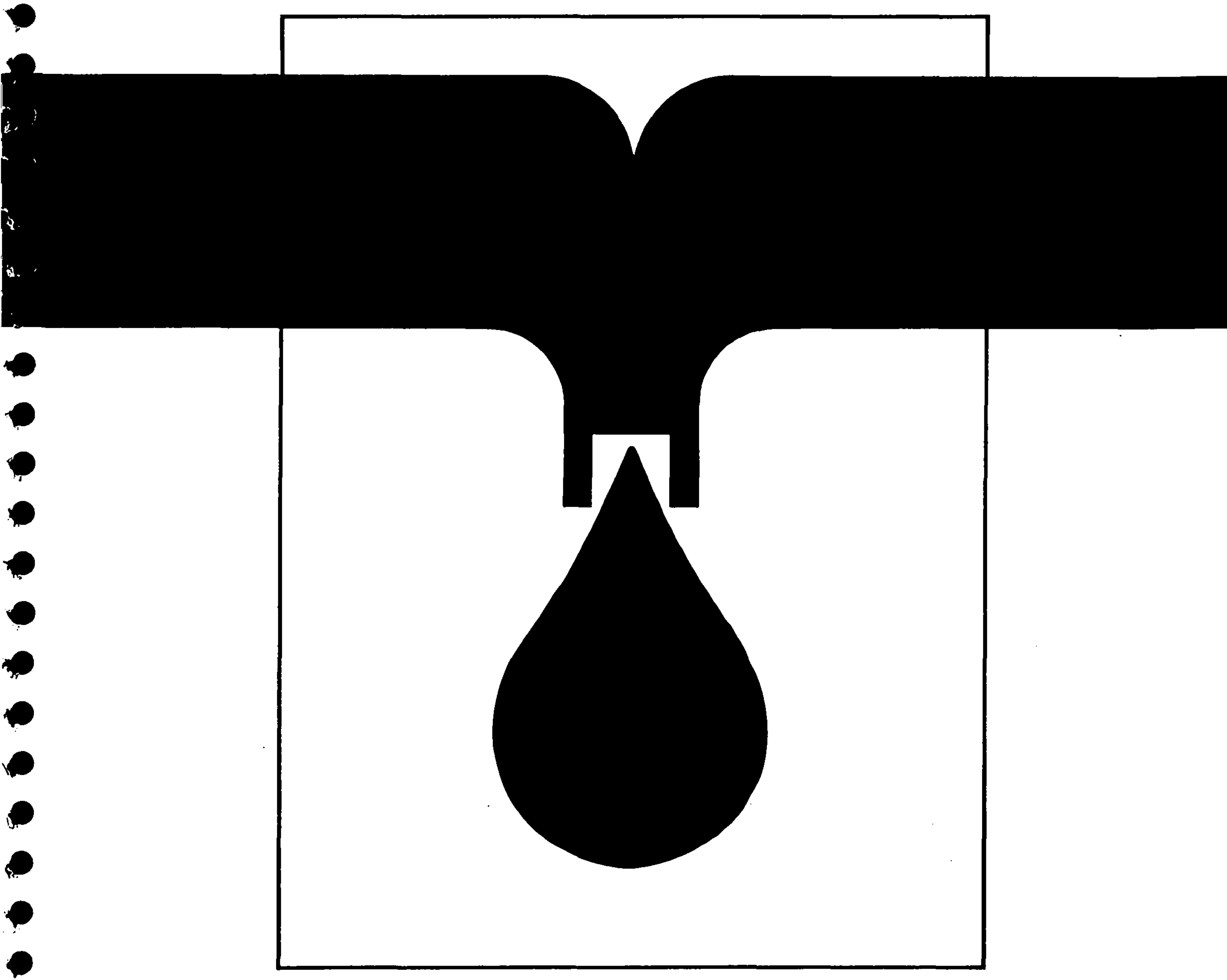
TRAINING MODULES
FOR
WATERWORKS PERSONNEL



Special Knowledge

2.4

Process control and instrumentation

Foreword

Even the greatest optimists are no longer sure that the goals of the UN "International Drinking Water Supply and Sanitation Decade", set in 1977 in Mar del Plata, can be achieved by 1990. High population growth in the Third World combined with stagnating financial and personnel resources have led to modifications to the strategies in cooperation with developing countries. A reorientation process has commenced which can be characterized by the following catchwords:

- use of appropriate, simple and – if possible – low-cost technologies,
- lowering of excessively high water-supply and disposal standards,
- priority to optimal operation and maintenance, rather than new investments,
- emphasis on institution-building and human resources development.

Our training modules are an effort to translate the last two strategies into practice. Experience has shown that a standardized training system for waterworks personnel in developing countries does not meet our partners' varying individual needs. But to prepare specific documents for each new project or compile them anew from existing materials on hand cannot be justified from the economic viewpoint. We have therefore opted for a flexible system of training modules which can be combined to suit the situation and needs of the target group in each case, and thus put existing personnel in a position to optimally maintain and operate the plant.

The modules will primarily be used as guidelines and basic training aids by GTZ staff and GTZ consultants in institution-building and operation and maintenance projects. In the medium term, however, they could be used by local instructors, trainers, plant managers and operating personnel in their daily work, as check lists and working instructions.

45 modules are presently available, each covering subject-specific knowledge and skills required in individual areas of waterworks operations, preventive maintenance and repair. Different combinations of modules will be required for classroom work, exercises, and practical application, to suit in each case the type of project, size of plant and the previous qualifications and practical experience of potential users.

Practical day-to-day use will of course generate hints on how to supplement or modify the texts. In other words: this edition is by no means a finalized version. We hope to receive your critical comments on the modules so that they can be optimized over the course of time.

Our grateful thanks are due to

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and
Ing.-Grad. H. Hack

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It is my sincere wish that these training modules will be put to successful use and will thus support world-wide efforts in improving water supply and raising living standards.

Dr. Ing. Klaus Erbel
Head of Division
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Eschborn, May 1987

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1 Measurement of Pressure

The pressure of a fluid is defined as the force it exerts in a direction perpendicular to a surface of unit area. A distinction is to be made between "absolute pressure", which is measured in respect to zero (absolute vacuum) and "gauge pressure" which is the amount by which the pressure exceeds the atmospheric pressure. Hence:

gauge pressure + atmospheric pressure = absolute pressure.

The actuating elements of pressure sensors perform 2 main functions. Measuring the pressure of the process variable and providing sufficient force to position a pen, a pointer, or an electronic transducer, which will generate an electrical signal. Inherent in the design of the actuating element must be the ability to withstand the pressure being measured. In addition they must provide the necessary accuracy.

Industrial pressure gauges have a standard accuracy of ± 1 percent of full-scale rated pressure. By more careful calibration, accuracy can be increased to ± 0.5 percent. The sensitivity and repeatability of commercial gauges is ± 0.25 percent or better. Below is a brief description of the most commonly used pressure sensors and gauges found in water supply and distribution systems.

1.1 "U" Tube Manometer

This is the simpest form of pressure gauge Fig. 1. It may either have both ends open to the atmospere (a) or one sealed arm (b) in which there exists a vacuum over the sealing liquid. With type (a) one arm is connected to the pressure p_1 to be measured and the other arm is in communication with atmospheric pressure (the reference pressure p_b). The difference in level H is a measure of difference in pressure p_1-p_b, i.e. H represents gauge pressure. The U tube manometer can be used as a differential gauge for measuring the difference between two pressures p_1 and p_2.

Where an inverted U tube is used to measure differential pressure of a liquid, the sealing medium is usually a gas Fig. 1c.

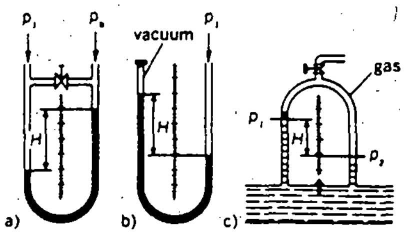


Fig. 1
"U" Tube Manometer.

1.2 Bourdon Tube Pressure Sensor

This is one of the most widely used types of pressure gauges in water supply systems Fig. 2. The pressure measurement is accomplished by deformation of an elastic measuring element, usually in the shape of a curved hollow tube, closed at one end with the pressure to be measured applied to the other. As the applied pressure increases, the tube tends to straighten itself out. A pointer or other means of pick-up attached to the end of the tube registers the deflection, which is proportional to the variation of applied pressure.

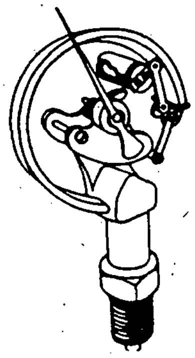


Fig. 2
Bourdon tube
pressure sensor.

1.3 Helix Pressure Sensor

This unit is another form of Bourdon tube, but is several times as long and wound in a compact helical form. It is made in this form in order to occupy a minimum amount of space. The element is formed by flattening a round tube to an elliptical shape and then wound in a helical form. When pressure is applied, the helix unwinds and this movement actuates a pen or pointer, or other transmitting device.

1.4 Diaphragm Sensor

The diaphragms are made of spring material and joined together at their circumference to form a compartment. When subjected to pressure, each compartment expands a slight amount. Depending on the full-scale range, a number of compartments are stacked together to provide the proper movement for actuation Fig. 3. The lower the pressure, the greater the area must be, and consequently the larger the diameter. The actuating mechanism is again connected to operate pointers or other transmitting devices.

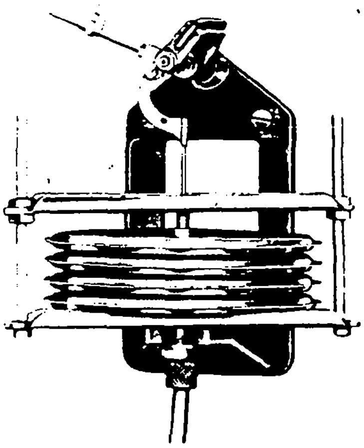


Fig. 3
Diaphragm
pressure sensor.

1.5 Diaphragm Boxes

These units are primarily used to sense liquid levels and therefore covered in section 3 (Measurement of liquid level).

1.6 Load Cell Pressure Sensors

These units are also primarily used to sense liquid levels and therefore covered in section 3 (Measurement of liquid level).

1.7 Remote Indication

In addition to direct indication by pointer as shown in Fig. 2 and 3, a transducer can be provided which converts the mechanical deflection of any hydraulic or pneumatic pressure sensor into an analogue electrical signal. Fig. 4 shows a typical block diagram of such a circuit for a Bourdon tube pressure sensor. Other pressure sensors have similar circuit arrangements.

The basic function of the circuit is as follows: The transducer (2) is connected to an oscillator (4) which is fed by a power supply unit (5) furnishing DC power to the oscillator. The transducer output varies with the deflection of the Bourdon tube sensor (1). This signal is then demodulated (3) and converted into a DC current signal analogue to the deflection of the pressure sensor (6) for connection to a remote indicating or recording meter (7).

