LEVEL MEASUREMENT

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LEVEL MEASUREMENT

Liquid level was probably the first of the process variable to be measured and controlled. History records early examples of level control in dams used for the storage and orderly release of water for agriculture use.

This section describes the operating principles and mechanical details of the different types of level measurement instruments currently used in petrochemical industries.

REASONS FOR LEVEL MEASUREMENT

- **Safety** - in boilers, a dangerous state can develop if the water level varies outside certain limits.

- **Economy** - Good level control of solids is also desirable, excessive build up in hoppers can be expensive to clear.

- **Monitoring** - Monitoring of level in bulk storage tanks and process vessels is necessary in order that:
  - Plant efficiency may be assessed and optimized.
  - Stock records may be kept.
  - Cost may be correctly allocated.

In the oil and natural gas industries. liquid level measurement is necessary to achieve the following objectives;

1. Compute tank inventories of hydrocarbon liquid products and utility liquids.
2. Protect equipment such as columns, compressors. turbines and pumps from damage.
3. Protect operating and maintenance personnel against injury resulting from hydrocarbon, corrosive or toxic liquid spillage.
4. Protect the environment from the release of objectionable liquids into the rivers and the sea.
5. Control phase separation processes and product loading operations.

Unlike the pressure and temperature, liquid level has no absolute value and is always relative to some reference point such as the bottom of the tank. It is the height or depth of a liquid above a reference point and is specific to a particular vessel.

Definition of Level

The measurement of level is defined as the '*determination of the position of an existing interface between two media*'. These media are usually fluids, but they may be solids or a combination of a solid and a fluid. The interface can exist between a liquid and its vapour, two liquids, or a granular or fluidised solid and gas.

Units of Level

Millimeters, mm	Inches, in
Centimeters, cm	Feet, ft
Meters, M	

Conversions between Units

From…	To…	Conversion calculation
Cm	Inches	Multiply cm by 0.394
Inches	Cm	Divide inches by 0.394
Meter	Feet	Multiply m by 3.28
Feet	Meter	Divide ft by 3.28

Notes :
1 in $\cong$ 2.54 cm
1cm $\cong$ 0.394 in
1 feet $\cong$ 0.3048 m
1 m $\cong$ 3.28 feet

Example of calculation:

1. 2 feet 4 inches of water is equivalent to how much water in meter?
   4 in = 4/12 ft
   = 0.33 ft
   $\Rightarrow$ 2 ft 4 in = 2.33 ft
   we know that, 1 ft = 0.305 meter,
   $\therefore$ 2.33 ft $\cong$ 2.33 $\times$ 0.305 m
   $\cong$ <u>0.71</u>

2. Convert 1.9 meter into feet-inches
   1.9 m = 1 m + 0.9 m
   $\Rightarrow$ 1 m = 3.28 ft
   $\Rightarrow$ 0.9 m = 3.28 $\times$ 0.9 ft
   $\cong$ 2.95 ft

   $\Rightarrow$ to convert 0.28 ft into inches:-
   $\Rightarrow$ 1 ft = 12 in
   $\therefore$ 0.28 ft = 12 $\times$ 0.28 in
   $\cong$ 3.36 in

   $\Rightarrow$ to convert 0.95 ft into inches:-
   $\Rightarrow$ 1 ft = 12 in
   $\therefore$ 0.95 ft = 12 $\times$ 0.95 in
   $\cong$ 11.4 in

   $\therefore$ we can say, 1.9 m $\cong$ (3 + 2) ft (3.36 + 11.4) in
   $\cong$ 5 ft (14.76) in
   $\cong$ <u>6 ft 2.76 in,</u> (or just approximately 6 ft 3 in)

Methods of Level Measurement

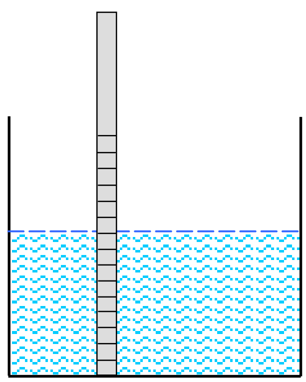
Two methods used to measure level; Direct or Mechanical method, and Indirect or Inferential methods.

A. Mechanical or Direct Method

Direct level measurement is simple, almost straightforward and economical; it uses a direct measurement of the distance (usually height) from the datum line, and used primarily for local indication. It is not easily adopted to signal transmission techniques for remote indication or control.

Dip Sticks and Lead Lines

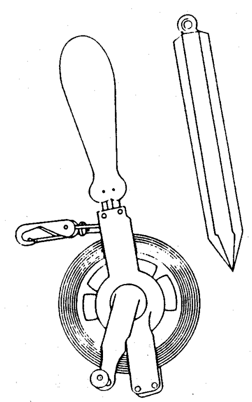
Flexible lines fitted with end weights called chains or lead lines have been used for centuries by seafaring men to gauge the depth of water under their ships. Steel tape having plump bob – like weights, and stored conveniently in a reel are still used extensively for measuring level in fuel oil bunkers and petroleum storage tanks. (*see figures below*)



While unit are normally in percent or length, volumetric units can be derived as;

For a cylindrical tank;
Volume = $\pi R^2 H$,
but $\pi R^2 = K$ (a constant),
therefore, Volume = KH

Dip Stick



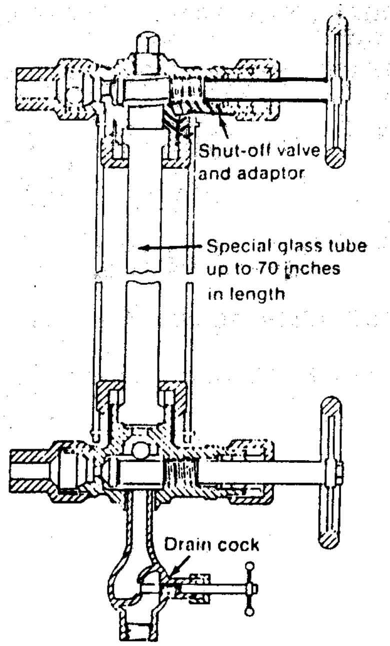
Steel Tape and Bob

Though crude as this methods seems, it is accurate to about 0.1% with ranges up to about 20 feet.

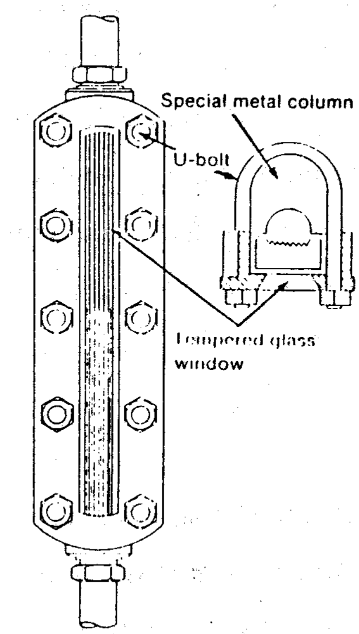
Although the dipstick and lead line method of level measurement are unrivalled in accuracy, reliability, and dependability, there are drawbacks to this technique. First, it requires an action to be performed, thus causing the operator to interrupt his duty to carry out this measurement. There cannot be a continuous representation of the process measurement. Another limitation to this measuring principle is the inability to successfully and conveniently measures level values in pressurised vessels. These disadvantages limit the effectiveness of these means of visual level measurement.

Sight Glass

Another simple method is called sight glass (or level glass). It is quite straightforward in use; the level in the glass seeks the same position as the level in the tanks. It provides a continuous visual indication of liquid level in a process vessel or a small tank and are more convenient than dip stick, dip rod and manual gauging tapes.



A. Low Pressure Sight Glass



B. High Pressure Sight Glass

Sight glass A is more suitable for gauging an open tank. A metal ball normal used in the tube to prevent the fluid from flowing out of the gauge. Tubular glass of this sort is available in lengths up to 70 inches and for pressure up to 600 psi. It is now seldom used.

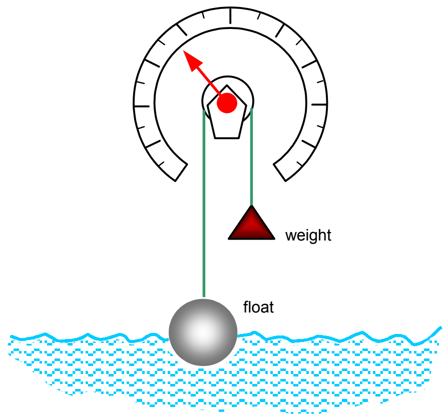
The closed tank sight glass B, sometimes called a '*reflex glass*', is used in many pressurized and atmospheric processes. The greatest use is in pressurised vessel such as boiler drums, evaporators, condensers, stills, tanks, distillation columns, and other such applications. The length of reflex glass gauges ranges from a few inches or eight feet, but like the tube type gauges, they can be gauge together to provide nearly any length of level measurement.

The simplicity and reliability of gauge type level measurement results in the use of such devices for local indication. When level transmitters fail or must be out of service for maintenance, or during times of power failure, this method allow the process be measured and controlled by manual means.

However, glass elements can get dirty and are susceptible to breakage thus presenting a safety hazard especially when hot, corrosive or flammable liquids are being handled.

Chain or Float Gauge

The visual means of level measurement previously discussed are rivaled in simplicity and dependability by float type measurement devices. Many forms of float type instruments are available, but each uses the principle of a buoyant element that floats on the surface of the liquid and changes position as the liquid level varies. Many methods have been used to give an indication of level from a float position with the most common being a float and cable arrangement. The operational concept of a float and cable is shown in the following diagram;



The float is connected to a pulley by a chain or a flexible cable and the rotating member of the pulley is in turn connected to an indicating device with measurement graduation. As can be seen, as the float moves upward, the counterweight keeps the cable tight and the indicator moves along the circular scale.

As in the **Figure A**, as the float moves, the weight also moves by means of a pulley arrangement as in the diagram above. The weight which moves along a board with calibrated graduations, will be at the extreme bottom position when the tank is full and at the top when the tank is empty. This type is more commonly used for closed tanks at atmospheric pressure.

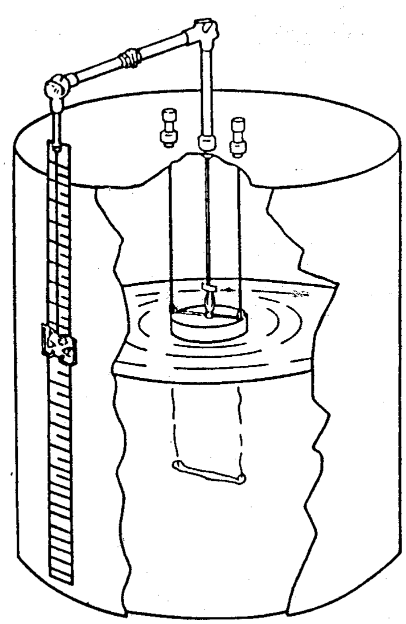


Figure A

When it is desired to add a bit of sophistication to the measurement systems for ease of reading the level at one location near the bottom of the tank and to gain a bit more accuracy, the system in the **Figure B** can be used.

In the system shown in Figure B, a perforated stainless steel tape connects the float to a spring or weight loaded drum that rotates as floats moves up or down. The position of the tape on the drum can be read through a window. This type of level float can also be adapted to remote reading capabilities by installing a transmitter assembly.

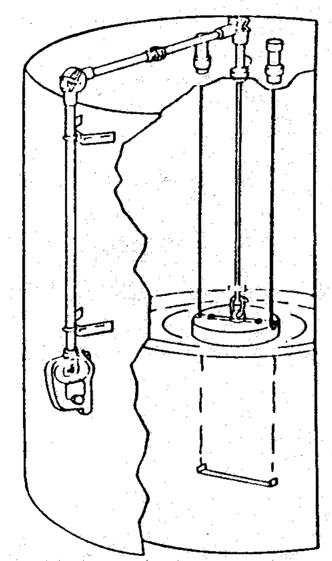


Figure B

B. Inferential or Indirect Methods

Indirect or inferred methods of level measurement depend on the material having a physical property which can be measured and related to level. Many physical and electrical properties have been used for this purpose and are well suited to producing proportional output signals for remote transmission. This method employs even the very latest technology in its measurement.

Included in these methods are;

A. **Buoyancy** :- the force produced by a submerged body which is equal to the weight of the fluid it displaces.

B. **Hydrostatic head** :- the force or weight produced by the height of the liquid.

C. **Sonar or ultrasonic** :- materials to be measured reflect or affect in a detectable manner high frequency sound signals generated at appropriate locations near the measured material.

D. **Microwave** :- similar to ultrasonic but uses microwave instead of ultrasonic beam.

E. **Conductance** :- at desired points of level detection, the material to be measured conducts (or ceases to conduct) electricity between two fixed probe locations or between a probe and vessel wall.

F. **Capacitance** :- the material to be measured serves as a variable dielectric between two fixed capacitor plates. In reality, there are two substances which form the dielectric -the material whose measurement is desired and the vapor space above it. The total dielectric value change as the amount of one material increases while the other decreases.

G. **Radiation** :- the material measured absorbs radiated energy. As in the capacitance method, vapor space above the measured material also has an absorbing characteristics, but the difference in absorption between the two is great enough that the measurement can be related quite accurately to measured material.

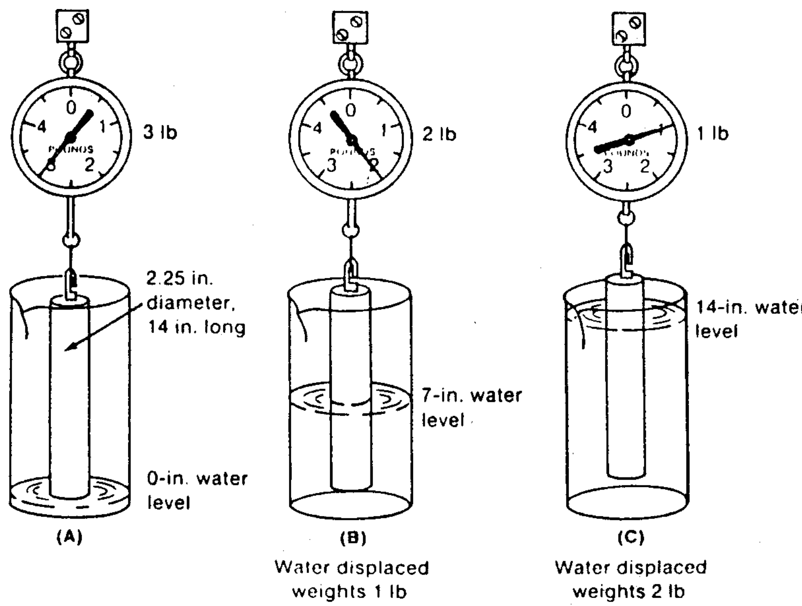
H. **Weight**: :- the force due to weight can be related very closely to level when its density is constant. Variable concentrations components or temperature variations present difficulties, however.

