TECHNICAL SPECIFICATION

# ISO/TS 15769

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# Hydrometric determinations — Liquid flow in open channels and partly filled pipes — Guidelines for the application of Doppler-based flow measurements

*Déterminations hydrométriques — Débit des liquides dans les canaux découverts et dans les conduites partiellement remplies — Lignes directrices pour l'application de mesurages du débit basés sur l'effet Doppler*



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# Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative documents:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed every three years with a view to deciding whether it can be transformed into an International Standard.

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

ISO/TS 15769 was prepared by Technical Committee ISO/TC 113, *Hydrometric determinations*, Subcommittee SC 1, *Velocity area methods*.

Annexes A and B of this Technical Specification are for information only.



# Introduction

Flow measurement using Doppler-based flowmeters fall into the category of velocity-area methods and, as with all variants of this approach, flow estimation is a two-stage process. Measurements are made to derive estimates of:

a) mean channel velocity, using the principle of Doppler shift,

b) depth, from which cross-sectional area is computed with a knowledge of the relationship between depth and area (i.e. the profile of the cross-section).

Most difficulties governing this method relate to the estimation of mean channel velocity and the degree to which computed velocities can be assumed to be representative of the true mean velocity through the measurement section. The accuracy with which the calculated velocities represent the mean velocity is influenced by various factors which are considered in clause 4. This guide focuses on the process of velocity estimation and the conditions and practices which may help to deliver optimum results. However, it should be recognized that the accuracy of overall flow determination also depends on the accuracy of depth measurement. The influence of meter location and sensitivity of cross-sectional area to depth variation will have a bearing on performance.

# Hydrometric determinations — Liquid flow in open channels and partly filled pipes — Guidelines for the application of Doppler-based flow measurements

## 1 Scope

This Technical Specification gives guidelines for the selection and use of Doppler-based flowmeters for the measurement of liquid flow in small open channels and partly filled pipes. It is applicable to whole-channel flow measurements using a single meter at a fixed point in the cross-section.

It is not applicable to flow measurements made using Doppler-based current meters for point velocity measurement nor using mobile profiling systems.

A limitation of this technique is that measurement is made of the velocity of particles or other reflectors being transported by the liquid rather than that of the liquid itself.

NOTE Though the title refers to liquid flow in general, the main use of flowmeters which use the Doppler principle is for water or water-based liquid and particular reference is often made in the text to water.

## 2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this Technical Specification. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this Technical Specification are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 772, *Hydrometric determinations — Vocabulary and symbols.*

ISO/TR 8363, *Measurement of liquid flow in open channels — General guidelines for selection of method.*

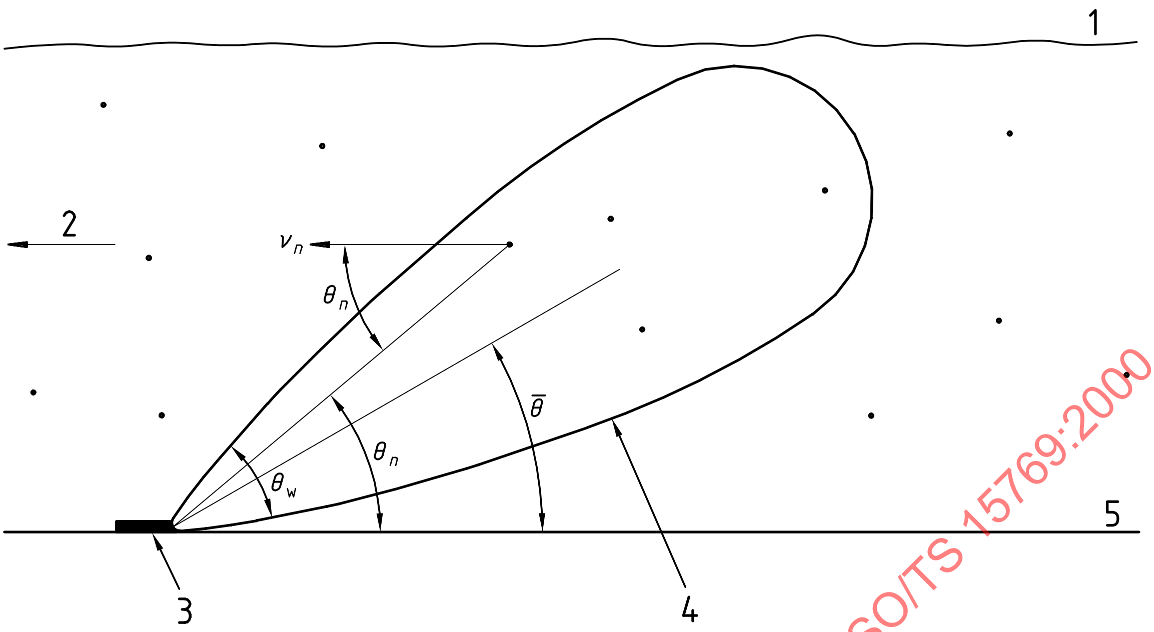
## 3 Terms and definitions

For the purposes of this Technical Specification, the terms and definitions given in ISO 772 apply.

## 4 Principle

This method of velocity measurement is based on a phenomenon first identified by Christian Doppler in 1843. The principle of “Doppler shift” describes the difference or shift which occurs in the frequency of emitted sound waves as they are reflected back from a moving body.

