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Department of Computer Science and Engineering

CSE-2205: Introduction to Mechatronics

Lec-12: Level and Flow Sensors

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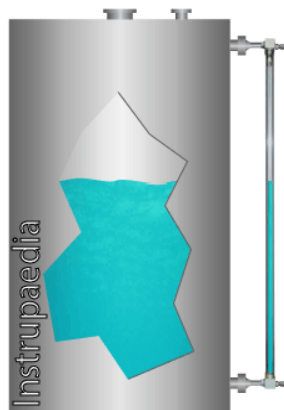
Level Measurements

Level measurement sensors are devices designed to determine the height or level of a liquid, solid, or powder within a container or a process vessel. These sensors play a critical role in various industries, ensuring process control, safety, and efficiency.

1. Sight glass level gauge

It operates based on the principle of the law of communicating vessels, which means that the liquid level in the sight glass will always be the same as the level inside the vessel it's connected to. Here's a clearer explanation with an example:

Principle: A sight glass is a transparent glass tube or pipe that is installed on the outside of a vessel, such as a tank, boiler, or reactor. It is typically connected at the bottom and the top of the vessel, creating a direct visual connection between the inside of the vessel and the outside through the transparent tube.



Sight glass level gauge

Operation:

1. As the liquid level inside the vessel rises or falls, the level in the sight glass also changes accordingly.
2. The liquid inside the sight glass and the vessel reaches the same level due to the law of communicating vessels, where liquids in connected vessels find a common level.

Example: Imagine you have a cylindrical tank filled with water. Attached to the side of this tank is a vertical, transparent glass tube, which is the sight glass. The bottom of the glass tube is connected to the bottom of the tank, and the top is connected to the top of the tank.

1. When the tank is empty, the water level in the sight glass will also be at its lowest point.

2. As you start filling the tank, the water level in both the tank and the sight glass will rise simultaneously.
3. When the tank is half full, the water level in the sight glass will also be halfway up the glass tube.
4. When the tank is completely full, the water level in the sight glass will match the tank's level, indicating that the tank is full.

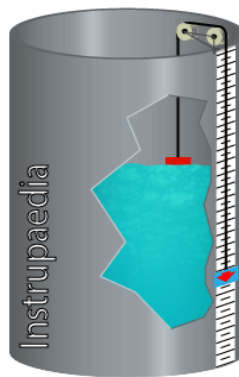
In some sight glasses, there are graduations marked on the glass tube, which allow for precise measurement of the liquid level in the vessel. In other cases, the sight glass simply provides a visual indication of the liquid level without specific measurements.

Sight glass level gauges are commonly used in various industries, such as chemical processing, food and beverage, and power generation, where a quick visual indication of liquid levels is required for monitoring and control purposes. They are simple, reliable, and offer real-time feedback on the status of the liquid in a vessel.

2. Float level gauge

A float level gauge is a traditional and simple technique used to measure the level of a liquid in a tank or vessel. This method was an early attempt to automate level measurement in tanks after manual measurements were made using ropes and attached floats. Here's a clearer explanation with an example:

Principle: A float level gauge operates on the principle of buoyancy. It takes advantage of the fact that a float, which has lower density than the liquid, will float on the surface of the liquid. As the liquid level in the tank rises or falls, the float is buoyed up or down, which is used to indicate the level of the liquid.



Float level gauge

Components:

1. **Float:** A buoyant object, typically made of materials like cork, plastic, or metal, is attached to a rope or chain.
2. **Rope or Chain:** The float is connected to a rope or chain, allowing it to move up and down with the liquid level changes.
3. **Pulleys:** The rope or chain is often passed over two pulleys to guide its movement.
4. **Counterweight:** The rope or chain extends to the outside of the tank where a counterweight is attached. The counterweight serves as an indicator and is often connected to a direct reading gauge board.