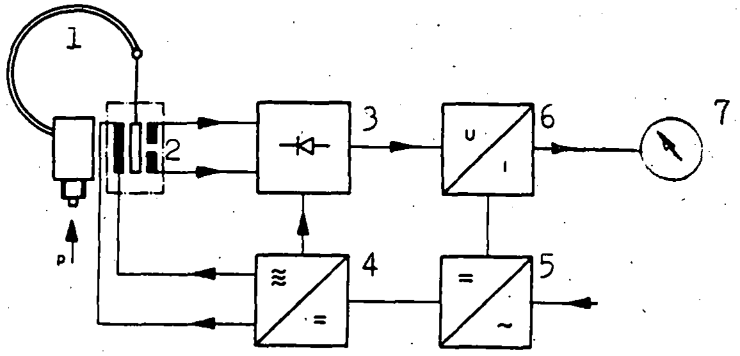


Fig. 4
Block diagram pressure transducer and controls for remote indication.

1 - Pressure sensor
2 - Signal transformer
3 - Demodulator
4 - Oscillator

5 - Power supply
6 - Signal converter
7 - Indicator or recorder

2 Measurement of Liquid Flow.

The rate at which a liquid flows through a conduit can be defined as the relationship of volume in respect to time, or

$$Q = \frac{V}{t}$$

whereby: Q - Flow-rate
V - Volume
t - Time

When flow rates in water supply systems are to be measured, one or more of the following basic methods of measurement are commonly used:

- the electromagnetic method, in closed conduits,
- the head pressure differential method in closed conduits,
- the flow-level method in open conduits and
- the mechanically actuated method in closed conduits.

The following chapters explain the concept of operation of these most commonly used methods to measure liquid flow.

2.1 Electromagnetic Flow Meters: Electromagnetic flow meters (Fig. 1) measure the flow of electrically conductive liquids in closed pipes. The measurement is largely independent of flow profile (laminar or turbulent) and takes place without head loss. The meter can be used to measure the flow of water or sewage.

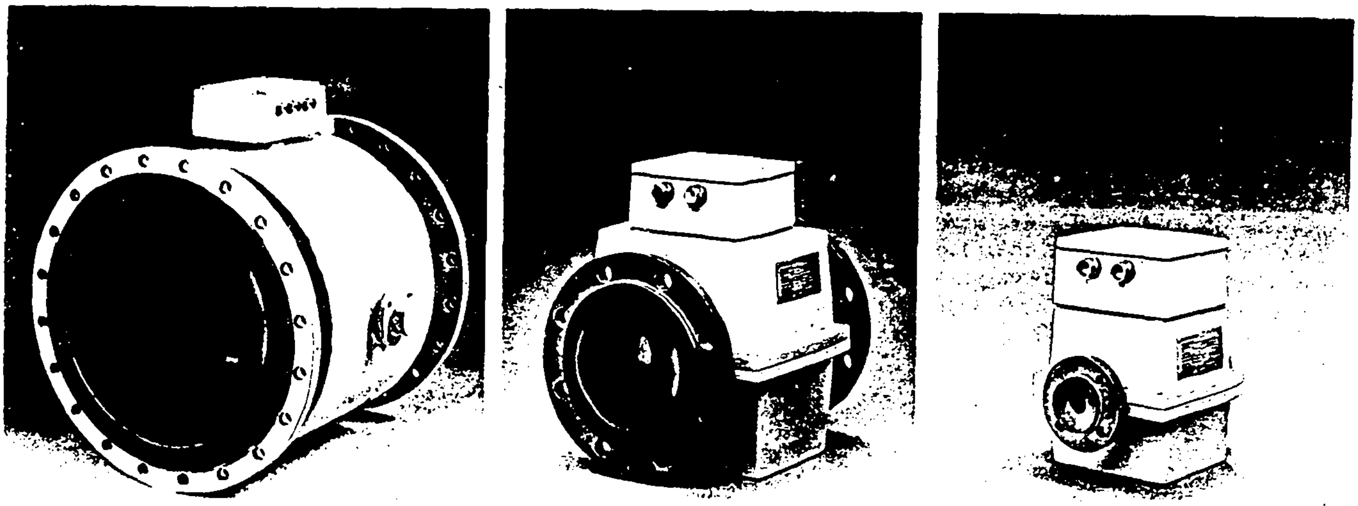


Fig. 1 - Illustration of typical electromagnetic flow-meters.

The operating principle of this type of flow meter is based on Faradays law of induction. The conductive liquid passing through the meter acts as a conductor of electricity. Enveloping this "liquid conductor" is an electro-magnetic field normally supplied by a pair of coils, energized by an electric current and located opposite each other on the circumference of the meter (Fig. 2). As the "liquid conductor" flows through this magnetic field (or as the fluid passes the meter), the magnetic lines of force will induce a voltage in the "liquid conductor". The voltage induced will depend upon the number of magnetic lines of force cut by the "liquid conductor" within a given unit of time, or by the velocity of the passing liquid. The induced voltage is therefore proportional to the flow rate. Assuming a constant magnetic field and pipe diameter this relationship can be expressed by the following formula:

$$U_e = B \times D \times v$$

whereby: U_e - Voltage induced in liquid passing through meter
B - Magnetic field
D - Diameter of pipe (length of conductor)
v - Velocity of liquid

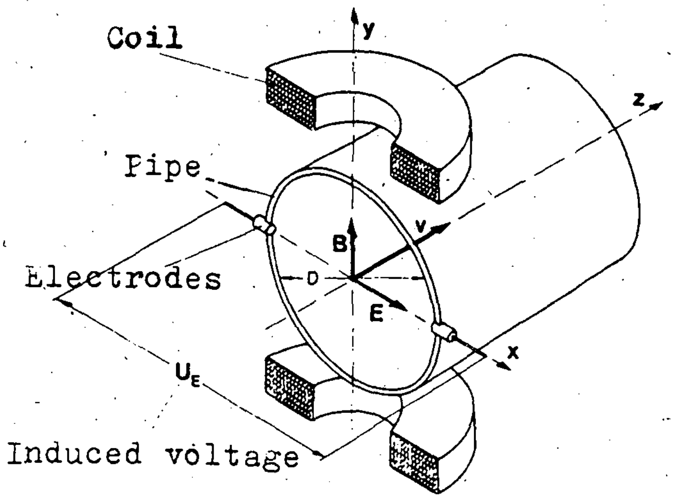


Fig. 2
Functional diagram,
electromagnetic flow meter.

To pick up the voltage induced in the fluid passing through such a meter, two isolated electrodes are mounted diametrically opposed to the magnetic field (or coil).

To insure a completely filled pipe at all times which is essential to accurately determine the volume rate of flow, it is sometimes practice to install the meter in a siphon dip pipe arrangement as shown in Fig. 3. This is normally easy to accomplish, because the electromagnetic flow meter does not need the long straight sections of pipe line immediately preceding and following it like a venturi flow meter for instance does. A straight section of three times pipe diameter immediately ahead of the meter is generally adequate.

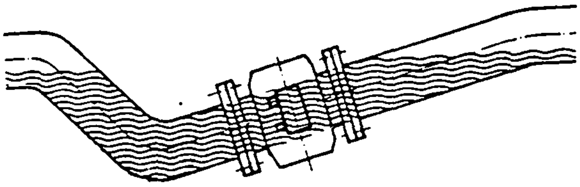


Fig. 3 Electro-magnetic flow meter installed in siphon dip.

Experience shows that flow velocities of 2 to 10 meter/sec provide the best measuring results, the size of the instrument is usually selected accordingly. Fig. 4 gives a tabulation or recommended sizes for certain flow rates.

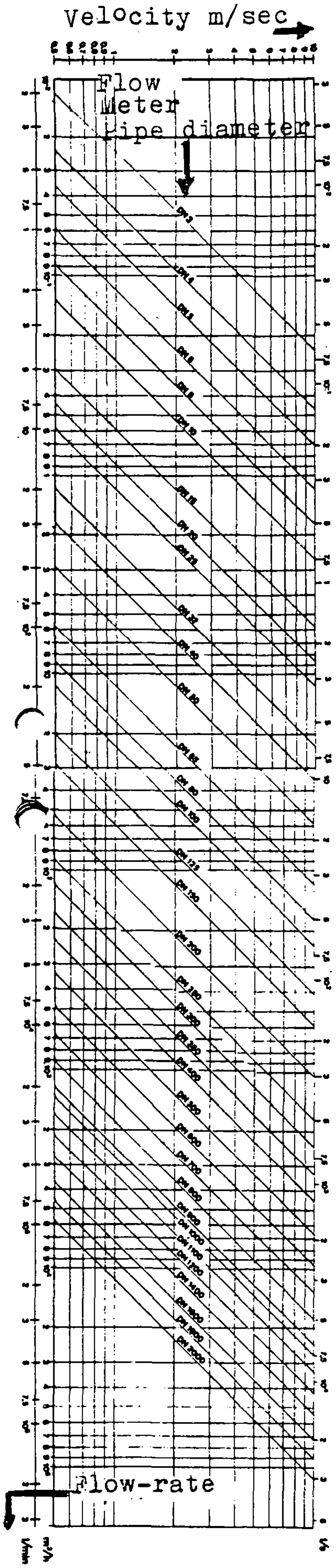


Fig. 4

The induced voltage picked up by the electrodes, mentioned above is amplified and converted for external utilisation into current signals for analogue indication or recording, or into a voltage impulse for digital counting or recording or into an on-off relay signal output to operate other remote control devices of the system at any desired threshold value.

2.2 Head Presssure Differential Flow Meters

a) Venturi FLow Meters: The increase in velocity and the corresponding decrease in head pressure at a reduced section in a closed conduit serves as the basis for this device. It is most widely used to measure flow rates in closed pipes of water supply systems. (Fig. 5). The device consists essentially of a short converging tube, followed by a longer diverging tube.

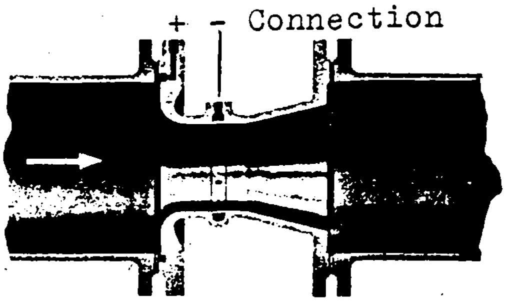


Fig. 5
Typical Venturi flow meter.