The sensors of Doppler systems normally contain a transmitting and a receiving device (see Figure 1). A sound wave of high frequency ($f_S$) is transmitted into the flow of water and intercepted and reflected back at a different frequency by tiny particles or air bubbles (reflectors). A typical reflector “$n$” produces a frequency shift $f_{D,n}$. The “shift” between transmitted and reflected frequencies is proportional to the movement of particles relative to the position of the sound source (i.e. the sensor).




$\theta_n$ is the angle between direction of motion of particle $n$ and the sensor

$\bar{\theta}$ is the angle between centre of beam and assumed flow direction (this is referred to as the "beam angle" or "projection angle")

$\theta_w$ is the beam width or spread

**Key**

1 Surface
2 Flow
3 Sensor
4 "Envelope" of ultrasonic beam
5 Bed

**Figure 1 — Principle of Doppler-ultrasonic flow measurement**



Doppler shift only occurs if there is relative movement between the transmitted sound source and the reflected sound source. The velocity of moving reflector "$n$" can be calculated from the following:

a) the magnitude of the Doppler shift;

b) the angle between the transmitted beam and the direction of movement;

c) the velocity of sound in the water.

It can be shown that:

$$v_n = \frac{f_{D,n} \cdot c}{2 f_s \cdot \cos \theta_n}$$

where

$v_n$ is the relative velocity between transmitted sound source and reflector $n$;

$f_{D,n}$ is the Doppler frequency shift produced by reflector $n$;

$f_S$ is the frequency of sound with no movement;

$c$ is the velocity of sound in water;

$\theta_n$ is the angle between the reflectors' line of motion (the assumed flow path) and the direction of the acoustic beam.

A Doppler flowmeter measures the resultant frequency shift produced by a large number of reflectors of which reflector $n$ is typical and from which the mean velocity can be computed. Consequently, the velocity of moving particles, and not the velocity of water, is measured. By measuring the velocity of many particles, the mean water velocity in front of the sensor can be estimated. Although the particles, if small, travel at almost the same speed as the water, sampling errors may occur. These errors depend on the spatial and velocity distribution of the particles as well as the extent of penetration of the ultrasonic beam. Instruments are neither point-velocity meters nor whole-channel meters. The area sampled by the ultrasonic beam can be visualized, by analogy, to shining a torch in front of the sensor. The purpose of using such an approach is to obtain a representative sample of the full cross-sectional velocity.

The cross-sectional area is also required for the velocity-area calculation of discharge. Most systems incorporate a pressure transducer in their sensors and by combining water depth with knowledge of the cross-sectional profile, the flow can be calculated.



## 5 Factors affecting operation and accuracy

### 5.1 General

The factors affecting the performance of Doppler flowmeters may be broadly divided into:

— characteristics of the instrument,

— characteristics of either the channel or the liquid flowing in it.

However, these factors interact and shall be considered together.

### 5.2 Characteristics of the instrument

#### 5.2.1 General considerations

The characteristics of the instrument and in particular the sensor have a bearing on its performance in any given situation. There is no optimal set of characteristics. Certain characteristics may make a particular instrument perform better under certain conditions but worse under others. A list of characteristics and their influence on the performance of the instrument are given in 5.2.2 to 5.2.6.

#### 5.2.2 Ultrasonic beam angle

The ultrasonic "beam" is usually transmitted in the approximate shape of a cone. The term "beam angle", or "projection angle" in this context, refers to the angle between the cone axis and the flow direction. The effects of beam "angle" should be considered together with those due to beam "width" (5.2.3).

The sensor has to be installed so as to remain beneath the surface of the liquid under all conditions and is positioned so that the beam cone reaches the lateral extremities of the channel as far as possible. The installation position is often a compromise and the installer is frequently obliged to install the sensor on the channel bed, somewhere near the centre of the cross-section. An off-centre position is also sometimes used.

Assuming the sensor is installed on the bed of the channel, a high angle between the flow direction and ultrasonic beam (e.g. between 30° and 50°) enable signals to be obtained throughout the depth up to the limit of the penetration of the beam. However, no signals are obtained close to the bed on either side of the sensor. Serious sampling errors can occur particularly when the ratio between the depth of water and width of the channel is low.

Conversely, a shallow beam angle allows flow to be measured close to the bed and is best for shallow depths. However, if the channel is too wide or not sufficiently long, a beam at a shallow angle may not reach the lateral extremities of the channel. In a long channel where, theoretically, the beam angle should be able to reach the extremities of the channel, the penetration (range) of the beam may not be sufficient to do so.

Beam width also has a bearing on the velocity sampling. See 5.2.3.

Figure 2 indicates the significance of the beam angle in relation to sampling.

It may be possible to adjust the beam angle, to improve suitability to the given site conditions, provided that an appropriate correction is made during the velocity calculation.

### 5.2.3 Beam "width"

Beam width is a loose term indicating the spread of the beam as shown in Figure 1. It is a function of sound frequency and diameter of the transmitter. The designer of the instrument may be constrained by other factors in his scope to vary the beam width.

A wide beam, i.e. one with a cone having a large spread, gives the best coverage because signals are obtained over a greater area of the channel. However, there is uncertainty in the velocity measurement since the wide beam means that the actual angle made by a particular reflector ($\theta_n$ in Figure 1) may be different from the mean beam angle assumed by the instrument ($\bar{\theta}$ in Figure 1). Furthermore, a bias can possibly occur and is dependent on the distribution of the velocity and on the reflector concentration.

A narrow beam width would have less angular uncertainty but a poorer coverage (sampling).

