INTERNATIONAL STANDARD

ISO 4373

Second edition
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Measurement of liquid flow in open channels — Water-level measuring devices

Mesure de débit des liquides dans les chenaux — Appareils de mesure du niveau d'eau

Reference number
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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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.

International Standard ISO 4373 was prepared by Technical Committee ISO/TC 113, *Hydrometric determinations*, Subcommittee SC 5, *Instruments, equipment and data management*.

This second edition cancels and replaces the first edition (ISO 4373:1979), which has been technically revised.

Annex A forms an integral part of this International Standard.

Introduction

The collection of water-level records with respect to time generally forms the basis for obtaining a systematic record of stream flow at a gauging station. This water-level record, together with periodic discharge measurements, can be converted by one or more methods (see ISO 1100) into a continuous record of discharge. The accuracy of the record of discharge is governed in large part by the accuracy of the record of water level. It is essential that this be detected and recorded efficiently and with an accuracy sufficient for the purposes for which the stream flow data are required.

Water-level records, besides being used to produce stream flow data, also have an intrinsic value in monitoring the level of any body of water. It must also be recognized that, however accurate the inherent performance of a water-level recording installation, the application of routine operational and maintenance procedures is essential to achieving design performance. Although the design and operation of water-level measuring devices is described in terms of the devices in current use, this International Standard is not intended to inhibit further development. Rather it is intended to encourage the introduction of improved instrumentation exhibiting better performance.

Measurement of liquid flow in open channels — Water-level measuring devices

1 Scope

This International Standard specifies the functional requirements and operational procedures for stage detecting, encoding and recording devices for measuring water levels in open channels. Because of the widespread use of stilling wells in the measurement of water levels, information on stilling wells is given in annex A to this International Standard.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 772:—[1], *Measurement of liquid flow in open channels — Vocabulary and symbols.*

ISO 1100-1:1981, *Liquid flow measurement in open channels — Part 1: Establishment and operation of a gauging station.*

ISO 1100-2:1982, *Liquid flow measurement in open channels — Part 2: Determination of the stage-discharge relation.*

3 Definitions

For the purposes of this International Standard, the definitions given in ISO 772 and the following definitions apply.

3.1 encoding: Method by which a data signal is changed into a suitable set of bits for data recording.

3.2 parity check: Addition of an extra bit to a data signal so that the total number of bits in a sample are either always even or always odd.

4 Accuracy of stage measurements

For the measurement of stage with respect to a gauge datum, an uncertainty of ± 10 mm may be satisfactory in some installations: in others, uncertainty of ± 3 mm or better may be required. However, in no case should the uncertainty be more than ± 10 mm or 0,1% of the range, whichever is greater. Exceptions can be made if sediment or unstable channel conditions make it impossible to obtain a complete and reliable record with standard equipment, and where special equipment must be used to obtain a complete record but with greater uncertainty (for example, see 8.2).

This clause applies in all cases, unless specifically stated otherwise.

5 Gauge datum

The stage of a stream or lake is the height of the water surface above an established datum plane. The datum of the gauge may be a recognized datum, such as mean sea level, or an arbitrary datum plane selected for the convenience of using gauge readings of relatively low numbers. ISO 1100-1 contains additional requirements regarding gauge datum, gauge zero and benchmarks.

1) To be published. (Revision of ISO 772:1988)

6 Environment

The following criteria generally apply. Exceptions, because of local conditions, shall be specified by the user.

6.1 Operating

Water level sensors and recorders shall operate satisfactorily over temperature, relative humidity and pressure ranges applicable to local conditions. The user shall specify the conditions that are likely to apply.

6.2 *In situ* resistance

Instrumentation shall withstand temperatures from − 50 °C to + 60 °C and relative humidities of 100 % (without condensation) in a non-operating condition.

6.3 Resistance during transport and storage

Instrumentation shall withstand temperatures from − 50 °C to + 60 °C and relative humidities of 100 % (without condensation) in a non-operating condition. Instrumentation shall be capable of withstanding vibrations and bouncing that normally occur in transport.

7 Direct water-level indicating devices

Water-level gauges may determine water levels either directly or indirectly. Measuring devices of the fixed or movable type, such as vertical and inclined gauges, needle gauges and wire weight gauges, are classified as direct-reading instruments. The significant feature of this group of water-level indicators is that the reading may be made directly in units of length, without any intervening conversions. These gauges are often used as a reference gauge for setting a water-level recorder.

7.1 Vertical and inclined gauges

Such gauges comprise a scale marked on or attached to a suitable surface.

7.1.1 Functional requirements

Vertical and inclined gauges shall be

a) accurate and clearly marked;

b) durable and easy to maintain;

c) simple to install and use.

7.1.2 Construction material

The material of which a gauge is constructed shall be durable, particularly in alternating wet and dry conditions, and also in respect of the resistance to wear or fading of the markings. The material should have a low coefficient of expansion with respect to temperature or wetting effects, commensurate with accuracy requirements.

7.1.3 Graduation

7.1.3.1 The graduations shall be clearly and permanently marked directly on a smooth surface or on a gauge board. The numerals shall be legible and placed so that there is no possibility of ambiguity. A typical example is shown in figure 1.

7.1.3.2 The graduations of an *inclined gauge* may be directly marked on a smooth surface or on a gauge board, as described in 7.1.3.1, or marked on manufactured gauge plates designed to be set to a specified slope. An inclined gauge should be calibrated *in situ* by precise levelling from the station benchmark.

7.1.3.3 *Gauge plates* shall be manufactured in suitable lengths, often 1 m, with the width of the scale not less than 50 mm.

7.1.3.4 The marking on the gauge should be made to read in multiples of millimetres. The smallest graduation shall depend on the accuracy required, but may correspond to 10 mm.

7.1.3.5 The markings of the subdivisions shall be accurate to ± 0,5 mm, and the cumulative error shall not exceed 0,1 % or 0,5 mm, whichever is smaller.

7.1.4 Installation and use

7.1.4.1 General

The gauge should preferably be placed near the side of the stream, so that a direct reading of water level may be made. If this is impractical because of excessive turbulence, wind effect or inaccessibility, the measurement may be made in a suitable permanent stilling bay or stilling well in which the wave actions are damped and the level of the water surface follows the fluctuations of the water level in the stream. To ensure this, intakes to stilling wells should be properly designed and located (see annex A).

The gauge should be located as closely as possible to the measuring section without affecting the flow conditions at this point. If possible, the gauge should not be placed where the water is disturbed by turbu-