As indicated by Fig. 6 connections are attached at the inlet section 1 and the throat section 2. As the fluid passes from the inlet to the throat, its velocity increases and its head pressure decreases. The difference between the pressure head at the inlet and at the throat is a measure of the difference in velocity head between the two sections. This difference of velocity head has a direct relation to the flow rate through the meter. It can be expressed by the following formula:

$$h = c \times Q^2$$

whereby: h - Head pressure difference between inlet and throat
c - Design constant of device
Q - Flow rate

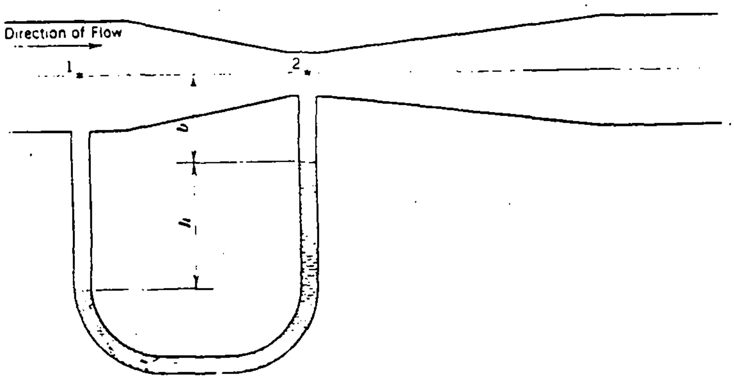


Fig. 6
Sketch of Venturi meter and U tube manometer

It is important to note that when disregarding the design constant (c) the head pressure difference (h) between point 1 and 2 varies to the square of the flow rate (Q).

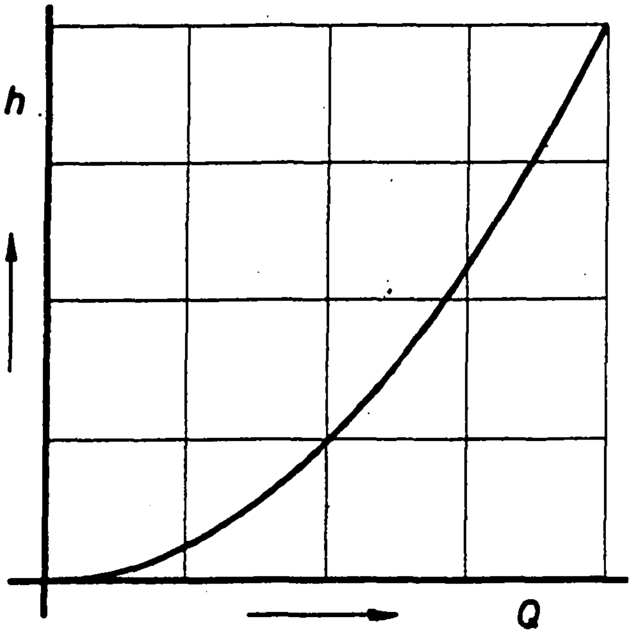


Fig. 7
Relationship of head pressure differential vs. flow rate for a typical Venturi meter.

The accuracy of a Venturi flow meter is significantly affected by irregularities in flow pattern, especially ahead of the converging tube. The cause of such irregularities are primarily bends, tee's or valves installed in the line within close proximity to the meter. It is therefore common practice to install a straight section of pipe without restrictions to flow immediately ahead as well as behind the Venturi meter. Depending upon meter design characteristics, these straight sections of pipe especially ahead of the inlet side of the meter should have a length equal to 5 to 50 times pipe diameter.

b) Orifice and Nozzle Meters: Closely related to the Venturi flow meters and based on th same principle of inducing a head pressure difference by flow restriction are the orifice and nozzle flow meters.

The flow nozzle shown in Fig. 8a consists of a short nozzle placed in the pipe line, while the orifice type meter Fig. 8b utilizes a flat plate, usually clamped between two flanges, containing a small hole or orifice.

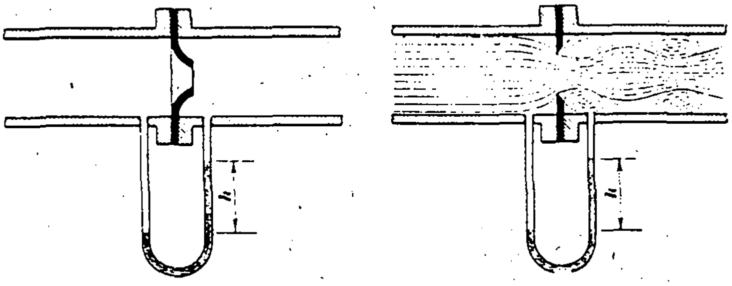


Fig. 8
Sketch of nozzle and orifice type flow meters.

In all three cases, may it be the orifice flow meter, the nozzle flow meter or the Venturi flow meter, the effective cross section of the stream of fluid passing through it is reduced at the throat section. The reduction in effective area results in an increased velocity and a decrease in pressure at the point of restriction.

The orifice and nozzle flow meters have considerable higher head losses than the Ventrui flow meter and of course also the electromagnetic type flow meter which has virtually none.

c) Differential Pressure Sensors, Converters and Transducers:
The simplest method to determine the flow rate through a Venturi or similar flow meter is to install a pressure differential manometer as shown in Fig.6. Furnishing it with the proper scale will enable the operator read off the momentary flow rate whenever desired.

The two pressures sensed by the flow meter can also be compared and their difference converted into a usable signal for indication or recording, such a device is shown in Fig. 10. The two pressures

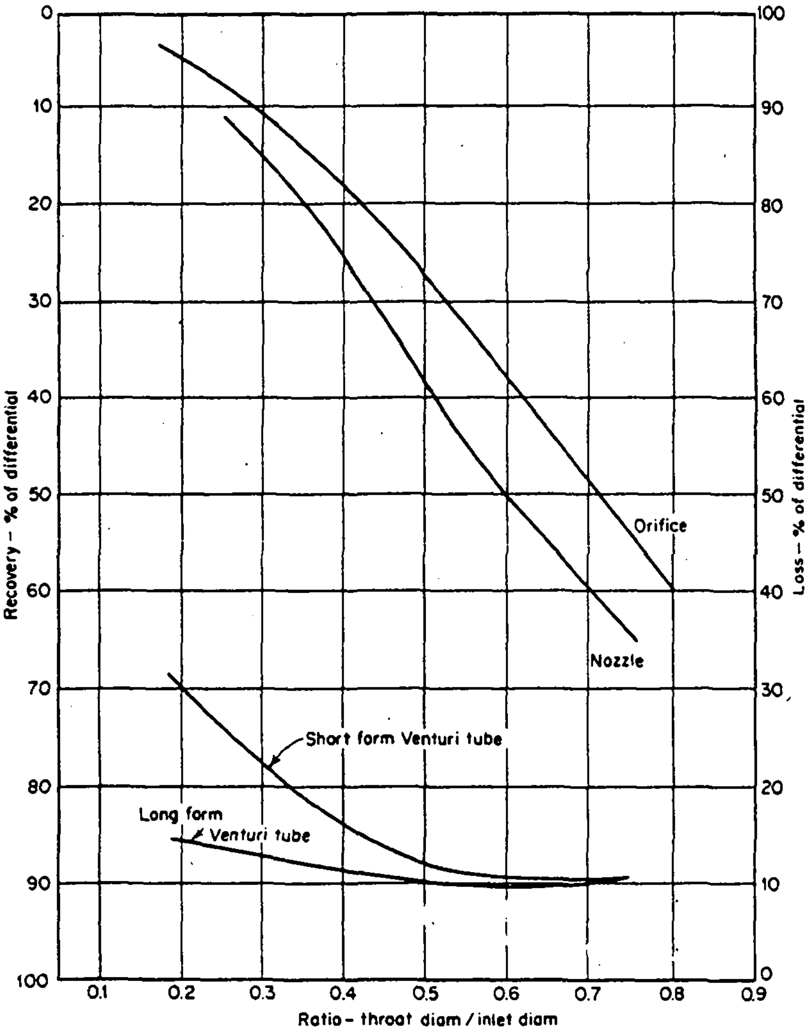


Fig. 9
Comparison of head losses Venturi vs. orifice and nozzle type flow meters.

(high and low), are admitted to the two end chambers.

The barrier diaphragms 3 and 4 transfer these pressures respectively into the usually silicone fill fluid in the center section of the meter body on either side of the measuring element. The higher pressure acts on the inside (5), and the lower pressure acts on the outside (6) of the measuring element.

If there is no flow, these two pressures are equal. With flow, the pressure in the left chamber and the low pressure side of the fill decreases, the element moves to the left, and high-pressure fill flows through the damping restriction (7). As the measuring element moves, it exerts a proportional torque through a connecting linkage on the force shaft (8). The force shaft extends to the outside. The transmitting unit fastens to the outer end of the force shaft.

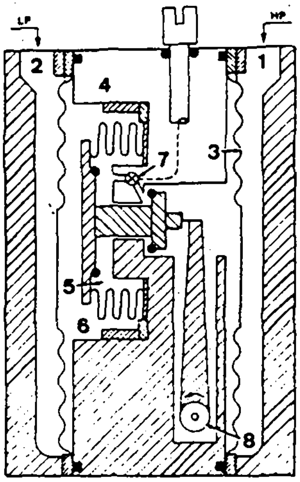


Fig. 10
Cross-section of a typical differential pressure sensor and converter.

The mechanical motion delivered by the force shaft is directly proportional to the pressure differential sensed by the flow meter. In some installations, the output of the force shaft is directly connected to a mechanical indicator or recorder.

The more common practice however, is to convert the shaft output into an electrical signal, especially when remote indication or counting is required. A typical mechanical to electrical signal transducer is shown in the block diagram Fig. 11.

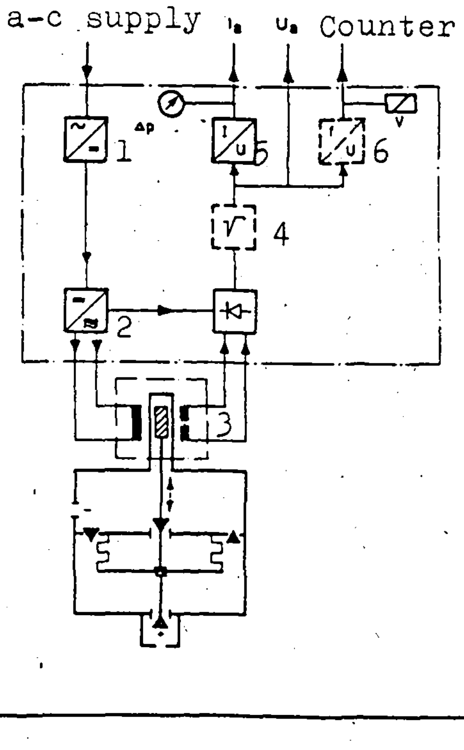


Fig. 11
Block diagram mechanical/electrical signal transducer for Venturi flow meters.

Here the transducer is connected to an ac auxiliary source to provide the required operating voltage. The operating voltage is first of all rectified to dc (1). An oscillator (2) changes the rectified dc into a high frequency oscillating voltage which is fed into the primary winding of a differential transformer (3). The force arm of Fig. 10 is connected to a movable core of the signal transformer. As this force arm moves the movable transformer core within the coil assemblies, it changes the output voltage of the secondary coil of the signal transformer. This change in voltage is proportional to the pressure differential delivered by the flow meter or approximately proportional to the square root of the flow rate through the meter.