Operation: Here's how a float level gauge works with a practical example:

1. Imagine you have a tank filled with a liquid, and you want to measure the level of the liquid using a float level gauge.
2. Inside the tank, a float is connected to a rope or chain. The float has lower density than the liquid in the tank.
3. The rope or chain passes over two pulleys and extends to the outside of the tank. The counterweight on the outside is connected to the end of the rope or chain.
4. As the liquid level in the tank rises or falls, the float moves up or down with it. This movement is transferred through the rope or chain to the counterweight.
5. The position of the counterweight on the outside of the tank serves as an indicator on a direct reading gauge board. By observing the position of the counterweight, you can determine the liquid level inside the tank.

Float level gauges are simple, reliable, and cost-effective. They are often used in applications where precise measurements are not required, and a visual indication of the liquid level is sufficient. However, they may not be suitable for highly corrosive or aggressive chemicals and may require regular maintenance to ensure accuracy.

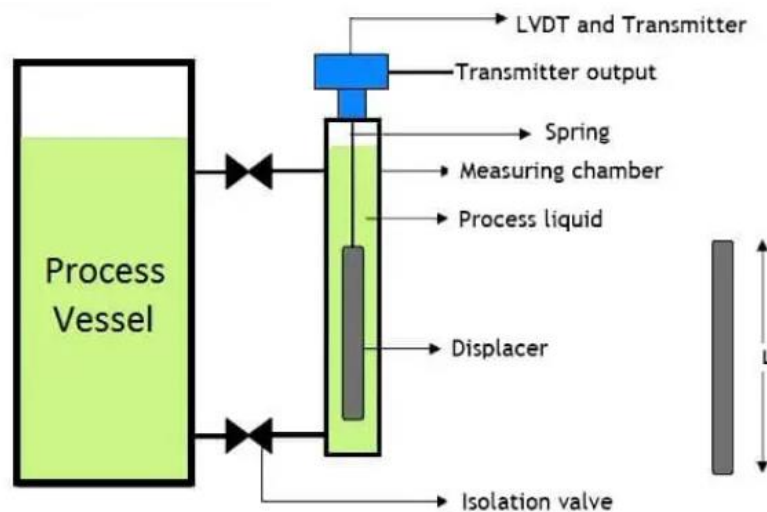
3. Displacer level transmitter principle

A displacer level sensor, also known as a displacer level transmitter, is a device used for measuring the liquid level in tanks and vessels based on Archimedes' Principle, which states that the buoyant force on an object submerged in a fluid is equal to the weight of the fluid displaced by the object. Here's a clearer explanation of how a displacer level sensor works, with a focus on its practical aspects:

Principle: A displacer level sensor continuously measures the weight of a displacer rod immersed in the process liquid. This sensor takes advantage of the buoyant force acting on the displacer rod, which changes as the liquid level in the tank rises or falls.

Components:

1. **Displacer Rod:** The displacer rod is typically cylindrical and can be of varying lengths. It is made of a material with a higher density than the process fluid. The length of the displacer rod is proportional to the liquid level being measured.
2. **Spring:** The displacer is attached to a spring, which restricts its movement as the buoyancy changes with varying liquid levels.
3. **Linear Variable Differential Transformer (LVDT):** The LVDT is a device used to track the rise and fall of the displacer rod as the liquid level changes. It produces a voltage signal proportional to the position of the displacer.
4. **Transmitter and Electronics:** Sophisticated electronics are used to process the voltage signal from the LVDT into a 4-20mA output signal. This output signal is used for level measurement and control purposes.



Operation: Here's how a displacer level sensor operates in a practical sense:

1. The displacer rod is immersed in the process liquid within the tank. When the vessel is full, the displacer rod is fully submerged, and its buoyant force is at its maximum.
2. As the liquid level decreases, the buoyant force on the displacer rod decreases as well, resulting in an apparent increase in the rod's weight.
3. The LVDT registers this change in position and sends a corresponding voltage signal.