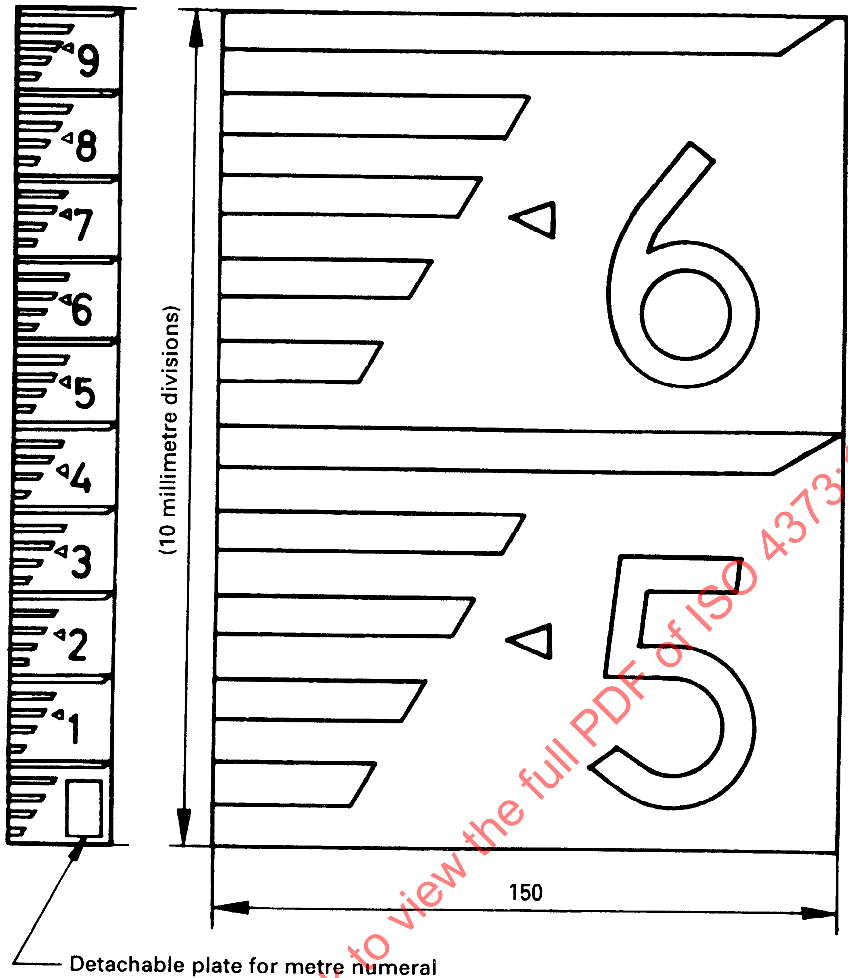


Figure 1 — Typical details of vertical staff gauge

lence, or where there is danger of damage by drift. Bridge abutments or piers are generally unsuitable locations. Wherever the gauge is situated, it shall be readily and conveniently accessible so that the observer may make readings as nearly as possible at eye level. The gauge board or plate shall be securely fixed to the backing but provision must be made for removing the gauge board or plate for maintenance or adjustment. The edges of the gauge board should be protected.

7.1.4.2 Vertical gauges

A suitable backing for a vertical gauge is provided by the surface of a wall having a vertical or nearly vertical face parallel to the direction of flow. The gauge board or backing plate shall be attached to the surface so as to present a vertical face to receive the graduations. The gauge board and backing plate shall be securely fastened to the wall. Gauges may be fixed to piles, either driven firmly into the river bed or banks, or set in concrete so as to be free from sinking, tilting or washing away. In either case the anchorage shall extend below the ground surface to a level free of disturbance by frost. In order to avoid velocity effects which may hinder accurate reading, a pile may be shaped to present a streamlined profile upstream and downstream or the gauge may be situated in a bay where it will not be exposed to the force of the current. Where the range of water levels exceeds the range of a single vertical gauge, additional sections may be installed on the line of the cross-section normal to the direction of flow.

7.1.4.3 Inclined gauges

An inclined gauge shall be installed in such a manner to follow the contour of the river bank. The profile of the bank may be such that a gauge of a single slope may be installed; frequently however, it may be necessary to construct the gauge in several sections, each with a different slope. The general installation requirements given in 7.1.4.1 apply.

7.2 Needle gauges

7.2.1 General

A needle water-level gauge consists of a device with an end point and some means of determining the point's exact vertical position relative to datum. The two types of needle gauges are

a) the **point gauge**, whose tip approaches the free surface from above, and

b) the **hook gauge**, which is hook-shaped, and whose tip is immersed and approaches the free surface from below (see figure 2).

The vertical position may be determined by a graduated scale, a tape with some vernier arrangements, or an arrangement to detect linear movement electronically with a digital indicator similar to a digital micrometer. The scale is movable and graduated to read downward from top to bottom in metres.

Application of needle gauges consists of positioning the needle of the gauge near the water surface and detecting the moment the tip touches the free surface, as if trying to pierce its "skin". Setting a point exactly at the water surface may be facilitated by electrical, visual [light-emitting diode (LED) display] and/or acoustic (electronic buzzer) indicators.

The advantage of water-level needle gauges is their high measuring accuracy, whereas their disavantage is their small measuring range, usually about 1 m. However, this disadvantage can be overcome by installing a series of datum plates at different levels.

7.2.2 Functional requirements

7.2.2.1 A hook- or point-gauge installation shall permit measurement of stage to be made at all levels, from below the lowest to above the highest levels anticipated.

7.2.2.2 There shall be good illumination of the place where the tip meets the free liquid surface; if this is not the case, gauges with electronic meters for indication shall be used.

7.2.2.3 The hook or point shall be made of metal sufficiently strong to resist deformation in transport and under field conditions of use. The tip shall be tapered to a point having an included angle of approximately 60° and the point shall be rounded to a radius of approximately 0,25 mm (see figure 3).

7.2.3 Material

A hook or point gauge and auxiliary parts shall be made throughout with durable corrosion-resistant materials.

7.2.4 Graduation

The graduation of a hook or point gauge shall be in millimetres and shall be clearly and accurately marked. A vernier or micrometer head may be provided which allows reading to 0,1 mm. However, such a reading accuracy is normally only required for laboratory measurements.

7.2.5 Installation and use

7.2.5.1 A hook or point gauge may be mounted over an open water surface at the edge of a stream if conditions permit. If this is not practical because of turbulence, wind effect or inaccessibility, a suitable permanent stilling bay or stilling well should be installed.

7.2.5.2 The location of the hook or point gauge should be as close as possible to the stage-measuring section and should be conveniently accessible to the observer.

7.2.5.3 The gauge shall not be installed in a location where the water surface is disturbed by turbulence, wind effect or afflux. The vicinity of bridge abutments or piers is generally unsuitable.

7.2.5.4 Where more than one datum plate or bracket is provided at different levels, it is preferable that all should lie on the line of a single cross-section normal to the direction of flow in the stream. If this is not practicable and it is necessary to stagger the points, all should lie within a distance of 1 m on either side of the cross-section line.

7.2.5.5 Datum plates and brackets shall be mounted on a secure foundation which extends below the frost line.

7.2.5.6 The elevation of the datum plates, with reference to which the level of the free water surface is determined, shall be established with great care. This elevation shall be checked from the station benchmark at least annually. The tolerance on the transfer of level from the station benchmark to each datum plate shall not exceed $\pm$ 1,0 mm.