This transformer output signal is now squared (4) and corrected to compensate for the error introduced by the flow meter design constant c (Fig. 6). The signal so modified corresponds to the actual flow rate through the flow meter. For external utilisation it is converted into a current signal primarily for analogue indication or recording (5), into a voltage impulse for digital counting and recording (6), or into an on-off relay output to operate other remote control devices of the system at any desired threshold value.

2.3 Open Channel Flow Meters: The measurement of liquid flow rates in an open channel is common practice in many water treatment facilities (Fig. 12).

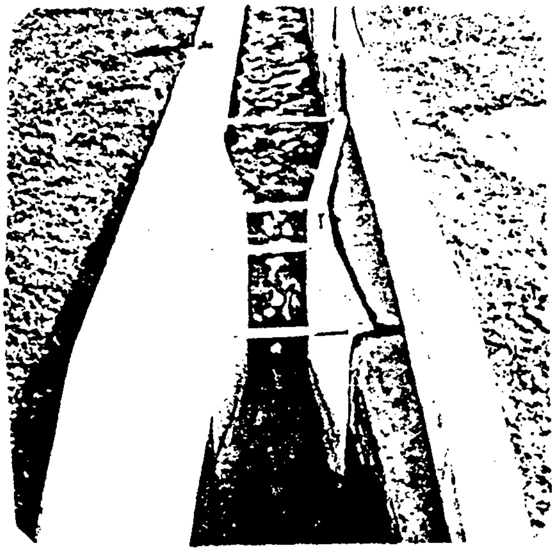


Fig. 12
Typical open channel flume.

It takes advantage of the relationship between flow-rates and depth of flow in open channels. The velocity or flow rate in any straight open channel can easily be determined by measuring the depth of the fluid passing a given point, provided pressure head and cross section of the channel is known and provided the flow is unrestricted. In case of fluid back-ups on the downstream side towards the point of level measurement this method of measuring flow rates can not be employed.

A second method of measuring flow rates in open channels is by installing flumes which operate on the previously described Venturi principle Fig. 13. These devices are also called Parshall flumes.

These flumes have a restriction similar to the throat restiction of the previously described closed pipe Venturi flow meters. However, since the open channel system is under atmospheric pressure which remains constant, there will be no pressure drop in the throat area due to the increased velocity of the medium as is the case in the closed pipe Venturi system. Instead of a pressure drop, the open channel constant pressure system will show a drop in fluid level which is proportional to the pressure drop in a closed pipe Venturi system or proportional to velocity or flow rate.

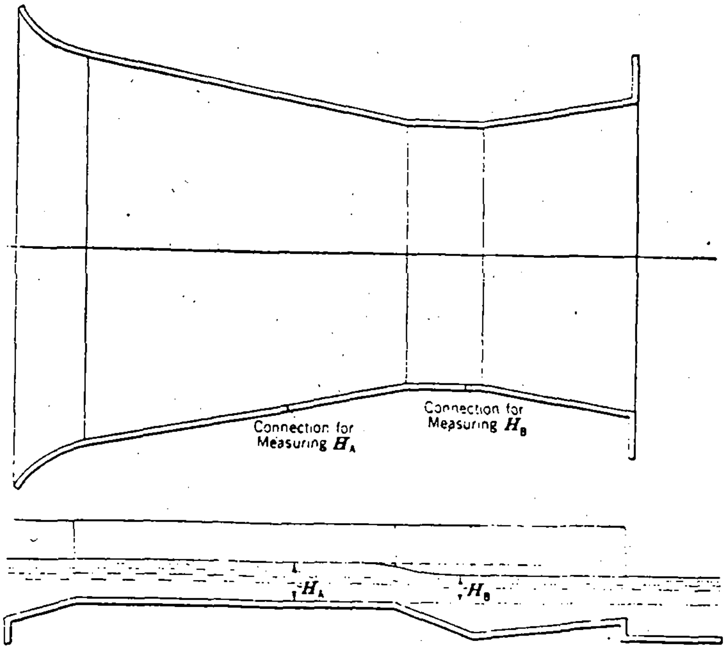


Fig. 13
Typical open channel Venturi (Parshall) flume.

The system requires two points of level measurement as shown in Fig. 13. The level differential is proportional to velocity or flow rate.

The third and most commonly used method of measuring flow rates in open channel systems functions as follows:
A flume, similar to the one shown in Fig. 13 is modified as shown in Fig. 14. The throat area of this flume is reduced to a cross section which will increase the velocity of the medium to a value, which will cause a change in flow pattern from a streaming flow at the intake to a shooting flow through the restricted throat area and then back to a streaming flow at the output.

This shooting glow at the throat which separates the streaming flows of input and output will prevent hydraulic disturbance on the downstream side such as back-ups from affecting a true flow rate measurement on the upstream side of the throat restriction. It is essential however, that the flume is operated within its design parameters.

These flow meters therefore need only one level sensor located on the upstream side and within close proximity of the throat restriction. As said above, it is absolutely essential that the shooting flow is present to insure an accurate flow-rate measurement. A simple way to verify this is to make sure a hydraulic jump takes place at the transition point from shooting flow back to streaming flow on the down-stream side of the throat restriction, Fig. 14.

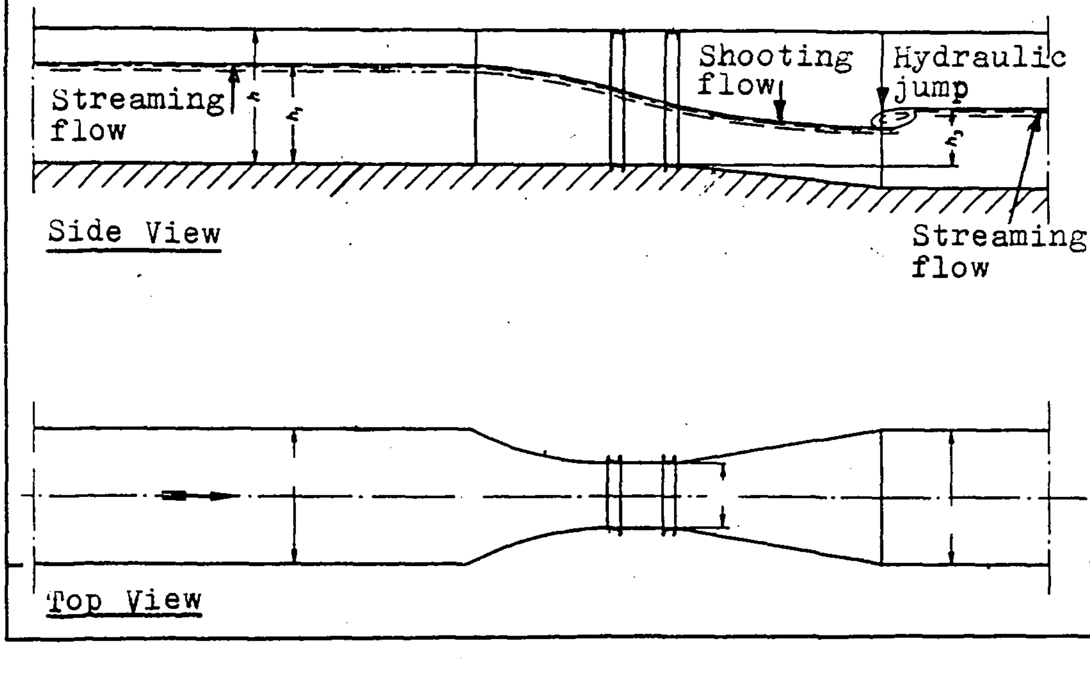


Fig. 14 Open channel flume requiring only one level measurement.

The relationship between flow-rate and fluid level in an open channel flume can be expressed by the following formula:

$$Q = c \times h^{3/2}$$

Whereby: Q - Flow-rate
c - Constant of flume, mainly consisting of coefficient of friction, width of throat, flow rate coefficient, acceleration due to gravity.
h - Level of fluid at point of measurement (usually immediately ahead of throat).

It should be noted, that the fluid must be streaming when entering the flume. To avoid deposits of solids on the channel bottom (especially in case of sewage), it is recommended to keep the velocity above 0.6 meters/sec. But shooting flows should never develop more than 30 to 35 times/h on the upstream side of the flume.

Level Sensors and Linearizers: The simplest way to monitor the flow rates is by attaching a properly calibrated scale to the flume wall, immediately ahead of the throat. The fluid levels or flow rates can then be read off at the device by an operator as desired.

Since such an arrangement is not always satisfactory, it is more common to install mechanical, pneumatic or electrically operated level sensors at the point of measurement. The function of such level sensors is described in their respective chapters. However, some additional modifications are needed when these level sensors are to be used to measure and indicate flow rates in open channel flumes.

As shown by the above formula, the flow rate change is not a linear function of the change in fluid level. To compensate for this difference, linearizers are added to the standard level sensors which produce an output signal proportional to flow rate for further use. In the case of float (Fig. 15) and pneumatic (Fig. 16) type level sensors, these linearizers consist of contoured discs which the mechanical linkage has to follow. In case of electrically operated devices, such as ultrasonic sensors Fig. 17, the linearizers consist of electronic units programmed to follow an output of the same contour as provided by the contoured discs of the mechanical linkage system.

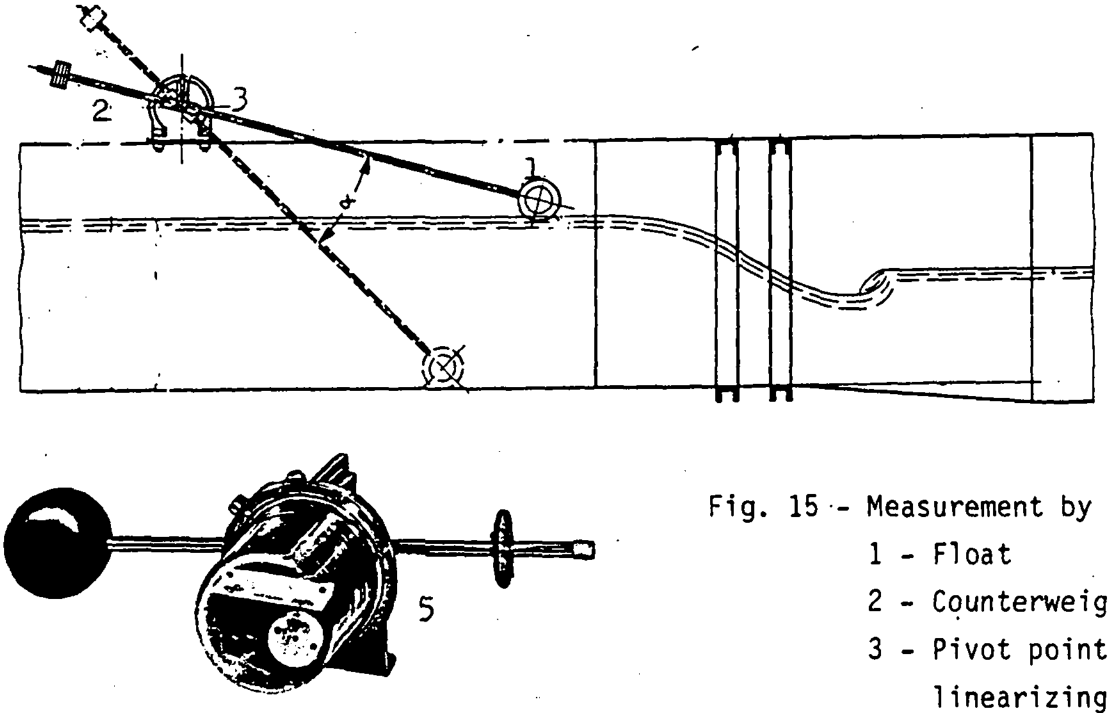


Fig. 15 - Measurement by float.
1 - Float
2 - Counterweight
3 - Pivot point and linearizing disc
4 - Float assembly with pivot-point, linearizing disc and potentiometer for remote flow-rate indication