I. **Resistance** :- Pressure of the measured material squeezes two narrowly separated conductor together, reducing overall circuit resistance in an amount proportional to level.

J. **Micro-Impulse** :- “time-of-flight”, electrical pulses launch and travels back in frequency directly proportional to the level of the liquid.

Buoyancy

Uses the theory of Archimedes Principle which states that "***the force produced when a body is submerged into liquid with a constant density is equal to the fluid displaced***"; which means that, when a body is fully or partially immersed in any liquid, it is reduced in weight by an amount equal to the weight of the volume of the liquid displaced.



In diagram A, the displacer is suspended by a spring scale that shows the weight of the displacer in the air. This would represent '0%' in the level measurement application. The full weight of the displacer is entirely supported by the spring (3 lbs).

In diagram B, the water is at level that represents '50%' of the full measurement span. Note that the scale indicates a weight of 2 lbs. The loss in weight of the displacer (1 lbs) is equal to the weight of the volume of water displaced.

When the water level is increased to a full level scale (diagram C), the net weight of the displacer is 1 lbs, which represent '100%' of the measurement. It lost 2 lbs when the water level arises along the longitudinal axis of the displacer.

We can see that the weight of the displacer is inversely proportional to the liquid level in the chamber where the displacer is immersed.

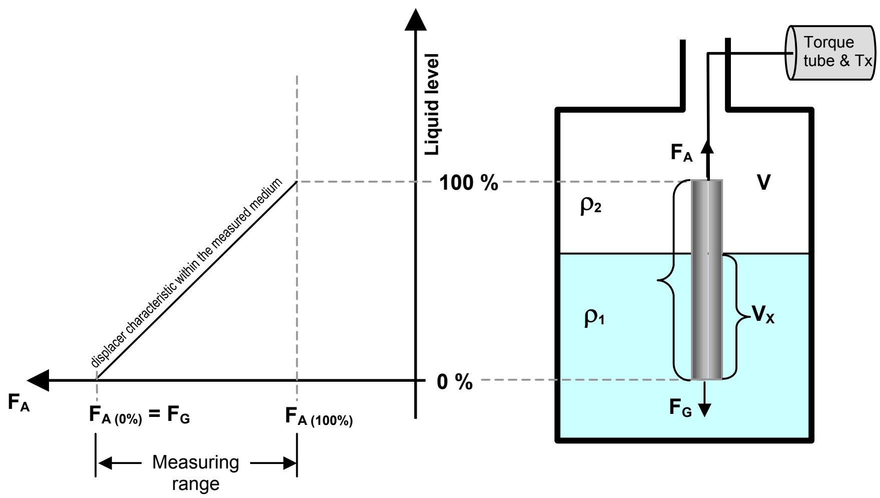
CALCULATING THE WEIGHT FORCES

The following applies in general to the buoyancy force acting on the displacer:

$$F_A = V_x \cdot \rho_1 \cdot g + (V - V_x) \cdot \rho_2 \cdot g$$

where, F_A = Buoyancy force
V = Volume of displacer
V_x = Volume of medium displaced by measuring body with density ρ_1
ρ_1 = Mean density of heavier medium
ρ_2 = Mean density of lighter medium
g = Local acceleration due to gravity (e.g. 9.81 ms^{-2})
F_G = Displacer body weight force

The force acting on the transmitter is inversely proportional to liquid level changes.



Determining the displacer diameters

To make optimum use of the transmitter, the displacer should be dimensioned so that the greatest possible buoyancy force is generated over the measuring range. On the other hand, the maximum possible diameter of the displacer must be taken into consideration.
The following equation can be used to exactly dimension the displacer:

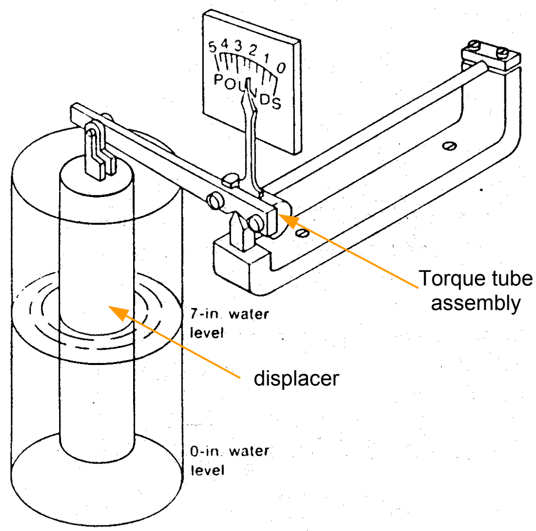
$$D = 1000\sqrt{\frac{4\,F_A}{\pi\, g\,(\rho_1 - \rho_2)\,L}}$$

where, D = Outside diameter of displacer in mm
F_A = Buoyancy force of displacer in N
g = Acceleration due to gravity (9,807 m/s²)
ρ_1 = Density of heavier liquid in kg/ m³
ρ_2 = Density of gas or lighter liquid in kg/m³
L = Measuring range in mm

(note : ρ_2 is negligible if ρ_2 = gas at atmospheric pressure or with ratio ρ_2 : ρ_1 less than 0.5 %.)

Displacer Actuated Level Instruments

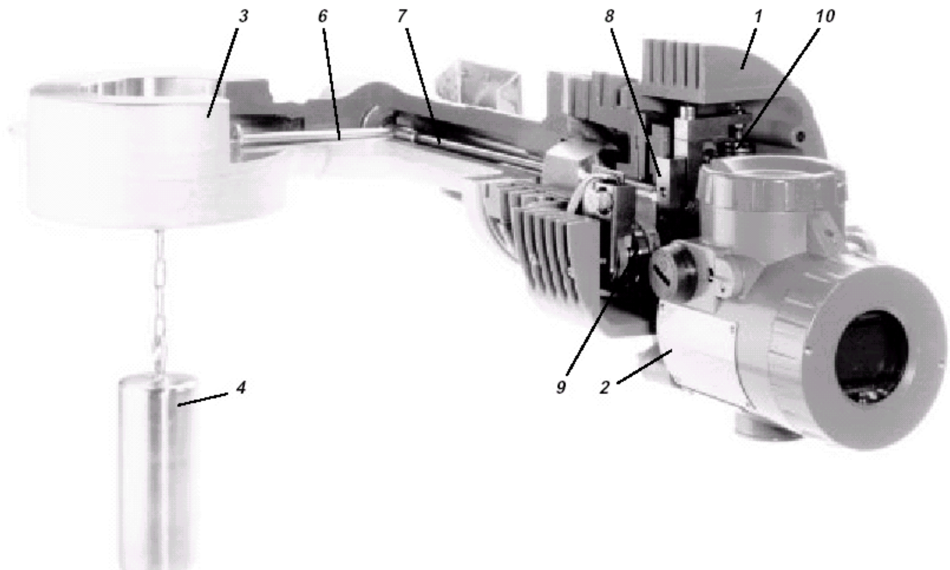
A simple working concept of this instrument can be illustrate in the figure below;



According to ***Archimedes Principle***, the displacer, when submerged in liquid, will 'lose' its weight, and this weight loss is proportional to the level of the liquid. Thus, a level, density, or interface level change in the measured fluid causes a change in the displacer position. This change is transferred to the torque tube assembly. As the measured fluid changes, the torque tube assembly rotates and the indicating needle attached to the torque tube will have indication.

This rotary motion can then be extent for remote signal and indication. It is transferred to the transmitter level assembly. The rotary motion moves a magnet attached to the lever assembly, changing the magnetic field that is sensed by the Half-effect position sensor. The sensor then converts the magnetic field signal to an electronic signal. The current drier circuit in the transmitter develops a 4~20mA signal proportional to the dc amplifier voltage output.

A displacer level transmitter

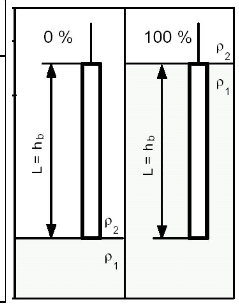


1 Sensor housing
2 Electronic amplifier
3 Topworks with heat sink and torque tube
4 Displacer with suspension chain
5 Version for left-hand mounting
6 Transmission lever
7 Torque tube
8 Clamping lever
9 Sensor with trimming network
10 Compensation spring

FORMULAS FOR WEIGHT DETERMINATION

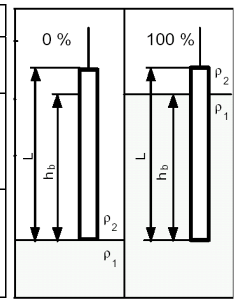
Displacer length = measuring range

Measurement type	Weight forces: Lower range value = 0 % output signal	Weight forces: Upper range value = 100 % output signal
Liquid level (ρ_2 = negligible)	$F_0 = F_G$	$F_{100} = F_G - V \cdot g \cdot \rho_1$
Interface (ρ_2 = not negligible)	$F_0 = F_G - V \cdot g \cdot \rho_2$	
Density (ρ_1 = max. density ρ_2 = min. density)		



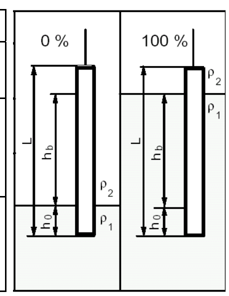
Displacer length > measuring range (without elevation)

Measurement type	Weight forces: Lower range value = 0 % output signal	Weight forces: Upper range value = 100 % output signal
Liquid level (ρ_2 = negligible)	$F_0 = F_G$	$F_{100} = F_G - V \cdot g \cdot \rho_1 \frac{h_b}{L}$
Interface (ρ_2 = not negligible)	$F_0 = F_G - V \cdot g \cdot \rho_2$	$F_{100} = F_G - V \cdot g \left(\rho_1 \frac{h_b}{L} + \rho_2 \frac{L - h_b}{L} \right)$



Displacer length > measuring range (with elevation)

Measurement type	Weight forces: Lower range value = 0 % output signal	Weight forces: Upper range value = 100 % output signal
Liquid level (ρ_2 = negligible)	$F_0 = F_G - V \cdot g \cdot \rho_1 \frac{h_0}{L}$	$F_{100} = F_G - V \cdot g \cdot \rho_1 \frac{h_0 + h_b}{L}$
Interface (ρ_2 = not negligible)	$F_0 = F_G - V \cdot g \left(\rho_1 \frac{h_0}{L} + \rho_2 \frac{L - h_0}{L} \right)$	$F_{100} = F_G - V \cdot g \left(\rho_1 \frac{h_0 + h_b}{L} + \rho_2 \frac{L - h_b - h_b}{L} \right)$



F_G = Weight force of displacer in atmosphere [N]

F_0 = Weight force acting on suspension point of displacer at lower range value [N]

F_{100} = Weight force acting on suspension point of displacer at upper range value [N]

F_A = Buoyancy force of displacer [N] ($F_A = F_0 - F_{100}$)

V = Displacer volume [m^3] (specified on data label)

ρ_1 = Liquid density [kg/m^3]

ρ_2 = Density of gas or lighter liquid [kg/m^3]

g = Local acceleration due to gravity (e.g. 9.807 m / s²)

L = Displacer length [m]

h_0 =Lower range value [m]

h_b = Measuring range [m]

ALTERNATIVE WAY TO DETERMINE SUSPENDED WEIGHT FOR CALIBRATION (adapted from Fisher manual)

Alternatively, the following equation can also be used for determining the suspended weight for calibration of displacer;

$$W_s = \frac{\{W_d - [(\rho_w)(V_s)(SG)]\}}{[1 - \alpha(\Delta T)]}$$

where; W_s = total suspended weight in pounds (or kilograms)

W_d = weight of the displacer – if top mounted sensors, also include the weight of the displacer stem.

ρ_w = density of water (SG = 1.0), 0.0361 lbs per cubic inch, (or 0.000992 kg per cm²)

V_s = volume of the displacer, in cubic inches (or cubic centimeters), that would be submerged at the level required by the calibration procedure.

[i.e. $\pi/4$ (displacer diameter)² × (length of displacer submerged)]

α = (% change in torque tube modulus per °F (or °C) ÷ 100%)

ΔT = (expected process temp.) − (temp. of torque tube during calibration)

SG = specific gravity of the process fluid at operating temperature.

► For **Interface level measurement**, use the following equation;

$$W_s = \frac{\{W_d - (\rho_w)(V)[(h_l)(SG_l) + (h_h)(SG_h)]\}}{[1 - \alpha(\Delta T)]}$$

where; h_l = relative length of displacer that is immersed in the lighter fluid.

[i.e. length in lighter fluid ÷ length of the displacer]

h_h = relative length of displacer that is immersed in heavier fluid.

[i.e. length in heavier fluid ÷ length of the displacer]

SG_l = specific gravity of lighter fluid at operating temperature.

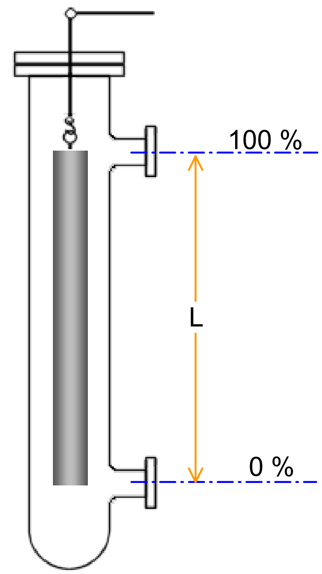
SG_h = specific gravity of heavier fluid at operating temperature.

V = volume of the displacer, in cubic inches (or cubic centimeters), that would be submerged at the level required by the calibration procedure.

