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Hydrometry — Echo sounders for water depth measurements

Hydrométrie — Sondeurs à écho pour le mesurage de la profondeur de l'eau

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 4366 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 5, *Instruments, equipment and data management*.

This second edition cancels and replaces the first edition (ISO 4366:1979), which has been technically revised.

Hydrometry — Echo sounders for water depth measurements

1 Scope

This International Standard provides information concerning the principles of operation, selection and performance criteria for echo sounders used in depth measurements for open-channel flow (and related) measurements. The use of standard terminology is promoted.

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*

ISO 6420, *Liquid flow measurement in open channels — Position fixing equipment for hydrometric boats*

3 Terms and definitions

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

3.1
tracking window
vertical distance of limited size that follows and automatically centres itself on the depth indicated by the last received echo

NOTE If the next echo falls within the window, the signal is accepted as correct; if it does not, the signal is rejected. The purpose of a tracking window is to screen out erroneous readings caused by reflecting materials in the water (fish, debris, etc.).

4 Units of measure

The units of measurement used in this International Standard are SI units and decibels.

5 Principles of operation

5.1 General

The state-of-the-art of echo sounders is well advanced, and sounders have been put into widespread use for many different applications. Consequently, a variety of specialized echo sounders have evolved to best meet the specific requirements of the application. A digital echo sounder with an integrated analog chart generated by a thermal or inkjet print head is the most common echo sounder used for open-channel applications. Multiple-transducer systems are in common use by many professional surveyors and the use of single-transducer, multibeam-swath systems is expanding rapidly.

5.2 Theory of operation

The echo sounder is an electroacoustic instrument that determines the depth of water by measuring the time required for a burst of acoustic energy to travel from a transducer to the streambed and reflect back to the transducer (Figure 1). The travel time of the reflected wave can be converted to distance by use of the following equation:

$$d = \frac{vt}{2} + k + d_r \quad (1)$$

where

d is the distance from the reference water surface to the streambed;

v is the average velocity of sound in the water column;

t is the travel time of the acoustic energy from the transducer to the bottom and back to the transducer;

k is the system index constant;

d_r is the distance from the reference water surface to the transducer (draft).

NOTE All distance units are consistent.

The velocity of sound varies with the density and elastic properties of the water, which are primarily a function of the water temperature and suspended or dissolved constituents (i.e. salinity). Large variations in temperature and/or salinity with depth are not uncommon. For practical depth measurement with an echo sounder, the velocity of sound is usually determined by calibration (see 8.1), since measuring and correcting for the actual variation at each depth interval is difficult.

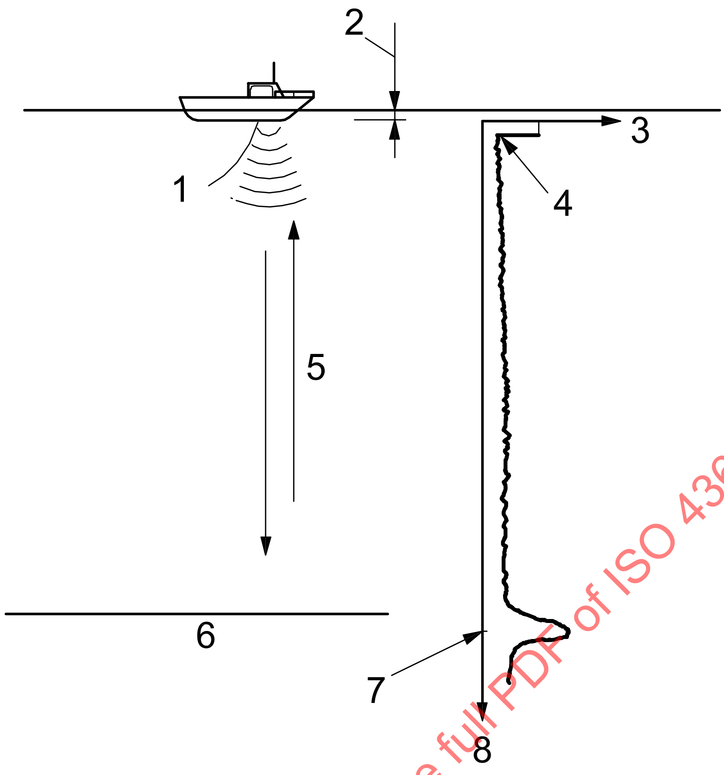
The travel time of the acoustic energy is recorded either electronically by a digital echo sounder or graphically by an analog chart echo sounder. The shape, or sharpness, of the reflected acoustic energy pulse plays a significant role in the accuracy of a depth measurement (Figure 1). The shape and magnitude of the reflected energy pulse is a function of the acoustic attenuation, background noise and acoustic reflectivity characteristics of the target.