If the distribution of reflectors and velocity are both fairly uniform, sampling is unimportant and a narrow beam width would give the best results because the measurement uncertainty relating to beam angle is minimized.

If the velocity distribution is non-uniform, a wide beam width gives a better sample of velocity than a narrow one. Furthermore, if the reflector distribution is uniform, the error relating to the beam angle may be acceptable and a wide beam width would be preferable.

If neither the velocity profile nor the reflector density is uniform, a significant uncertainty of measurement can be expected whatever the beam width.

### 5.2.4 Ultrasonic frequency

A lower frequency generally penetrates further (greater range) but requires a larger transducer for a given beam width. Therefore, a lower frequency transducer is preferable for a channel of larger width or greater depth if the larger sensor size does not cause serious obstruction.

In practice, frequencies between 500 kHz and 1 MHz are generally used.

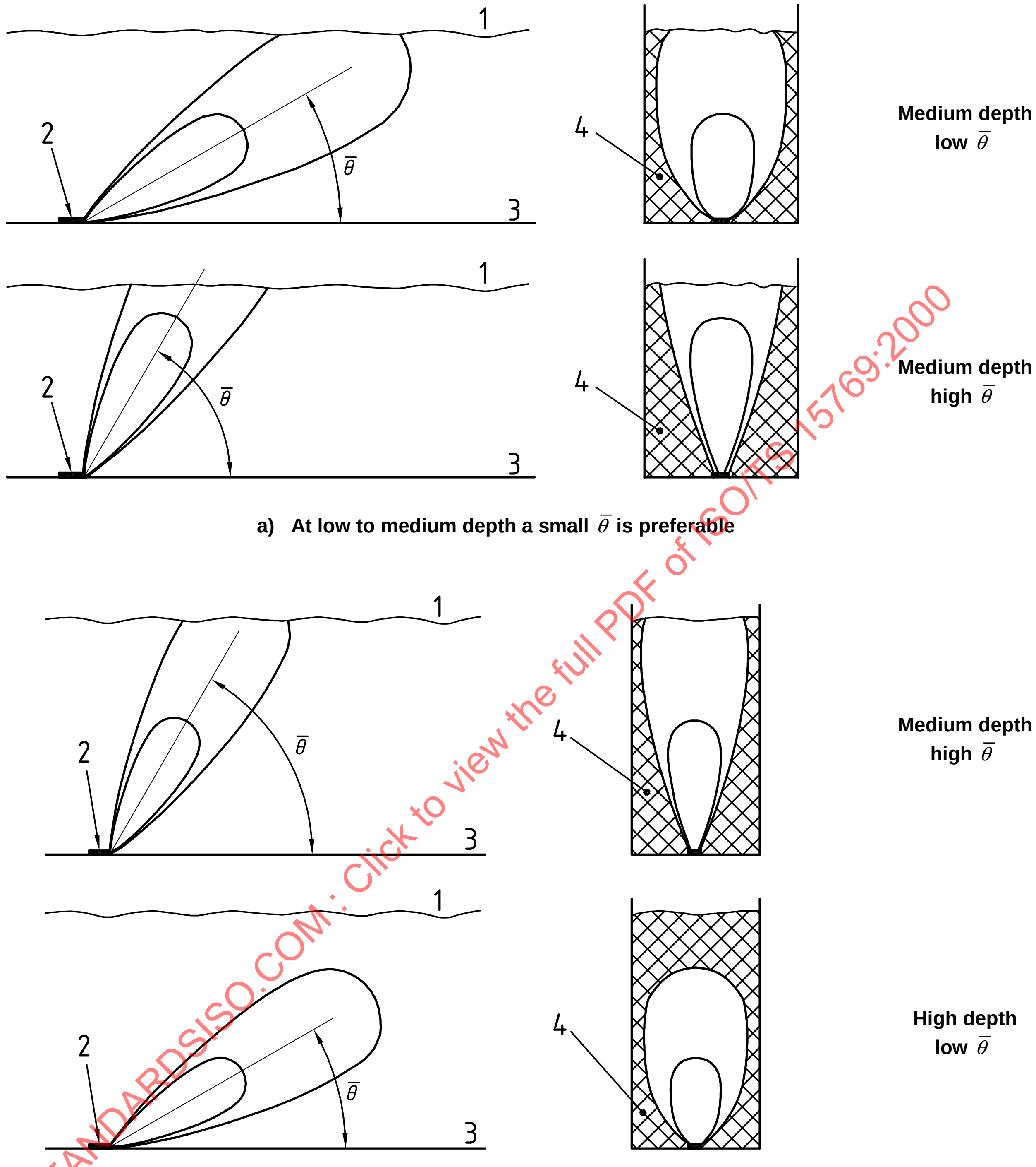
### 5.2.5 Method of determining velocity of sound

The velocity of sound in water varies with density, which is a function of temperature and dissolved material (e.g. salinity). Since velocity of sound appears in the flow formula, errors can be made if no adjustment is made. Some instruments have no dynamic adjustment though it is possible to put in a fixed calibration factor. This is acceptable provided the conditions of measurement do not change. Other instruments have a temperature sensor and provide a dynamic correction for temperature effects. This is acceptable for conditions where the content of dissolved material in water remains constant but the temperature changes.

When the temperature and dissolved particle content both vary, the only satisfactory solution is for the instrument to actually measure the velocity of sound.

Alternatively, if the temperature and salinity are measured or estimated separately, a retrospective correction can be made to the recorded data.