[i.e. $\pi/4$ (displacer diameter)² × (length of displacer submerged)]

DRY CALIBRATION FOR LEVEL APPLICATIONS (BY USING PRECISION CALIBRATION WEIGHT)

➲ Determine the calculated dry span scale setting ($PB_{process}$) required for 100% level calibration point by using the formula below;



$$PB_{process} = (SG_{process}) \times (PB_{water})$$

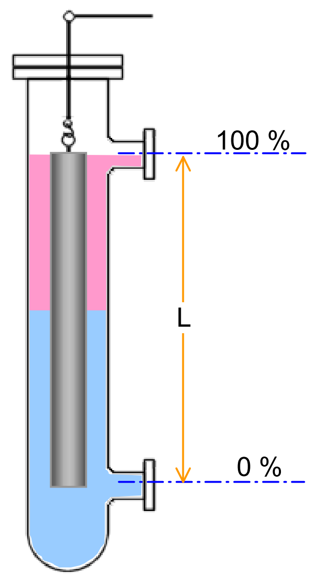
where, $SG_{process}$ = specific gravity of process fluid.

PB_{water} = recorded or marked dry span scale value from wet calibration procedure (i.e. the mechanical proportional band of the torque tube when using water at ambient conditions as the process fluid)

➲ For **Interface level** or density measurement applications, use the following setting;

$$0\% \text{ scale setting} = (SG_{min}) \times (PB_{water})$$

$$100\% \text{ scale setting} = (SG_{max}) \times (PB_{water})$$



where, SG_{min} = lowest specific gravity for density or specific gravity of top phase for interface.

SG_{max} = highest specific gravity for density or specific gravity of bottom phase for interface.

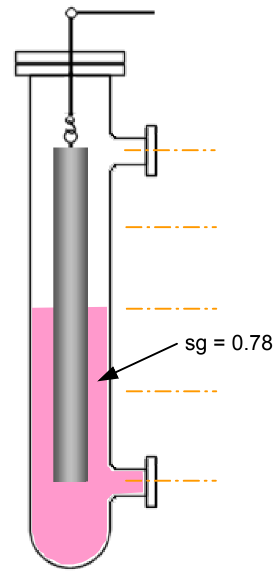
PB_{water} = recorded or marked dry span scale value from the wet calibration procedure (equivalent to the mechanical proportional band of the torque tube when using water at ambient conditions as the process fluid).

Example 1

A steel displacer of volume 0.25 cubic feet is 50% immersed in oil of relative density 0.78;

⇒ the density of steel = 490 lbs per cubic foot

⇒ the density of water = 63 × lbs per cubic foot



Calculate the apparent weight of the displacer.

⇒ true weight of displacer $= 0.25 \times 490$
$= 122.5$ lbs

⇒ volume of oil displaced $= 0.25 \times 0.5$
$= 0.125$ cubic feet

⇒ weight of oil displaced $= (0.125 \times 0.78 \times 63)$ lbs
$= 6.143$ lbs

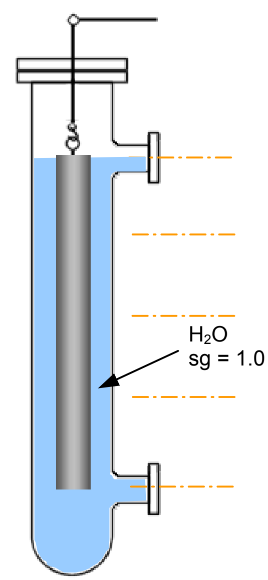
∴ Apparent weight of displacer = true weight – displaced weight
$= 122.5 - 6.143$ lbs
= **<u>116.36 lbs</u>**

Example 2

A steel displacer of volume 0.1 cubic feet is to be used as a level sensor in a vessel to store water. Calculate the following;

1:- the maximum and minimum weights of the displacer.

2:- the maximum range of level able to be sensed, if the diameter of the displ. is 2 inch.



⇒ true weight of displacer $= 0.1 \times 490$ lbs = 49 lbs

⇒ volume of water displaced = 0.1 cubic feet

⇒ weight of water displaced $= 0.1 \times 63$ lbs = 6.3 lbs

∴ min. weight of the displacer $= 49 - 6.3$ lbs = **<u>42.7 lbs</u>**

∴ max. weight of the displacer = **<u>49 lbs</u>**

⇒ volume of the sensor $= \pi r^2 L$

⇒ $0.1\ ft^3 = 3.142 \times (0.0833)^2 \times L$
$= 0.0218 \times L$

($\pi = 3.142$; 1 in = 1/12 ft = 0.0833ft)

hence, the length of displacer, $L = \dfrac{0.1}{0.0218}$ ft
= **<u>4.587 ft , or 55 inches</u>**

Example 3

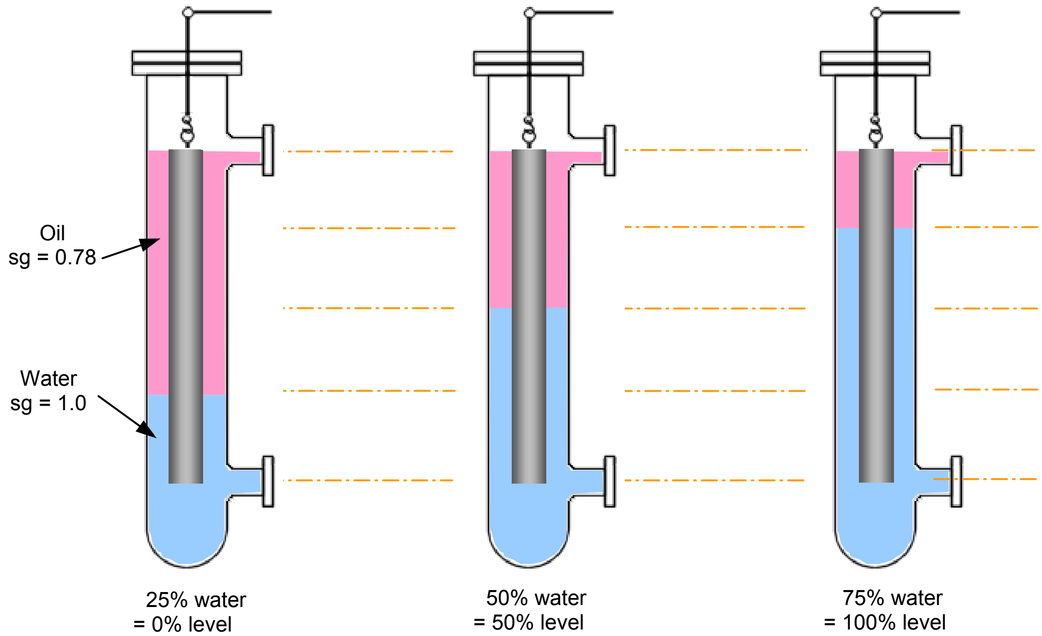
A steel displacer 1 metre long, and volume of 1000 CCs. is to be used to measure the interface level in an oil and water separator. The SG of oil is 0.78, the density of water is 1 kg/litre. Density of steel is 8000 kg per cubic meter.

Find, 1:- the diameter of the displacer.

2:- the displacer weight in air, oil & water.

3:- the "0%" and "100%" weights, if the 50% interface level is set at the displacer's mid-point, and the span is 0.5 metres.

The displacer is assumed to be totally covered with oil or water.



⇒ volume of the displacer $= \pi r^2 h$

$1000 \text{ c.c.s} = 3.142 \times r^2 \times 100 \text{ cm}$

thus, we now have, $r^2 = \dfrac{1000}{3.142 \times 100} = 3.183 \text{ cm}^2$

∴ the radius of displacer, $r = \sqrt{3.183} \text{ cm} = 1.78 \text{ cm}$

hence, the diameter of displacer $= 1.78 \times 2 \text{ cm} = \underline{\mathbf{3.56 \text{ cm}}}$

Note that volume unit has to be inconsistent with density unit 1ccs = 10^{-6} m^3

⇒ displacer's weight in air = density × volume

$= 8000 \text{ kgm}^{-3} \times \dfrac{1 \times 10^3}{10^6} \text{ m}^3$

$= \underline{\mathbf{8.0 \text{ kg}}}$

⇒ displacer's weight in oil = (weight in air) – (weight loss in oil)

$= 8.0 - (0.5 \times 1 \times 0.78) \text{ kg}$

$= \underline{\mathbf{7.61 \text{ kg}}}$

⇒ displacer's weight in water = (weight in air) – (weight loss in water)

$= 8.0 - (0.5 \times 1 \times 1) \text{ kg}$

$= \underline{\mathbf{7.50 \text{ kg}}}$

⇒ at 0% interface level, the displacer's length will be covered 25% with water and 75% with oil. Hence, the displacer's total weight will be made up of 75% of its weight in oil and 25% weight in water;

∴ displacer weight at 0% = $(0.75 \times 7.61) + (0.25 \times 7.5)$
= **<u>7.582 kg</u>**

⇒ at 50%, the displacer's total weight will be made up of 50% weight in water, and 50% weight in oil;

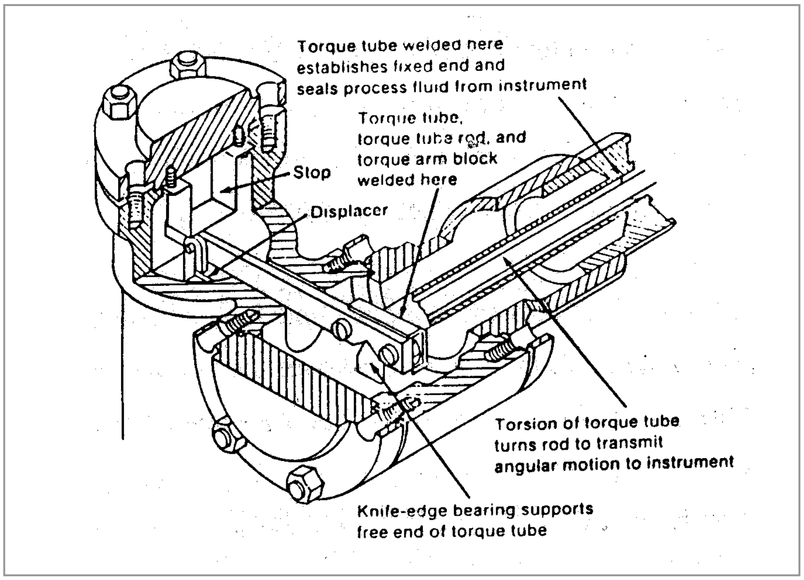
∴ displacer weight at 50% = $(0.5 \times 7.61) + (0.5 \times 7.5)$
= **<u>7.555 kg</u>**

⇒ at 100%, the displacer's total weight will be made up of 75% weight in water, and 25% weight in oil;

∴ displacer weight at 50% = $(0.25 \times 7.61) + (0.75 \times 7.5)$
= **<u>7.527 kg</u>**

Torque Tube

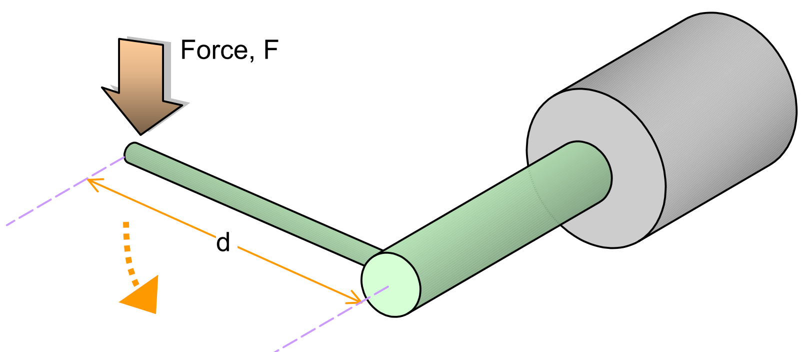
The torque tube is in a fact a special type of spring that acts in an upward direction in opposition to the weight of the displacer. Any changes in the weight of displacer will cause the torque tube to rotate. The less heavy the displacer becomes, the torque tube will rotate in an upward direction; this occurs with an increase of level of the fluid. Conversely, a decrease in fluid level will increase the displacer's weight and causes the torque tube to rotate in a downward direction.



Example of torque-tube assembly

What is torque?

Torque is the twisting force. It is defined as the product of the force and the distance of its line to the axis about the arm which the twisting takes place.



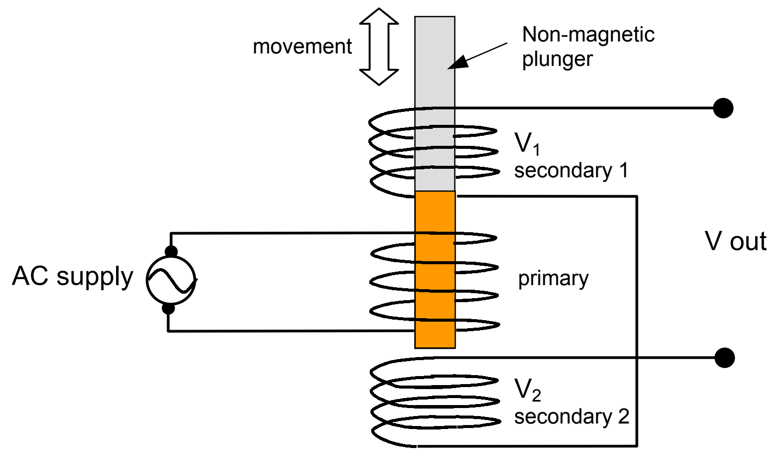
Torque, $\tau = F \times d$

How do we measure torque electronically?

One way is by using strain gauges laid out diagonally on a shaft. They are laid out at 45 ° this way to maximise sensitivity to torque along their active axis. To get the output of the strain gauges, we usually use rotating slip rings and brushes. This method is used in many electronic level transmitters with applications of ***Linear Variable Differential Transformer (LVDT)***.

What is LVDT?

The circuit diagram is shown in the diagram below:



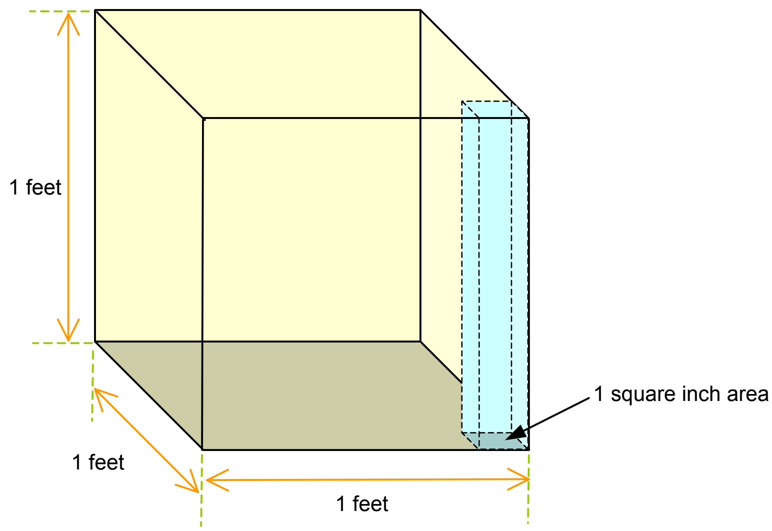
Linear Variable Differential Transformer (LVDT)

The basic construction is that it contains three coils and a moveable transformer, with a ferro-magnetic armature. The non-magnetic armature (usually aluminium), moved by the displacement being measured carries a ferrous armature passes through the coils. The three coils consist of an AC energised primary coil and two secondary coils wound and connected as shown in the diagram.

