bed, which may contaminate the velocity measurement near the bed. Therefore, there is an area near the bottom that cannot be measured due to side-lobe interference. This distance is computed as shown in Formula (1):

$$[1 - \cos(\theta)] \times 100 \qquad (1)$$

where θ is beam angle.

Thus, for a 20°system, it is 6 % of the range from the transducer. As the profile approaches the boundary, interference occurs due to reflection of side-lobe energy taking a direct (shorter) path to the boundary (see Figure 5).



Key

1 side lobe
2 main beam
3 maximum slant range
4 depth of sensor and draft of boat
5 blanking distance
6 depth of measured discharge
7 side-lobe interference
8 stream bed

Figure 5 — Depth zones within the water column

To ensure that there is no bias in the velocity estimate, the ADCP and its software should ignore that portion of the water column affected by side-lobe contamination near the bed. This is undertaken automatically by the ADCPs in current use. The user manual should provide information on this.

To measure the velocity at a precise depth, it is necessary to have a reliable measurement on three beams at this depth. Any data beyond the range of the shortest beam is suspect because it may be contaminated by reflections from the boundary of the shortest beam. Only data above the shortest beam should be used.

As illustrated in Figure 6, the ADCP is unable to make velocity measurements in three areas:

— near the surface (due to the depth at which the ADCP is located in the water and, added to this, the blanking distance);