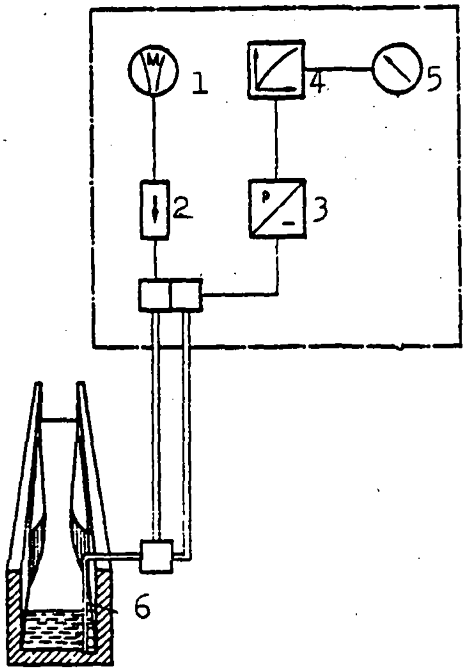


Fig. 16 - Measurement by bubbler
1 - Small compressor
2 - Pressure regulator
3 - Transducer
4 - Linearizer
5 - Level indicator
6 - Bubbler pipe

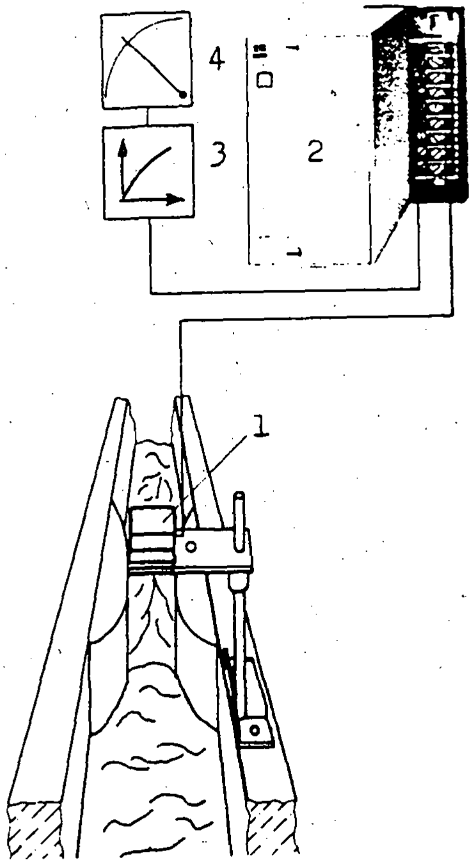


Fig. 17 - Measurement by ultrasonic sensor.

1 - Ultrasonic sensor
2 - Amplifier
3 - Linearizer
4 - Level indicator or recorder

Flumes and linearizers are matched devices, they are as a rule not randomly interchangeable. Electronic linearizers normally have external means of adjustment to match flumes of varying design.

2.4 Mechanical Flow Meters

Mechanical flow meters are a very widely used device to measure flow rates in closed conduits of water supply and water distribution systems. These meters function on either one of the following two operating principles:

- the volumetric principle
- the rate-of-flow principle

a) Volumetric Meters: Fig. 18 shows a volumetric meter of the ring-piston design. It consists of chambers of known volumetric capacity. The chambers are continuously filled and emptied as illustrated in Fig. 19. The ring-piston will rotate at a speed relative to the pressure difference thereby displacing a varying number of chamber volumes of liquid between inlet and outlet side of the meter within a given unit of time.

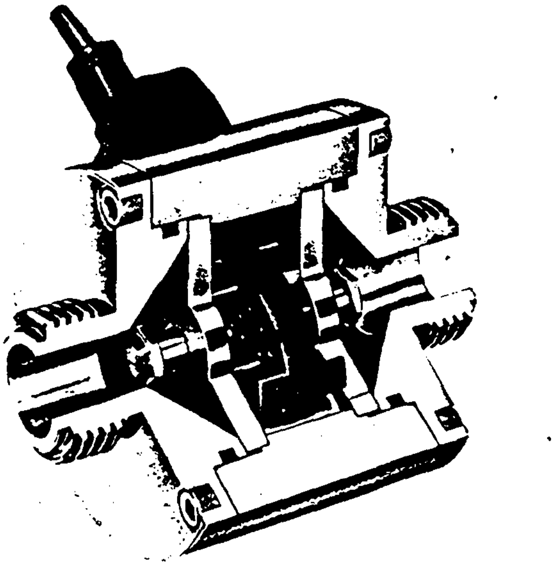
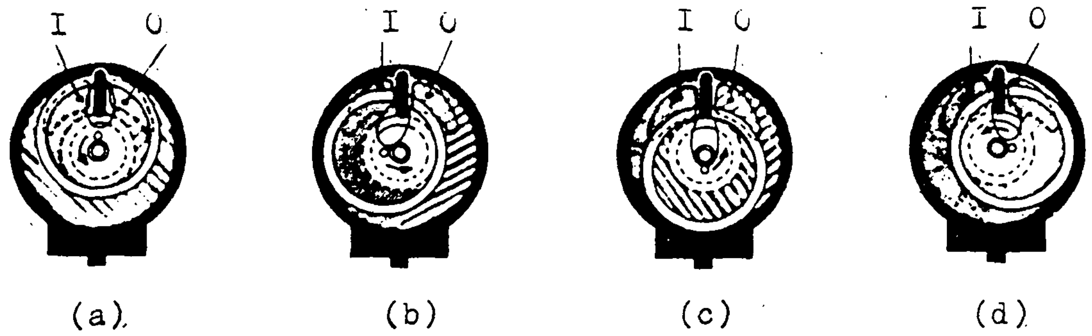


Fig. 18
Cross-section of ring-piston volumetric meter. This meter has a proximity switch or reed relay pick-up which counts ring-piston revolutions.



(a) (b) (c) (d)

Fig. 19 - Operating principle of ring-piston volumetric meter.

a) The liquid enters the inside of the ring-piston chamber through inlet opening (I). As a result of the pressure difference between inlet and outlet side of the meter, and proportional thereof, the ring-piston chamber rotates in the direction indicated by the arrow.

b) Liquid in the right outside chamber of the ring-piston is now displaced and leaves the meter through outlet opening (O), while new liquid enters the chamber to the left side of the ring-piston through inlet opening (1).

c) As new liquid enters, the previously liquid filled ring-chamber is rotated towards outlet opening (0).

d) As the ring-chamber reaches outlet opening (0), it empties its content and the process repeats itself.

Volumetric meters are primarily used to measure low volumes of flow, like monitoring the dosage of chemical additives for instance. They are very accurate, but sensitive to contamination by solid matter, unless they were designed for this purpose. They do however have a very wide viscosity range.

b) Rate-of-FLow Meters: Water supply systems use primarily two types of rate-of-flow meters which are very similar in their basic design concepts. They are:

- The propeller type meter, commonly used to measure water consumption of small consumers such as residential dwellings etc.
- The turbine type meter which is primarily used to measure consumption of large consumers, such as industrial plants as well as to monitor parts of water treatment supply and distribution systems.

Fig. 20 shows the cross-section of a propeller-type water meter. The water entering, passes through a filter cage (1) to the propeller section (2) and leaves the meter through the outlet. The rotating propeller shaft drives the counting gear section (3) which in turn moves the consumption indicating handles or totaliziers located in compartment (4).

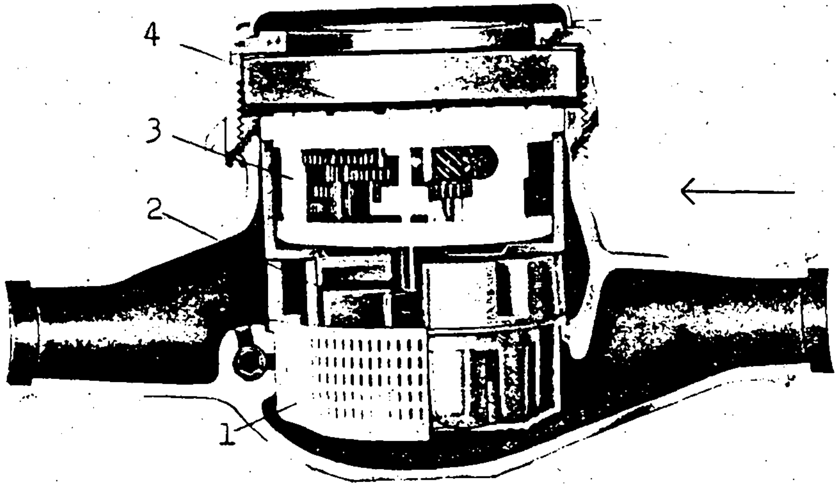


Fig. 20
Propeller type
water meter
a) Cross-section.

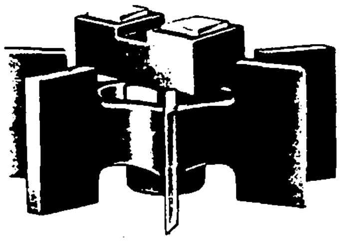


Fig. 20 - cont'd
b) Typical propeller.

Fig. 21 shows a cross-section of a turbine type water meter. These meters have a turbine wheel (1) placed in line with the axis of flow. The turbine is normally preceded and at times followed by guide vanes (2) to stabilize the flow. The turbine wheel shaft is connected to a transmission gear (3) and indicating or counting compartment (4). Other designs have proximity switch pick-ups which detect turbine wheel revolutions without physical contact to the turbine for further registration or counting. Turbine wheel revolutions are linear and directly proportional to liquid velocity or flow-rate. Some of these meters need straight pipe sections immediately preceding and following them to insure accurate performance. The length of these straight sections range up to 10 times pipe diameter ahead and 5 times pipe diameter behind the meter, depending upon design.