The system index constant (k) contains all electrical and/or mechanical delays inherent in the measuring system, including return signal threshold detection variations. The system index constant also contains any constant correction due to the change in the velocity of sound between the upper surface level and the average velocity used for the site. Therefore, the draft (d_r), set during calibration, is not necessarily the actual draft of the transducer that would be obtained by a physical measurement from the water surface to the transducer, but also includes corrections for the system index constant determined during on-site calibration.

5.3 System components

The echo sounder consists of two elements: the electronic assembly, which usually includes a display and/or recording device, and the acoustic assembly commonly called the transducer. The electronic circuitry generates high frequency electrical energy and provides regulated bursts of this energy to the transducer. When a burst of energy is released, time is measured until the reflected energy is received, then Equation (1) is solved and the depth is displayed or recorded.

The transducer is an electroacoustic assembly that acts as a two-way energy conversion device. During transmission, it converts pulses of electrical energy into pulses of acoustic energy that travel through the water to the bottom. During reception, it receives the reflected acoustic energy (echo) from the streambed and converts it into electrical energy for processing by the electronic circuits.



Key

1 depthsounder transducer
2 draft
3 signal
4 time acoustic pulse is transmitted
5 reduced energy
6 acoustically reflective bottom
7 time reflected pulse is received, $(\frac{2}{v})$ (depth $- k - d_r$)
8 time

Figure 1 — Illustration of an acoustic depth measurement [2]

5.4 Non-recording echo sounders

The most common type of non-recording echo sounder has a liquid crystal display (LCD) that displays the depth numerically. Many of these echo sounders also display the return echo graphically and are commonly used as fish finders by fishermen. The numerical depth determination requires the same processing as a digital echo sounder (see 5.6). The non-recording echo sounders typically have wider beamwidth transducers and no calibration adjustments, resulting in a lower accuracy than survey-grade digital echo sounders. Some of the non-recording echo sounders digitally output the depth to an external device through a serial communications port.

5.5 Analog recording echo sounders

Traditionally, analog recording echo sounders have used an electric timing motor to rotate a stylus at a constant speed across heat-sensitive paper. When the stylus passes over the zero contact, it burns a mark on the paper and simultaneously triggers the release of acoustic energy. The stylus continues to move until reflected acoustic energy is received at the transducer generating an electrical current that is applied to the stylus to cause it to burn a mark on the chart again. The stylus continues to rotate until it reaches the zero contact and the cycle is repeated. As the stylus rotates, the chart is being moved by another motor and the resulting succession of marks made by the stylus creates a time-time graph. The stylus speed is adjusted through calibration to equal the speed at which the acoustic energy travels to the streambed and back, thus the distance between the zero mark and other marks on the chart are proportional to the distance between the transducer and the streambed. The speed at which the chart moves is arbitrary so that the chart transit does not necessarily indicate the distance the boat travelled.

Modern analog recorders, which are often combined with a digital display and output (see 5.6), use a fixed thermal or inkjet printing head in place of the rotating stylus. This helps reduce the potential synchronization error and allows electronic filters and processing algorithms to be applied to the data to compensate for the velocity of sound and allows electronic annotation of the chart. The mass, dimensions and power consumption of the fixed-head recorders are less than the rotating stylus design.

