TECHNICAL SPECIFICATION

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Hydrometry — Measuring river velocity and discharge with acoustic Doppler profilers

Hydrométrie — Mesure de la vitesse et du débit des rivières au moyen de profileurs à effet Doppler

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Foreword

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ISO/TS 24154 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 5, *Instruments, equipment and data management*.

Hydrometry — Measuring river velocity and discharge with acoustic Doppler profilers

1 Scope

Acoustic Doppler profilers are instruments and software packages used to measure water velocity, channel bathymetry, and river discharge. This Technical Specification gives the principles of operation, construction, maintenance and application of acoustic Doppler profilers to the measurement of velocity and discharge, and discusses calibration and verification issues. It is applicable to open-channel flow measurements with an instrument mounted on a moving vessel.

It is not applicable to measurement of liquid flow in small channels or partly-filled pipes using a single Doppler-based flowmeter at a fixed point in the cross section.

2 Normative references

The following referenced documents are indispensable for the application 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, *Hydrometric determinations — 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.

3.1
Doppler shift
⟨general⟩ change in frequency of a sound source as it approaches and recedes from an observer

3.2
Doppler shift
⟨acoustic Doppler instruments⟩ difference or shift in frequency of emitted sound waves as they are reflected back from moving particles in the water

3.3
Doppler-based flowmeter
class of instruments that uses the principle of Doppler shift to compute water velocity and discharge

NOTE These instruments can be deployed at a fixed point in a cross section or on a moving vessel.

3.4
acoustic Doppler profiler
ADP
instrument that uses the principle of Doppler shift to compute water velocity and discharge

NOTE The instrument is usually mounted on a vessel that transits across a river channel perpendicular to flow.

3.5
ping
series of acoustic pulses of a given frequency transmitted by an acoustic Doppler instrument

3.6
ensemble
collection of pings

NOTE Because the measurement results from a single ping have a relatively high error, the results of more than one ping are usually averaged to obtain a single measurement.

3.7
transect
collection of ensembles from a single pass across a river, lake, or estuary

NOTE When measuring streamflow with an acoustic Doppler profiler, one transect may constitute a single measurement of discharge.

4 Background

Acoustic Doppler instruments for measuring water velocity have been in use for about 25 years, primarily in the study of ocean currents and estuaries. In the late 1980s, acoustic Doppler instruments began to be used to make velocity measurements from a moving vessel [3], [13]. The early instruments were narrow-band acoustic Doppler instruments that required deep water (> 3,4 m), which limited their use to deep rivers and estuaries. In 1992, a more advanced acoustic Doppler instrument, known as a Broadband Acoustic Doppler Current Profiler, was developed that could be used to measure velocities in shallow waters (as shallow as 1,0 m) with a high degree of vertical resolution (0,10 m).

Throughout the 1990s, acoustic Doppler profilers were continually developed and enhanced by several manufacturers. The instruments have been refined from very cumbersome and heavy units that were 1 m in length and weighing as much as 50 kg to compact and light units as small as 14 cm long and weighing 7 kg. The acoustic Doppler profilers now include advanced acoustic instrumentation designed specifically for use in rivers and software for real-time and post-processing of river velocity and discharge measurements. Acoustic Doppler profilers (3.3) are routinely used to measure discharge in estuaries, rivers, and canals where conventional discharge-measurement techniques are either very expensive or impossible due to stratification of the flow. They are also routinely used to measure discharge in large rivers, in part because of cost savings and reduced uncertainties due to smaller changes in discharge during the measurement.

5 Principles of operation

In moving vessel deployments, the acoustic Doppler instrument is mounted to a vessel (usually a motorized boat) that moves across the water body perpendicular to the current being measured. Water velocities are measured by the acoustic Doppler instrument, which transmits acoustic pulses along three or four beams at a constant frequency between 75 kHz to 3 000 kHz. The beams are positioned at precise horizontal angles from each other (120° for 3-beam instruments and 90° for 4-beam instruments (see Figure 1). The beams are directed at a known angle from vertical, typically 20° or 30°. The instrument detects and processes echoes throughout the water column along each beam.