The AC primary coil induces an AC voltage in the secondary coils as would a transformer. The output is not “linear”, only the fact that the transducer is measuring a straight-line displacement. If the ferro-magnetic is centred between the coils, the output will be; $\mathbf{V_1 = V_2}$, is zero, out from V_{out}. The secondary windings are connected in series opposition. The output from V_{out} is the difference between the coils (hence differential ?).

Hydrostatic Head or Differential Pressure

This method rely on the pressure of the measured liquid head to provide level indication. The pressure exerted by a column of liquid is equal to the height of the column, *h*, times the specific gravity of the liquid, *sg*. ($P=h\cdot(sg)$, where $sg=\rho\cdot g$). Thus, from this we can calculate the level of the liquid in a vessel or tank, (i.e. the *h)*, if we know the pressure at the bottom of the tank and the specific gravity of the liquid, *sg*.



By referring to the figure above, the weight of one cubic foot container of water is seen to be 62.4 pounds (from its weight), and this force is exerted over the surface of the bottom of the container.

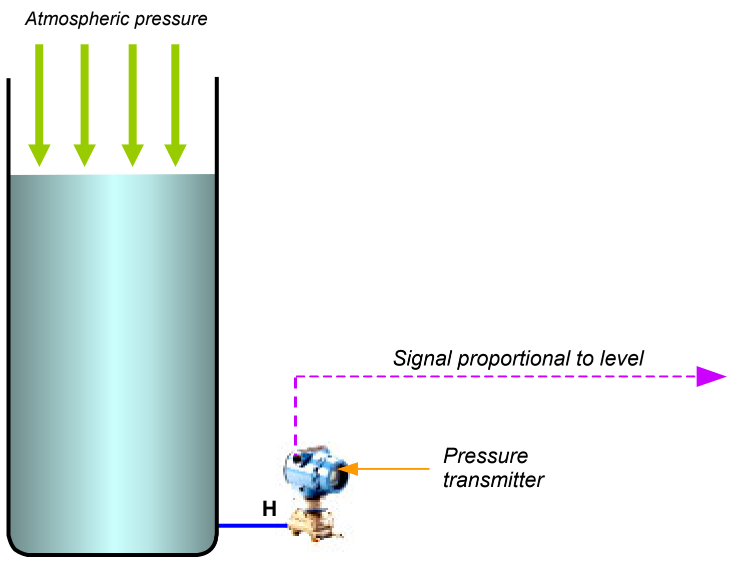
Area, $A = 12 \text{ in} \times 12 \text{ in}$
$= 144 \text{ in}^2$

Since 1 ft = 12 in

Pressure exerted on the area, $P = \dfrac{F}{A}$

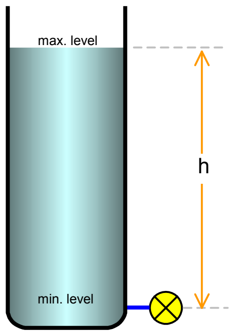
$$= \frac{62.4 \text{ lbs}}{144 \text{ in}^2} = 0.433 \text{ lbs/in}^2$$

Open tank head type measurement



The figure above illustrates an application where the level value is inferred from a pressure measurement. When the level is at the same elevation point as the measuring instrument, atmospheric pressure is applied to both sides of the pressure transmitter and the measurement is at ‘zero’ reference level. When the level in the tank increases, the force created by the hydrostatic head of the liquid is applied to the measurement side of the transmitter, resulting in an increase in the instrument output. The instrument response is caused by the head pressure is used to infer a level value. The relationship between pressure and level is as mentioned earlier, $P = \rho \cdot h \cdot g$. Note that any changes in atmospheric pressure does not affect the measurement because the changes are applied to both sides of the pressure transmitter.

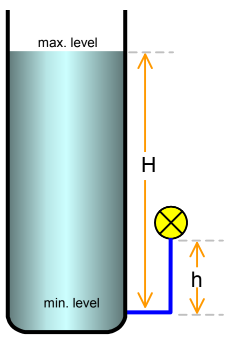
CONFIGURATIONS FOR OPEN-TANK MEASUREMENT



Normal installation (transmitter mounted leveled with min. level tap)

Regardless of whether with/without seal system;

Span = $\rho_p \cdot g \cdot h$,or alternatively, Span = $SG_p \cdot h$



Elevated-Zero installation (transmitter mounted <u>above</u> the HP tap)

Without seal system;

Note that this configuration is not advisable, because the xmtr tends to be unstable when the liquid level gets below the xmtr level – causing bubble trap, unless seal system is used.

With seal system;

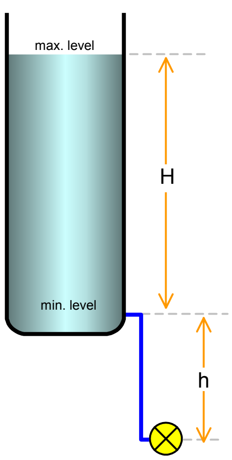
Zero Elevation = $-(\rho_f \cdot g \cdot h)$, or,
= $-(SG_f \cdot h)$

Span = $\rho_P \cdot g \cdot H$, or,
= $SG_p \cdot H$

Therefore, for calibration;

4mA (LRV) = Zero Elevation

20mA (URV) = Span + Zero Elevation



Suppressed-Zero installation (xmtr. mounted <u>below</u> the HP tap)

Without seal system;

(the xmtr leg is assumed to be filled with process fluid at all time)

Zero Suppression = $\rho_f \cdot g \cdot h$

Span = $\rho_p \cdot g \cdot H$, or,
= $SG_p \cdot H$

With seal system;

Zero Suppression = $\rho_f \cdot g \cdot h$, or,
= $SG_f \cdot h$

Span = $\rho_p \cdot g \cdot H$, or,
= $SG_p \cdot H$

Therefore, for calibration;

4mA (LRV) = Zero Suppression

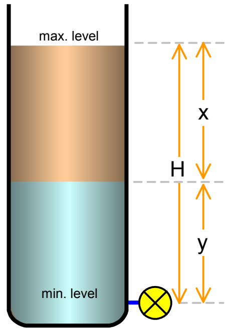
20mA (URV) = Span + Zero Suppression

NOTE:
ρ_p = density of process liquid in the tank
ρ_f = density of fill-liquid in the tubing
ρ_u = density of upper liquid
ρ_l = density of lower liquid

SG_p = std. gravity of process liquid.
SG_f = std. gravity of fill liquid
SG_u = std. gravity of upper liquid
SG_l = std. gravity of lower liquid

INTERFACE APPLICATIONS

Normal installation (transmitter mounted leveled with the HP tap)



Without seal system;
(*assume the leg is always filled with lower liquid*)

LRV = $\rho_u \cdot g \cdot H$, or,
= $(SG_u \cdot H)$

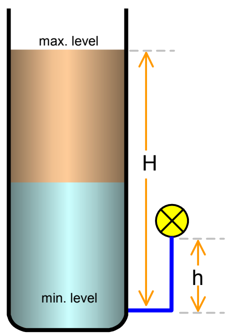
URV = $\rho_l \cdot g \cdot H$
= $(SG_l \cdot H)$

With seal system;

LRL = $\rho_u \cdot g \cdot H$, or,
= $(SG_u \cdot H)$

URL = $\rho_l \cdot g \cdot H$, or,
= $(SG_l \cdot H)$

Elevated-Zero installation (transmitter mounted above the HP tap)



Without seal system;

Not preferable

With seal system;

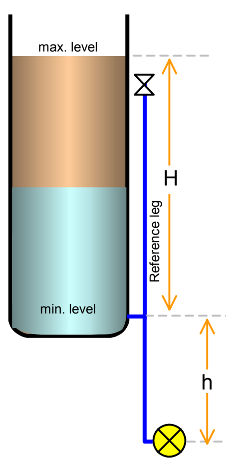
Zero Elevation = – $(\rho_f \cdot g \cdot h)$

Min. Head = $\rho_u \cdot g \cdot H$, or,
= $(SG_u \cdot h)$

Span = $\rho_l \cdot g \cdot H$, or,
= $(SG_l \cdot h)$

Therefore, for calibration;
4mA (LRV) = Min. Head + Zero Elevation
20mA (URV) = Span + Zero Elevation

Suppressed-Zero installation (transmitter mounted below the HP tap)



Without seal system;

Zero Suppression = $\rho_l \cdot g \cdot h$

Min. Head = $\rho_u \cdot g \cdot H$, or,
= $(SG_u \cdot h)$

Max. Head or Span = $\rho_l \cdot g \cdot H$

With seal system;

Zero Suppression = $\rho_f \cdot g \cdot h$

Min. Head = $\rho_u \cdot g \cdot H$, or,
= $(SG_u \cdot h)$

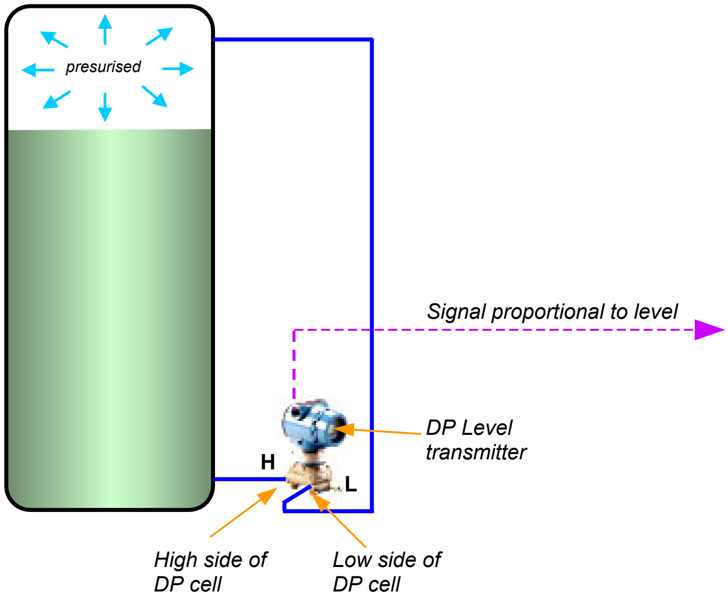
Span = $\rho_l \cdot g \cdot H$, or,
= $(SG_l \cdot h)$

Therefore, for calibration;
4mA (LRV) = Min. Head + Zero Suppression
20mA (URV) = Span + Zero Suppression

NOTE:
ρ_p = density of process liquid in the tank
ρ_f = density of fill-liquid in the tubing
ρ_u = density of upper liquid
ρ_l = density of lower liquid

SG_p = std. gravity of process liquid.
SG_f = std. gravity of fill liquid
SG_u = std. gravity of upper liquid
SG_l = std. gravity of lower liquid

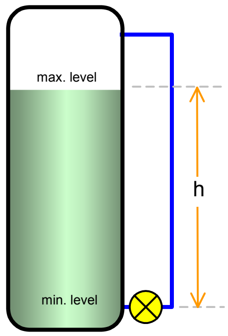
Closed tank level measurement



Hydrostatic head instruments for measuring liquid level in vessels operating above atmospheric pressure uses the full capability of the differential pressure instruments with both sides of the measuring element connected to the vessel.

The differential pressure transmitter, enables an automatic subtraction of the pressure on the LP side, from the total pressure appearing at the HP side. This is accomplished as shown in diagram above, where the LP is connected above the maximum predicted level. With this arrangement, each increment of pressure above the liquid surface is applied to both capsule assemblies of the transmitter, and since they are in opposition, the increment is cancelled. Only the hydrostatic pressure, which is applied to the HP, is effective in causing any response to the transmitter, which is proportional to the level.

CONFIGURATIONS FOR CLOSED-TANK MEASUREMENT



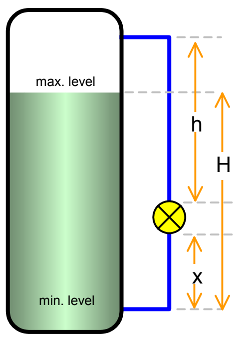
Transmitter mounted leveled with the min. level)

With dry leg ;

Span = $\rho_p \cdot g \cdot H$, or,
= $SG_p \cdot h$

With wet leg ;

Span = $\rho_p \cdot g \cdot H$, or,
= $SG_p \cdot h$



DP Transmitter mounted <u>above</u> the min. level)

With dry leg ;

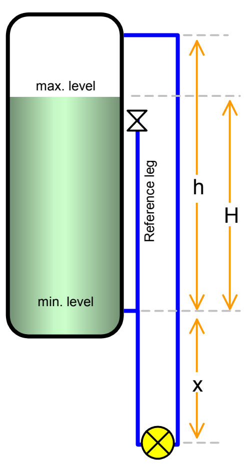
Not preferable

With wet leg ;

Zero Elevation = $-(\rho_f \cdot g \cdot x)$

Span = $\rho_p \cdot g \cdot H$

Therefore, for calibration;
4mA (LRV) = Min. Head + Zero Elevation
20mA (URV) = Span + Zero Elevation



Transmitter mounted <u>below</u> the HP tap ;

With dry leg ;

P_w at min. level = $(SG_f \cdot x)$
P_w at max. level =
$(SG_f \cdot x) + (SG_p \cdot H)$

Span = $SG_p \cdot H$

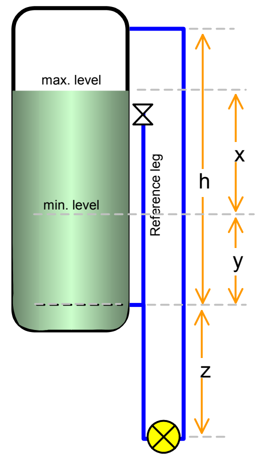
With wet leg ;

Zero Suppression = $-(\rho_f \cdot g \cdot h)$,or,
= $-(SG_f \cdot h)$

Span = $\rho_p \cdot g \cdot H$, or,
= $SG_p \cdot H$

Therefore, for calibration;
4mA (0%) = Zero Elevation
20mA (100%) = Span+Zero Suppn.