5.6 Digital echo sounders

5.6.1 General

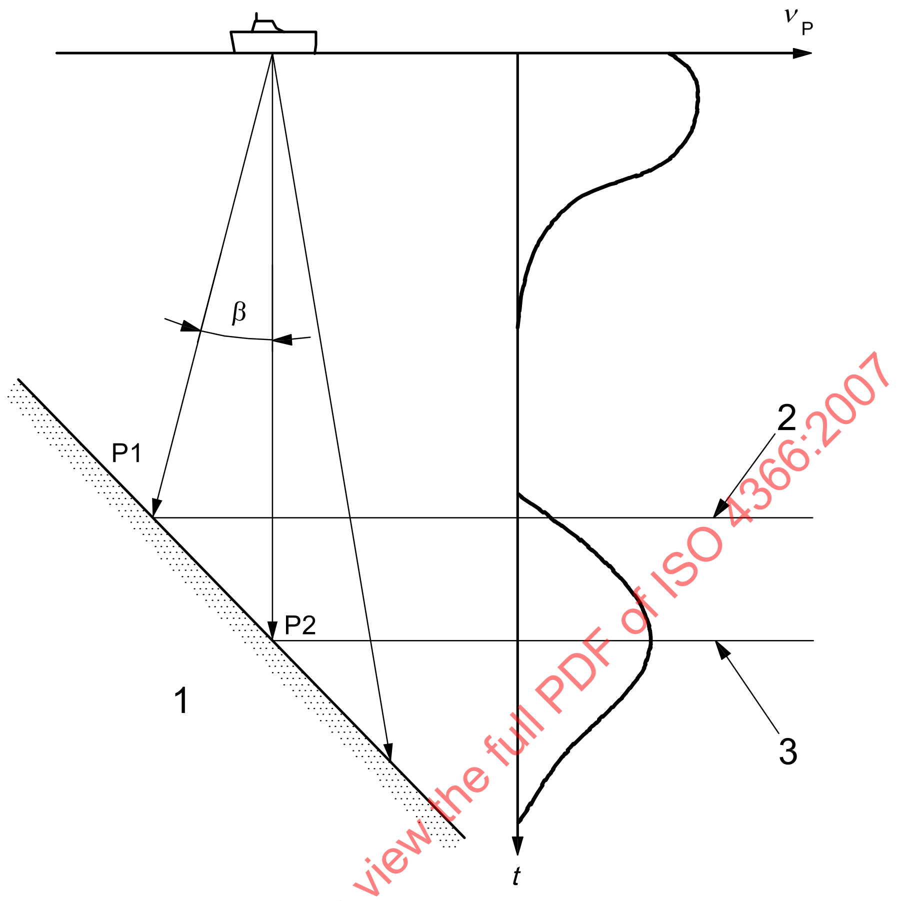
In the digital echo sounder, acoustic pulses are released at set intervals. When an acoustic pulse is released, a counter is started and counts the output of an oscillator. When the reflected acoustic energy is received, the oscillator counts are used to measure the elapsed time and the depth is computed using Equation (1). The accuracy of the depth measurement is highly dependent on the digitization techniques and filters that are used to determine what oscillator count represents the streambed.

Digital echo sounders are the most common echo sounders available. They range from non-recording LCD units to survey-grade echo sounders that usually combine an analog recorder with a numerical display and digital output.

5.6.2 Digitization techniques

Two digitization techniques are commonly used to screen erroneous data and improve the reliability of the acoustic data. The most common technique is threshold detection. Threshold detection measures the time from transmission of the acoustic signal until the energy of the reflected energy exceeds a predetermined threshold or strength. The remaining acoustic energy is not analysed. The threshold value may be adjusted by the user on advanced echo sounders, but it is often fixed and not user selectable. A more robust technique, employed on some survey-grade echo sounders, is peak value detection. Peak value detection analyses all of the reflected energy and computes the time from acoustic release to the peak of the reflected energy or strongest signal. Figure 2 illustrates the difference between the two techniques on a sloping bed. The peak value detection technique produces a measured depth more representative of the centre of the acoustic footprint of the transducer. The peak value technique can significantly reduce the effective beamwidth of the transducer, providing a more accurate representation of the streambed directly below the transducer.

Any material such as fish, debris or air bubbles between the transducer and the streambed can reflect acoustic energy. Peak value detection is less sensitive to these unwanted reflections than threshold detection; however, nearly all survey-grade echo sounders employ techniques to reduce or eliminate erroneous readings caused by reflectors in the water column. A tracking window that rejects all signals except those within a given tolerance of the preceding depth is commonly provided. These reflections from objects in the water column are recorded on the analog chart in addition to the bottom echo. The analog chart is very valuable for verifying the accuracy of the digitized depth. Despite the techniques employed in digital echo sounders, erroneous readings are still common, particularly around obstructions such as bridge piers and sea walls. Depth measurement in such areas without an analog presentation of the data is not recommended.