The effect of not making full or partial allowance for these variations is described in 5.3.5.




a) At low to medium depth a small $\bar{\theta}$ is preferable

b) At high depth a high $\bar{\theta}$ is preferable



**Key**

1 Surface

2 Sensor

3 Bed

4 Unsampled area (hatched)

**Figure 2 — Beam angle effects**

### 5.2.6 Signal processing

The calculation of flow velocity is based on the assumption that a frequency shift results from a single moving reflector. However, in reality, many reflectors are involved, moving at different speeds in different parts of the beam. The processor has to employ averaging methods for measuring frequency shifts.

Processing methods vary. Simple, analogue methods are likely to give a higher weighting to stronger signals from nearby reflectors. This method may give erroneous results if the velocity profile is not uniform and an additional non-uniform effect may need to be considered with respect to beam angle and width.

Instruments employing more sophisticated processing methods attempt to remove the signal strength effect, for example by using Fourier transform techniques. Though this is an improvement, such instruments remain sensitive to non-uniform effects in the water itself.

Some instruments employing “time-gating” or “range-gating” methods attempt to separate the signals from different parts of the space in the beam so as to produce information about the distribution of velocity. This is possible by transmitting signals in timed bursts and examining the received reflections at different delays so as to estimate the velocity variation with respect to the distance from the sensor. However, it is not possible to determine the angle from which the signals have come within the beam width. Although this information is useful for profiling-type instruments where velocity profiles are determined in deep water in which the beam is generally aimed across the flow (usually downwards), it is of little value in flowmeters where the beam angle is generally aimed lengthwise in the channel. This is the consequence of information being received from different distances along the channel and not across it. Nonetheless, such methods prevent the processor from becoming saturated from an overload of very close, strong signals since they can be identified by the short-time delay.

An exception to these observations would be the case of an instrument incorporating multiple narrow beams or a single narrow beam whose direction is capable of automatic variation. In such cases, velocities from small defined volumes within the channel can be measured. Such facilities are not normally available in instruments that fall within the scope of this Technical Specification.

It is important to remember that although instruments employing techniques like time gating or Fourier transform analysis are likely to perform better in terms of short range bias, their range is still limited by beam penetration. As the channel size increases, these techniques are prone to another type of range-related sampling error.

### 5.2.7 Depth measurement

In instruments of this type, depth is commonly measured by means of an integral pressure-activated sensor. The accuracy of these devices is dependent on the range for which they are designed (± 0,5 % of range is a typical figure). The manufacturer’s specification should be consulted. The effect of surface irregularities may degrade the accuracy further. The significance of the depth uncertainty depends on the channel shape, see section 5.3.7.

Care should be taken in the case of a closed conduit which sometimes runs full and at other times only partly full. When full, the pressure can significantly exceed that produced by a head of water equal to the height of the conduit. This can cause problems for a pressure depth-transducer. The depth transducer should be capable of withstanding the maximum pressure. If it is not capable, then alternatively a low-sensitivity transducer (i.e. with a range much greater than the conduit height) should be used, thus limiting the accuracy. Again the manufacturer’s specification should be consulted. A special transducer or an alternative method of measuring depth may be required.

## 5.3 Channel and water characteristics

### 5.3.1 Channel geometry

As the channel becomes wider, the limited range of the instrument causes the sampled velocity to be obtained from a limited part of the whole channel. The consequences of this limited sampling range depend on the homogeneity of flow velocity and particle distribution. Moreover, the density of particles also affect this range as does the depth of water. As a general guide, care should be taken if the width is greater than 2 m.



For a small channel, particularly when the depth is also low, the size of the sensor can cause serious obstruction resulting in channel back-up and possibly silt-up (discussed below). The size of the sensor can cause turbulence thus disrupting the velocity distribution in close proximity.

It is preferable to place the sensor in a long, straight reach of uniform cross-section so as to maintain a regular flow pattern over the length of flow from which the instrument samples particle velocities. The straight reach should usually be a longer distance than that required by other methods (e.g. ultrasonic time-of-flight or electromagnetic), particularly if the beam is at a small acute angle to the flow, as is often the case. As a general rule, the sampling length should be at least five times the width. It may be possible to employ flow straighteners though they tend to block in dirty water conditions.

The length may not be the major problem if the water is particularly shallow since lack of depth is likely to be the greater limitation.

Most instruments allow the cross-sectional shape to be entered into their software programme. This is used to convert the depth measurement into area which is then multiplied by the velocity measured by the instrument to calculate the flowrate. Some systems can only process symmetrical cross-sections. Others require complex geometrical calculations to specify the channel shape. In most cases, the measured velocity is assumed to be the mean velocity. Some systems take the highest velocity and calculate the mean velocity with a calibrated conversion factor. However, there can be parts of the cross-section not reached by the beam, so the velocity cannot be sampled from the whole area. This effect can be worse for channels with complex shapes with step changes or low flow channels in the bottom. Even a rectangular channel is not necessarily a good shape, particularly if the water is shallow. Again, the importance of this effect depends on the homogeneity of the velocity and reflector distribution.

Circular, U- or V-shaped channels tend to be the best geometric shape, although they can suffer from problems relating to siltation.

A sensor facing downstream may be preferable in some circumstances provided the instrument can cope with negative velocity measurements. The required straight reach may be reduced by facing the sensor downstream. If a regular flow pattern is established at the point where the sensor is mounted, this solution may be acceptable because the beam would be localized near its source. Another advantage for such a configuration would be to reduce the tendency for silt or ragging to build-up on the sensor face. However, in shallow conditions or small channels, in cases where the sensor is the cause of flow disturbance, this configuration would not be acceptable because the sensor would make erroneous readings in an area of turbulence created by itself.