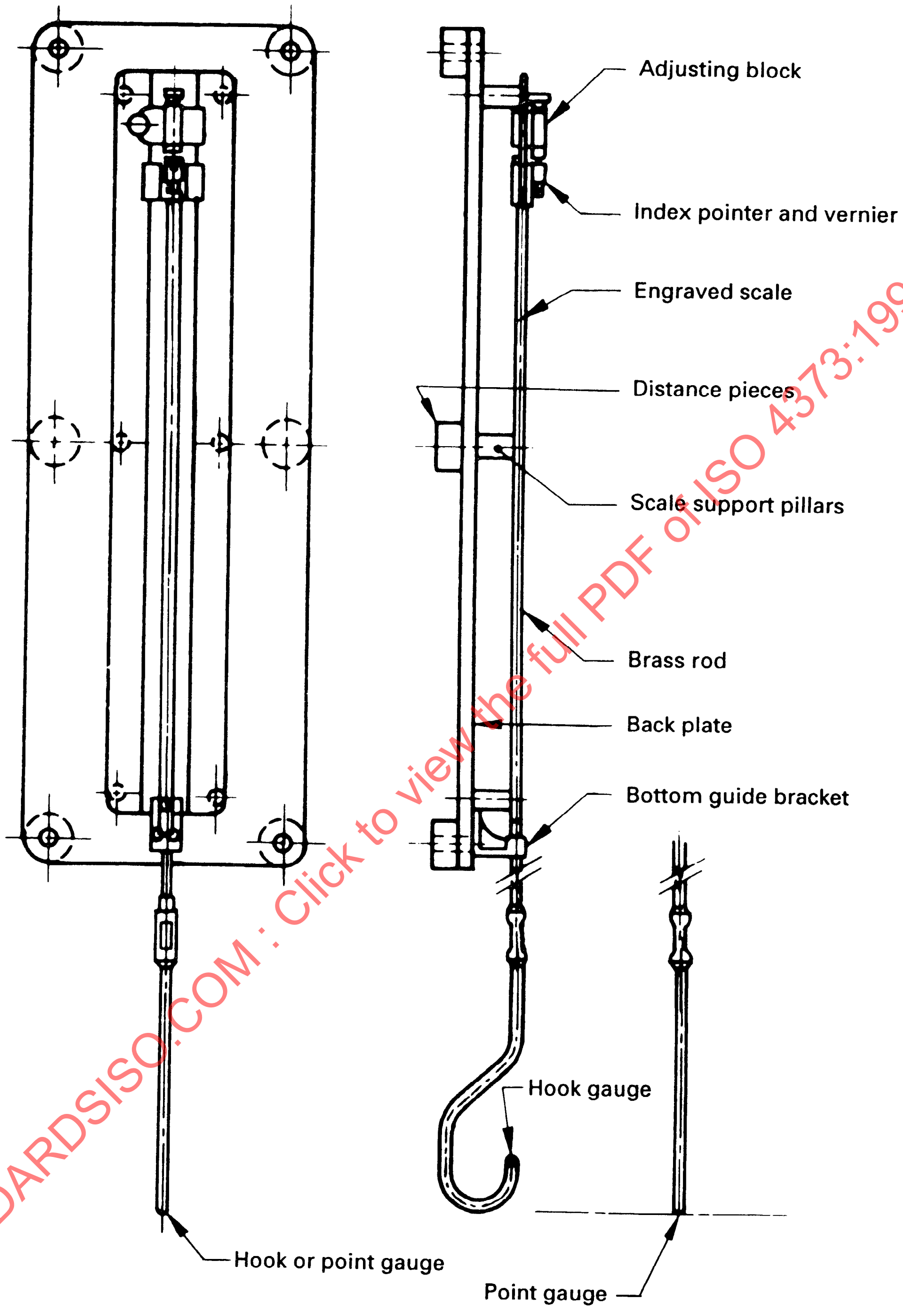


Figure 2 — Arrangement of hook, point and electrical depth gauges

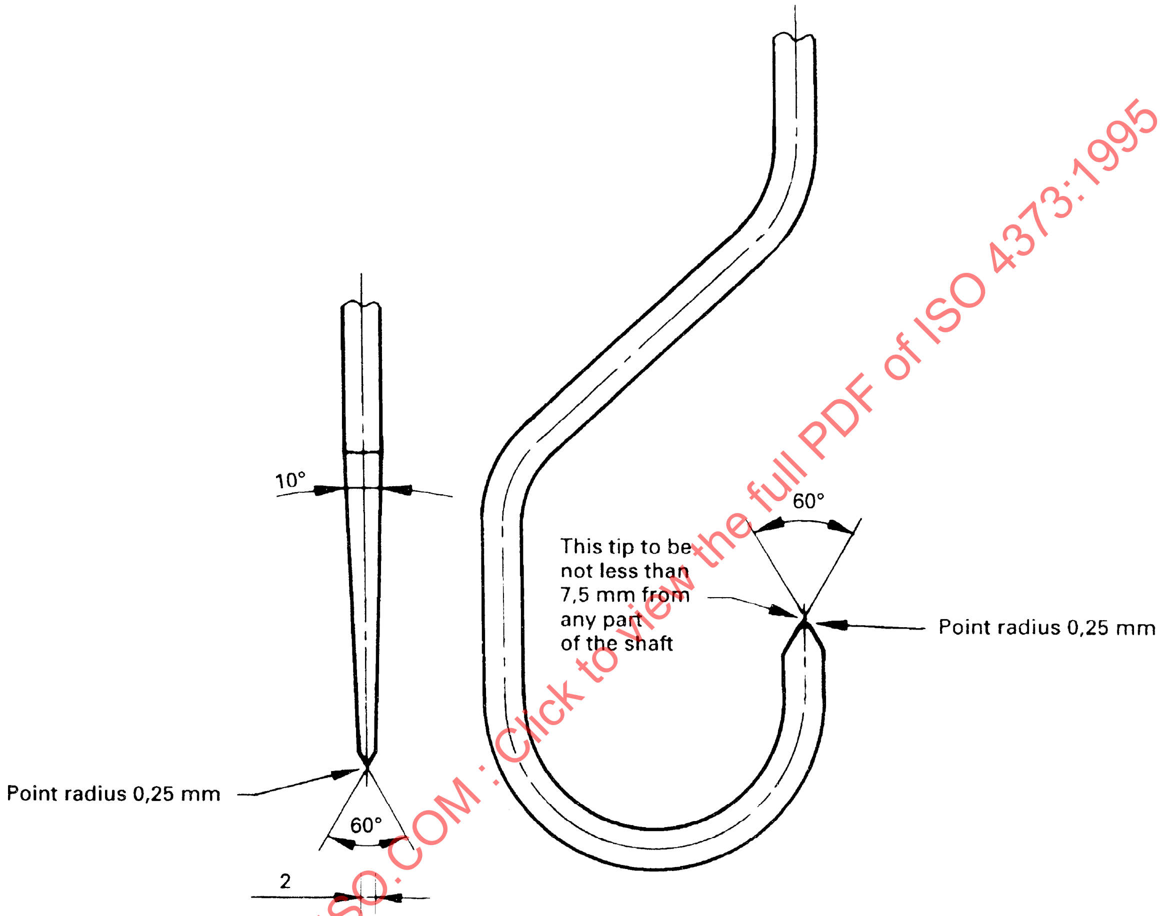


Figure 3 — Details of the hook and of the point of hook and point gauges

7.3 Float gauges

7.3.1 General

The float gauge is used chiefly as an inside reference gauge in water stage measurements. The typical float gauge consists of, for example, a float operating in a stilling well, a graduated steel tape, a counterweight, a pulley and a pointer. The float pulley is grooved on the circumference to accommodate the steel tape, runs slip-free over the pulley in the gauge shelter above the well, and is kept taut by a counterweight at the free end or by a spring. In this way stage fluctuations are detected by the float which positions the tape with respect to the pointer. A float gauge may also be coupled directly to a water-level recorder. Such use, however, is discouraged unless there is another completely independent reference gauge for the recorder.

7.3.2 Functional requirements

7.3.2.1 A float gauge installation shall permit measurement of stage to be made at all levels, from below the lowest to above the highest levels anticipated.

7.3.2.2 Float and counterweight dimensions and the quality of the elements of the mechanical device for remote indication shall be selected so that there is a sufficiently high indication accuracy and working reliability. Clause 10 of this International Standard discusses float system errors.

7.3.2.3 The float shall be made of durable corrosion-resistant and antifouling material. It shall be leakproof and function in a truly vertical direction. Its density shall not change significantly.

7.3.2.4 The float shall be checked at frequent intervals to make sure that it is floating properly, and care should be taken to see that the tape does not become twisted or fouled and that the indicated stage is the same as the water level in the stream. Care should be taken to prevent the float from dragging against the well sides or against other objects.

7.3.3 Graduation

The graduations of the float gauge shall be in millimetres and shall be clearly and accurately marked.

7.4 Wire-weight gauge

7.4.1 General

The typical wire-weight gauge consists of a drum wound with a single layer of cable, a bronze weight attached to the end of the cable, a graduated disc and a counter, all enclosed within a protective housing (see figure 4). The disc is graduated and is permanently connected to the counter and the shaft of the drum. The cable is guided to its position on the drum by a threading sheave. The reel is equipped with a pawl and ratchet for holding the weight at any desired elevation. The gauge is set so that when the bottom of the weight is at the water surface, the gauge height is indicated by the combined readings of the counter and the graduated disc.

7.4.2 Functional requirements

A wire-weight gauge should permit measurement of stage to be made at all anticipated stage levels.

7.4.3 Material

A wire-weight gauge shall be made throughout with durable, corrosion-resistant materials.

7.4.4 Graduation

The graduation of the wire-weight gauge should be in millimetres.

7.4.5 Installation and use

7.4.5.1 The wire-weight gauge may be used as an outside reference gauge where other gauges are difficult to maintain. The wire-weight gauge is usually mounted where there is a bridge or other structure over the water.

7.4.5.2 The gauge shall be installed in a location where the water surface is not disturbed by turbulence, wind effects or afflux.

7.4.5.3 The check bar elevation of the wire-weight gauge should be read frequently to ensure reliability of the correct base elevation.

7.5 Crest stage gauges

The crest stage gauge is used to record the peak stage occurring at a given location during a given time period, or from the time when the gauge was reset. Typically, the gauge consists of a vertical tube containing a float or a floating substance (such as cork dust). The tube is perforated at the bottom to permit the entry of water, using a hole configuration that will not cause drawdown or pileup, and that contains an air outlet at the top.

