REVIEW OF WATER STAGE GAUGING INSTRUMENTATION FOR RIVERS, CANALS AND RESERVOIRS

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1. INTRODUCTION

1.1 Water stage variation measurements in natural streams, canals and reservoirs assumes great importance for varied purposes and reasons. It is required for the determination of discharge of rivers, or of small streams with the measuring structure constructed on it. Similarly, it is needed for determination of water levels in canals, an information of immense help, in canal regulation measures. On reservoirs, it greatly helps in reservoir operations.

1.2 Instrumentation techniques for water stage measurements assumes various forms with the sole aim of providing reliable and accurate measurements. Evolution of various techniques in this regard is attributable to a number of factors, such as:

- measurement application
- site conditions
- accessibility of site
- frequency of data collection
- accuracy requirements
- type of instrument: *in situ* indicating or recording/logging
- power requirements: mains, battery or none
- safety from tampering and proliferation
- simplicity of operation
- automatic operation requirements etc.
- cost economics

1.3 **The water stage variations can be viewed as one of the following:**

i) displacement of elevation of water surface,

ii) variation of distance of the water surface from a given datum,

iii) variation of hydrostatic pressure at a fixed point underwater.

Therefore, amongst the available technologies within the science of instrumentation suited for the purpose, measurement of one of the physical quantities out of displacement, range or distance (short hauls), position sensing or pressure (hydrostatic or counter pressure) are employed. The techniques to carry out these measurements may include principles of sensing that may be mechanical, electrical, acoustic, magnetostrictive or any other known technique.

2. CLASSIFICATION OF WATER STAGE GAUGING INSTRUMENTATION

2.1 It would be convenient to classify the water stage gauging instruments from application (use) point of view as follows:

i) water stage indicators with manual read-off.

ii) water stage recorders with *in situ* recording facility.

iii) water stage sensors producing electrical signals permitting *in situ* data logging and teletransmission.

These are dealt with in detail as follows:

2.2 The instruments/devices used in the category under 2.1 (i) above range from simple staff gauges to electronic gadgets with digital display. They are by far the simplest and the cheapest in the hierarchy. The staff gauges are purely mechanical devices and need no elaboration here. With the introduction of electronics into instrumentation technology simple, easy to read digital display, attached to water level sensors are also finding acceptance as water level indicators, to be used either as stand alone or as part of the water stage data collection using telemetry network, as they have become economically viable and affordable.

2.3 The *in situ* water stage recorders under 2.1 (ii) above encompass instruments employing *in situ* recording facility mostly on paper. The water stage variation, in a purely mechanical system is sensed generally by a float-counterweight-on-pulley mechanism which is connected to the pen mechanism that writes on chart paper mounted on a drive mechanism. There are a number of variations in the types of recorders viz. drum type or flat bed type, with mechanical spring or electric motor chart drive, ink or thermal recording, vertical or horizontal recording, extended recording, recorders accepting electrical signals, short term or long term recorders etc. Recording devices are sometimes even connected to water level sensors for *in situ* recording as back-up information.

2.4 The water stage sensors under 2.1 (iii) are designed to meet the need of data logging and teletransmission applications in addition to simple *in situ* display and/or recording. The sensors have now taken common place to even meet the requirements of water stage indication for 2.1 (i) and recording either using chart paper or in solid state memory for 2.1 (iii).

3. SENSING TECHNIQUES AND INSTRUMENTS

3.1 The Float-Counterweight-on-Pulley-Mechanism

3.1.1 General

3.1.1.1 This is the classical sensing device widely used and accepted the world over. The basic mechanism has a proven record of reliability and the desired accuracy.