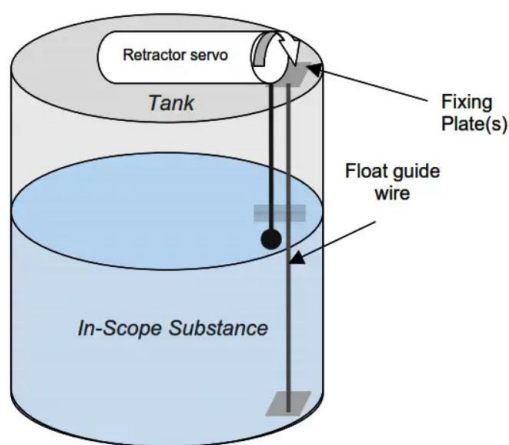
4. The transmitter and associated electronics process the signal, and based on the displacement of the displacer, they generate a 4-20mA output signal that represents the liquid level.
5. The range of the instrument is determined primarily by the length (L) of the displacer rod specified for the given application.
6. The specific gravity (density) of the displacer rod must be higher than that of the process fluid being measured. The range of specific gravity for liquids where the displacer level sensor is applied typically falls in the range of 0.25 to 1.5.
7. The sensor is factory-calibrated to ensure it provides accurate and reliable measurements over its specified range.

Displacer level sensors are commonly used in various industries, such as petrochemical, chemical processing, and refining, where accurate and reliable level measurements are essential for process control and safety. They are particularly suitable for applications involving a wide range of liquid densities and varying process conditions.

4. Servo level transmitter principle

Servo-operated float level measurement is a method used to continuously measure the liquid level in tanks or vessels. It relies on a displacer, typically in the form of a float, which is moved through the tank's open space until it makes contact with the liquid surface. This system continuously maintains the displacer in equilibrium, providing level measurements and the capability to trigger alarms. Here's a clearer explanation with an example:

Principle: Servo-operated float level measurement is based on the principle of maintaining the displacer (float) in equilibrium. As the liquid level in the tank changes, the system adjusts the position of the float to keep it at the liquid's surface, which provides a level measurement.



Components:

1. **Displacer (Float):** The displacer is typically a float made of a material with a specific gravity different from the liquid in the tank. The float's buoyancy allows it to rise or fall with changes in liquid level.
2. **Servo System:** The servo system controls the movement of the float to maintain it at the liquid surface. It is equipped with sensors to detect the float's position and adjusts it as necessary.
3. **Alarms:** The system can be configured to trigger alarms, such as high-high or low-low level alarms, based on the float's position.

Operation: Here's how a servo-operated float level measurement system operates with a practical example:

1. Imagine you have a tank filled with a liquid, and you want to measure the liquid level using a servo-operated float level measurement system.
2. The system adjusts the position of the float within the tank to maintain it at the liquid's surface. As the liquid level rises or falls, the system continually monitors the float's position and ensures it is in equilibrium with the liquid.
3. If the liquid level increases, the system will lower the float to maintain its contact with the liquid's surface. Conversely, if the liquid level decreases, the system will raise the float to keep it in equilibrium.
4. The system continuously provides real-time level measurements based on the float's position. It can also be programmed to activate alarms when certain level thresholds are reached, providing an additional layer of safety and control.

Material Composition and Accuracy: The material composition of the float can affect the accuracy of the level measurement. Magnetic floats, particularly those using magnetostrictive technology, are preferred for their high measurement accuracy.

Limitations and Maintenance: Servo-operated float systems require regular maintenance and cleaning to prevent contamination of the system instruments by tank contents. They are also sensitive to vibrations and wire snapping, which can impact calibration.

Testing: To ensure the accuracy of the level measurement, it is common practice to test these systems by manually moving the float to the top of the tank and allowing it to return to the liquid surface. Modern servo-operated float gauges often have built-in functions to facilitate testing and maintenance.