As water enters the tube, the floating substance rises and clings to the tube when the water level falls. The peak stage is determined by precise levelling of the float from the station benchmark or by reading a vertical gauge if the crest stage gauge is attached.

7.6 Electric tape gauges

The electric tape gauge can be used to detect the water level in a stilling well from a shelf or bracket in the instrument shelter. It can be constructed similarly to a wire-weight gauge, or have a reel holding a steel tape that can be read directly. The tape is wrapped around a reel for storage and for lowering into the well. There is a weight on the end of the tape that makes electrical contact, completing an electrical circuit, when it touches the water. A voltmeter, light or buzzer is used to let the user know when the water surface has been reached. With the weight held in the position of the first water surface contact, the tape reading is observed at the index provided on the reel mounting frame. The electrical circuit requires a battery and a wire from the bottom of the well to the reel frame (see figure 5).

7.7 Other direct-reading gauges

There exist other direct-reading gauges of various types, for example, those where the water level is detected by one or several points or by a small float, which may be attached to a pivoting arm, or where the sensing element is positioned with a servo-mechanism. However, these instruments are not widely used in the measurement of stage in open channels and are not included in this International Standard.

8 Indirect water-level indication devices

Indirect water-level indication devices include those gauging systems which convert a pressure, electrical, acoustic or other signal to an output which is proportional to the water level. Of the indirect devices available, those in most common usage are the pressure type, such as the mercury manometer, the transducer and the servo-beam balance.

NOTE 1 Mercury is an environmental hazard and the use of mercury manometer gauges is not permitted in some countries.

8.1 Pressure gauges

Pressure gauges are frequently used at sites where it would be too expensive to install stilling wells. They are also used on sand-channel streams because the intake line can be extended to follow a stream channel that shifts its location, and if the gas-purge technique is used, the gas flow tends to keep the orifice from becoming plugged with sand.

8.1.1 General

Water level may be determined by measuring the height of a column of water with respect to some datum plane. This can be accomplished indirectly by detecting the water pressure at a fixed point below the water surface, and then utilizing the hydrostatic principle that the pressure of a column of liquid is proportional to its depth. All pressure-actuated instruments should provide a means of damping short-term oscillations in water level. Normally a damping period of 10 s to 120 s is sufficient.

8.1.1.1 Transmission of pressure

The method of transmitting pressure from the water column to the sensor may be direct or indirect. When the sensor is located below the point in the water column at which the pressure is to be measured, the water pressure may be transmitted directly to the sensor. However, if the sensor is located above the water column, the direct method is usually not satisfactory because gases entrained in the water can create air locks in the line. If the liquid is highly corrosive, it is undesirable to bring it into direct contact with the sensor.

8.1.1.2 Gas-purge (bubbler) technique

The gas-purge technique is a widely used method of indirectly transmitting pressure. This technique may be used regardless of the elevation of the pressure-detecting device with respect to the water column; and because the water does not come into direct contact with the pressure sensor, it is suitable for use in highly corrosive liquids (see figures 6 and 7).

In the gas-purge technique a small discharge of non-corrosive gas (for example, nitrogen or compressed air) is allowed to bleed into a tube, the free end of which has been lowered into the water and fixed at a known elevation below the water column to be measured. The sensor, which is located at the opposite end, detects the pressure of the gas required to displace the liquid in the tube: this pressure being directly proportional to the head of liquid above the orifice.