NOTE:
ρ_p = density of process liquid in the tank
ρ_f = density of fill-liquid in the tubing
ρ_u = density of upper liquid
ρ_l = density of lower liquid
SG_p = std. gravity of process liquid.
SG_f = std. gravity of fill liquid
SG_u = std. gravity of upper liquid
SG_l = std. gravity of lower liquid



Transmitter mounted <u>below</u> the HP tap ;

With dry leg ;

P_w at min. level =
$(SG_f \cdot z) + (SG_p \cdot y)$

P_w at max. level =
$(SG_f \cdot z) + (SG_p)(x+y)$

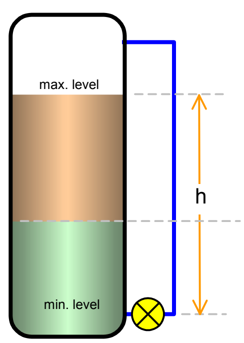
Span = $SG_p \cdot H$

With wet leg ;

P_w min = $(SG_p \cdot y) - (SG_f \cdot d)$
P_w max = $(SG_p)(x + y) - (SG_f \cdot d)$

Span = $\rho_p \cdot g \cdot x$, or
= $SG_p \cdot x$

<u>INTERFACE APPLICATION</u>



Normal installation (transmitter mounted leveled with the HP tap)

With dry leg ;

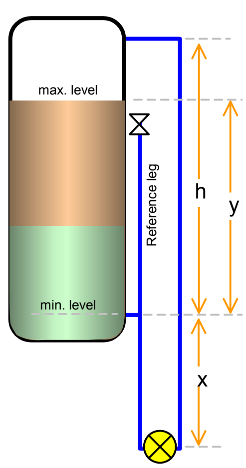
LRV = $\rho_u \cdot g \cdot h$, or,
= $(SG_u \cdot h)$

URV = $\rho_l \cdot g \cdot h$, or,
= $(SG_l \cdot h)$

With wet leg ;

LRV = $\rho_u \cdot g \cdot h$, or,
= $(SG_u \cdot h)$

URV = $\rho_l \cdot g \cdot h$, or,
= $(SG_l \cdot h)$



Transmitter mounted <u>below</u> the HP tap ;

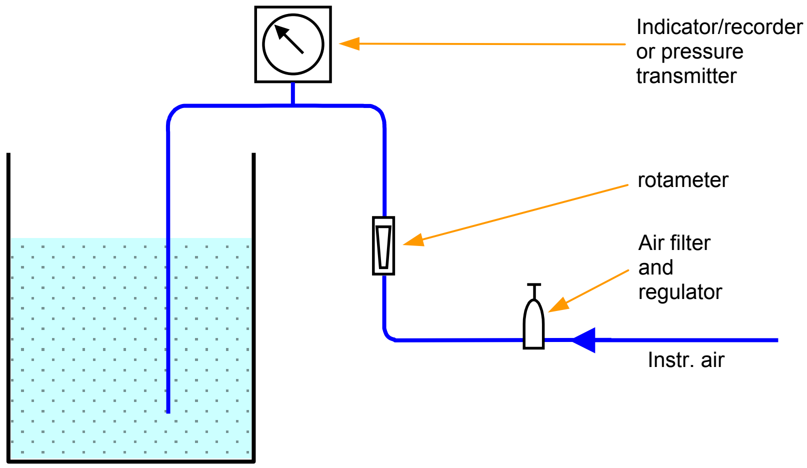
With dry leg ;

With wet leg ;

NOTE:
ρ_p = density of process liquid in the tank
ρ_f = density of fill-liquid in the tubing
ρ_u = density of upper liquid
ρ_l = density of lower liquid

SG_p = std. gravity of process liquid.
SG_f = std. gravity of fill liquid
SG_u = std. gravity of upper liquid
SG_l = std. gravity of lower liquid
P_w = equivalent head of water

Air Bubblers

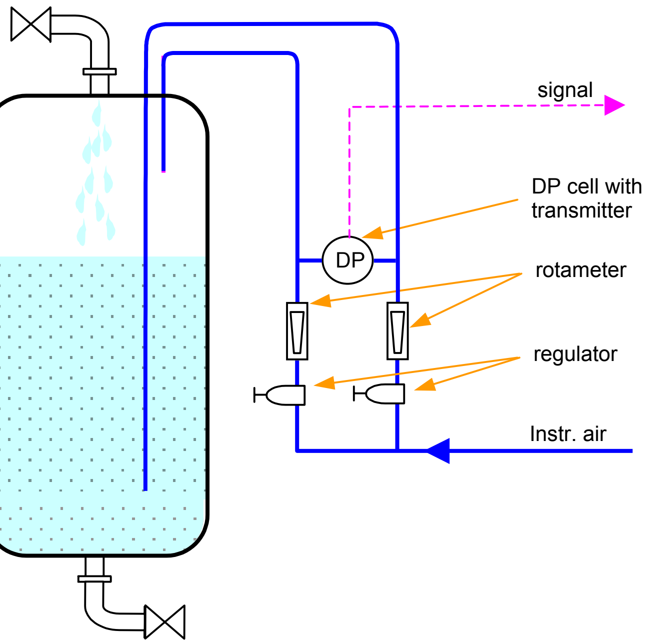


One of the oldest and simplest methods of level measurement is called the **air bubbler**, **air purge**, or **dip tube**. With the supply air blocked, as can be seen in the diagram above, the water level in the tube will be equal to that in the tank. When the air pressure from the regulator is increased until the water in the tube is displaced by air, the air pressure on the tube is equal to the hydrostatic head of the liquid in the tube.

The pressure set in the regulator must overcome the liquid head and bubble up through the measured liquid. This will be indicated by a continuous flow, which is evidence by the formation of bubbles rising to the level of the liquid in the tank.

As it may not be convenient to visually inspect the tank for the presence of the bubbles, an air flow indicator will usually be installed in the air line running into the tank. A rotameter is generally used for this purpose. The importance of maintaining a flow through the tube lies in the fact that the liquid in the tube must be displaced by air and the back pressure on the air line provides the measurement, which is related to level. The level or static head is measured by an indicator or a DP cells. Readout may be local or remote. When transmission distances exceed 15 to 20 meters, differential pressure transmitters are usually used to transmit standard signals to remote locations.

For the closed tank application, the following bubbler system can be used. Two dips are installed with the shorter one dipped for “maximum” level of liquid to be measured, and a longer dip has its tip at “minimum” level. Instrument air is supplied to the system (normally adjusted to 4 bar) at both dips. A DP cell transmitter is placed to sense and measure the level, and produce a proportional signal according to the level.



Zero adjustment is initially set-up when the tank or drum is empty, i.e. no differential pressure present. The “maximum” level is set either by filling the tank/drum with process liquid, or by calculation (if the density of the liquid is known).

An important advantage of the bubbler system is the fact that the measuring instrument can be mounted at any location and elevation with respect to the tank. This application is advantageous for level measuring applications where it would be inconvenient to mount the measuring instrument at the zero reference level. An example of this situation is level measurement in underground tanks and water wells.

Air and nitrogen are the most commonly used gases for bubbler installations. Liquid may be used if there is reason not to use gas. If process material has a tendency to plug the dip tube, a bypass maybe installed around the flow regulator to blow out the line periodically.

Bubbler systems are used rather infrequently now. One drawback is that it is undesirable in many process to introduce air, nitrogen or other purge material to the process. They do provide economical installation, however, particularly for local readout on clean services.

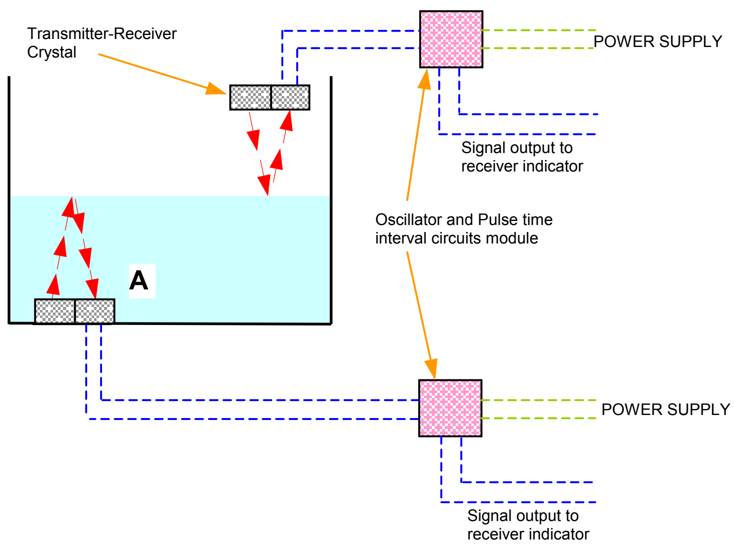
The accuracy of the bubbler system is about as good as the differential device used for readout. Its accuracy is independent on the constancy of the density of the material whose level is measured.

Sonar or Ultrasonic Type Detector

In level measuring applications where contact of the measuring instrument with the liquid in the process is not desirable, it may be feasible to employ the use of a sonic or ultrasonic device (normally refers to as 'radar'). These types of level measurement really measure the distance from one point in the vessel, usually a reference point, to the level interface with another fluid. The general operating principle of both sonic and ultrasonic devices is similar, and distinction between the two will not be made other than to define the frequency range of ultrasonic instruments to be around 20 kHz and that of sonic level instruments to be around 10 kHz and below.

The theory of sonic electronic level measurement is based on a sound wave emission source (transmitter) and the reflection of a sound wave pulse (echo) to receiver. Measurement of the transit time of this pulse provides a means for level detection and measurement.

The following figure is an illustration of commercial units available;



The equipment includes a transmitter that periodically sends a sound pulse to the surface from the transducer; a receiver (which is included in the transducer) that amplifies the returning pulse and a time interval counter that measures the time elapsing between the transmission of a pulse and receipt of the corresponding pulse echo. Echo pulses are ordinarily reflected back from the surface of the liquid; however, the line of demarcation interface between immiscible liquids also reflects sufficient energy to allow the system to gauge these obscure interface levels.

One transducer and its single coaxial cable constitute the only installation equipment usually required to gauge and individual tank. The receiving indicator may be switched to gauge as many transducer-equipped tanks as desired.

Although echo type devices are sound in theory and operate well under carefully controlled conditions, as in a laboratory, they are dependent upon environmental changes, notably temperature, pressure, and chemical composition - all factors which affect the velocity of acoustic propagations and upon which the measurement is fundamentally based. In processing operations for example, where chemical composition changes may be expected, these can severely affect calibration. For example, the velocity of sound in air at 0° C is 1 087.42 fps ; in ammonia, 1 361 fps ; in carbon dioxide, 1 106 fps ; in chlorine, 674 fps ; in helium, 3 182 fps, etc. of course at considerable expense and complexity, some of these factors can be compensated automatically.

Ultrasonic detectors with single sensor

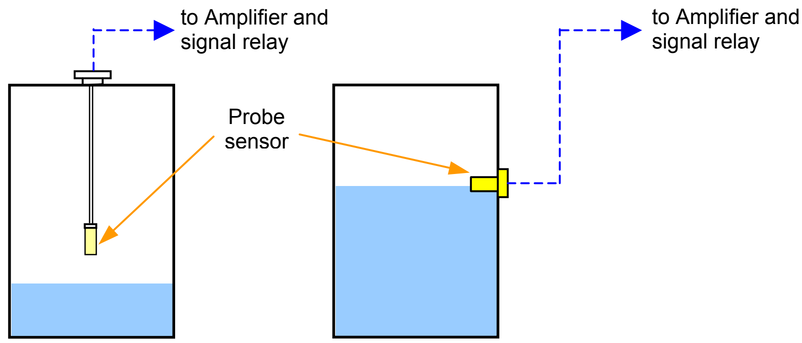


Figure A *Figure B*

A typical single-sensor liquid level indicator is the Sonic shown in **Figure A** and **Figure B**. The sensor is a small, hermetically sealed probe whose front face oscillates at a relatively high frequency-such as 35 000 to 40 000 Hz. When rising liquid covers at least half the face or the sensor (if mounted horizontally), or the whole face (if mounted vertically), the oscillating action of the sensor is damped out. This damping is recognised by the amplifier and causes a relay in the amplifier to drop out and actuate either an ON or OFF signal (high level) and/or suitable control action through relays or other actuators.

The sensors are generally small, approximately 1 in. diameter, made of stainless steel, and can easily be placed a fitting or tank. A sensor is not limited by physical properties of various liquids, such as pressure, conductivity, or density. A sensor may be used with flammable liquids.

Ultrasonic detectors with two sensors

In this system, which is generally used for dry or solids level control, one transmitting sensor creates the sonic beam, and sound waves are picked up by a receiving sensor. See **Figure C**. This can be accomplished by a direct path or by surface and are rejected back to the receiving sensor.

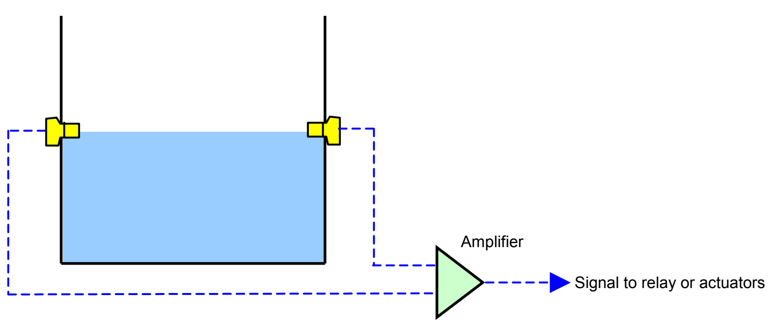


Figure C

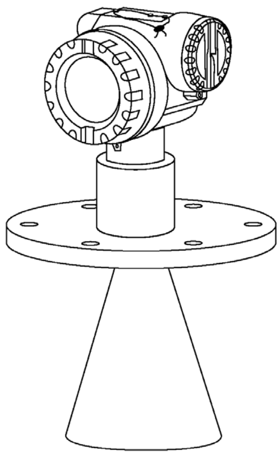
Sensors can be placed as close as 114 in. or as far apart as 10 ft in a direct beam path. They can pipe their beams through tubing where sensor beams cannot be direct, but generally the tubing length should be limited to 6 ft.