3.1.2 Principle of working and operation

3.1.2.1 The float-counterweight-on-pulley arrangement is basically a mechanism devised to convert vertical displacement of water surface, on which the float rests, into a rotational motion of the pulley. The counterweight helps in balancing so that it takes minimum force for the displacement. The rotational motion is used for:

i) water stage indication through dial gauges, or digital indication, through mechanical revolution counters coupled to the pulley through a gear mechanism.

ii) water stage recording on paper with the pen mechanism coupled to the pulley reconverting the rotational motion of the pulley into translational motion, but to a reduced scale.

iii) water stage sensing with proportional electrical output in the form of an analogue signal using potentiometer or digital signals using shaft recorders which could be absolute or incremental type. The electrical signal can be used for :

a) indication using electronic digital display.

b) recording using strip chart recorders accepting electrical signals (e.g. potentiometric recorders).

c) logging data on electronic data loggers with solid stage memory devices.

d) remote data collection using telemetry links.

3.1.2.2 The equipment configuration comprises of the float-counter-weight-on-pulley mechanism installed in a gauge well coupled to a sensor/recorder.

3.1.3 Features and Performance

3.1.3.1 The float type sensing technique is a direct measurement and is proven and hence widely used. It however requires a stilling well. Its performance therefore depends on how effective is the stilling well performance. Stilling wells provided in reservoirs perform well, so the float type devices are most suited for reservoir water stage measurements. On rivers, however, the problem of choking of inlet pipes, due to siltation, pose difficulties, resulting in unreliable operation of the equipment. Proper gauge well maintenance however obviates the problem.

3.1.3.2. Accuracies upto 10 mm as required as per ISO are achievable.

3.1.4 The float sensor is also used by some manufacturers in different but innovative ways for sensing water levels. These include:

i) The float with a magnet mounted on it, travelling in a tube (about 150 mm dia). The tube is open at both ends and is of a length more than the range of water level variation to be measured. The tube is designed to have a concealed side cavity along the length. In the cavity, are mounted, at every centimeter, a series of magnetic reed switches each connected by wires of a multicore cable, which is brought out from the top of the tube. The tube made of PVC material is attached to a structure, available or erected in a stream. As the float follows the water surface elevation, each reed switch operates because of the magnet proximity depending on the position of the float. Operation of the reed switch is then converted into digital data which can be read off using digital display and/or stored using solid state memory data logger.

ii) The float is designed so as to exert a buoyancy force on a load sensor connected rigidly above it through a tie bar chain link. The load sensor can be strain gauge based and is mounted on top. The float assembly is placed in a tube or a stilling well. The load sensor signal is proportional to the water variation in the stilling well.

iii) The float, a circular disc in shape, is integrated with the circular magnet. The float has a central hole so that a tublar probe penetrates through, that senses the float position through magnetostrictive action generated by passing a short duration current pulse through a copper wire provided in the probe tube. Instruments based on this principle are very precise.

Among other methods, the float is attached through a tie bar to a linear displacement sensor such as Linear Variable Displacement Transformer (LVDT), Linear potentiometer. The electrical signal produced by the displacement devices is proportional to the water level variation.

3.1.5 For all float sensor type arrangements a gauge well is a must. This is to protect the float from disturbances from other forces such as wind. The gauge well design is governed by the considerations at site conditions, such as the availability of structures such as bridges, vertical walls etc. Mostly, in dams and barrages a guage well is provided for the purpose of water level monitoring, if not, one can be erected as the structure provides ample alternatives. In locations at river banks, however, it needs to be designed and erected considering aspects such as the possibility of silting, choking of inlet pipes, stilling effect and, of course, the cost.

3.2 Purge Bubble/Pneumatic System

3.2.1 General

3.2.1.1 This type of water level measuring technique has been devised to obviate the difficulty of requiring a gauge well for flood types of instruments. The mechanism also has a proven record provided, however, attended to properly.

3.2.2 Principle of working and operation

3.2.2.1 If compressed air is let into the water through a tube, at a given location, below the minimum water level through an orifice and is regulated to bubble out at a constant rate, then the pressure of the air required to do so is equal to the hydrostatic pressure in terms of water column over the orifice. Thus the water level can be measured in terms of air pressure sensed out of water. The air pressure can be:

i) indicated as the water level on a bourdon gauge or manometer.

ii) recorded using servo balance type recorder.

iii) converted into electrical signal using pressure transducer for:

- a) electronic digital display,
- b) recording, using electrical strip chart recorders,
- c) logging data in solid state memory,
- d) remote data collection using telemetry links.