Key

1 sea bottom

2 threshold point, v_{P1}

3 peak point, v_{P2}

t time

β beamwidth

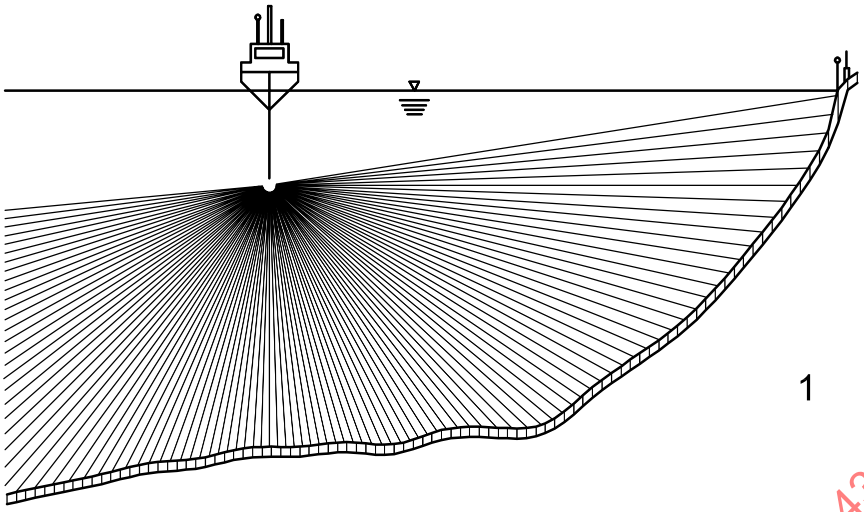
Figure 2 — Illustration comparing threshold and peak value detection techniques

5.6.3 Multiple-transducer systems

A variety of multiple-transducer channel sweep systems have been used since the mid-1970s. These systems are designed to provide a broad area of coverage, rather than a single line, for each pass of the vessel. Channel sweep systems are simply a series of standard transducers mounted on a vessel and/or on booms attached to the vessel. Sweep systems may use any number of transducers. The spacing between the transducers is determined by the nominal water depth, transducer beamwidth, and desired overlap of the transducers' acoustic footprints. The sweep width is determined by the type of vessel. The sweep width must be optimized with vessel manoeuvrability; wide sweeps are difficult to control. Both analog and digital data may be collected. When more than eight transducers are employed, digital terrain modelling display techniques are helpful for interpreting the large amount of data collected.

5.6.4 Single-transducer swath systems

Single-transducer swath survey technology was developed in the early 1960s for deep-water bathymetric mapping. Recently, this technology has been developed and marketed for shallow-water applications. These systems employ scanning or phased-array techniques to generate a series of measurements over a given arc (Figure 3).



Key

1 revetment mat

Figure 3 — Illustration of measurements made in an arc by a single-transducer swath system [2]

The scanning system physically rotates a single transducer through an arc and takes measurements at specified intervals. A complete scan may take up to 40 s, but the actual time is dependent on the resolution and accuracy specified. Scanning systems that rotate about two axes are available and allow a complete circular area of the streambed to be mapped from a single location.

Phased-array systems eliminate the time lapse required by scanning systems to complete a swath because there are no moving parts. These systems typically contain up to 120 simultaneous sonar beams to form a geometrically correct cross-section profile through an arc of up to 180°. A complete cross section is sounded in a single pulse. They are capable of updating a sonar image of the cross section 30 times per second and can output a complete 120-sounding cross-section profile at a rate of over 15 profiles per second.

Single-transducer swath systems generate an enormous amount of data requiring high-speed computers and storage devices for operation. Several software and/or hardware systems are available to support bathymetric mapping with single-transducer swath systems.

6 Selection of instrument

6.1 General

There are a number of characteristics of echo sounders that must be considered in selecting an echo sounder to measure water depth. Without proper consideration of these characteristics, the data collected may not provide an accurate representation of the streambed or lakebed.

6.2 Effect of operating frequency

The frequencies commonly used for echo sounders lie in the range from 5 kHz to more than 1 000 kHz. Transmission losses associated with frequency generally restrict the maximum depth range of high frequency sounders (300 kHz) to 100 m or less. Depths encountered in open-channel flow measurements are almost always less than 100 m. High frequency echo sounders offer three advantages for open-channel work:

a) better discrimination of abrupt changes;

b) finer resolution of depth; and

c) sharper definition of the bed.

In general, transducers designed for the higher frequencies have a much narrower beamwidth and therefore, better discriminate abrupt changes in the streambed.