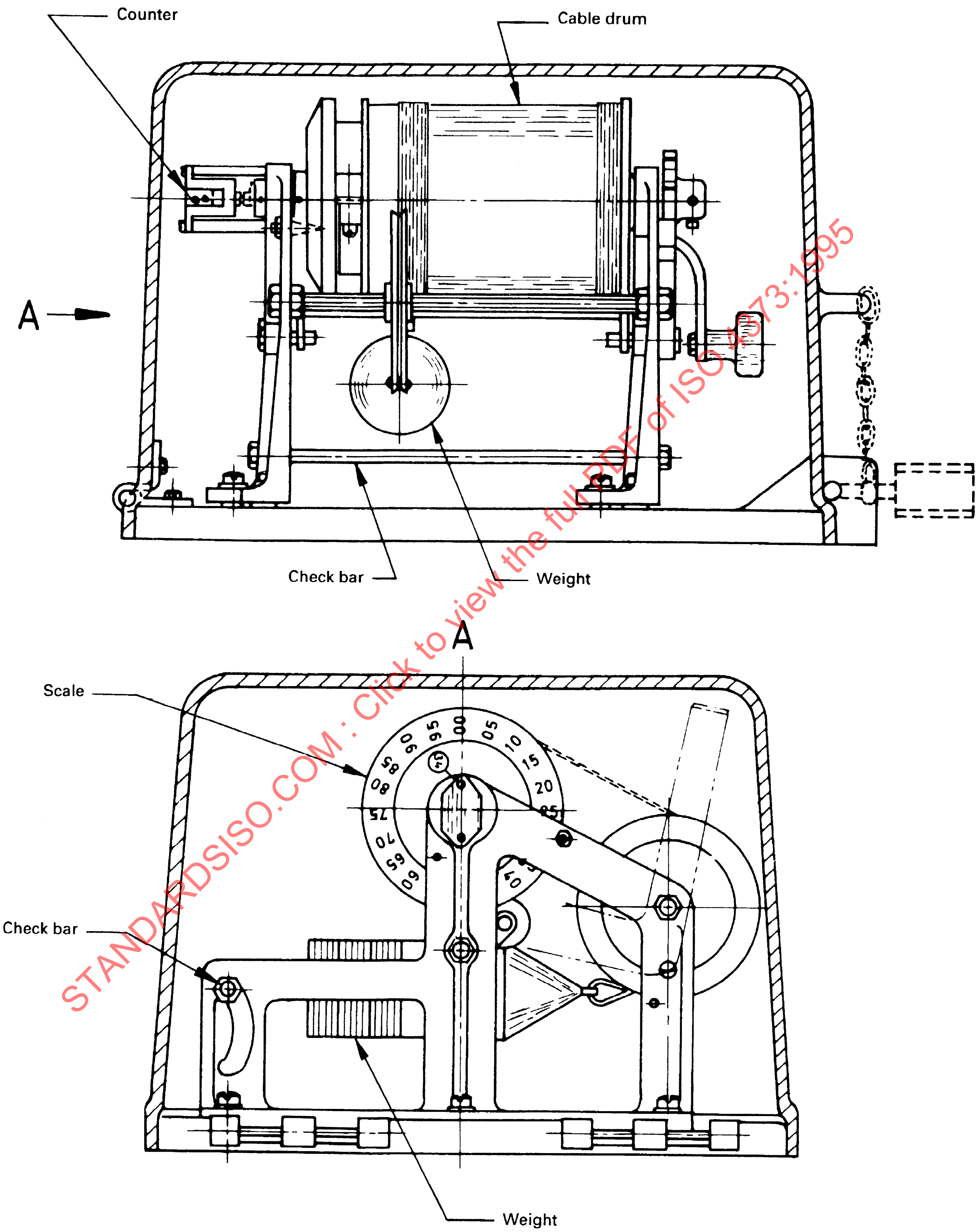
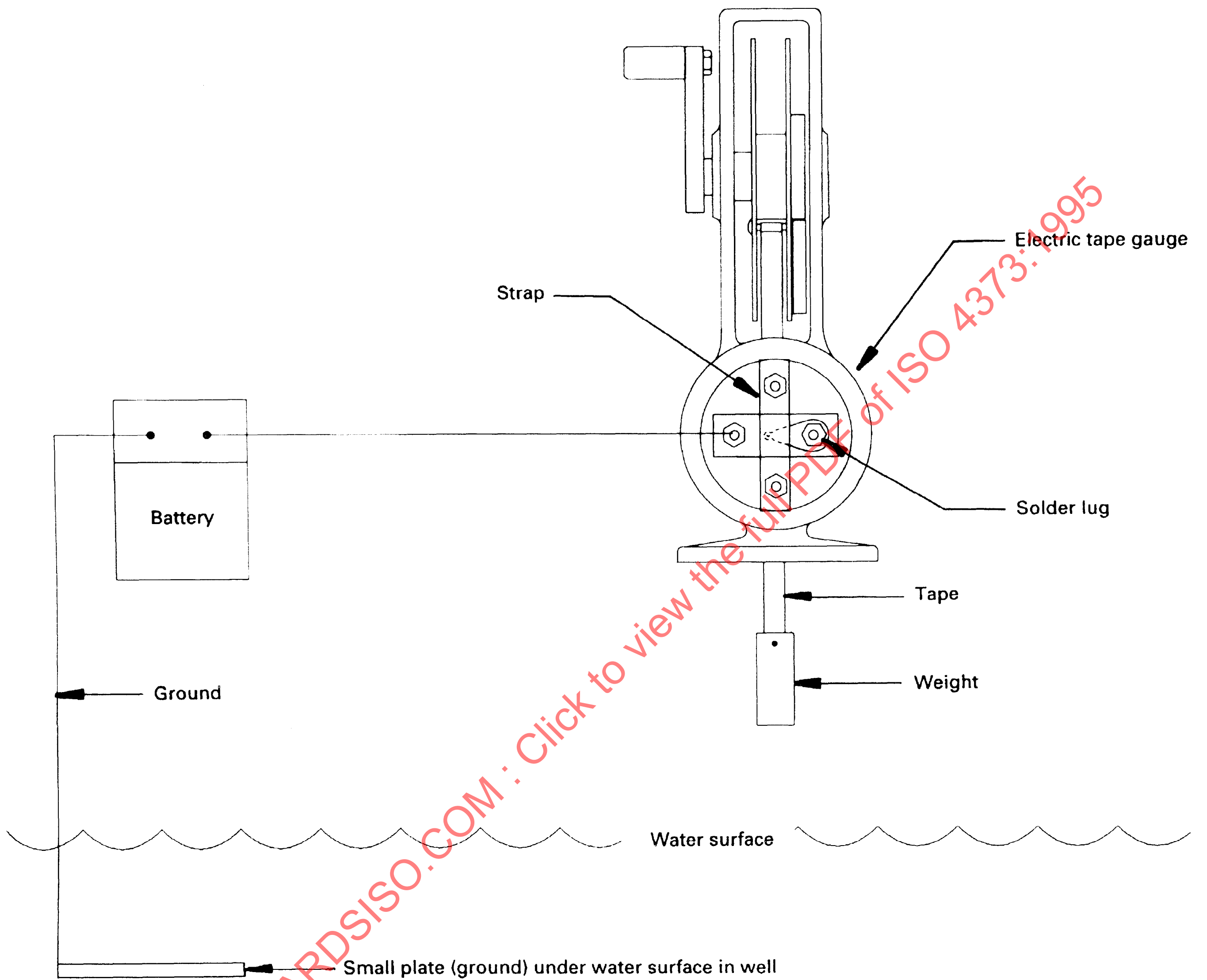
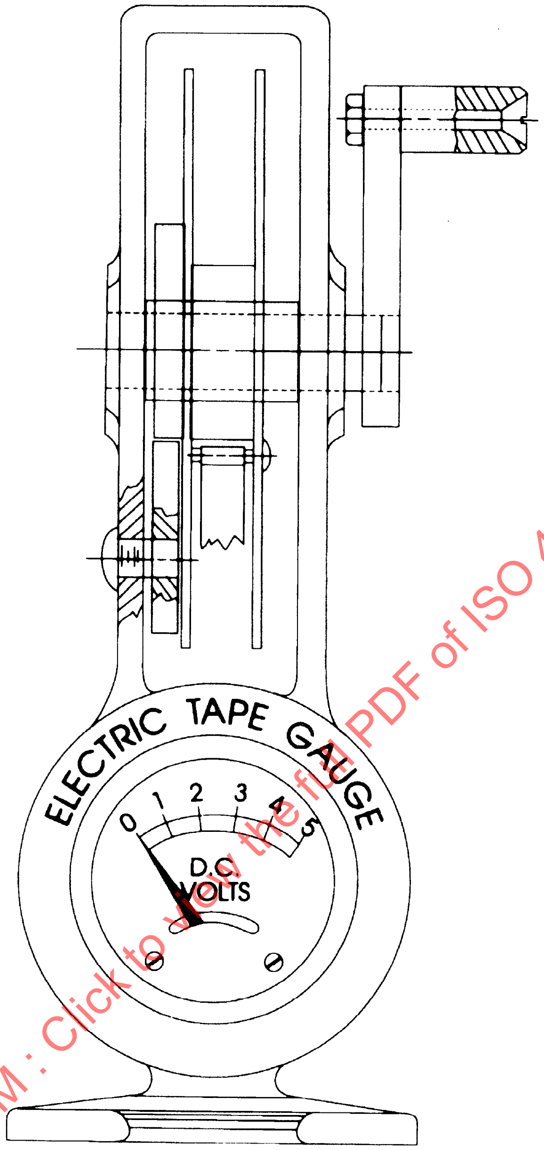
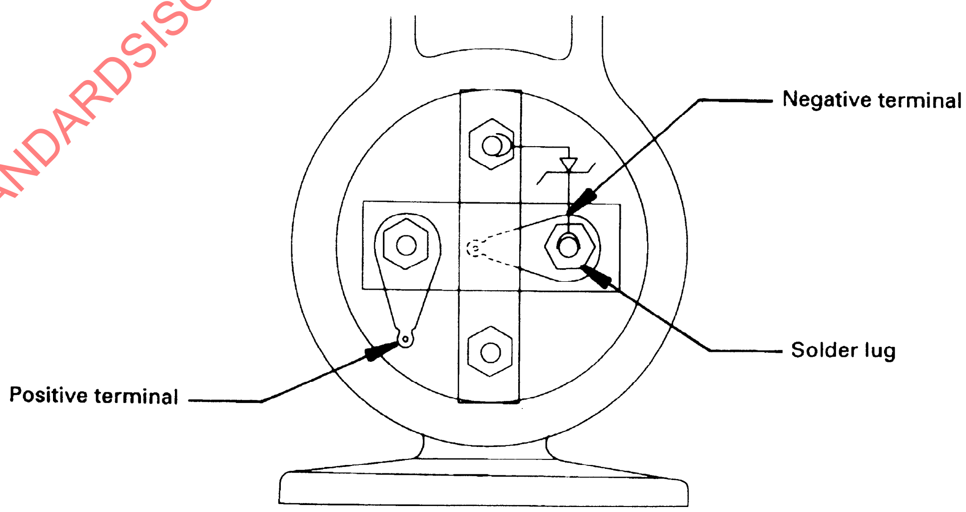