Servo-operated float level measurement systems are suitable for various applications, including custody transfer, inventory management, and density measurement. When properly maintained and calibrated, they can provide reliable and highly accurate level measurements in industrial settings.

5. Weight and cable level transmitter

A weight and cable level transmitter, also known as an electromechanical level transmitter, is a device used to measure the level of solids or liquids in a tank or vessel. While it's typically used for solids, it can also measure liquid levels by using a floating probe instead of a weight. The operation of this type of transmitter is similar to that of servo level transmitters, with the main difference being in the control of the probe and the internal sensors. Here's a clearer explanation with an example:

Principle: The principle of operation of a weight and cable level transmitter involves lowering a probe (which can be a weight or a floating probe) through the roof of the tank until it makes contact with the surface of the material being measured. When contact is made, the cable becomes slack, and the unwinding of the cable is stopped. The probe is then raised back upwards, and measurements are taken during both the downward and upward movements. Any difference between these measurements is used to calculate the level, volume, or weight of the material in the tank.

Components:

1. **Probe:** The probe is the part of the transmitter that makes contact with the material being measured. It can be a weight or a floating probe, depending on whether solids or liquids are being measured.
2. **Cable:** The cable is used to lower and raise the probe. Its length is measured during both the downward and upward movements.
3. **Electronics:** The transmitter includes electronics that process the measurements and convert them into an output signal that corresponds to the level, volume, or weight of the material in the tank.



Weight and cable level transmitter

Operation: Here's how a weight and cable level transmitter works with a practical example:

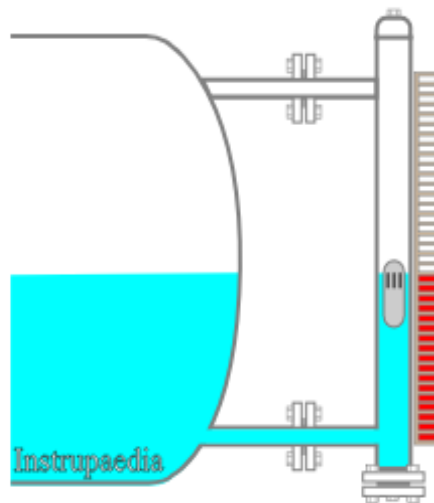
1. Imagine you have a tank containing a material (solid or liquid), and you want to measure the level using a weight and cable level transmitter.
2. The probe (weight or floating probe) is lowered through the roof of the tank until it comes into contact with the material's surface. At this point, the cable becomes slack, and the unwinding of the cable is stopped.
3. The probe is then pulled back upwards, and measurements of the cable's length are taken during both the downward and upward movements.
4. The electronics of the transmitter compare the measurements from the downward and upward movements. Any difference between these measurements is indicative of the level change in the tank, which can be used to calculate the level, volume, or weight of the material.
5. The transmitter converts this information into an output signal that corresponds to the level or volume/weight in the tank, which can be displayed, recorded, or integrated into a control system for monitoring and control.

Weight and cable level transmitters are versatile and can be used to measure both solids and liquids. They are particularly useful in applications where other types of level measurement technologies may not be suitable, such as in environments with extreme temperatures, high pressures, or when measuring the levels of bulk materials. However, regular maintenance and calibration are necessary to ensure accurate measurements.

6. Magnetic level gauge principle

Magnetic level gauges are devices used to measure the liquid level in tanks or vessels, and they operate based on the principles of magnetism and buoyancy. They consist of a vertical pipe, often referred to as 'the chamber,' that contains the process fluid and a float equipped with a magnet. An essential part of the gauge is a transparent enclosure mounted to the chamber with a series of indicators (flags), which are magnetically coupled to the float. Here's a clearer explanation of how a magnetic level gauge works with an example:

Principle: Magnetic level gauges operate on the principle of magnetism and buoyancy, making them a reliable and visually clear way to measure liquid levels.