The limiting resolution of a measurement is dependent on the spacing of the sound waves. Therefore, a higher frequency system is capable of much finer resolution than a lower frequency system. Furthermore, for flow-measuring work, the depth of the water above the top of the unconsolidated material is the desired information. Low frequency sound can penetrate unconsolidated material. Higher frequency sound is reflected from the unconsolidated bed material instead of penetrating it, thus giving a sharper, more clearly defined echo and a more distinct water-depth measurement.

6.3 Effect of beamwidth

The beamwidth of a transducer typically ranges from 3° to 20°. A beamwidth less than 8° is recommended. The beamwidth can be approximated for a circular transducer and a given frequency as:

$$\beta = \frac{65\lambda}{d_t} \qquad (2)$$

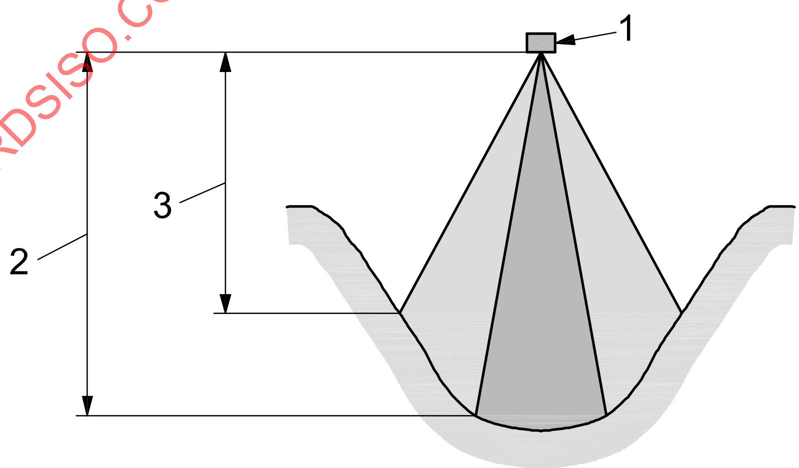
where

β is the beamwidth, in degrees;

λ is the wavelength of the acoustic frequency;

d_t is the diameter of the transducer expressed in the same units as λ.

The acoustic footprint is directly related to the beamwidth. A wide beamwidth results in a large footprint and less accurate measurements on steep slopes or rapidly changing bottom (Figure 4). A narrow beamwidth is desired for measuring channel bathymetry to ensure that all the streambed features are accurately measured. A narrow beam also concentrates the energy and allows operation over a greater range than with a wide beamwidth transducer for the same energy expenditure.



Key

1 transducer

2 depth measured by narrow-angle transducer

3 depth measured by wide-angle transducer

Figure 4 — Illustration of the effect of transducer beamwidth on the acoustic footprint and the potential errors resulting from wide beamwidths

6.4 Type of data display

6.4.1 Non-recording echo sounders

Normally, non-recording echo sounders have no provisions to correct for changes in the velocity of sound and overall system index. This class of echo sounder frequently comes standard with a 20° beamwidth transducer. In general, this type of sounder is not satisfactory for most data collection purposes because the accuracy is low. Such sounders can sometimes be useful for preliminary surveys.

6.4.2 Analog recording echo sounders

Provision for the correction of changes in the velocity of sound is made on the better quality recording sounders, and the accuracy of the depth measurement can be improved in comparison to non-recording devices if proper and frequent calibrations are made. If the marks on the chart of an analog recording echo sounder are sharp and if the scale of the chart is adequate, it is possible to interpret the depths to a resolution of about $\pm$ 0,15 m or better.

6.4.3 Digital echo sounders

The resolution of the numerical display of a digital echo sounder should be $\pm$ 0,05 m or better. If provision is made for correcting for changes in the velocity of sound and if proper and frequent calibration is performed, accuracy can be very high.

The tracking window described in 5.6.2 is a costly but necessary item for most hydrographic surveys. Digital echo sounders without this feature are not as reliable because false readings can occur frequently. To determine the validity of the digitized depth an analog chart is necessary. Nearly all survey-grade echo sounders have an analog chart in addition to the numerical display and digital output. Electronic filtering by a tracking window or other algorithms may be effective in many situations but the chart should be used to verify all digital information to avoid erroneous data. Thus, for high accuracy work, both digital and analog data should be recorded.