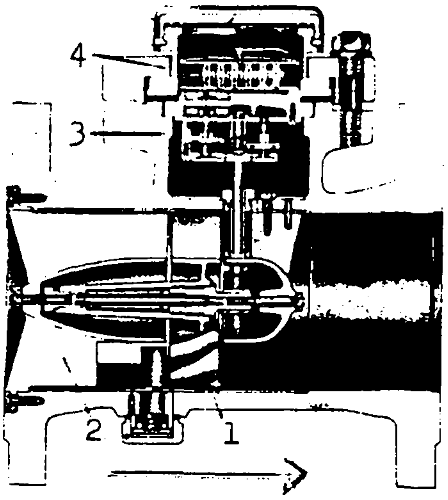
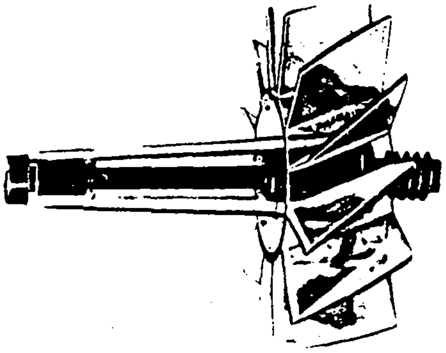


Fig. 21
Turbine type flow meter
a) Cross-section.



b) Typical turbine wheel

c) Remote Indication: Aside from the indicating dials which are normally an integral part of these meters, remote indicators such as mechanical strip chart recorders may be attached directly to the meter (Fig. 22), in which case the chart recorder indicator can be directly connected to the rotating shaft of the meter Fig. 22. In case of electrically-operated chart recorders or counters (Fig. 23), the rotating motion of the metering wheel is converted into digital electrical impulses which vary directly with the change in flow-rate (1). These digital impulses are converted into an analogue signal proportional to the flow-rate (2) and then fed into a chart recorder (3) or indicator (4). If digital counting of liquid flow is required, the digital signals from the transducer on the meter (1) are amplified (5) and counted (6).

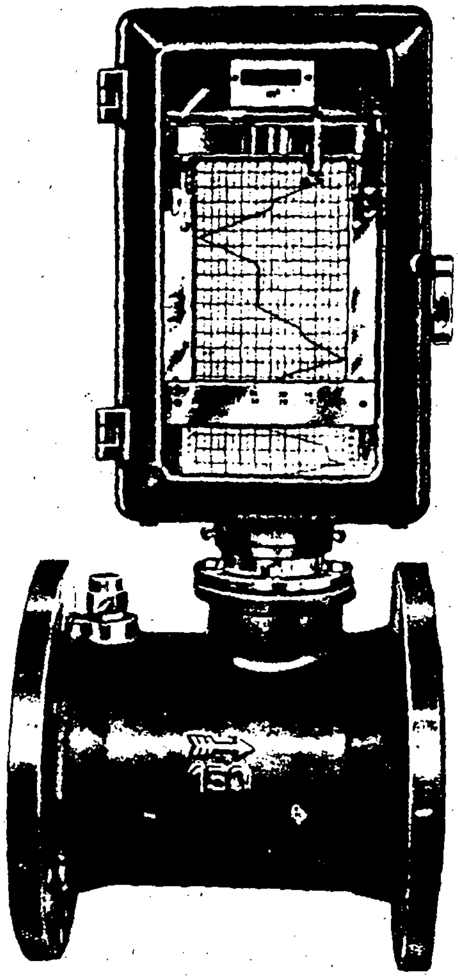


Fig. 22 - Turbine type flow meter with top mounted flow recorder.

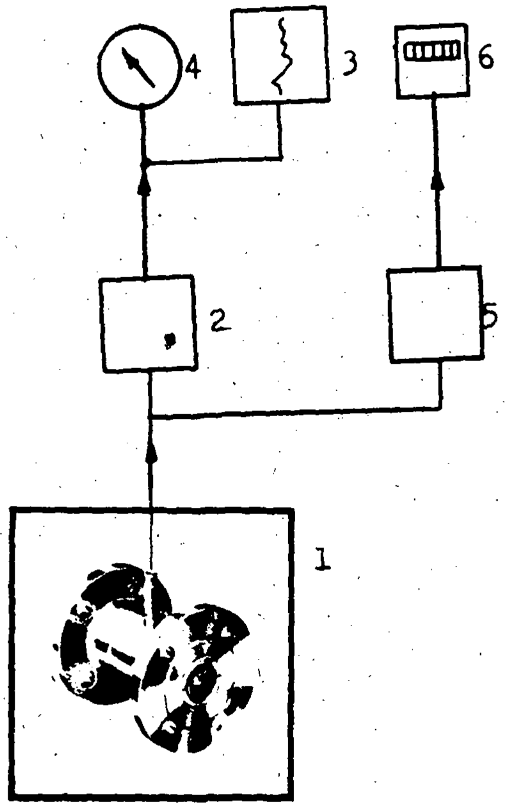


Fig. 23 - Block diagram remote flow rate indication for turbine type flow meters.

3 Measurement of Liquid Levels

Liquid levels are measured under a variety of conditions. The liquid may be under atmospheric pressure, as in an open tank or reservoir, or in a process vessel under pressure. This section covers continuous level measurement techniques in open vessels.

3.1 Static Pressure Method

One of the most flexible and convenient ways to measure liquid level is the static pressure method (Fig. 1). It is based on the fact that the static pressure exerted by a liquid is directly proportional to the height of the liquid above the point of measurement (which is centerline of pressure sensor or gauge) regardless of the volume. A pressure gauge or electronic transducer then can be calibrated in terms of height of a given liquid and used to measure level under atmospheric pressure.

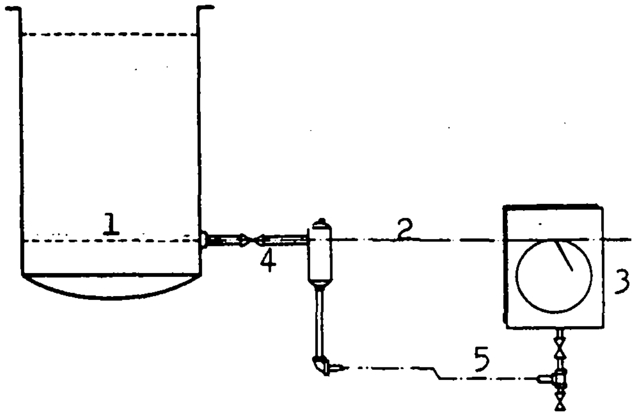


Fig. 1 - Operating principle, static pressure sensor.
1 - Minimum level
2 - Centerline pressure-sensor
3 - Pressure-sensor and recorder/indicator
4 - Shut-off valve
5 - Pressure line (slope!)

3.2 Diaphragm Boxes

For some applications such as measuring water levels in a reservoir, a connection cannot be made at the minimum level. For these applications, level can be measured by means of a diaphragm box (Fig. 2). It can be lowered into the reservoir (a) or be connected at the minimum level (b).

Within the box is a flexible diaphragm made of rubber, neoprene or similar material. The box is connected to the gauge or transducer by small box tubing. The volume in the box is large, compared with the volume in the tubing and actuating element.

In operation, the pressure of the liquid head is exerted against the underside of the diaphragm, resulting in an upward movement of the diaphragm until the pressure within the closed system is equal to the head of liquid. The gauge measures air pressure, but is calibrated in terms of liquid level.

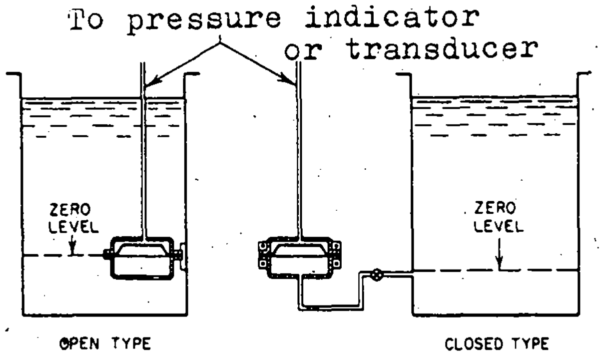


Fig. 2
Operating principle, diaphragm box sensor.

3.3 Air Purge Method

Fig. 3 illustrates the air purge of liquid level measurement. This method is often used to measure liquid levels in open channels to determine flow rates. A probe is immersed in the liquid to be measured, to its minimum level, with the pressure controlled by a differential pressure regulator, to assure a slow bubbling of air through the liquid. The gauge, or transducer measures air pressure, but can be calibrated to indicate liquid level or flow rate.

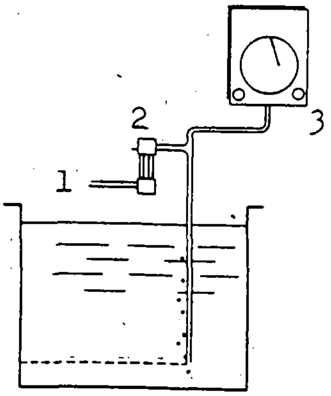


Fig. 3
Bubbler type
liquid level measurement.

1 - Air supply
2 - Differential regulator
3 - Pressure (level) recorder or indicator.

3.4 Float Method

This method is commonly used to monitor water levels in reservoirs of water distribution systems. It consists of a float connected by a wire rope to a counter-weight (Fig. 4). The float is lowered into the reservoir, usually inside a stand pipe which serves as a guide for the float as it moves up and down with the changing water level. The rope is slung over an indicator assembly mounted on top of the reservoir. The indicator moves analogue to the changing water level in the reservoir.

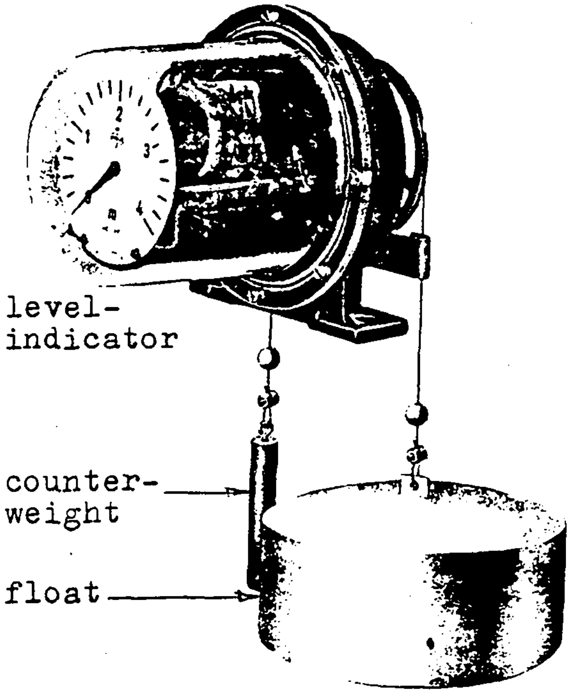


Fig. 4
Float level indicator.