Magnetic level gauge

Components:

1. **Vertical Chamber (the chamber):** This chamber contains the process fluid and allows the float to move up and down with the liquid's surface.
2. **Float:** The float is equipped with a magnet and is placed inside the chamber. As the liquid level changes, the float rises and falls accordingly.
3. **Transparent Enclosure:** An enclosure made of transparent material is mounted to the chamber. It contains a series of indicators (flags) that are magnetically coupled to the float.

Operation: Here's how a magnetic level gauge operates with a practical example:

1. Imagine you have a tank filled with a liquid, and you want to measure the liquid level using a magnetic level gauge.

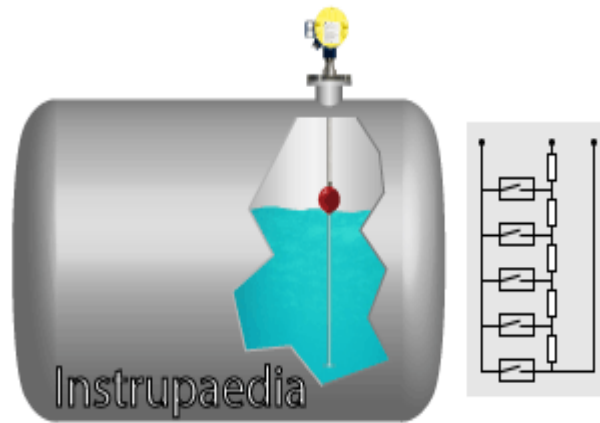
2. Inside the tank, a vertical chamber with the float is connected. The float, which contains a magnet, moves up and down with the liquid's surface as the level rises and falls.
3. The transparent enclosure, mounted to the chamber, contains several indicators (flags) aligned along the outside of the chamber. These flags can rotate around their axes.
4. Each time the float passes by one of the flags, the magnetic fields of the float and the flag become coupled. This magnetic coupling causes the flag to rotate around its axis.
5. As the flag rotates, it changes its orientation. The rear of the flag often has a different color or appearance than the front. When the rear of the flag becomes visible due to the rotation, it serves as a clear visual indicator of the liquid level at that point.
6. As the liquid level continues to change, the float will move up and down, causing different flags to rotate and indicate the liquid level at various points within the tank.

Magnetic level gauges provide a real-time and easily readable indication of liquid levels in a tank. They are commonly used in various industrial applications, such as chemical processing, petrochemical, and power generation, where precise level measurement and visual monitoring are crucial for safety and process control. Magnetic level gauges are particularly useful in environments with harsh conditions or when dealing with corrosive or hazardous materials, as they are sealed and do not require direct contact with the process fluid.

7. Resistive chain principle

A resistive chain level sensor is a device used for measuring the level of a liquid in tanks or vessels. It operates based on the float principle and works in a manner similar to a magnetic level gauge. The sensor consists of a float with an embedded permanent magnet that moves up and down a vertical guide tube. The tube contains a built-in 3-wire potentiometer, which consists of multiple individual resistors in series, each with its own reed contact. Here's a clearer explanation of how a resistive chain level sensor works with an example:

Principle: A resistive chain level sensor operates based on the principle of changing resistance as the float moves up and down the guide tube. The changing resistance is directly proportional to the liquid level in the tank.



Resistive chain

Components:

1. **Float:** The float contains a permanent magnet and moves up and down along the guide tube with changes in the liquid level.
2. **Guide Tube:** The guide tube provides a vertical path for the float's movement and houses the resistive chain and reed contacts.
3. **3-Wire Potentiometer:** The guide tube contains a potentiometer, which is essentially a chain of resistors connected in series. This potentiometer has three wires: one for the starting point, one for the ending point, and one for tapping at various positions.
4. **Reed Contacts:** Reed contacts are located at specific levels along the guide tube. As the float moves, its magnetic field closes the reed contact that corresponds to its position.