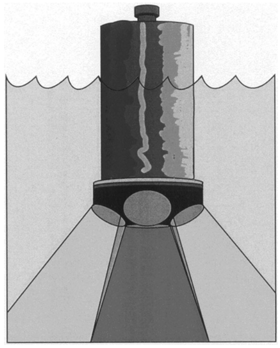


Figure 1 — Schematic diagram of an acoustic Doppler instrument with a 4-beam configuration

The difference in frequency (shift) between successive echoes is proportional to the relative velocity between the acoustic Doppler instrument and suspended material in the water that reflects the pulses back to the instrument. This frequency shift is known as the Doppler effect. The acoustic Doppler instrument uses the Doppler effect to compute a water-velocity component along each beam, and the system software computes water velocity in three directions using trigonometric relations. Velocities are determined at preset intervals called bins along the acoustic path. The instrument setup parameters can be adjusted to optimize the system for the river cross section being measured. These parameters include the depth cell size, the number of depth cells, the number of pings, and velocity reference commands.

The water-velocity measurements incorporate both the true water velocity and the boat velocity. The boat velocity can be measured by using the Doppler shift of separate acoustic pulses reflected from the river bottom. This technique, referred to as bottom tracking, is commonly used; it was first used with early sonar to measure the speed of a moving vessel. In addition to measuring boat velocity, the depth of the river is estimated from the amplitude of the bottom-track echoes (echoes returned from the bottom). Real-time differential global-positioning systems (DGPS) provide an alternative technique for measuring the boat velocity.

When the acoustic Doppler instrument is being used to measure discharge, it transmits a series of acoustic pulses known as pings (3.5). Pings for measuring water velocities are known as water pings, and pings for measuring the boat velocity are known as bottom-tracking pings. Normally, water pings and bottom-tracking pings are interleaved during transmission. A group of these interleaved water and bottom-tracking pings are referred to as an ensemble (3.6). The user sets the number of water and bottom-tracking pings per ensemble. An ensemble is analogous to one vertical in a conventional discharge measurement. For example, a typical ensemble is composed of a combination of water pings and bottom-tracking pings. The velocities and depths measured for each ping are averaged to yield a single velocity profile and depth for each ensemble. In a conventional discharge measurement, velocity is measured at one point in the vertical when the depth is less than 0,8 m and two, three or five points in the vertical when the depth is greater than 0,8 m. Depending on its characteristics, an acoustic Doppler profiler can measure velocities every 0,25 m in the vertical, so that one ensemble for a vertical 10 m deep may contain as many as 34 velocity measurements.

6 Application of acoustic Doppler profilers to measurement of river discharge

6.1 Instrumentation and equipment requirements

Making discharge measurements with acoustic Doppler profilers requires three main pieces of equipment: the acoustic instrument/transducer assembly, a vessel for mounting the instrument, and a portable computer. The instrument includes a pressure case that contains most of the electronics and a transducer assembly (see Figure 1). The transducer assembly may have a convex or concave assembly. The instruments come in a variety of sizes, beam configurations, and frequencies depending on the size and characteristics of rivers to be measured and the type of deployment. The small units are less than 30 cm tall and weigh about 7 kg; large units are 1 m tall and weigh 50 kg.

The type of acoustic Doppler profiler deployed depends on the river being measured. For small rivers, the system can be mounted in the bottom of a small boat, raft or catamaran. A remote-control motor can power the boat or a tether can be used to pull the boat and system across the river. Attaching a line from each bank or traversing the river with a single line from a bridge or cableway can be used for a tethered deployment. Measurements in large rivers require that the acoustic Doppler profiler be suspended in the water column from a mounting bracket on a boat powered with a gas or diesel engine. Examples of these two types of deployment are shown in Figure 2.

The system software processes and displays a large amount of data so a laptop computer with a minimum of 200 MHz processor and > 64 MB of RAM memory is recommended. The computer screen display should be visible in direct and diffuse sunlight.