Figure 4 — Wire-weight gauge



a) General view





b) Detailed view

Figure 5 — Electric tape gauge

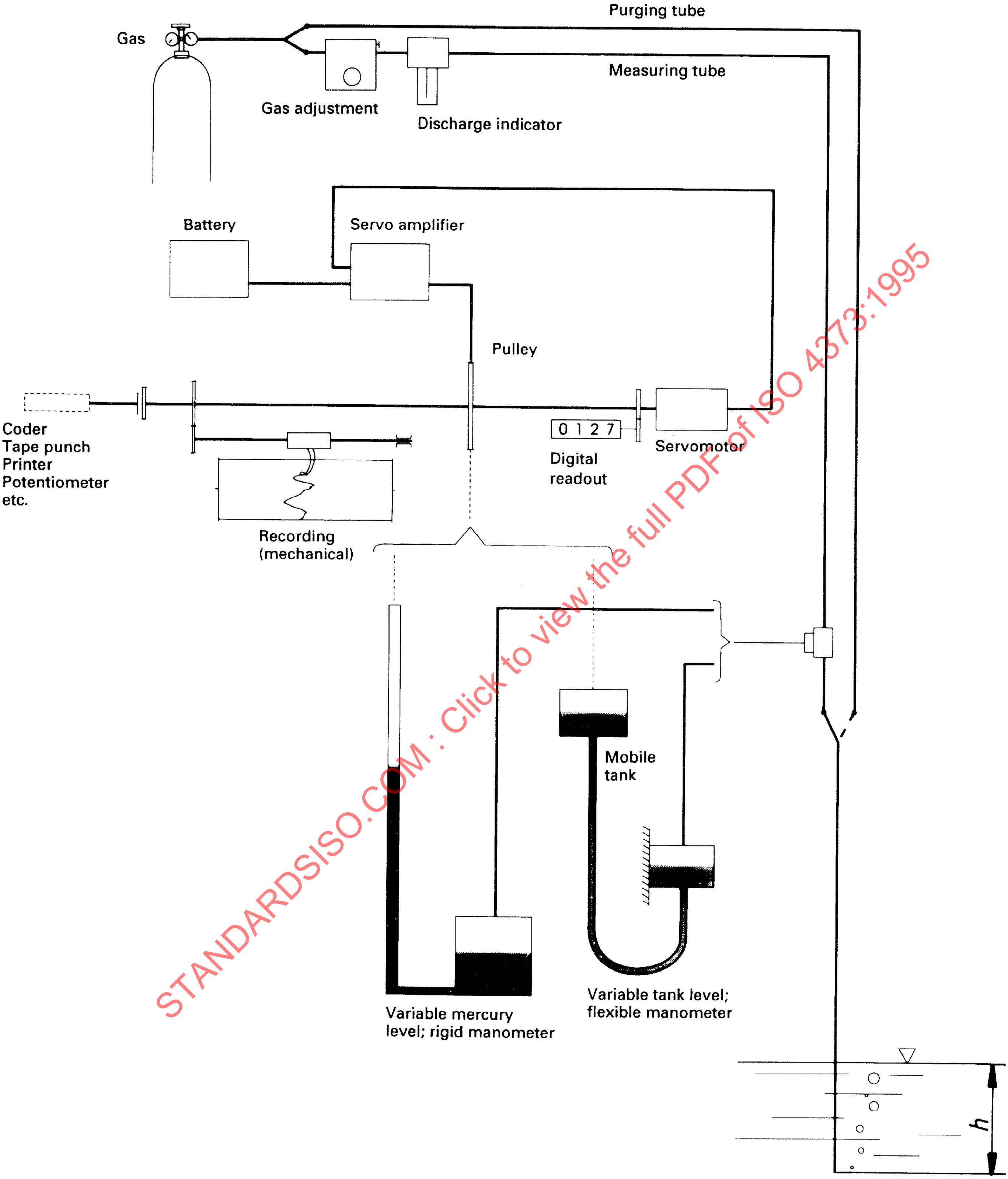


Figure 6 — Gas purge (bubbler) recorder (servo manometer type)

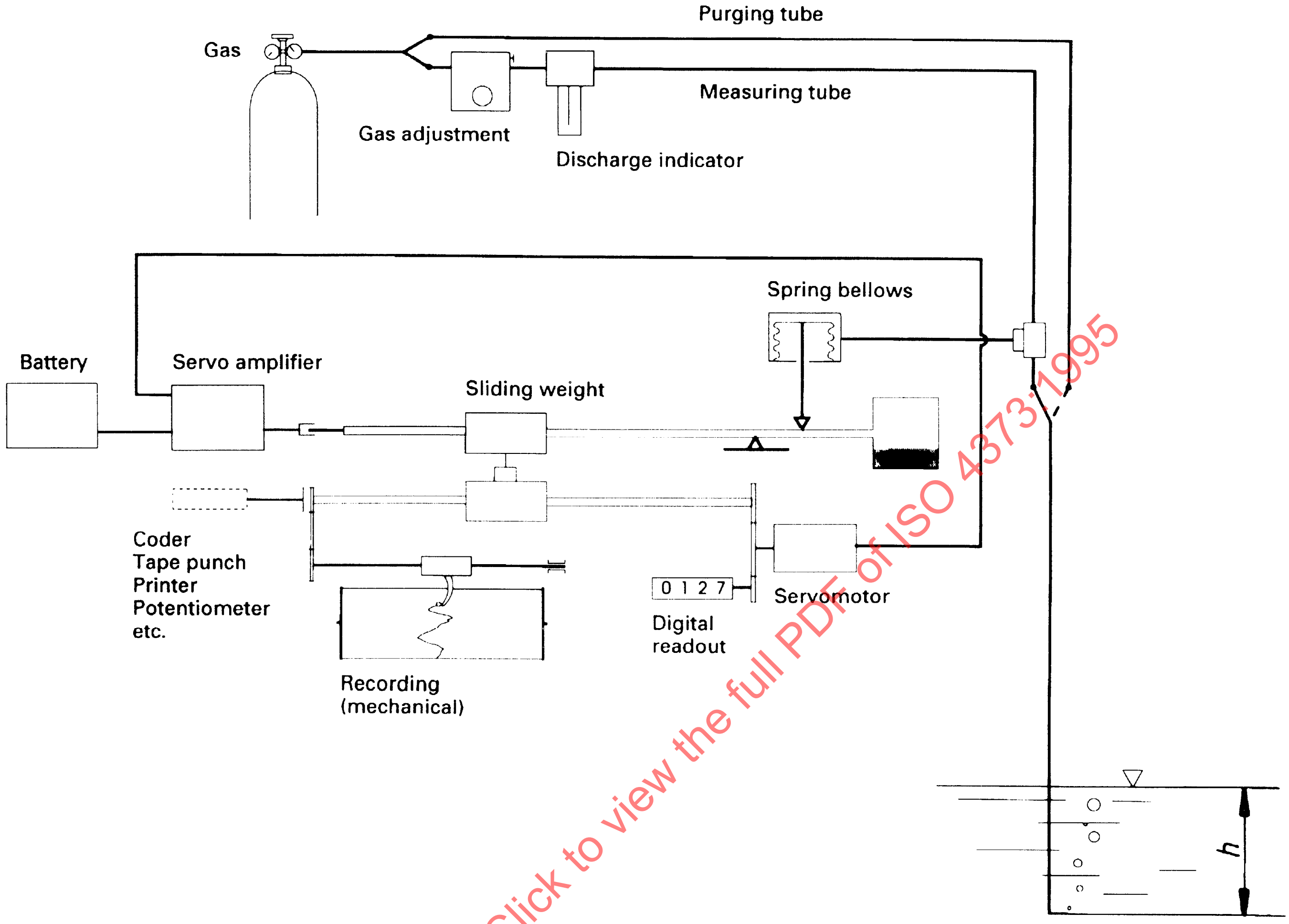


Figure 7 — Gas purge (bubbler) recorder (servo-beam balance type)

When using the gas-purge technique, there are certain installation and operation requirements that should be observed. The principal ones are

a) an adequate supply of gas or compressed air must be provided. A continuous flow of gas to the tube is necessary to prevent the liquid from entering it when the water level is rising. A particular rate of gas supplied will cause the pressure in the system to rise at the same rate as the head. If gas is supplied at a lower rate, liquid will enter the tube; and conversely, a higher rate will provide an unnecessarily high discharge of gas from the tube. The gas is usually supplied from a cylinder or by an air compressor. In either case, the supply must have a delivery pressure in excess of the range to be measured;

b) a pressure-reducing valve must be provided so that a pressure safely in excess of that of the maximum range can be set. A flow control valve and some form of visual flowrate indicator is necessary, so that the discharge of gas supplied to the system can be properly adjusted. The pressure should be set to prevent water from entering the tube, even under the most rapid rates of stage change expected;

c) incorrect readings due to the friction of the gas moving through the tube should be minimized. Long lengths of tube or very small diameter tubing aggravate the friction problem. This difficulty is frequently solved by running two tubes to a junction very near to the orifice, with one tube serving as a gas-supply line and the other as a pressure-detection line. Under this arrangement the movement of gas in the pressure-detection line is kept to a minimum, thereby reducing the friction to a minimum;

d) the tubing should be installed with a continuous negative slope to the orifice.

8.1.1.3 Pressure-bulb system

Where there is no gas supply available, a pressure-bulb system is sometimes used to transmit pressure to the detector. This device, frequently referred to as an elastic pressure bulb, is usually made of a casting in the form of a short hollow cylinder with one open end. The open end is sealed with a slack, highly flexible diaphragm, and the cylinder is connected by means of tubing to the pressure sensor. The whole unit forms a closed gas system with pressure and is fixed at an elevation below the water column to be measured. The slack diaphragm permits water pressure to compress the gas in the cylinder until the pressure within the system is proportional to the height of the water column above.