Operation: Here's how a resistive chain level sensor works with a practical example:

1. Imagine you have a tank filled with a liquid, and you want to measure the liquid level using a resistive chain level sensor.
2. Inside the tank, a guide tube is connected vertically. The guide tube contains the float with the embedded permanent magnet.
3. The guide tube also houses the 3-wire potentiometer, which consists of a series of individual resistors connected in series. The resistors have reed contacts located at different levels.
4. As the liquid level in the tank changes, the float moves up and down the guide tube.
5. When the float reaches a specific level, its magnetic field closes the reed contact located at that level.
6. The closed reed contact effectively becomes the tapping point on the potentiometer, dividing its total resistance into two parts.

7. The potentiometer is designed so that one part of the resistance chain represents the measured value, which is directly proportional to the liquid level in the tank.
8. This resistance value can be directly transmitted as a resistance value or converted into a current signal for further use in monitoring and control systems.

The resistive chain level sensor provides virtually continuous level measurements, as the resistance changes incrementally with the float's movement. This sensor is suitable for applications where precise level measurement is required, and it offers an alternative to other level measurement methods, such as magnetic level gauges. It is commonly used in industries like petrochemicals, food and beverage, and wastewater treatment.

8. Hydrostatic level measurement principle

Hydrostatic level measurement is a method used to measure the level of a liquid in a tank or vessel based on the principle of hydrostatic pressure. This method relies on pressure sensors to measure the hydrostatic pressure at a specific depth within the liquid column. The hydrostatic pressure is then used to calculate the height of the liquid level in the tank. Here's a clearer explanation of how hydrostatic level measurement works with an example:

Principle: Hydrostatic level sensors utilize the concept of hydrostatic pressure, which is the pressure exerted by a fluid due to the weight of the fluid above a specific depth. In the case of a liquid in a tank, the hydrostatic pressure depends on the depth of the liquid, the density of the liquid, and the acceleration due to gravity.



Hydrostatic level

Components:

1. **Pressure Sensor:** A pressure sensor is the key component of a hydrostatic level measurement system. It is placed at a specific depth within the liquid in the tank.
2. **Density (ρ):** The density of the liquid in the tank is a crucial parameter in the hydrostatic pressure calculation. It is a measure of the mass of the liquid per unit volume.
3. **Gravity (g):** The acceleration due to gravity (usually represented as 'g') is another critical factor in determining the hydrostatic pressure. It is a constant and typically considered to be 9.81 m/s^2 on Earth.

Operation: Here's how hydrostatic level measurement works with a practical example:

1. Imagine you have a tank filled with a liquid, and you want to measure the liquid level using a hydrostatic level sensor.
2. A pressure sensor is installed at a specific depth within the liquid column. It measures the hydrostatic pressure at that depth.
3. The pressure sensor provides this pressure reading to the measurement system.
4. The system uses the hydrostatic pressure reading, along with the known values of density (ρ) and gravity (g), to calculate the height (h) of the liquid level in the tank using the formula: $P_{\text{hydro}} = \rho gh$.
5. Any change in the density of the liquid (due to variations in temperature or composition) or changes in the local gravitational field can affect the accuracy of the level measurement.
6. Hydrostatic level transmitters are commonly used in two types of vessels: open or vented vessels where the gas phase above the liquid is at ambient pressure, and sealed or gas-tight vessels where the pressure above the liquid can vary.
7. In open vessels, one side of the pressure sensor is exposed to the liquid, while the other side is exposed to the ambient pressure. In sealed vessels, the pressure sensor's other side is exposed to the variable pressure above the liquid.
8. By compensating for the pressure on the liquid surface, the hydrostatic pressure measurement becomes more accurate and can provide a reliable indication of the liquid level.

Hydrostatic level measurement is widely used in various industrial applications where precise level monitoring is crucial, such as in chemical processing, water treatment, and oil and gas industries. It is known for its reliability and accuracy in providing continuous level measurements.