3.2.2.2 The equipment configuration consists of pressurised gas (air) cylinder connected to tubings through a 'T' junction, one limb of which is let into the water through an orifice and the other limb to the pressure sensing device. To facilitate controlling and observing the bubble purging rate of gas/air gadgets such as, pressure reducer, control valve and purge bubble indicator are provided at the instrument end in the limb terminating in the water.

3.2.3 Features and performance

3.2.3.1 The purge bubble/pneumatic type technique for water level sensing came into existence solely to counter the necessity of gauge wells required for the float type sensors. Thus, the use of purge bubble/ pneumatic technique has the following advantages:

a) savings in the cost of construction of a gauge well.

b) elimination of attendant maintenance problems of the gauge well.

c) location of the measuring instrument can be at a location away from the water course.

d) space requirement at the measuring point is minimum.

e) installation involves the laying of tubing and the orifice.

f) siltation problems are automatically reduced due to constant air purging action.

g) siltation to some extent does not affect working.

3.2.3.2 The purge bubble/pneumatic type water level measuring equipment is however costlier compared to the float type. Besides, the equipment is required to have a housing and dry nitrogen gas/ air cylinder supply ensured for its functioning. Because of its slow response to water level change it tends to be unsuitable for flashy streams. Installations for the tubing and the purging orifice to the bank and bed at datum level respectively has to be done carefully so that they remain anchored inspite of drag force due to high velocities or mobility of bank and bed.

3.2.3.3 Accuracies upto 10 mm as required as per ISO are achievable.

3.3 Hydrostatic Pressure Sensing Devices

3.3.1 General

3.3.1.1 Hydrostatic pressure sensing using various forms of underwater pressure sensing devices have been employed for measurement of water level variations. The sensing devices being under water, the pressure signal needs to be transmitted through a convenient location for indication/recording.

3.3.2 Principle of working and operation

3.3.2.1 The pressure transducer placed under water basically senses the hydrostatic pressure above it and generates an electrical signal in the form of proportional voltage or current. There are different methods of generating the electrical signal. Following are some of the typical ones:

i) Diaphragm with electrical strain gauges either wire or semiconductor type,

ii) Diaphragm with a vibrating wire device attached to it.

iii) Diaphragm attached to capacitance variation device.

3.3.2.2 The pressure transducer of one of the above or any other type is placed under water below the minimum water level either anchored to a pedestal built on the bed of the stream or attached to an available structure (e.g. bridge pier) or one specially constructed (e.g. pile) for the purpose. The electrical signal, in the form of voltage or current is transmitted through an electrical cable to the reading/ recording unit. The cable is specially designed to withstand abuses of embedment/anchoring to the bank, high flow velocities and abrasion due to bed material movement. In some installations the cable is passed through a metallic conduit for protection which in turn is anchored to the bed firmly. The cable is also provided with a vent tube to maintain gauge pressure reading.

3.3.2.3 The available electrical signal can be:

i) indicated as digital display in convenient units of water column.

ii) recorded using galvanometric or potentiometric strip chart or drum recorder.

iii) used for data logging using solid state memory.

iv) fed to telemetry link for teletransmission.

3.3.3 Features and performance

3.3.3.1 Pressure transducers have been in use since long for applications of pressure measurements in proccess industries, space research, thermal and atomic power stations etc, where its design is governed by factors other than bodily immersion under water. In water stage measurements underwater applications governed the design aspects in respect of water tightness of the pressure transducer itself, that of the cable and the cable exit as well as the use of noncorrosive material like stainless steel for the body. The cost of pressure transducers may tend to forbid their use in water level measurement applications in comparison to some other simple and economical methods described earlier.

3.3.3.2 Like purge bubble type sensors the pressure transducers also have the following advantages:

i) savings in the cost of construction of a gauge well and elimination of attendant problems of the gauge well.

ii) location of gauge reading equipment can be at a safe and convenient location away from the water course.

iii) minimum space requirements for sensing device.

iv) installation involves only laying of pressure transducer and its cable.

v) siltation does not affect working.