One of the major disadvantages of this device is that ultimately an excessive amount of gas will escape from the system with a resultant stretching of the diaphragm. When this occurs, the pressure within the system will no longer be equal to the pressure head. This disadvantage can be overcome by periodic renewal of gas within the system or replacement of the pressure bulb and tubing. It is difficult to maintain the accuracy stipulated under clause 4 with this device.

8.1.2 Mercury manometer and servo-beam balance

Both the mercury manometer and the servo-beam balance are pressure sensors that convert the pressure detected to a rotational shaft position proportional to the height of the column of water. The shaft position is used for driving a recorder and water-level indicator. As the name implies, the mercury manometer is essentially a manometer with a mercury system for detecting and following the liquid differential within the manometer. The servo-beam balance is a beam balance with a pressure bellows on one side of the beam and a weight on the other. The servo-system positions the weight so that the beam is in balance and detects this position (see figures 6 and 7).

8.1.2.1 Water-density compensation

Since the density of the water which the sensor is to measure will vary with temperature and also with chemical and silt content, either automatic or manual means of compensating for these changes should be provided. Density changes can introduce errors in all pressure-actuated devices; these errors are discussed further in clause 10.

8.1.2.2 Change in gas weight

If one of the gas techniques is used to transmit pressure, provisions should be made for compensating for changes in the weight of the gas, as all gases vary in weight with changes in temperature and pressure.

8.1.2.3 Range

The range of the instrument shall be adequate to accommodate any anticipated range of water level.

8.1.2.4 Response

The response of the instrument shall be sufficiently rapid to follow any expected rate of change in water level.

8.1.3 Miscellaneous pressure sensors

There are many pressure sensors available operating on a number of principles. Most of these are differential pressure transducers having an electrical output that is proportional to the pressure detected. They are occasionally used for the measurement of water level, the proper selection being dependent upon the particular application involved. Their application is generally restricted to limited ranges because the accuracy requirements of clause 4 are difficult to meet over extended ranges. They also may be subject to calibration drift as components age, thus making accuracy requirements difficult to maintain over a period of time. If one chooses carefully the type of transducer, for example the vibrating quartz crystal or capacitance type, the accuracy can be met for periods over one year. The strain-gauge type of transducer typically exceeds the 0,1 % of full-range accuracy at a constant temperature. It is recommended that all types of transducer have a calibration for changes in temperature, and that the temperature be measured with a temperature sensor each time the pressure is measured, so the transducer output can be corrected.

8.2 Acoustic distance-measuring systems

These devices use sound to detect the position of the water surface by monitoring the sound signal returned from the surface.

Noncontact acoustic systems are used at sites where it is difficult or impractical to install or maintain intake lines or gas-purge line orifices. Sites subject to frequent mud or ice flows that damage intakes and orifices are good sites for noncontact acoustic systems. This technology allows measurements in a range of water levels up to 10 m with an accuracy of about ± 30 mm.

These systems have acoustic transducers that can be attached to existing structures, such as bridges, usually with minimum labour and cost; thus they are an economical, auxiliary water-level sensor at remote flood-warning sites requiring real-time data.

8.2.1 General

In principle, acoustic systems measure the vertical distance from a fixed point to a water surface. Non-contact acoustic systems are mounted above the water surface and require no stilling well or sound-wave guide pipe. Contact acoustic systems are mounted either above or below the water surface and require wave guide pipes.

8.2.2 Acoustic systems

The systems consist of an acoustic transducer/receiver and a measuring instrument (electronic unit) connected by a cable. The measurement instrument can be located in an instrument shelter up to 300 m distant from the transducer. The transducer, attached to a fixed point sufficiently above the flood level or mounted under water, emits acoustic pulses and picks up the echoes reflected by the water surface. The elapsed time between the emission of the pulses and pickup of the echoes is utilized by the measuring instrument, which then computes the water level.

8.2.2.1 Influence of temperature

Calculation of the distance between the transducer and the water surface directly depends upon the velocity of sound in air or water. For transducers mounted above the water, compensation for the variation in the velocity of sound at the base of the transducer is possible (based on temperature observations at the base of the transducer), but, in the majority of cases, is not satisfactory.

Compensation for the variation in the velocity of sound in air resulting from air-temperature variations is partially achieved by using the echo from a fixed reference distance. A small reference bar located in the sound beam at a given distance from the transducer reflects a number of the pulses. The measuring instrument makes a comparison between the measurement of this fixed distance and that down to the water surface and thereby compensates for the variations in the velocity of sound in air. Compensation for the variation in the velocity of sound in water can be partially achieved by using one or more reference bars installed in a wave guide pipe, or by direct measurements of density. These density-related errors are discussed further in clause 10.

8.2.2.2 Frost

In winter, humid air at low temperatures can cause frost problems for noncontact acoustic devices. Frost forms on the reference bar, thereby causing measurement errors, or collects on the surface of the transducer, thereby reducing or eliminating sound pulses. This drawback can be avoided by slightly heating the reference bar and transducer, if power is available from sources other than batteries.

8.2.2.3 Waves

In order to ensure a good average reading from a water surface which has waves, it is recommended that the measuring instrument be programmed so that it calculates an average of several intermittent measurements.

8.2.2.4 Protection against lightning

As the cable connecting the measuring instrument to the acoustic transducer can be several hundred metres long, protection against atmospheric lightning is recommended.

8.3 Other indirect stage-measuring devices

A number of stage-measuring devices, based on the measurement of the changes in electrical properties of an element with depth of immersion or the reflection of an optical signal from a water surface, have been developed to measure liquid levels in tanks and other storage vessels. Some of these devices are characterized by a very rapid rate of response to water level changes and thus are often used to measure wave height. If used in open channel applications, the output signal must be damped considerably to provide a usable record. This can be done electronically.

9 Recording devices

9.1 General

Many water-level measuring devices produce an output, often a mechanical movement or an electrical signal, that is analogous to water level. This output provides the basis for recording water-level data. Recorders can be classified as either analog or digital depending on the nature of the record produced. The analog recorder produces a continuous graphical record of the rise and fall of parameter values with respect to time, while the digital recorder produces a record of coded parameter values on a medium such as paper tape, magnetic tape or in solid state data storage memory chips at preselected time intervals. Digital recorders may alternatively record the times at which a parameter changes by a preselected value.

Electronic data recorders should have a digital display to allow the user to review current and recorded values.

9.2 Recording principles

The linear movement of the water surface is converted to angular movement of a shaft for the convenience of recording.

The shaft angular-input arrangement is frequently used in recording water levels. The angular movement of the input shaft drives the stylus of an analog recorder or the encoding mechanism of a digital recorder or separate encoder. This angular input is converted to a record of the water level by many different mechanical, electromechanical or electronic means.

Some pressure sensors and those based on measurement of an electrical property, such as capacitance or resistance, or on acoustic or optical principles produce an analog electrical signal which can be recorded in analog or digital format.

Irrespective of the recording principle used, the water level recording or encoding device should satisfy, where applicable, the requirements in 9.3 to 9.10.

9.3 Driving torque

Because mechanical linkages generate some friction, sufficient driving torque shall be supplied to overcome resistance to motion. For a water-level recorder, this driving force is usually supplied by water surface movement displacing a float and is transmitted by a float line and counterweight to the drive pulley. If the friction is high, that is, the driving torque required to position the recording element is high, then an appreciable lag following a change in the water level will result. It is therefore desirable for the driving torque to be as low as feasible, and in no case should it exceed 7 mN·m.

9.4 Levelling of the input shaft

If the input shaft is not horizontal, then entangling of the float line with the pulley may occur; and, if sufficiently out of level, the line will jump off the pulley. Means of horizontal levelling of the input shaft shall be provided. This is usually accomplished by providing the recorder or encoder with adjustable feet that are securely fastened to an adequate shelf or table top.