Figure 2 — Photographs showing acoustic Doppler profilers deployed on a small, tethered boat (A) and a power boat (B)

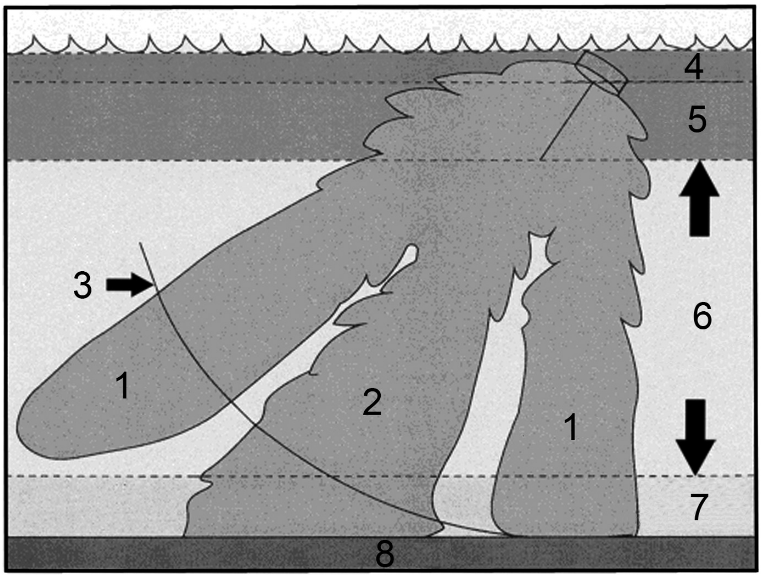
6.2 Making the measurement

A discharge measurement is made with an acoustic Doppler profiler by traversing the river cross section with the boat or tethered boat. A single traverse, called a transect (3.7), consists of a collection of ensembles. A typical transect will contain 300 to 1 000 ensembles, whereas a conventional discharge measurement will typically consist of 25 to 30 verticals. When measuring under relatively steady flow, four transects are made at each measuring location. Pairs of transects on reciprocal headings are used to minimize any directional bias that may be present. If the discharge measured on any given transect varies by more than 5 % of the mean discharge for all the transects, a second set of four transects is made. The mean of the discharges of all transects is used as the measured discharge. The time required to make four transects with an acoustic Doppler profiler is typically less than 30 min whereas a conventional discharge measurement may take 1 h to 2 h or more.

With rapidly-changing stage and unsteady flow conditions, a single transect may be used as a discharge measurement. However, two to four single-transect measurements should be made to help define and verify the stage-discharge rating at a streamgaging station.

6.3 Computing the measurement

Acoustic Doppler profilers have some limitations for measuring discharge in a river cross section. They cannot measure water velocities near the surface and near the bed. Water velocities near the surface are not measured because of the draft of the transducer (depth of the transducer face below the water surface) and the blanking distance of the instrument. The blanking distance is equal to the distance travelled by the signal when the vibration of transducer during transmission prevents the transducer from receiving echoes or return signals. The draft of a transducer can range from 0,2 m to 1 m and the typical blanking distance is 0,3 m. Velocity near the riverbed cannot be measured because of interference from side lobes of acoustic energy at 30° to 40° angles from the main beams. The reflections of the side-lobe energy from the riverbed overwhelm the echoes of the main beam from particles near the bottom of the water column. The effect of draft, blanking distance, and side lobe interference are shown in Figure 3.



Key

1 side lobe
2 main beam
3 maximum slant range
4 draft
5 blanking distance
6 area of measured discharge
7 side lobe interference
8 streambed

Figure 3 — Schematic diagram of areas where velocity is not measured near the water surface and near the streambed [12]

In order to accurately measure discharge, the near-surface and near-bed velocities must be estimated. The constant method or the power-law method is most commonly used for estimating the water velocities near the surface or near the bottom.

With the constant method, the velocity at the surface or the bottom is assumed to equal the velocity of the first or last measured depth cell, respectively. This method is not considered appropriate for estimating the velocities near the bottom because it does not accurately represent typical vertical-velocity distributions for open-channel flow. In open-channel flow, the velocity approaches zero as the bottom is approached.

The power-law method is based on a power-law velocity distribution. In this method, a least-squares fit of the measured water velocities is obtained using the power-law velocity distribution. The user can select the exponent of the function, which typically is set to 1/6 [2]. The function is then used to estimate velocities in the unmeasured part of the water column. Conceptually, the power-law method is better for estimating the unmeasured part of the water column near the bottom.