Further information about installation is given in A.3.



### 5.3.2 Depth

A large depth can be a problem for the range of the beam, particularly if the sensor is designed with an acute beam angle. In order to operate at shallow depth, an acute angle is preferred, in which case, the range of the beam is unlikely to allow penetration to the surface as the depth increases.

A shallow depth in a relatively wide channel can cause sampling problems in cases where a small surface area is measured. Generally, ratios of channel depth to width of less than 1 : 5 should be treated with caution.

A large depth range restricts the use of the alternative side-mounting arrangement which may otherwise be employed to avoid the siltation problems as described in 5.3.6.

### 5.3.3 Reflector density and efficiency

These instruments require sound reflectors to operate. In general most water courses, with the exception of extremely clean water, contain sufficient reflectors to allow operation.

Suspended solids or air bubbles act as reflectors. The content of particles (i.e. density of water) required depends to some extent on the instrument. However, little guidance is offered by most manufacturers.

Air bubbles act as good reflectors but it is almost impossible to estimate their concentration, size or spatial distribution. Air bubbles tend to be located towards the surface, although it is unlikely they would be moving at the average velocity. Too much air can restrict the range of the beam.

Though samples can be taken to assess suspended solids content, the size and nature of the particles can affect their efficiency as reflectors. A high concentration of suspended solids gives good local signals but limits the range.

The particle distribution throughout the water affects the velocity sampling (see 5.2.6 and 5.3.1). This distribution is affected by the settling rate, itself a function of the density and size of the particles.

Best results are obtained when there is good mixing and an adequate concentration of particles is present, for example a few hundred milligrams per litre.

#### 5.3.4 Homogeneity

It has already been pointed out that inhomogeneous distributions of either velocity or reflector concentration affect the accuracy of flow determination to some extent. If both occur at the same time, errors are inevitable because the velocity sampled is not the average velocity of the water. It is possible to obtain velocity distribution data in relatively large channels using a current meter and to take samples at different locations of the cross-section so as to measure the content of suspended solids. Such measurements may provide an indication of the extent of inhomogeneity at the measurement site.

#### 5.3.5 Velocity of sound

The temperature and dissolved chemical content (e.g. salinity) affect the velocity of sound in water. If the actual velocity of sound is not measured or if no allowance is made for its variation (see 5.2.5), uncertainty of up to ± 5 % over a temperature range 0 °C to 25 °C may result as follows:

- the variation of velocity of sound in water with respect to temperature from 1 400 m/s at 0 °C to 1 500 m/s at 25 °C is 7 %;
- the variation of velocity of sound in water with respect to salinity from 1 480 m/s for fresh water to 1 520 m/s for seawater at 20 °C is 2,7 %.

The total variation in this example is almost 10 %, or ± 5 % if the instrument is set up for mid-range conditions.

#### 5.3.6 Siltation and sensor position

The obvious location of the sensor is on the bottom since this location guarantees it remains in the water. However, it is also the most likely place to be covered with silt or other water-borne debris. Furthermore, the presence of the sensor can create flow disturbances by catching debris or slowing the flow.

To reduce the problem of siltation effects, it may be possible to raise the sensor by spacing it off the bottom, to displace it off-centre in a circular-bottomed channel, or to side-mount it (see Figure 3). However, spacing it off the bottom increases the obstruction and tendency to snag debris and alter the velocity profile. Mounting it off-centre only works in suitably-shaped channels. Side-mounting cannot work for situations where the depth is shallow or in wider channels where the beam is less likely to penetrate the channel width than if the sensor was central.

Nevertheless, silt build-up always affects flowrate measurements, regardless of the position the sensor, because it the channel cross-sectional area is continually being reduced. This problem also affects other flowrate measurement methods based on velocity and area to some extent although the electromagnetic method is fairly tolerant of silt build-up.

Practical considerations relating to sensor position are described in A.3 of annex A.

Figure 3 indicates positioning options for sensors in silty conditions.

#### 5.3.7 The significance of depth uncertainty

The depth of water is required by the processor so as to calculate the channel cross-sectional area which is to be programmed into the software of the instrument. The flowrate, equal to the product of area and velocity, can then be calculated. Hence uncertainty in the measurement of area is equally important as that in velocity. The relationship between area and depth, hence the sensitivity to depth-measurement uncertainty, depends on the shape.



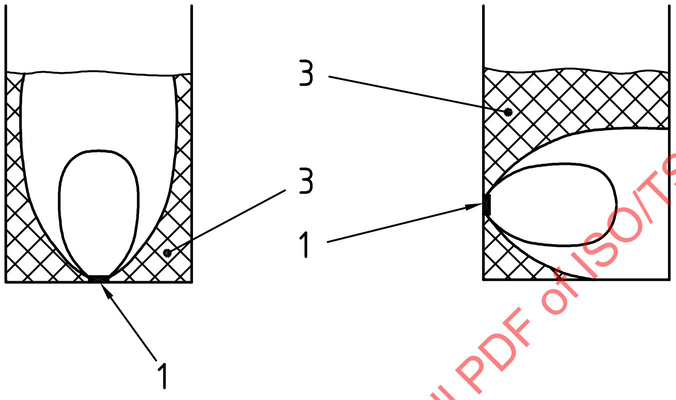
 

For example, there is a linear relationship in a rectangular channel, but at low depths in a circular channel a small change in depth produces a larger proportional change of area.