A sensor's sound beam is unaffected by mist, smoke, dust, or fumes, since it is interrupted only by solid or liquid entering into the beam path.

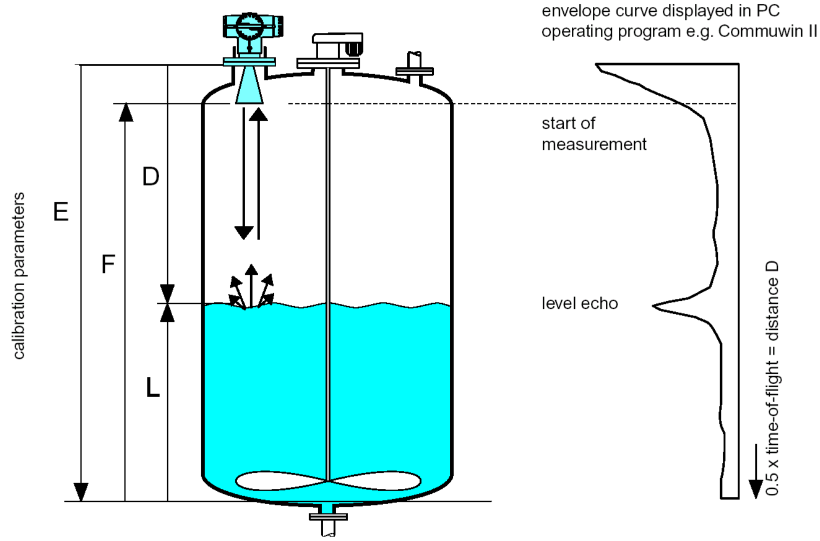
Ultrasonic level measurement techniques are more expensive and generally of a higher degree of sophistication than more conventional measuring types. They are, therefore, generally used only when the application of other types would be more difficult and yield less successful results. When the transmitter and sensing probes can be kept clean, they are reliable and relatively maintenance free because there is a lack of moving parts and the generally sealed solid-state electronic components are in sealed housings. Except for the noninvasive type, and unless isolation chambers are used, maintenance may require the emptying and evacuation of the process vessel. Calibration is usually accomplished by empirical means.

Microwave (Radar)

The microwave transmitter is designed for continuous, non-contact level measurement of liquids, pastes and slurries. It finds particular use in storage, buffer and process tanks as well as in applications where high temperatures, high pressures, inert gas blankets, or vapour are present.



Horn type antenna



Short microwave pulses are beamed by the antenna towards the product, reflected by its surface and detected as a temporal record of the echoes – the envelope curve – by the same arrangement. The distance to the product surface is proportional to the time-of-flight of the microwave pulse:

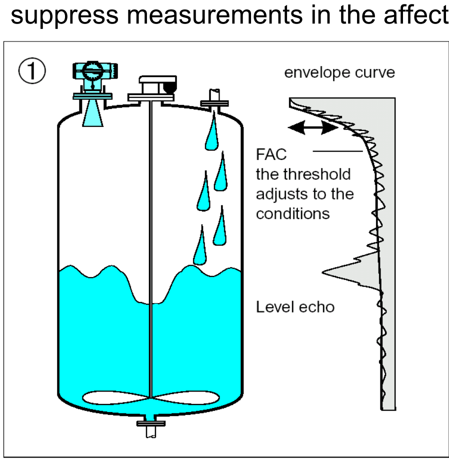
$$D = c \cdot \frac{t}{2}$$

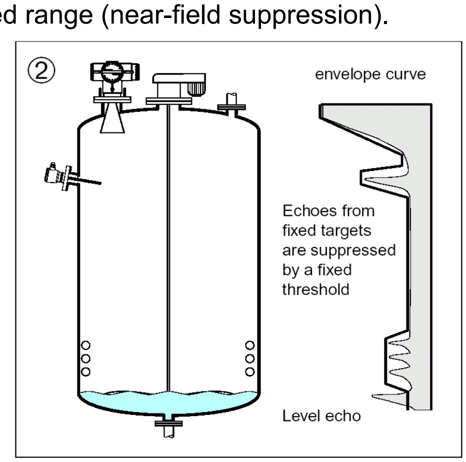
where, D = distance sensor - product surface,
c = velocity of light,
t = time-of-flight.

The Micropilot is calibrated by entering the empty distance E, the full distance F and an application parameter A, which automatically tunes the instrument to the measuring conditions. In order to correctly identify the level echo, two evaluation algorithms can be used. Normally, both are activated:

- The Floating Average Curve (FAC) – this is particularly good for suppressing interference echoes due to tank filling and product agitation.
- The Time Dependent Threshold (TDT) – this suppresses interference echoes from tank fittings (fixed targets).

For non-invasive measurements or when build-up forms near to the antenna, it is also possible to suppress measurements in the affected range (near-field suppression).

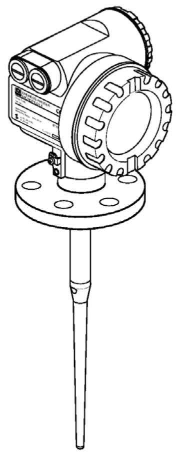




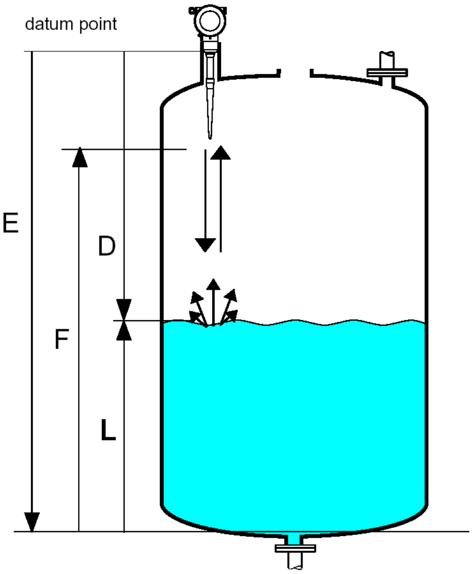
1*.*
A floating average curve adjusts to the conditions in the tank

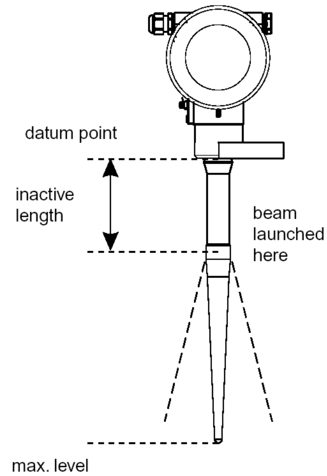
2*.*
For fixed target suppression, a fixed, time-dependent threshold (TDT) is imposed upon the envelope curve

Rod-antenna type microwave level meter



Rod-antenna type



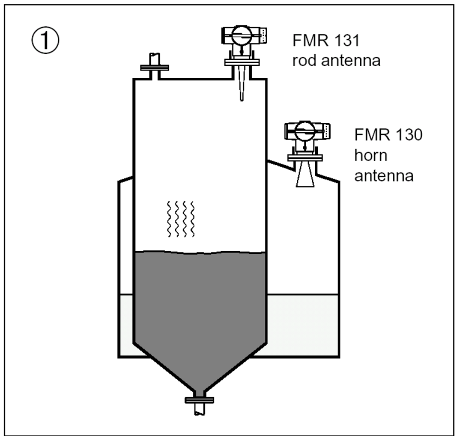


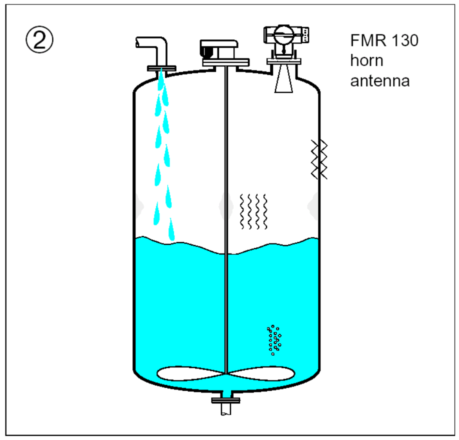
Short microwave pulses are beamed by the antenna towards the product, reflected by its surface and detected by the same arrangement. An inactive length at the start of the rod antenna delays the launch of the pulse for a distance of 100 mm or 250 mm, ensuring that condensation or build-up in the mounting nozzle does not affect the measurement. The reflected microwaves are detected by the antenna and passed on to the electronics. Here a microprocessor evaluates the signal and identifies the echo produced by the reflection of the beam at the product surface. The algorithms used for signal processing are based on many years of experience in time-of-flight measurement.

The principle of measurement is the same as the horn type microwave meter.

Methods of installing the microwave level meter

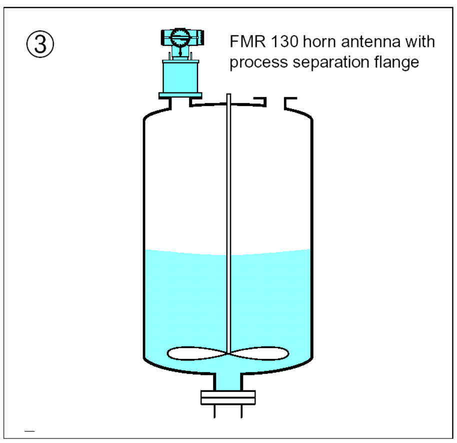
Since some processes vessels or drums may have stirrer or agitator, the liquid to be measured may be wavy and the surface is practically unstable, some methods had been developed to reduce this problem and obtain a reliable process reading.

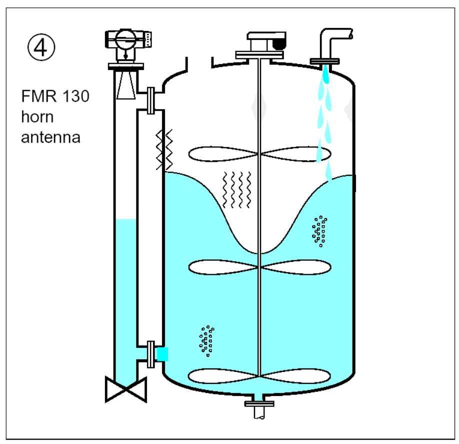




1.
Measurement in storage and buffer tanks using the horn or rod antenna

2.
Measurement in process tanks using the horn antenna





3.
Non-invasive measurement, e.g. with process separation flange

4.
Measurement in by-pass pipes using the horn antenna

Conductance

As the name implies, conductivity level switches operate on the principle of electrical conductivity. Electrodes located within containers at the point of control make or break contact with the conductive material, thus completing an electrical circuit which operates load contacts for pumps and solenoid valves or performs other control or alarm functions.

The schematic of a heavy-duty switch of this type is shown in **figure D** below. When a source of alternating current is connected to the primary coil, a magnetic flux is set up which induces a voltage in the secondary coil. Current flows in the secondary coil however, only when the rising liquid completes the circuit between the two electrodes. Completion of the secondary coil circuit and the resultant current flow sets up a bucking action in the lower bar of the transformer core. This tends to divert lines of magnetic flux to the core legs and sets up an attraction that moves the armature, closing or opening load contacts.
One pair of contacts connect the secondary circuit to ground when liquid contacts the upper electrode and acts as a holding circuit to maintain the relay in its closed position until the liquid falls below the lower electrode. This holding circuit provides control of the load circuit through the bottom contacts of the relay over any desired range in the liquid level, depending upon the distance between the upper and lower electrodes.

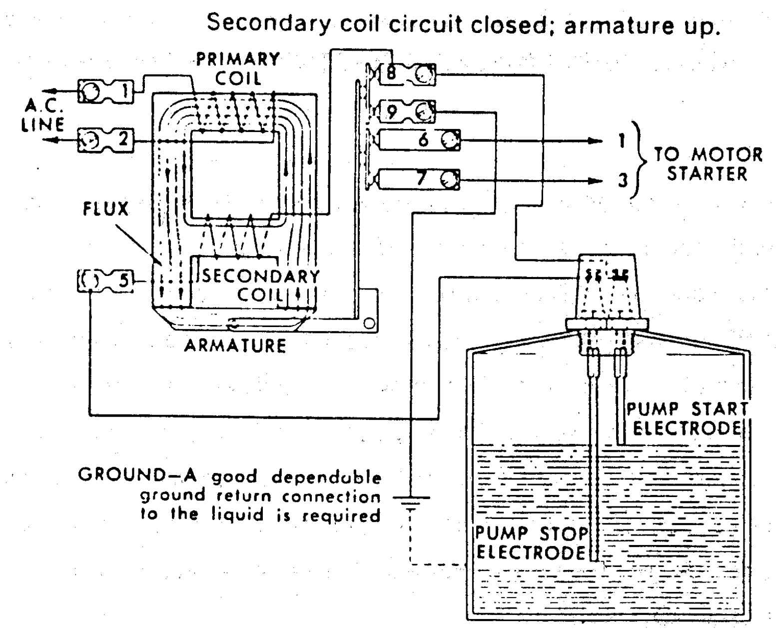


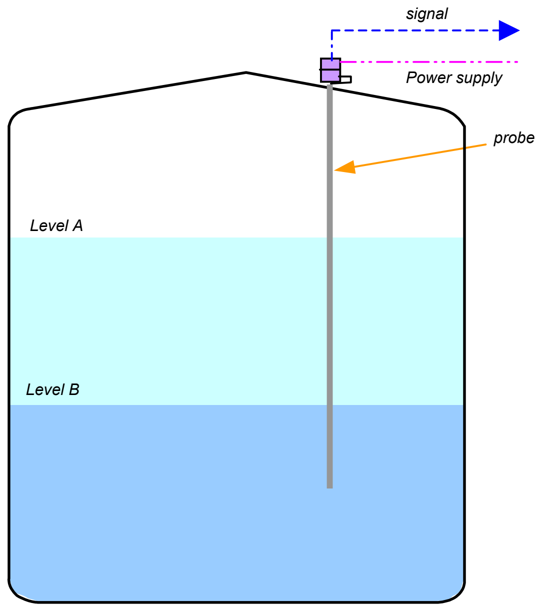
Figure D

The flow of current through the low energy secondary circuit is very small and varies with the voltage of the secondary coil. The secondary coil is selected to operate over the resistance of the liquid being controlled.
The two-electrode system shown operates a pump to maintain a desired level in a vessel -from a simple on-off action where one electrode and the container complete a circuit via the conductive material to multielectrode assembly where several switch actions occur at various container levels.
Conductivity switches are economical and have no moving parts in contact with the measured material. Early, heavy-duty designs were used primarily on water applications because of the high energy levels which could result in sparking to produce fires or explosions. However, manufacturers now offer solid-state designs, operating at low energy levels, which can be considered intrinsically safe.