9.5 Hysteresis (lost motion)

The mechanical linkage mentioned in the preceding paragraph also results in some hysteresis. Usually either gear trains or sprockets and chains or a combination thereof form the mechanical linkage, and the play between the teeth of gears or the slack in the sprocket chain is the cause of this hysteresis. If the input shaft is rotated in one direction until the stylus follows and then the direction of rotation is reversed, the total hysteresis is that amount of motion required to cause the stylus to follow in the reversed direction. It is desirable to minimize such lost motion but in no case should it exceed the limits of accuracy, that is, 3 mm, keeping in mind other components of error.

9.6 Timing device

A sturdy and reliable timing device forms an essential part of any water-level recording device. In the case of analog recorders, the timing device either rotates the chart paper past the stylus or governs the rate at which the chart paper moves past the stylus. In the case of the digital recorder, the timing mechanism programs the interval at which data are recorded. Timing devices often consist of a mechanical clock element; however, electric and, increasingly, solid state electronic devices are also in use. High timing precision is not as important as reliable operation but both are of consequence. Therefore, best results will be obtained if the device is of high quality. It should also be protected from dirt, moisture, corrosion and insects by its own housing.

9.6.1 Accuracy

The accuracy of the timing device shall be within ± 30 s a day (cumulative) to be measured over a period of at least 30 days and over the entire range of anticipated environmental conditions as specified in clause 6. While this accuracy is easily obtainable by modern electronic devices, it should be noted that some specific water-level recording applications may require much greater accuracy. This accuracy must apply under operating conditions when the timing device is mounted in the recorder; separate bench testing of the timer may produce different results.

9.6.2 Adjustments

In the case of mechanical timing devices, a movement adjustment shall be provided to permit regulation within the accuracy requirements set forth above.

Where the timing device selects discrete intervals for actuating a digital recorder, the recording frequency should be capable of adjustment to a selection of intervals including 5 min, 15 min, 30 min and 60 min.

9.7 Paper (chart or tape)

Paper expands and contracts with changes in both temperature and humidity; the dimensional stability depends upon the quality of the paper. A great portion of the accuracy of an analog recorder depends upon the accuracy with which the scale is printed on the chart paper and the stability of the paper. The paper tape from a digital recorder is machine-readable without errors only if the paper is stable within reasonable tolerances throughout the range of temperature and humidity conditions expected at both the recording site and at the processing center.

9.8 Material

All parts of the recorder shall be manufactured of materials which will resist corrosion under conditions of field use.

9.9 Housing

The recorder shall be housed in a drip-proof, weather-resistant case. It is desirable, when the recording medium is an analog chart or perforated paper tape, that the case contain a window so that visual inspection of the record can be made without opening the case.

9.10 Analog recorders

Analog recorders are of two basic types, those which record continuously for an indefinite period of time and those which record continuously for a fixed period of time (daily, weekly, monthly, etc.). Most analog recorders are essentially mechanical although the chart transport mechanism may be electrically driven. Such recorders require a shaft angular input.

Also in limited use are electronic recorders in which the function of the operating mechanism is to position the stylus to the proper location on the chart in response to signals produced by sensors such as those described in 8.1.3 and 8.2. These recorders either have a direct-operating mechanism or an electronic drive mechanism. The low torque and relatively limited output motion of a direct-operating mechanism will position only a light, low friction stylus over a limited range, whereas the electronic drive mechanism has ample power and a much wider range of motion.

The following criteria apply to analog recorders.

9.10.1 Readability

Recorder charts and scales shall be designed to ensure that accuracy requirements in clause 4 are not jeopardized. The sensitivity of the operating mechanism (stylus) should therefore be adequate to allow discrimination of the smallest increment to be read. The chart paper shall be wide enough to accept the full range of stylus movement. Many recorders are equipped with reversal mechanisms that permit infinite variations in water level to be recorded. A ratio of stylus movement to parameter variation of 1:10 or better is recommended.

The most suitable chart time-scale should be determined from consideration of the expected rates of change of water level and the purpose for which the water level is recorded. As a minimum, 24 mm in 24 h for open channels and 12 mm in 24 h for lakes is recommended.

9.10.2 Stylus

The stylus of an analog recorder is usually a pen or pencil. If a pen is used, the pen and ink shall be such that an easily readable trace is produced under local environmental conditions without blotting or otherwise running. When a pencil is used, its hardness shall be matched to the chart paper. A pencil that is too hard will fail to produce a legible trace and may tear the chart paper. A pencil that is too soft will wear rapidly and quickly fail to produce a legible trace.

9.10.3 Stability

The stability of the recorder is the ability of the recorder to maintain the same reading, within a given tolerance, for the same input. A recorder used in recording water levels should be stable within plus or minus two readability divisions over a 30-day period. In many cases a readability division is 1 mm.

9.11 Digital recorders

The basic function of an encoder is to convert physical values into digital information. As water-level sensors produce an analog signal, either as a shaft rotation or electrical signal, an essential first step in digital recording is the encoding of analog signals into discrete digits. This encoding may be performed at the same time and place as the recording, or separately. There are a number of different types of encoders and recorders.

9.11.1 Water-level encoders

Encoders can be classified as either absolute or incremental. An absolute encoder is one in which each shaft position or level of an electrical signal is uniquely encoded. An incremental encoder detects changes in position or signal level from an initial setting and generates up-or-down pulses which are subsequently converted to a water-level reading. Incremental encoders are generally less expensive than absolute encoders, while absolute encoders tend to be easier to operate and consume less power.

Encoders can also be classified as mechanical, electromechanical, optical or electronic. Mechanical or electromechanical encoders require a shaft angular input and generally comprise coded discs or coded drums capable of absolute encoding of digits from 0000 to 9999. Optical encoders also require a shaft angular input and may be either absolute or incremental. Optical encoders consist of a light source, an etched grating or pattern mounted on a shaft, and a light detector. As the shaft rotates, the coded disc interrupts the light and pulses corresponding to water levels or water-level changes are generated.

The accuracy of encoding depends on the accuracy of etching and the mechanical integrity of the system. Electronic encoders are generally used with electrical voltage signals and consist of signal conditioning circuitry to filter or smooth the signal and an analog-to-digital converter. Accuracy varies with the quality of circuitry and the workmanship of the mechanical parts employed.

Another type of electronic encoder uses the Hall effect. Magnetic pulses are detected by two magnetic sensors. The circuitry converts the pulses to counts. Any of these types of encoder can be designed to meet the accuracy requirements of clause 4; however, the range of the encoders using voltage signals may be limited compared to the other types. Accuracy figures are generally quoted as "one-bit", "two-bit", etc. meaning one or two counts in the total range of the encoder.

9.11.2 Digital recording

Water-level recorders generally store data using perforated tape, magnetic tape or solid-state memory. Perforated tape recording, either on paper or plastic tape, is widely used and several tape formats exist. Data are usually punched as four binary coded decimal digits in parallel on 16-channel tape or serially on five- to eight-channel tape. The serial formats often provide for a parity bit. Magnetic tape recording is not widely used because of difficulty in meeting environmental specifications, and is rapidly being supplanted by solid-state recording.

Solid-state recorders often include data encoders and telemetry devices as integral parts of the instrument and may be capable of recording more than one parameter. Moreover, the recorder itself may perform several of the following functions in addition to simply storing data:

— receive one or more input signals in a number of different formats;

— condition the signals for subsequent recording;

— control sampling interval in accordance with rate of change or level of signal;

— average input values over time, record means or extremes, or both;

— record data for future error detection and correction, such as parity;

— record system diagnostic data;

— assign times and dates to recorded data.

No matter which method of digital recording is selected, it is essential that the method not only include on-site recording but a practicable procedure for transporting the data and translating the data into a format suitable for further processing.

10 Errors

Several sources of error exist in sensing and recording water levels. Some have been mentioned previously.

10.1 Float system errors

10.1.1 Friction

The error E_1, caused by friction in the driving mechanism, can be calculated, in metres, from the following formula:

$$E_1 = \frac{F}{\pi R_1^2 R_2 \rho g}$$

where

F is the driving torque, in newton metres;

ρ is the density of the gauged liquid, in kilograms per cubic metre;

R_1 is the radius of the float, in metres;