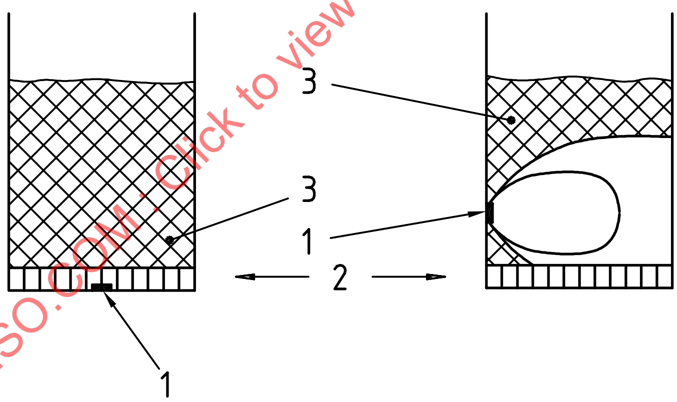
For channels which become narrow at the bottom, depth measurement at low depths is often the dominant factor in the uncertainty of flow measurement.

### 5.3.8 The effect of weed

As well as silt, all other obstructions should be avoided since they interfere with the beam. In particular, weed contains gas (air or $CO_2$) in which sound, of the frequency used by the instrument, does not travel. This can effectively block the beam and at least reduce the range.




**a) No silt**




**b) Silt**



**Key**

1 Sensor

2 Silt

3 Unsampled area (cross-hatched area)

NOTE A bed-mounted sensor is generally preferred unless the channel is prone to silt deposition.

**Figure 3 — Position of sensor**

## 6 General expectations of performance

In view of the factors described in clause 5 which can have an adverse effect on the performance of the flowmeter, it is important to have a realistic expectation of the sort of accuracy that may possibly be achieved by this method. Ideal conditions, i.e. long, straight uniform sections with even distribution of velocity and particles and with adequate depth, are rarely encountered. The uncertainty of the flowrate value is consequently often no better than 10 % and can be much worse. Claims or assumptions of much better accuracy are unfounded. However, in many cases the Doppler flow measurement technique may be the only possible method and a 10 % uncertainty or more may be quite acceptable.

## 7 Considerations when selecting equipment

The purpose in making such considerations is to establish what a potential user or customer really requires. This can have dual benefits. The potential user should be encouraged to critically assess and define their own requirements and objectives. Equally, manufacturers and suppliers should be presented with a more informed proposal and more comprehensive specification, rather than having to make assumptions due to gaps in knowledge and information from the potential user. The combined result significantly increases the potential of obtaining a satisfactory outcome, with equipment that is, as far as possible, appropriate to needs.

A questionnaire can offer an easily understandable, step by step, structured approach, with relevant questions helping to focus on the key issues which govern the overall suitability and performance of the Doppler flow-measurement technique.

A sample questionnaire is given in annex B.

## 8 Evaluation and verification

Flowmeters of this type require verification. Performance can be improved by *in situ* calibration as opposed to verification. Most instruments allow the use of a correction factor, usually fixed, but possibly an algorithm which can change with velocity or depth. Use of an algorithm may require additional processing beyond the instrument's own software. A temporary comparison (or check) method of flow measurement is required. A good estimate of the experimental uncertainties enable the flow measurement from the Doppler instrument to be assessed with a known degree of confidence. If the nature of the experimental uncertainty is random, the confidence can be improved by repeated checks.

There are a number of methods that can be employed, for example:

— current metering using point velocity meters;

— dilution gauging;

— temporary installation of a weir (provided the velocity distribution is not affected);

— volumetric methods;

— creating or using limited circumstances whereby the flow also passes through another measuring point up or downstream.

These methods are listed and reviewed in ISO/TR 8363 and practical considerations are discussed in A.4 of annex A.

# Annex A
(informative)

# Other practical considerations

## A.1 General

Physical and hydraulic characteristics of the proposed monitoring site and the needs and objectives of measurement vary in each case. There are a number of further considerations with regard to Doppler instruments, choice of system and their installation and operation which can assist the potential user in identifying and, as far as possible, in meeting all objectives.

## A.2 Capital cost

Instrument specifications vary considerably and accordingly so do their costs. It is important to make a prior judgement of the value of the data before making purchases and as far as possible match the instrument to the particular requirement. Consideration should also be given to the full cost of ownership. Therefore, allowance should be made for further costs of installation, operation, maintenance, verification, and the retrieval, processing and validation of data before committing initial expenditure on the instrument.

## A.3 Installation

Installation requirements and procedure depend greatly on characteristics of the equipment, the site, the flow regime and the period over which monitoring is envisaged. A longer term monitoring programme and sites vulnerable to human or animal interference, or likely to be affected by high flows, demand a more robust installation.

Doppler sensors should be fixed firmly in position, normally to the bed of the channel, usually facing directly upstream (with debris-prone sites and ragging problems, facing the sensor downstream may be a solution; see 5.3.1) and aligned both vertically and horizontally with the flow. See 5.3.6 for further guidance on sensor positioning.

Sensors should be installed in a stable reach since a stable depth versus area relationship is required to accurately calculate the area component of the discharge equation. A stable bed can also minimize build-up of sediment on top of the sensor, or even its damage or displacement by higher flows laden with debris.

Consideration should also be given to the position and nature of the instrument housing, bearing in mind the need for safe and easy access, protection from all anticipated water levels, human or animal interference and the elements. This may be in a secure building or kiosk, underground with manhole access (see A.9; intrinsic safety considerations) or within the sensor itself as some instruments do not comprise separate logger and sensor.