6.5 Accuracy

The accuracy of depths measured by echo sounders depends on a number of factors. Among these factors are readability, calibrations to correct for changes in the velocity of sound, calibration to correct for the system index, and the beamwidth and frequency of the transducer. It is impossible to determine the accuracy of echo sounders for general situations. Under ideal conditions, accuracy can approach the readability or resolutions presented in 6.4. When the accuracy required of an echo sounder is better than 1 % of the measured depth, the user should be familiar with and consider the factors described in Clause 7.

6.6 Type of transducer system

The level of detail desired, the size of the area to be surveyed, the vessel size, and cost are important factors in selecting a single-transducer, multiple-transducer, or single-transducer swath system. The single-transducer systems are roughly a tenth the cost of the single-transducer swath system, but can require considerable time to obtain detailed coverage of a large area. The multiple-transducer and single-transducer swath systems require larger vessels, typically with an environmentally controlled cabin where equipment and computers can be permanently mounted. These multiple-transducer and single-transducer swath systems also require real-time measurements of the heave, pitch, roll, and yaw of the vessel because the vessel attitude can significantly affect the data collected. The high cost of implementing a swath-type system can be offset by the reduced time required to survey a large area.

7 Instruments performance criteria

7.1 General

It is evident from the previous clauses that no one type of echo sounder can meet all potential operational requirements. Therefore, no single specification can be written for such an instrument. Nonetheless, what can be specified is the information that a prospective user should give to an instrument manufacturer and in return, the information which a manufacturer shall supply to the user, to enable the equipment to meet, as nearly as practical, the user's requirements.

7.2 Information to be specified by the user

The user should specify the following information:

a) range of depth to be measured;

b) anticipated characteristics of the streambed;

c) anticipated characteristics and extent of suspended matter, if known;

d) anticipated pollution, salinity, or other factors that might affect the velocity of sound in water;

e) desired accuracy of the depth measurement;

f) environmental conditions affecting instrument performance (temperature, humidity, etc.);

g) available electrical power;

h) distance between transducer and recorder;

i) size and type of survey vessel;

j) size of area to be surveyed;

k) desired density of the depth measurements over the survey area.

7.3 Information to be specified by the manufacturer

The manufacturer should supply the following specifications:

a) frequency or frequencies at which the equipment operates;

b) transducer beamwidth;

c) practical resolution of depth measurements;

d) maximum and minimum depths the instrument will sound;

e) frequency at which measurements are updated, the data rate;

f) requirements for vessel attitude compensation;

g) computer and interface requirements for data logging;

h) anticipated accuracy of the depth measurement with regard to all of the factors listed above.

In addition, the manufacturer should provide documentation on the installation of the equipment with full instructions adequately illustrated, operation and calibration procedures, maintenance requirements, and special instructions for control of equipment environment.

7.4 Housing

Portable echo sounders are often used in open boats; thus, the electronics and display and/or chart should be housed in a splash-proof container for protection from spray and inclement weather. For multiple-transducer and single-transducer swath systems, an environmentally controlled cabin is usually required and the equipment is usually supplied in rack mountable enclosures. Transducers should be housed to minimize air entrainment.

7.5 Additional features

7.5.1 Non-recording instruments

A sensitivity control should be provided so that adjustments can be made to produce the most reliable indication of depth under varying conditions.

7.5.2 Recording instruments

7.5.2.1 Chart readability

The recorder unit should have a sufficiently wide chart so that the desired readability can be achieved. The stylus or print head should produce a clearly readable trace. Two or more selectable chart speeds should be provided so that the trace can be produced at a speed appropriate for the application. It is desirable that the recorder indicate "zero" or the initial point of signal transmission.

7.5.2.2 Viewing window

A viewing window should be provided so that the record can be monitored with the case closed.

7.5.2.3 Depth-range selector switch

The echo sounder should provide multiple depth-range settings within the maximum range of the echo sounder. The ability to set the range of the chart to a range close to the maximum depth in the study area is important to optimize the resolution and readability of the chart.

7.5.2.4 Event marker

A mark switch should be incorporated so that the operator can insert a reference mark on the record.

7.5.2.5 Sensitivity control

A sensitivity control should be provided so that changes in sensitivity of signal gain can be made in order to produce the most readable trace as water conditions and/or depths change.

7.5.2.6 Draft adjustment

The sounder should be equipped with a draft adjustment control. Such adjustment is to provide a means of correcting for the distance the transducer is placed below the water surface and to assist in calibrating the instrument.

7.5.2.7 Velocity of sound adjustment

A control should be provided for correcting for changes in the velocity of sound in water.