3.5 Load Cell Method

This method of level measurement is actually a measurement of head pressure and functions in a similar manner as the Static Pressure (3.1) and Diaphragm Box (3.2) methods, except that the pick-up element is a load cell which emits an electrical signal analogue to the head pressure. The measuring unit (Fig. 5) which is at times also called a "Piezometric Cell" consists of a load cell (1) mounted in a silicon oil filled pressure chamber (2) capped off and sealed by a stainless steel flexible diaphragm (3).

The pressure exerted on the outside of the diaphragm (3) is transfered by the oil to load cell (1) which emits an electrical signal analogue to the pressure it senses. This signal is then amplified (4) for remote indication (5). Fig. 6 shows the installation of a unit monitoring deep well water levels; an application for which they are ideally suited.

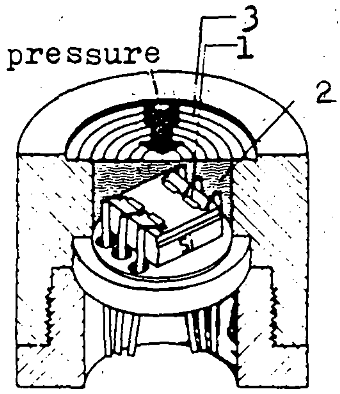


Fig. 5
Cross-section of load cell pressure sensor.

1 - Load cell
2 - Oil chamber
3 - Steel membrane

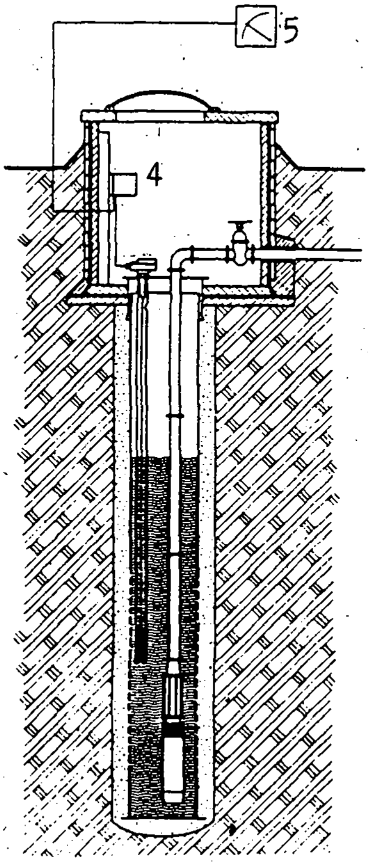


Fig. 6
Level sensor installed in deep well.

4 - Amplifier and converter
5 - Indicator or recorder

3.6 The Ultrasonic Method

This technique is based on the transmission of sound in a gas, such as air and its reflection from the surfaces of liquids or solid matter Fig. 7. A transmitter emits ultrasonic sound-wave trains in a fast sequence. When these wave trains hit the surface of liquids or bulk materials, a large number of them - depending upon the medium -, are reflected or echoed back (Fig. 8). A sensor registers the reflected wave trains and calculates the time it took a wave train from the instant of transmission to the instant it reached the sensor. This time is directly proportional to the distance between surface of material and measuring device, or between bottom of tank and liquid level.

The frequency of these sound waves is above audible range, usually between 35 and 40 kilocycles/sec at 20°C. Since the speed of sound through air changes with temperature, the controls are, as a rule equipped with compensators which automatically cut reflection time with rising temperatures and vice versa for a given distance.

The output signal of the sensor is amplified and converted into a DC current signal analogue to the liquid level for indication or registration. These devices have no contact with the medium to be measured; they are well suited to measure liquid levels (or liquid flow) in open channel flow meters (see sect. 2).

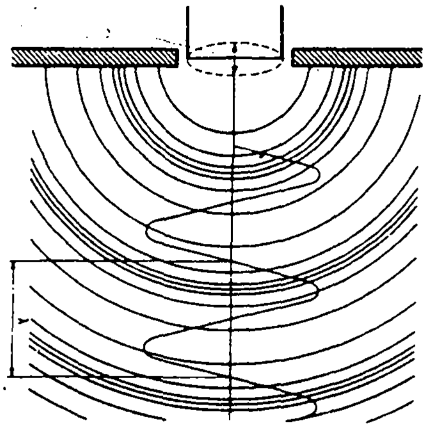


Fig. 7

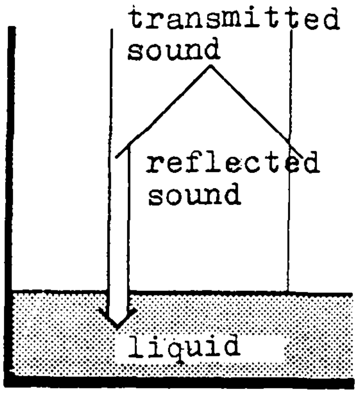


Fig. 8

Operating principle, ultrasonic level sensor.

3.7 The Capacitance Method

This method of level measurement is based on the properties of a capacitor. The capacitance of such a unit is a function of distance (d) and area (A) of the two plates separated by a dielectric material, Fig. 9.

The two capacitor plates of a liquid level detector are made up of an electrode which protrudes down the full depth of the tank to form one plate. The other plate is formed by the tank wall, or by a second electrode. In case of an electrically non-conductive tank wall, such as a concrete reservoir structure, the dielectric material between the two plates is the liquid or air in the tank. Air and water for instance have different dielectric values Fig. 10. As the liquid level in the tank changes, the dielectric value between plates will vary, changing the capacitance of the unit. This change of capacitance is directly proportional to the liquid level.

Just as is the case with other detectors, this change of capacitance generates an electrical signal which is amplified and converted to an analogue current signal for indicating and recording. Capacitive level measuring devices can be applied in all parts of water supply and distribution systems. For liquids as well as bulk materials, they are applicable over a wide range of temperature and pressure.

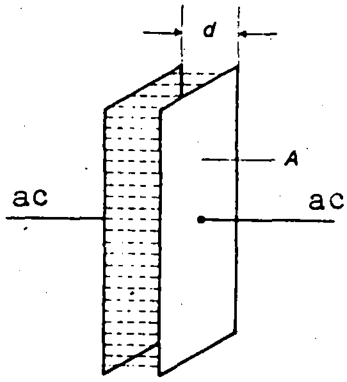


Fig. 9
Operating principle,
capacitor.

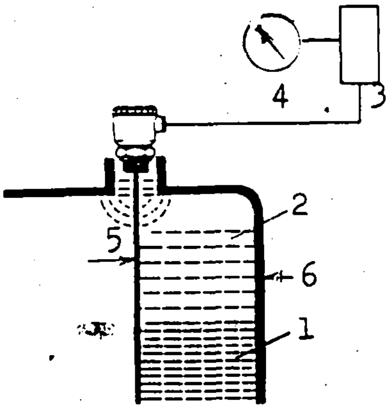


Fig. 10
Operating principle,
capacitive level sensor.

1 - Electric field in liquid, dielectric value 1.
2 - Electric field in air, dielectric value = 1.
3 - Amplifier and converter.
4 - Indicator or recorder.
5 - Electrode 1.
6 - Electrode 2 (electrically conductive tank wall).

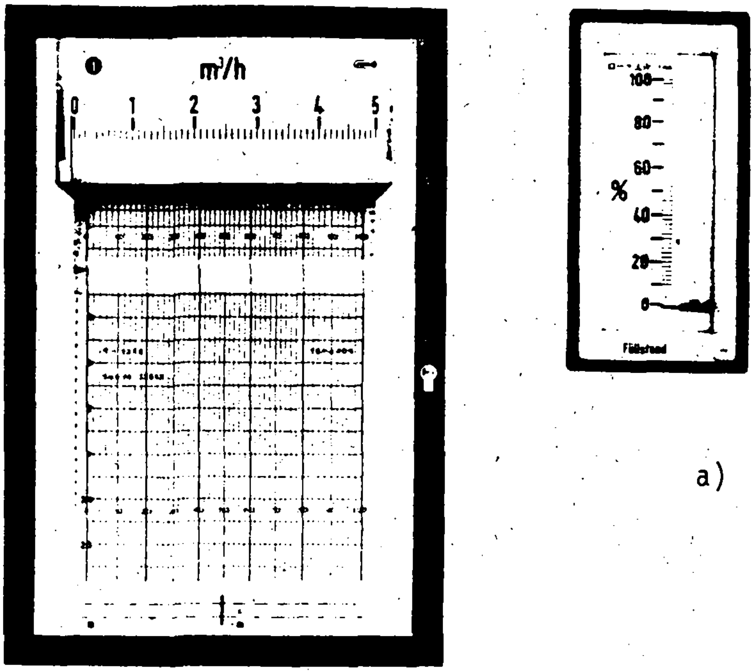
4 Indicating and Recording Instruments

The output sensors and gauges described in section 1 through 3 are in most cases connected to indicators or recorders, located at the point of sensing or at some key location such as central control rooms for instance. The information collected by the sensing devices and displayed by the indicating and recording equipment are to aid the supervisory personnel in operating and maintaining a reliable system, as well as to provide adequate records for administrative and managerial use.

4.1 Indicators and Recorders, Analogue Display

As covered in previous sections, a physical quantity such as pressure etc. is changed into an analogue electrical signal at the point of sensing by a device called a transducer. The signal can be a small variable voltage or current; the current signal being most commonly use. Such a signal ranges for instance from 0 to 20 milliampere over the range sensed and indicated or recorded. As an example, the transducer of a flow-meter with a range of 0 to 500 m^3/h will have an output of 20 milliampere at maximum flow-rate, 5 milliampere at 25 percent and 15 milliampere at 75 percent of 500 m^3/h.

The recorder or indicator is nothing but a milliammeter with a linear full-scale deflection of 20 milliampere, calibrated as desired in percentage of between 0 and the maximum rating of the sensor (0 to 500 m^3/h for the above example). Fig. 1 shows a typical indicator and recorder. The indicator scale is calibrated in percent, whereas the recorder scale is calibrated in m^3/h. The instrument is a 0 to 20 milliammeter in both cases.



a)

b)

Fig. 1
Typical analogue display.
a) Indicator
b) Recorder

4.2 Indicators, Digital Display

Digital counters are used to keep track of a total quantity processed by the system. In water supply systems it is commonly used to register total flows through pipelines, treatment plants, or pumping stations. The impulses are furnished by the transducers at the location of the sensing equipment (see sect. 3). Contrary to the analogue sensing signal, these counting impulses emitted are normally a voltage impulse. The counter consists of a relay which advances a counting mechanism by one notch every time it is energized or every time a counting impulse arrives. Fig. 2 shows such a relay operated digital counter.

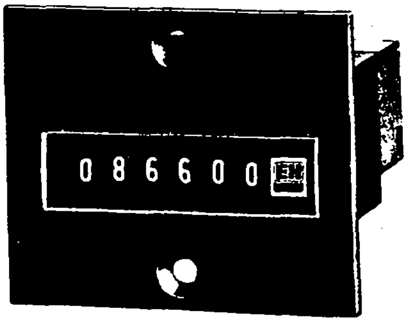


Fig. 2
Typical counter digital display.