## A.4 Calibration and verification

Consideration should be given to the calibration requirements of the chosen systems. Key questions are whether the sensors are factory calibrated or require on-site calibration, what performance or uncertainty levels apply and over what period the calibration can be expected to hold for. It is recommended that, if possible, instruments are obtained with certification and if this is not possible, are tested before installation.

For all systems, including those that claim factory-calibration, it is essential that verification measurements are routinely made with visits to the installed monitoring site. The frequency of verification measurements may normally be reduced with time after installation unless a reason emerges not to do so. In selecting monitoring sites some consideration should be given to the feasibility of undertaking subsequent verification measurements. Independent check level measurements should be taken relative to a datum and it is recommended that check velocity measurements are performed regularly to establish an estimate of mean channel velocity or possibly improve the performance by on-site calibration.

Clause 8 offers a number of potential options for making check flow measurements at the site. It is important that an independent technology is used for these measurements. Where possible some attempt should be made to assess the uncertainty of the check gauging and if concerns exist over performance of the Doppler system, consider the suitability of the monitoring site or the instrument. In all cases, a log of records should be maintained and referred back to with each subsequent verification visit to identify possible trends or deterioration in performance.

## A.5 Power requirements

Power consumption can vary between different systems but can be heavily dependent on the sampling and logging frequencies employed (see A.6). Availability of an on-site display may be a requirement for certain applications but benefits may need to be balanced against the greater power requirements. Guidance should be sought from manufacturers on power needs for the particular system and mode of operation. Battery or mains power options may need to be considered, specifically in accordance with manufacturer's operating instructions. When using rechargeable batteries these should be put through a full charge cycle to avoid "topping up" and deterioration in capacity.

## A.6 Instrument logging mode: Response times, sampling and logging frequencies

### A.6.1 General considerations

A wide variety of logging modes exist and reference should be made to manufacturers or suppliers for a detailed specification of a particular instrument. However, the following should be considered before contacting manufacturers or suppliers:

- sampling frequency;
- averaging mode and logging frequency;
- response times;
- trigger levels;
- integrated instrumentation.

### A.6.2 Sampling frequency

This refers to frequency at which the sensor takes and records relevant data readings, i.e. depth and velocity.

Very few, if any, flow loggers record data continuously. This is because the power requirement would be considerable and limit the use of battery powered units to very short logging periods. Instead most instruments "power up" the sensor for short periods. Typical operating modes may be:

- powering the sensor for a 15 s period once every 2 min;
- powering the sensor for a sufficient period to record a reading every 10 s.

Continuous data recording is normally only suitable for mains powered devices and should only be necessary when data may need to be used in a "real time" situation.



### A.6.3 Averaging mode and logging frequency

The recorded data is usually stored in temporary memory and averaged out over a pre-set period, prior to an average depth and velocity value being committed to memory.

On most instruments the pre-set period over which data can be averaged can be varied to suit the operators requirements. Typical examples may be one of the following.

— Wastewater flows: averaged over 2 min, to give sufficient resolution to enable storm responses to be observed. Alternatively, if only dry weather flows are required, an averaging of 15 min may suffice.

— Watercourse flow: a coarser recording is often sufficient where flow is relatively constant and not subject to sudden variations. Hourly recording may be adequate although 15 min is typical.

— Industrial process flows: a “real time” information system may be necessary when it is vital that any variations in flow are known immediately. In such cases recording may be continuous and the flow is computed and updated say, once every 10 s.

### A.6.4 Response times

For most applications depth and velocity data are recorded, averaged and stored in a solid state memory. The sites are remote, require battery power and only be visited occasionally. Weekly, fortnightly or monthly visits can be typical to retrieve data, check battery power and instrument condition and to perform verification checks. In such cases, response times are not an important consideration.

However, for some applications the instrument may need to be used as part of a real time control system. In such cases the response time is important. Typically it is necessary for the instrument to warn of a sudden change in the flow. Urban sewerage real-time control systems and certain industrial processes require instruments capable of continuously computing flows from the measured depth and velocity.

### A.6.5 Trigger levels

Some instruments have the ability to sample, average and log data at different time intervals depending upon the flow conditions. An example of this would be a depth and velocity monitor that is required to measure both dry weather and storm flows where battery power and memory space may be critical. Reducing the recording and memory logging interval during dry weather to, say hourly intervals, considerably reduces the power consumption and memory space used but still enables adequate data to be collected. During storms the logger can be pre-set to record and commit to memory at a more frequent rate, thereby enabling adequate storm data to be collected.

Experience has shown that such facilities can be advantageous in being able to reduce the frequency of site visits. However, a considerable amount of knowledge is necessary because it is very easy to set a trigger level too high and not record some of the storm flow, or conversely, set the trigger prematurely. Therefore triggers should generally only be used if the operator already has a detailed knowledge of the flow range.

### A.6.6 Integrated instrumentation

Sometimes it may be necessary for flow (velocity and depth) monitors to be able to talk to other equipment such as effluent auto-samplers. A typical example may be where sewage samples are required during a storm to measure the “first foul flush” effect. In such cases a depth trigger, based on the instruments recorded depth level, can be used to activate an auto-sampler.

## A.7 Memory capacity

Signals generated may pass immediately to another system which would limit the memory capacity requirements of the Doppler instrument. However, in many cases an integrated or connected data logger form part of the system and its memory capacity should be sufficient to satisfy the required logging rates and the download frequency. It may also be relevant to establish whether systems operate with either roll-over or finite memory or whether this is user-selectable.