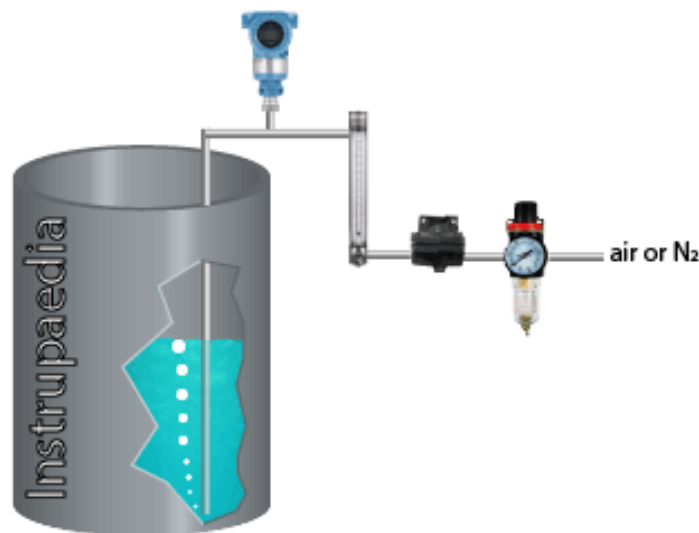
9. Bubble tube principle

Bubble tube level measurement is a method used to measure the level of a liquid in a tank or vessel based on the hydrostatic pressure principle. This approach involves the use of a dip tube, a pressure transmitter, a flow restrictor, and a source of compressed gas. Here's a clearer explanation of how bubble tube level measurement works with an example:

Principle: Bubble tube level measurement is based on the hydrostatic pressure principle. The pressure of the gas in the dip tube is adjusted until it equals the hydrostatic pressure of the liquid at the open end of the tube. This hydrostatic pressure can be measured, and with knowledge of the liquid's density and gravitational acceleration, the level of the liquid in the tank can be calculated using the formula $P_{\text{hydro}} = \rho gh$.

Components:

1. **Dip Tube:** The dip tube is a vertical tube that is inserted into the liquid in the tank. It extends from the liquid's surface to a few centimeters from the tank's bottom.
2. **Pressure Transmitter:** The pressure transmitter is connected to the dip tube and measures the hydrostatic pressure at the open end of the tube.
3. **Flow Restrictor:** A flow restrictor, such as a needle valve or a V-notch ball valve, is used to control the flow of compressed gas into the dip tube.
4. **Source of Compressed Gas:** Air or dry nitrogen is used as a source of compressed gas. This gas is connected to the opposite end of the dip tube.



Bubble tube

Operation: Here's how bubble tube level measurement works with a practical example:

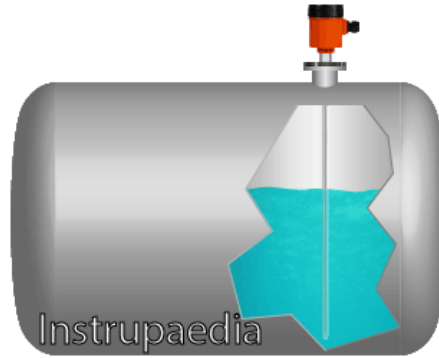
1. Imagine you have a tank filled with a liquid, and you want to measure the liquid level using a bubble tube level measurement system.
2. A dip tube is inserted into the tank and extends from the liquid's surface to a point a few centimeters from the tank's bottom.
3. A pressure transmitter is connected to the open end of the dip tube, and a flow restrictor (e.g., a needle valve) is installed in the gas line that connects to the other end of the dip tube.
4. Compressed gas, such as air or dry nitrogen, is supplied to the dip tube. The gas pressure is adjusted and controlled using the flow restrictor.
5. With the liquid level at 100%, the gas flow can be adjusted so that only a small number of bubbles per minute flow out of the dip tube.
6. As the gas flows through the dip tube, it creates a pressure in the tube. This pressure will rise until it matches the hydrostatic pressure of the liquid at the open end of the tube.
7. The pressure transmitter connected to the dip tube measures this hydrostatic pressure.
8. With knowledge of the liquid's density (ρ) and gravitational acceleration (g), the transmitter can use the formula $P_{\text{hydro}} = \rho gh$ to calculate the liquid level.