4.3 Printers, Analogue and Digital

There are many printers available on the market, ranging over a wide spectrum of sophistication and price depending upon application requirements and pocketbook.

Process variables of water supply and distribution systems are relatively slow changing during their normal course of operation, a printer to register them does therefore not require a high degree of sophistication. Fig. 3 shows such a printer which can print out analogue and digital inputs; they are available to print digital numbers or analogue bar charts in addition to dates, time etc.

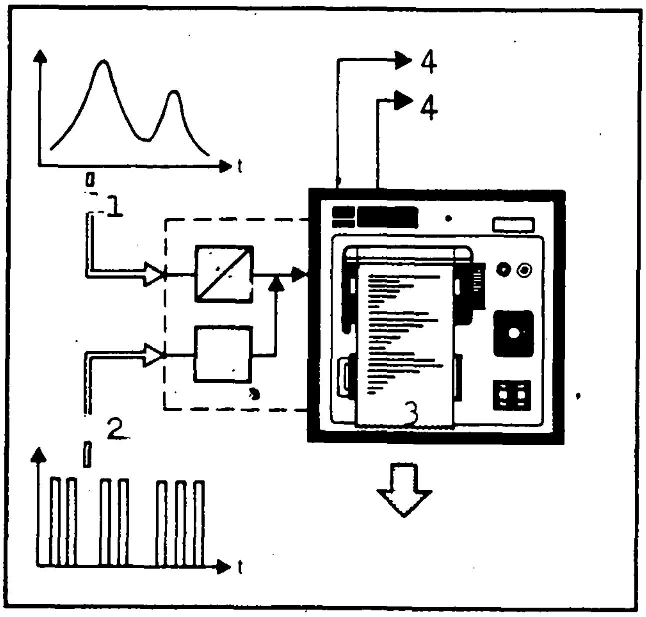


Fig. 3
Typical printer, analogue display.

1 - Analogue input
2 - Digital input
3 - Analogue printer (bar chart)
4 - Adjustable auxiliary contact output (sect 4.4)

4.4 Auxiliary Functions of Instruments

Many parts of water supply systems work automatically or semi-automatically. This may require the automatic starting and stopping of pumps, the opening and closing of valves, the cleaning of filters, the sound of alarms etc. whenever a certain condition within the system is sensed. All the above instruments can be furnished with adjustable auxiliary contacts, which can be programmed to initiate such action whenever the preset value within the range of the instruments is reached.

Fig. 4 shows an indicating instrument with two such auxiliary contact adjustment handles set at 30 and 70 percent. Such a setting could be used, for instance, to automatically start the supply pumps to a reservoir, when the level drops to 30 percent fill and to stop them again when 70 percent fill has been reached.

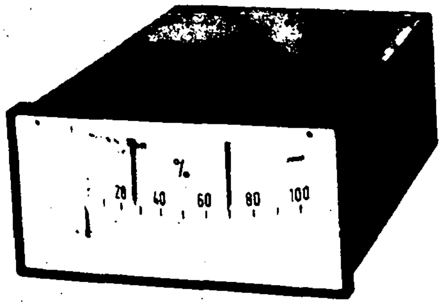


Fig. 4
Indicator with two adjustable auxiliary contact outputs.

5 Signal Transmission

The sensors of process variables used in water supply systems and the indicating and recording equipment which registers these process variables (sect 1 through 4) must be interconnected to form a working system. The same applies to control components, such as push-buttons and motor starters.

The physical distance between these various devices may range from a few meters to many kilometers. Depending on distance, topography, number and type of signals to be transmitted, the type and means of signal transmission is chosen.

Where short distances are involved within a pumping station or treatment plant for instance, a pair of wires is normally used for each signal or command function. Where long distances have to be bridged for several signals or command functions to remote reservoirs, to remote unmaned pumping stations, or to monitor pipeline performance for instance, the "one pair/one signal" method becomes technically and economically unfeasible.

Over long distances, a number of signals is usually transmitted over the same pair of wires. If the topography does not lend itself to control cable application, a wireless high frequency transmitting system may be better suited to pass on the same information between two antennas through the air.

Urban areas with high-rise buildings are generally not ideally suited for wireless transmission because the air space between transmitting antennas has to be and has to remain unobstructed. In these cases it is sometimes more advantageous to refrain from new cable installations and rent the required pairs of wire from the Telephone Company instead. This arrangement has the advantage, that the cables are - at least to a large extent - already in place and are being more reliably maintained by specialists in this field.

Regardless of wire or wireless, the transmission of several signals over the same pair of wires, or over the same frequency channel, is called a multiplex system. Multiplex systems can transmit many signals, may they be analogue, digital, or on/off switching signals, simultaneously. The number of signals per channel varies with design and manufacturer; the average is about 25 signals per channel or pair of wires.

The block diagram of Fig. 5 shows a multiplex signal transmission arrangement over a pair of telephone wires. The arrangement shown, transmits two digital signals from position (A) to position (B) and one analogue signal from position (B) to position (A).

Each transmitting station (1a), (1b) and (5) has a corresponding receiver (2), (4a) and (4b) at some other point of the system. Transmitter and corresponding receiver are assigned one specific frequency under which they communicate. Up to 25 different frequencies, or up to 25 different signals, analogue or digital are commonly transmitted over the same pair of wires in any direction. Such a system is called a frequency multiplex system.

Another similiar system which also permits the simultaneous transmission of a multitude of signals over a single pair of wires, assigns time slots instead of frequencies to each pair of corresponding transmitters/receivers. These systems are called time multiplex systems.

When renting telephone lines for signal transmission, it is customary to install adaptors at each point of connection to the telephone system (3a), (3b) Fig. 5. These adaptors will prevent any electrical interference between transmission signals and other communication signals which may be carried by the telephone company over the same cable. When using private cables, these adaptors can be omitted.

As stated previously, the multiplex signal transmission may also be carried over wireless systems instead of cables as described above. In such a case, the telephone wires are substituted by wireless transmitters, receivers and antennas.

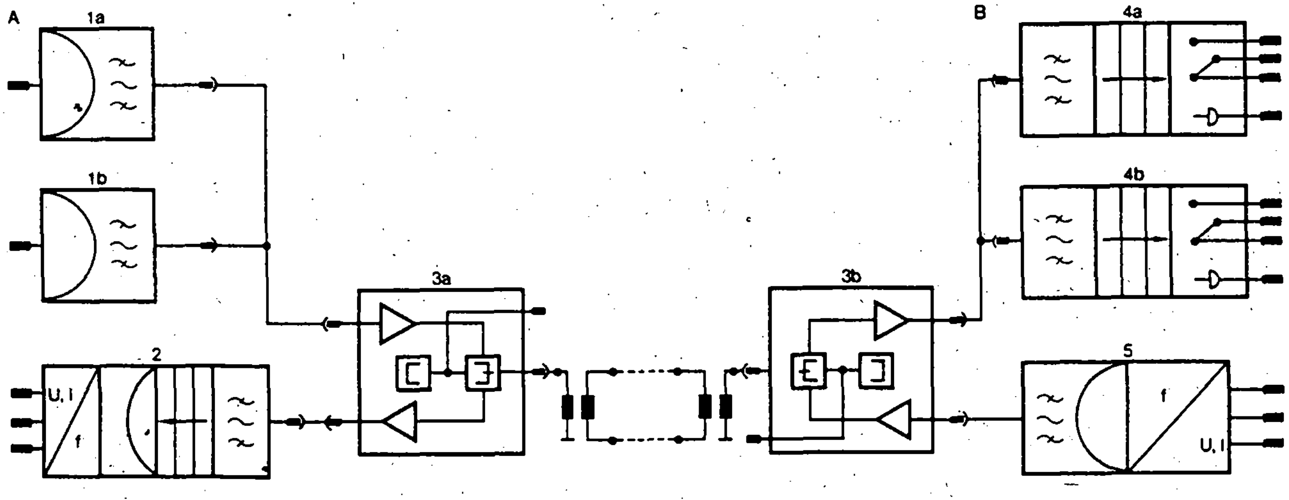


Fig. 5 - Block diagram, frequency multiplex signal transmission.
A,B - Location of equipment
1 - Transmitter for digital signals
2 - Receiver for analogue signals
3 - Adaptor
4 - Receiver for digital signals
5 - Transmitter for analogue signals

Illustrations shown in this module by courtesy of:

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Fig. 3	Honeywell Inc	Minneapolis, Min. USA
Fig. 4	The Spanner Pollux GmbH	Ludwigshafen W Germany

Section 2

Fig. 1,2,3,12,17, 19, 23	The Endress and Hauser GmbH	Maulburg W Germany
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Section 3

Fig. 4	The Spanner Pollux GmbH	Ludwigshafen W Germany
Fig. 5,6,7,8,9,10	The Endress and Hauser GmbH	Maulburg W Germany

Section 4

Fig. 1,4	The Spanner Pollux GmbH	Ludwigshafen W Germany
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1.1 The function and technical composition of a watersupply system
1.2 Organisation and administration of waterworks

Special Knowledge

2.1 Engineering, building and auxiliary materials
2.2 Hygienic standards of drinking water
2.3a Maintenance and repair of diesel engines and petrol engines
2.3b Maintenance and repair of electric motors
2.3c Maintenance and repair of simple driven systems
2.3d Design, functioning, operation, maintenance and repair of power transmission mechanisms
2.3e Maintenance and repair of pumps
2.3f Maintenance and repair of blowers and compressors
2.3g Design, functioning, operation, maintenance and repair of pipe fittings
2.3h Design, functioning, operation, maintenance and repair of hoisting gear
2.3i Maintenance and repair of electrical motor controls and protective equipment
2.4 Process control and instrumentation
2.5 Principal components of water-treatment systems (definition and description)
2.6 Pipe laying procedures and testing of water mains
2.7 General operation of water main systems
2.8 Construction of water supply units
2.9 Maintenance of water supply units Principles and general procedures
2.10 Industrial safety and accident prevention
2.11 Simple surveying and technical drawing

Special Skills

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3.2 Performance of simple water analysis
3.3a Design and working principles of diesel engines and petrol engines
3.3b Design and working principles of electric motors
3.3c –
3.3d Design and working principle of power transmission mechanisms
3.3e Installation, operation, maintenance and repair of pumps
3.3f Handling, maintenance and repair of blowers and compressors
3.3g Handling, maintenance and repair of pipe fittings
3.3h Handling, maintenance and repair of hoisting gear
3.3i Servicing and maintaining electrical equipment
3.4 Servicing and maintaining process controls and instrumentation
3.5 Water-treatment systems: construction and operation of principal components: Part I - Part II
3.6 Pipe-laying procedures and testing of water mains
3.7 Inspection, maintenance and repair of water mains
3.8a Construction in concrete and masonry
3.8b Installation of appurtenances
3.9 Maintenance of water supply units Inspection and action guide
3.10 –
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