Capacitance

Capacitance is the property of a circuit that stores electrons and thus opposes a change in voltage in the circuit. A capacitor is an electrical component that consists of two conductors separated by a dielectric or insulator. The capacitance value of a capacitor is measured in Farads (F), and the value is determined by the area of the conductors (usually called plates), the distance between the plates, and the dielectric constant of the insulator between the plates.

Generally, one thinks of a capacitor as having two small parallel plates separated by air or another type of dielectric. For capacitance level measuring applications, however, one plate is a probe while the other plate is comprised of the tank of the level vessel (see **figure of capacitance below**). The dielectric is the material in the vessel which will determined the capacitance value when it rises and falls. The liquid in the tank will be measured by the capacitance measurement meter. Capacitance level measurement probes are mostly used in on / off applications for alarms or switches and control functions. For such applications, the probes can be mounted horizontally, perpendicular to the level surface, so that a large plate area is effectively used.



Capacitance level measurement devices play an important role in the manufacturing and processing industries, but under some operating parameters they require special consideration. Generally, the capacitance values of a probe should be high compared to the capacitance of the lead wires connecting it to the measuring circuit. The wire capacitance should be swamped by the probe capacitance variations. Otherwise, instability and erratic operation may result.

Some advantages of capacitance level devices are the following :

- They contain no moving parts
- Simple and rugged design is possible
- Design for corrosive application is possible
- Generally, they are easy to clean
- Sanitary design is available for the food processing industry
- Extreme temperature and pressure requirements are possible by careful design
- They can be designed for explosion proof service

As is true with most measuring systems, certain limitations do exist for capacitance level techniques. The following are some of the most notable :

- Measurement is subject to error caused by temperature changes affecting the dielectric constant of the material to be measured
- Coating of the probe by conductive material causes error in measurement. An example of this is the condensation of water vapor in the vapor phase of a vessel, forming water droplets on the probe
- Usually empirical calibration techniques are used
- In solids measurement, variations in particle size affect the dielectric constant

Radiation

Nuclear radiation devices were first used in instrumentation and related industries in the early 1950s. These devices are used where other applications prove unsuccessful.

Like many of the other level measurement devices discussed, nuclear radiation measurement can be used for either point or continuous applications. The measuring principle is the same for both applications; the hardware and its arrangement is different.

In point measurement, there are two basic components: a ***radiation source*** and a ***detector*** with an associated amplifier. Generally, the source is located one side of the process vessel and the detector is located on the opposite side of the vessel. As illustrated in ***Figure 19***, more than one detector can be used for level indication at various points. It should be noted, however, that the ability to use more than one detector depends on several factors such as the source size, the distance between the level points, and the vessel diameter. The detector is usually a *Geiger-Mueller* tube with a solid-state amplifier and associated power supplies.

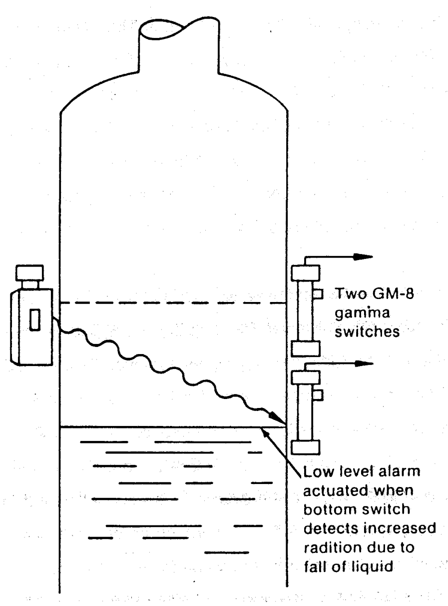


Figure 19

Gamma rays are emitted by the source and pass through the walls and the material in the tank. The variation in transmission of gamma rays will be a function of the medium through which the rays travel on their path from the source to the detector. When the level is below the elevation point of the detector, the intensity of the field will be greater than when the level reaches the

detector. When the liquid interrupts the path of the gamma rays, the percent of transmission will decrease, and the output of the detector amplifier will decrease sharply. This will activate a control relay, signifying the presence of a liquid level at the elevation point of the detector. Although satisfactory for level detection at one point, when more than one or a few measuring points are desired, a continuous measurement should be used.

Continuous level measurement is depicted in ***Figure 20***. In ***Figure 20-A***, a point source is shown with a detector covering the entire desired measuring span of the instrument. The radiation of gamma rays is emitted in all directions and the percent of transmission decreases as the liquid level increases, interrupting more of the nuclear energy of the gamma rays. As the level continue to rise, fewer of the gamma rays are transmitted or absorbed and radiation slowly increases to a peak value as the source for that detector or portion of the detector is completely covered. This procedure continuous for the next detector until the entire measurement span has been covered.

As shown in the curve in ***Figure 20-A***, this method of measurement yields non-linear results.

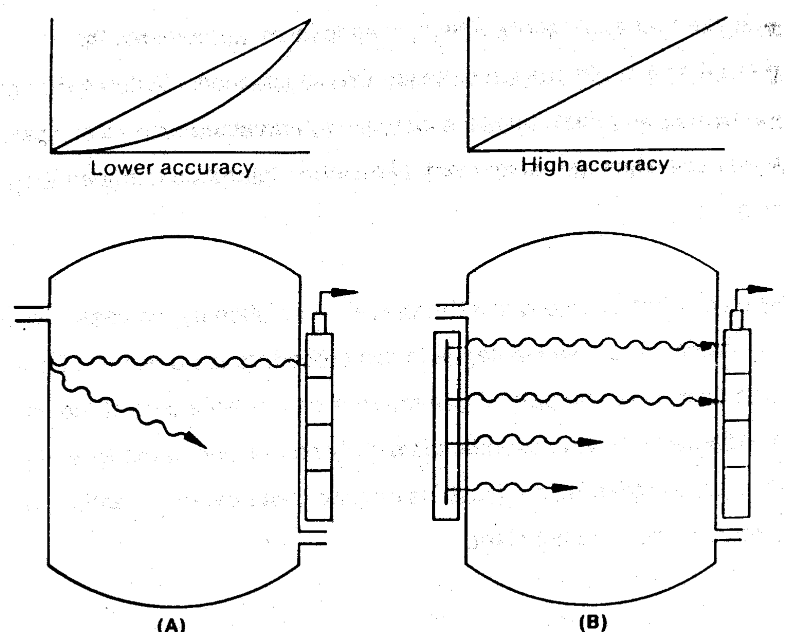


Figure 20

A better method of continuous measurement is shown in ***Figure 20-B***. Each measuring cell receives radiation from each source along the span or from all points of a strip source when that type is used. The cells at the center of the vessel have a shorter mean distance from every source than those at the end, so a small amount of nonlinearity exists, which can usually be reduced to a - tolerable level.

Electronic measuring cells can be used instead of the Geiger Mueller tubes. These cells generate current when a fill gas is ionized by the radiation that strikes the tubes. The small current caused by ionization is amplified to produce a current output proportional to level.

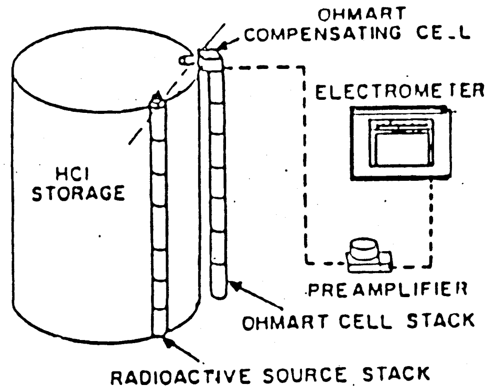


Figure 21

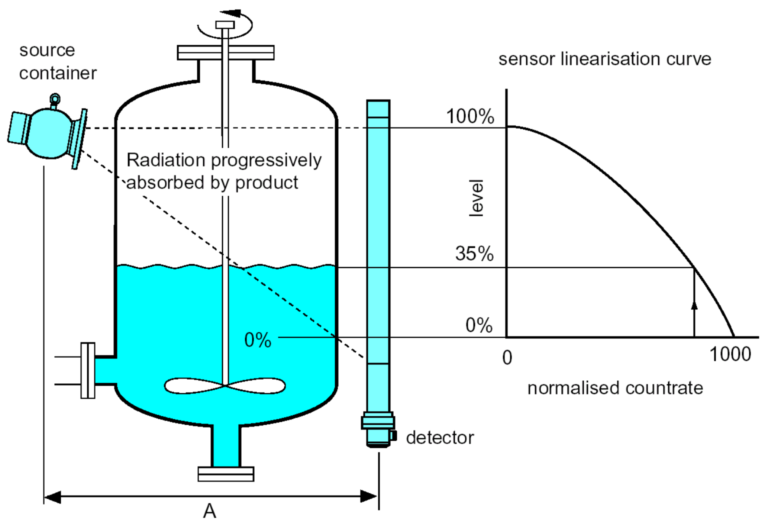
The **Ohmart** gauges employed for liquid or solids level measurement are based on a patented Ohmart cell which converts gamma radiation energy directly into electric energy. See ***Figure 21***. This cell contains two electrodes, which have different work functions. They are separated by a filling gas, which when it is forcibly ionised by exposure to nuclear radiation, attracts positive ions to the electro negative electrode and electrons to the electro positive electrode, thus an electric current is generated which can be amplified.

Radiation level measurement is expensive but provides the most reliable operation for applications where other level measurement means would be difficult and would provide questionable satisfaction. When the walls of the vessel are very thick, as is the case in high-pressure processes, error may be significant when the ratio of wall and probe absorption to material absorption is high.

By placing the source within the vessel, absorption by the vessel walls can be eliminated. The disadvantages to this procedure are obvious. For vessels with large diameters, the path of gamma rays can be on a cord of the vessel instead of a diameter. Since absorption is not only a function of the type of process material, all other factors (such as density) that govern transmission and absorption must be constant.

Example : E+H Gammasilometer

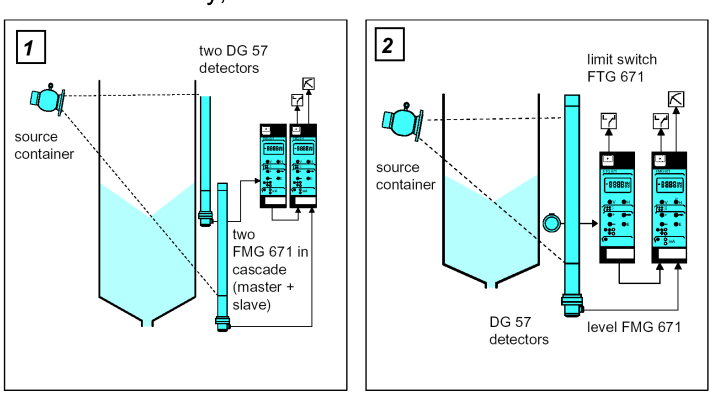
The Gammasilometer FMG 671 is a transmitter for continuous level measurement in industrial environments which can be used with a variety of radioactive sources and a DG 57 detector. It must be installed by qualified personnel according to the instructions manual. The operating manual must have been read and understood before the equipment is installed: instructions are to be followed exactly.
The Gammasilometer FMG 671 is designed as a non-contact, level measurement transmitter for containers (mixers, reactors, hoppers, silos, tanks) e.g. with inflammable, poisonous and aggressive bulk material and liquids. It is also suitable for applications in the food processing industry.



When Gamma radiation penetrates a material, it is absorbed to a degree dependent upon the density ρ, and thickness **d** of the material as well as the linear absorption factor μ, which is also dependent on the material and source. The attenuation $\mathbf{F_s}$ is given by:

$$\mathbf{F_s = e^{\mu \cdot \rho \cdot d}}$$

The radiation also decreases with the square of the distance **A** between source and detector. For level measurement, μ, ρ, and **d** are constants (for usual tank diameters) and the detected radiation level depends upon the presence or not of material in the beam. The countrate is at a maximum when the beam is completely free and at a minimum when all radiation has to travel through the material. The maximum and minimum countrates $\mathbf{N_{max}}$ and $\mathbf{N_{min}}$ are obtained when the transmitter is calibrated; the measured countrate is normalised and lies between 0 and 1000. The relationship between normalised countrate and level is non-linear and dependent upon the geometry of the vessel. A so-called sensor linearisation, which may be individually entered for maximum accuracy, ensures correct level measurement.



1.
Measurement with two detectors: both detectors are controlled by a Gammasilometer

2.
Measurement with automatic calibration correction

Weight

The weight method is seldom used nowadays. It use a weighting machine attached to the tank to weigh the liquid. .It has the tables to compensate between weight measured and height. For an example, 1 kg of liquid is calibrated equally to 1 foot height.

One of the drawbacks of this method is the specific gravity and the density of the liquid changes due to the temperature changes. The arrangement in ***Figure 22*** below shows a tank or other process vessel supported on three load cells. The empty weight of the tank is nulled to give a zero reading on the indicator; additions of material into the tank result in a response at the indicator. The load cells may be hydraulic or electrical strain gauges.

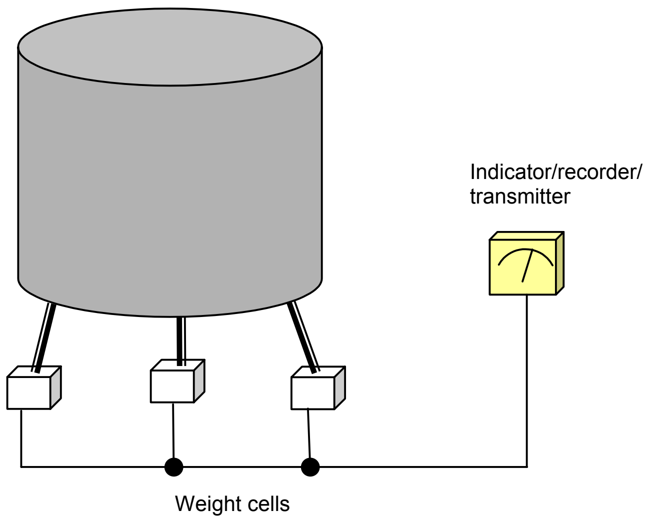


Figure 22

Resistance

Because of the simplicity involved in electrical resistance transducers and the ease in measuring a resistance quantity and converting that measurement to an inferential value representing a process condition, resistance devices are used when feasible. A device that has gained prominence in level applications consists of a tape type resistance-sensing element (called metritape) and is illustrated in ***Figure 23***.