3.3.3.3 The pressure transducer needs similar care during installation as is required for the purge bubble equipment. Care is also required to be taken for the vent tube to remain intact. Since the pressure transducer is installed in remote locations it would need to be operated from a battery supply. The battery condition therefore needs be monitored and attended to for charging/replacement.

3.3.3.4 Choice of a pressure transducer for a given range of water level variation has to be made to achieve the desired resolution because the pressure measurement accuracy and resolution in the water level measurement depends on the design range of pressure for the pressure transducer. Unlike the purge bubble type sensing the pressure transducers have very fast response to water level variations and hence are most suited for flashy streams. Also pressure transducers are less sophisticated and are direct pressure measuring devices as compared to the purge bubble type and yet have all its advantages. Accuracies upto 10 mm is required as per ISO are achievable, within the specified range.

3.4 Ultrasonic/Acoustic Devices

3.4.1 General

3.4.1.1 Echo sounders are well known in the application of water depth measurements. These work on the principle of reflection of sound waves (in the ultrasonic frequency range) from the bed which act on the reflecting barrier. The same principle can be extended and reflections can be received from the water surface so that the water surface elevation variation can be measured with respect to a fixed datum point underwater or above the water surface.

3.4.2 Principle of working and operation

3.4.2.1 If the ultrasonic sound waves are targetted to the water surface so that they are incident on the surface at normal, from a convenient point, the reflected waves from the water surface can be detected as an echo at the transmitting point and the water surface position can be computed by knowing the velocity of sound in the media it is travelling (water or air in this case) and the time required between transmission of sound waves and receipt of the echo.

3.4.2.2 The configuration of the equipment can of be two types viz:

i) underwater type also known as inverted echo sounder, and,

ii) the type operated through air also known as ultrasonic distance meter.

In either case the equipment consists of an ultrasonic transducer and an electronic unit that has the following functions viz. to generate voltage of ultrasonic frequency to excite the transducer, receive and detect echoes, carry out time measurements and convert the time measurements into water level for display/record. The equipment works in pulsed operation so that one ultrasonic transducer can act as transmitter and receiver.

3.4.2.3 In the underwater type, the ultrasonic transducer is installed underwater at a known datum looking upwards. It could be at the bed or attached to a structure, available or built for the purpose, below the minimum water level. The transducer is connected to the electronic unit, placed at a convenient location on the bank through an underwater cable.

3.4.2.4 In the case of the type operated through air, the transducer is mounted above the water surface looking downward, fixed to a structure made for the purpose. The electronic unit connected to the transducer is placed by the side. The echo ultrasonic frequency operable in air are lower than that in water.

3.4.2.5 The ultrasonic transducers are normally configured on ceramic crystal material such as barium titanate or lead lerconate titanate (PZT), having disc shape and is housed and encapsulated in a circular metallic or plastic housing with radio frequency grade cable of appropriate length.

3.4.2.6 The electronic unit is battery operated.

3.4.3 Feature and performance

3.4.3.1 Both the methods mentioned earlier are in vogue. Installation of either type can be made, effects due to waves, if any, on the surface of water have to be minimised by averaging a number of records (which is possible). This can be achieved through the electronics provided in the electronic unit. The transducer in either case can also be installed in a small and inexpensive gauge well so that the wave effect can be eliminated.

3.4.3.2 Accuracies of 10 mm as required as per ISO are achievable.

3.4.3.3 The instrument needs calibration and it is recommended that out calibration be carried out whenever required as the propagation velocity of sound in water and air is also dependent on factors like water quality, temperature etc. This is achieved by keeping a target in front of the transducer at a known distance and adjusting the display to read the exact value. In case of air type instrument the temperature can be monitored simultaneously for correcting the propagation velocity.

4. CONCLUSIONS

Deployment of a type of water level gauge at a site is governed by the factors listed in para 1.2. Among these are conflicting ones and trade-off (s) usually decide the optimum type of an instrument for a site.