## A.8 Portability

Portability of systems may be a consideration in the case of applications which involve repeated very short term installations and movement from site to site, particularly where access is less than ideal.

## A.9 Access and safety considerations

In confined spaces, and thus potentially explosive atmospheres, it should be ascertained that instruments are designed, constructed and used in accordance with appropriate standards to ensure the safety of operators, the general public and the sewer or channel system. This responsibility largely rests with the designer or manufacturer or supplier and it has become common practice for equipment to be designed and constructed to meet latest national or equivalent European or International Standards. Users are recommended to seek certification when purchases are made.

Access and safety should be considered from the point of view of both the installer and the operator since the sensor and the data logger/battery pack may be separate and be associated with different safety requirements.

## A.10 Harsh environments

Consideration should be given to the capabilities of instruments, both sensors and logging equipment, to withstand extreme conditions of temperature or direct sunlight. The level of water proofing of both sensors and logging equipment should also be established.

## A.11 On-site display

Consideration should be given to whether there is a need to have an integral display facility within the logger. Where these are used, checks should be made to establish whether the display is constantly live or activated from a keypad since there may be significant implications for power consumption.

## A.12 Maintenance requirements

Essential maintenance checks should form part of every routine quality assurance visit and this section gives some recommended points to consider. In addition reference should be made to the manufacturer's guidance and operating instructions.

- Check the sensor for secure fixing, alignment and for build-up of coatings or silt.
- Ensure the channel is clear of debris, silt deposits and weed.
- Perform battery checks and replace as necessary.
- Check seals on instrument, according to manufacturer's instructions.
- Check vent to ensure pressure sensor is not blocked (or filled after flooding).
- If present, check cables and ducting (for condition and secure fixing).
- If present, check the instrument housing or kiosk for signs of interference, secure fixing, lock operation, etc.

- Check for evidence of either scour or deposition at the site. This affects the validity of the cross-sectional area versus depth relationship used for discharge computations. The measuring section should also be periodically checked to amend or reaffirm the validity of this relationship.
- Note the current hydraulic conditions at the site and check for adverse changes since installation.
- Check the instantaneous or most recent flow or velocity readings.
- Undertake comparison with another gauging method if scheduled for the visit.



# Annex B
(informative)

# Sample questionnaire — Doppler-based flowmeter

## B.1 Proposed use of the instrument(s)

### B.1.1 Duration

**For what recording duration will the instruments normally be used?**

(Please tick the most relevant box.)

| | |
|---|---|
| 1 day to 4 weeks | |
| 1 month to 3 months | |
| 3 months to 12 months | |
| Over 1 year | |

Other comments

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### B.1.2 Use of the site

**Where will the instruments be used?**

[Tick appropriate boxes. Include only the principal use(s) for which the instrument(s) is (are) being purchased.]

| | |
|---|---|
| **Small watercourses** | |
| **Sewers** | |
| — Foul sewers | |
| — Surface water sewers | |
| — Combined sewers | |
| **Industrial** | |
| a) Sewage | |
| b) Other effluents (Please specify) | |



 

## B.2 Site characteristics

### B.2.1 Channel use

**Where will the instrument(s) be used?** (Please tick appropriate boxes.)

| | |
|---|---|
| **Enclosed culverts** (Please state material) | |
| Partly full flows | |
| Full pipe flow (at all times) | |
| **Open culverts** | |
| **Other** | |

### B.2.2 Channel shape

**Where will the instrument(s) be used?** (Please complete appropriate boxes.)

If the instrument is to be used predominantly at one site or very similar sites, please give the average dimensions.

If the instrument is to be used at a range of sites, please give the maximum/minimum range of typical sizes.

| | | Average dimensions<br>mm | Minimum size<br>mm | Maximum size<br>mm |
|---|---|---|---|---|
| Circular pipe (diameter) | | | | |
| Box culvert | Width<br>Height | | | |
| Open culvert | Width<br>Height | | | |
| Watercourse | Width<br>Depth | | | |



### B.2.3 Channel length

The instrument's accuracy will, amongst other things, depend upon the hydraulic conditions at the proposed location. Ideally, steady flow conditions are required.

Please give flow condition details at the proposed monitoring site. For example, how far upstream is it until the flow condition alters significantly, through a change in channel shape, gradient, pipe material or through the presence of joining flows?

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### B.2.4 Other details

Is **mobile sediment** likely to be present? (Sediment, if present in sufficient quantities, it may cover the sensor and effect the instrument's velocity sensing.)

If yes, please give details.

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Is **weed** or other vegetation likely to be present? (If present in sufficient quantities, it may cover the sensor and effect the instrument's velocity sensing.)

If yes, please give details.

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**Other information** (Anything else relating to the proposed measuring site that may be relevant.)

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## B.3 Flow conditions

### B.3.1 Instrument

Please describe the flow conditions where the instrument is likely to be used.

If the instrument is to be used predominantly at one site or very similar sites, please give the average dimensions.

If the instrument is to be used at a range of sites, please give the maximum/minimum range of typical sizes.

### B.3.2 Typical depths

Dimensions in millimetres

| Average | Minimum | Maximum |
|---|---|---|
| | | |

### B.3.3 Typical velocities

Dimensions in metres per second

| Average | Minimum | Maximum |
|---|---|---|
| | | |

NOTE If uncertain about actual velocities use descriptions such as very fast, steady flow, virtually stationary, etc.