The level sensor is in the form of a tape that is about 1.5 in. wide and 0.3 in thick. The length can vary from about 6 to 100 feet. The sensor has an internal helixal resistance winding, similar to a slidewire, with one turn per centimeter and a resistance value of 1Ω per turn. This wound helix is spaced away from a gold plated contact or shorting strip, and the two electrical elements are held within a sealed flexible plastic sheath.

The sensor is suspended within the level process vessel, and when the level is devoid of liquid the full resistance value of the sensor helix appears across the two lead wires from the sensor top. For example, if the sensor is ten (10) meters in length with the resistance length relationship of 1 ohm per centimeter, the total resistance of the sensor is 1000 Ω. This resistance would be measured between the two sensor wires when the process is empty or at zero percent level condition.

As the level increases immersing the sensor in liquid, the hydrostatic pressure exerted by the liquid on the flexible plastic sheath causes the helixal winding to be displaced, pushing against the contact strip and shorting the windings at that point. The resistance between the two sensor wires then is reduced by a percent equal to the increases in level in the process vessel. If the level increase were 25% of the sensor length, the total resistance value of the sensor would be reduced to 75% of the empty process vessel. Compensation for the resistance of connecting lead wire wires is usually not required because the total sensor resistance value is large compared to that of the lead wires.

The tape sensor can be used in closed tank applications. Process pressure is equalised directly by venting the inner sensor cavity to process pressure by a specially designed capillary breather equalizer. The static process pressure is applied to both sides of the jacket system, which acts as a pressure receiving diaphragm. The process environment is sealed from the helical cavity so that use in corrosive conditions is possible. *Figure 24* shows the construction of a tape type level sensor.

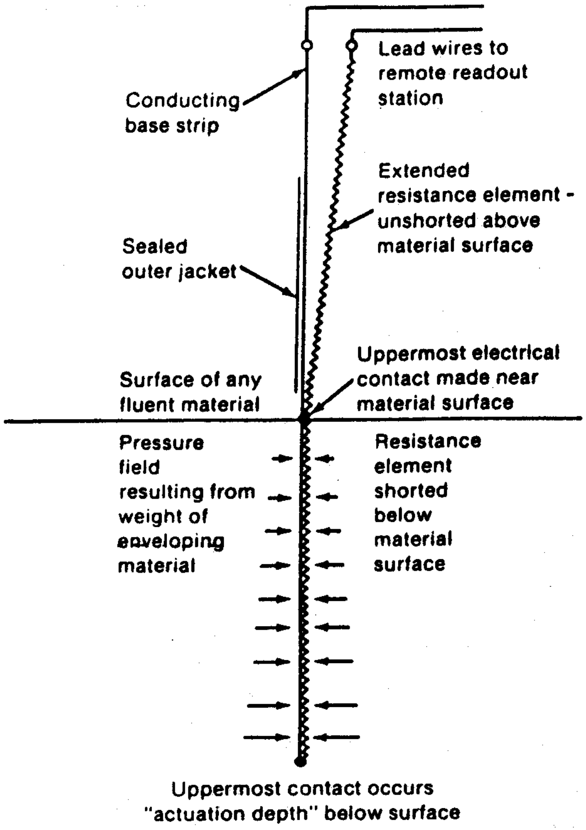


Figure 23 : Tape type resistance level sensor

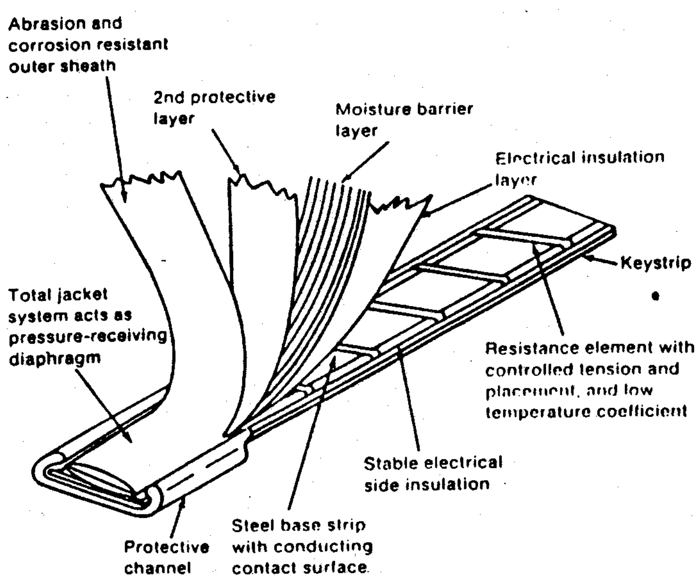
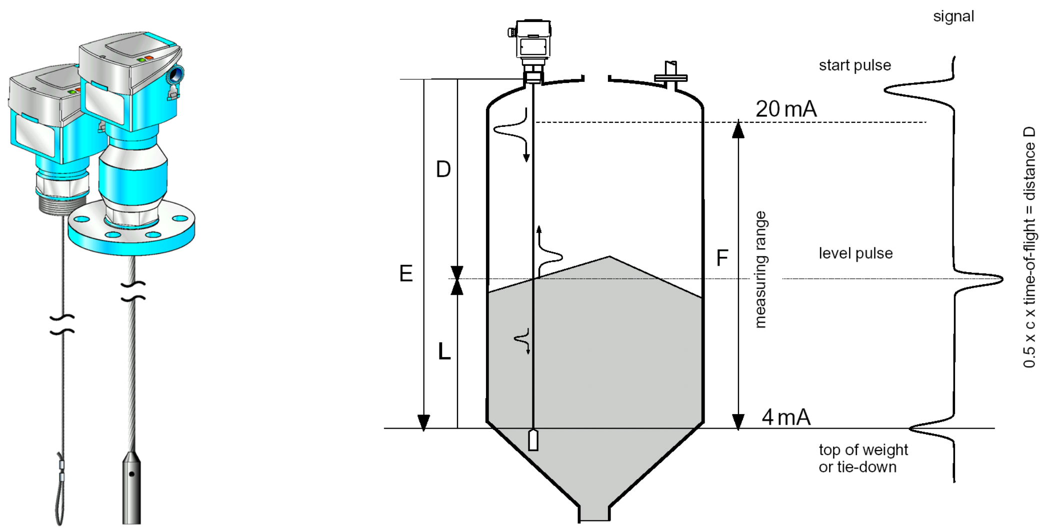


Figure 24 : Construction of tape type level sensor

Micro-impulse

Levelflex is a "downward-looking" time-of-flight system, which measures the distance from the probe mounting (top of silo) to the material level. An electrical pulse is launched and guided down the probe rope, which acts as a surface wave transmission line.
When the surface wave meets a discontinuity in the surrounding medium, i.e. a sudden change in dielectric constant, it is partially reflected. The reflected pulse travels back up the probe to the pulse sampler where it is detected and timed.



Each point along the probe is sampled for its pulse reflection behaviour. The information accumulated over the sampling cycle is captured and passed onto the signal processing, which identifies the signal produced by the change in dielectric constant at the air/product interface. The distance D to the surface of the product is proportional to the time of flight of the pulse t:

$$D = c \bullet \frac{t}{2}$$

whereby c = velocity of light.

Since the empty distance E is known to the system, it is a simple matter to calculate the level L.

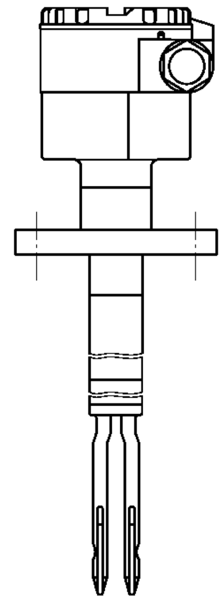
$$L = E - D$$

The top of the ballast weight or tie-down loop is zero, the span is set to 30 cm below the top thread of the process connection. For digital outputs and the display, 0% and 100% level.
When hanging free, it is capable of measuring at all points from the top of the ballast weight to within 30 cm of the mounting point. The measured error is ±1%.
Depending upon application, it may be possible to measure to the end of the ballast weight or tie-down loop.

This type of meter is capable of measuring the continuous measurement of bulk solids with grain size up to 20 mm, e.g. sands, minerals, plastics, agricultural products, foodstuffs, pharmaceuticals and solid fuels. The measurement is independent of the moisture content of the bulk solid or a change in product. Silo geometry, angled material surfaces and bulk solid properties also have no effect on the measurement.

Tuning fork

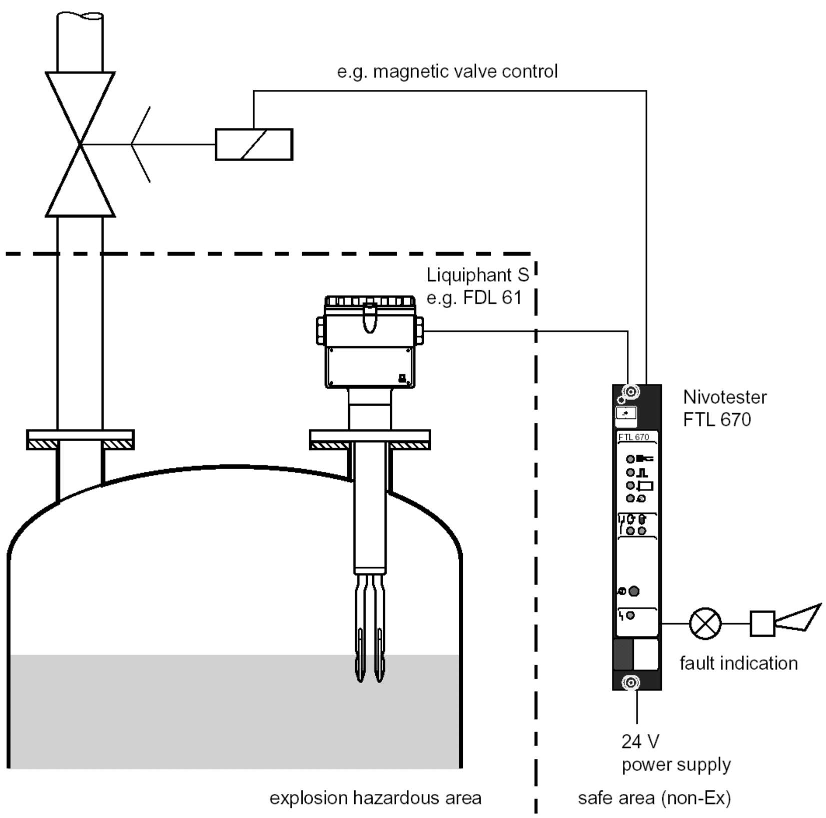
Example of this is E+H, Liquiphant S.

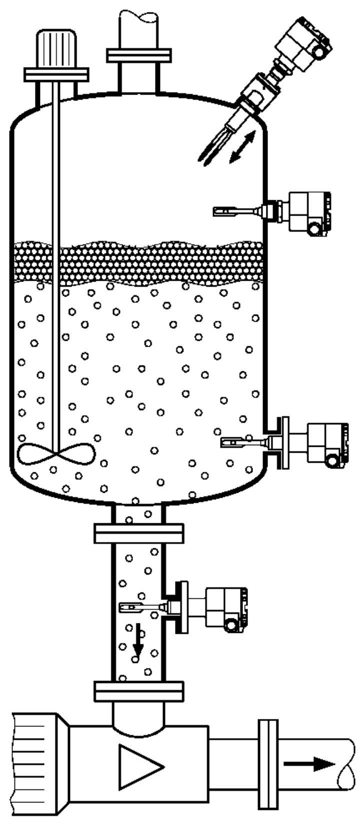


The fork of the Liquiphant S sensor is made to vibrate in air at its resonant frequency by piezo-electric elements. The frequency changes when the fork is submersed in a liquid. The frequency is converted to an interference-immune, pulse frequency modulated signal (PFM) and is transmitted over a two-wire cable to the Nivotester FTL 670. The complete system has an in-built redundancy and a continuous self-checking function. The sensor has two independent electronic sensing circuits which are given identification tags for correct evaluation at the Nivotester FTL 670.

Approved liquids

- Liquids with a viscosity □max. 10000 mm2/s, density □min. 0.5.
- Liquefied gas to DIN 51 622, density □min. 0.44.
- Temperature and pressure, see Technical Data.
- For the Liquiphant "1.4571", all liquids against which 1.4571 steel is sufficiently resistant
- For Liquiphant "Hastelloy C" all liquids against which 2.4610 steel is sufficiently resistant.





ADVANTAGES/DISADVANTAGES OF LEVEL MEASURING SYSTEMS

PRINCIPLE	№	SYSTEM	CHARACTERISTICS	
			ADVANTAGE	*DISADVANTAGE*
Sight	1	Dipstick	Simple, cheap, instant	Need to remove to read
	2	Sight glass	Cheap, fairly foolproof, pressure up to 700 Mpa and 300ºC.	Need to careful handling, brittle.
Floats	3	Tape/float	Cheap, can be used with corrosive liquids, but opening for tape.	Low pressure /atmospheric only. Can stick.
	4	Potentiometer float	Voltage output as above.	Stiction.
	5	Magnetic	as above	Stiction.
Displacers	6	Spring balance	Can be used for interfaces, limited range	Expensive.
	7	Torque tube	Most displacer transmitters use this, accurate but limited range.	Limited range.
Pressure	8	Pressure gauge	Cheap, open and closed tank.	Not available readily in low range inH_2O.
	9	Bubbler method	Can be used for slurries, or corrosive mixtures	Requires air supply.
Weight	10	Load cells	Accurate non-contact method.	Need frequent re-calibration.
Electrical	11	Conductivity	Rugged, requires little maintenance.	Limited to conductive liquids.
	12	Resistance	Rugged, requires little maintenance.	First few inches not accurate.
	13	Capacitive	Rugged and accurate.	Tank must be metal if only one probe is used.
Ultrasonic	14	Echo type	Non-contact.	High pressurise wont work, expensive.
Radiation	15	Absorption	Non-intrusive.	Expensive, not accurate, hazardous source.
Thermal	16	Thermistor	New method, cost reasonable.	On/off only