Bubble tube level measurement is commonly used in various industrial applications, especially when measuring the level of corrosive, viscous, or turbulent liquids. It is also suitable for applications where other level measurement technologies may be less reliable due to harsh environmental conditions. The system provides continuous and accurate level measurements, making it valuable in various industrial processes.

10. Capacitive level sensor principle

A capacitive level sensor is a device used to measure the level of a liquid in a tank or vessel. It operates based on the principle of capacitance, where changes in the dielectric material between two metal plates result in variations in capacitance. The sensor typically consists of a metal probe that serves as one plate of a capacitor, and the metal tank wall represents the other plate. The liquid inside the tank acts as the dielectric material between these plates. Here's a clearer explanation of how a capacitive level sensor works with an example:

Principle: A capacitive level sensor operates on the principle of capacitance, where the capacity to store electrical charge is affected by the dielectric material between the plates of a capacitor. In this case, the dielectric material is the liquid in the tank.



Capacitive level

Components:

1. **Metal Probe:** The metal probe serves as one plate of the capacitor. It is typically placed in the tank and is in contact with the liquid.
2. **Metal Tank Wall:** The metal tank wall represents the other plate of the capacitor. It surrounds the tank and is electrically connected to the sensor.
3. **Liquid:** The liquid inside the tank serves as the dielectric material between the two plates.
4. **Reference Probe (if needed):** In cases where the tank is made of non-conductive material, a reference probe is used as the second plate of the capacitor.

Operation:

Here's how a capacitive level sensor works with a practical example:

1. Imagine you have a tank filled with a non-conductive liquid (e.g., oil), and you want to measure the liquid level using a capacitive level sensor.
2. Inside the tank, a metal probe is inserted, and the probe is in contact with the liquid. The metal tank wall serves as the other plate of the capacitor.
3. The space between the metal probe and the tank wall is filled with the non-conductive liquid. This liquid acts as the dielectric material.
4. A capacitor is formed, and its capacitance is determined by the area of the plates, the distance between them, and the dielectric constant of the liquid.
5. As the liquid level rises in the tank, it comes into contact with more of the metal probe, effectively increasing the area of the plates in the capacitor. This increase in plate area results in a higher capacitance.
6. The capacitive level sensor measures this change in capacitance and converts it into a level reading. The change in capacitance is directly proportional to the height of the liquid in the tank.
7. The sensor can provide real-time and continuous level measurements and is often used in various industrial applications where accuracy and reliability are crucial.

8. In cases where the tank is made of non-conductive material (e.g., plastic), a reference probe is used to complete the capacitor. The reference probe serves as the second plate, and the operation is similar to the example above.

Capacitive level sensors are widely used in industries like chemical processing, food and beverage, and wastewater treatment. They are known for their accuracy and reliability in measuring various types of liquids, including those that are corrosive or viscous. These sensors are also suitable for applications where other level measurement methods may not be practical.

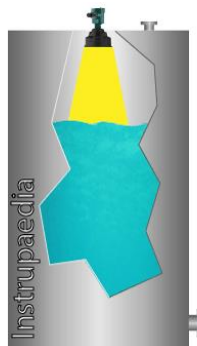
11. Ultrasonic level transmitter principle

An ultrasonic level sensor is a device used to measure the level of a liquid or solid material in a tank or vessel. It operates based on the principle of time-of-flight (TOF) of ultrasound pulses, where a high-frequency ultrasound pulse is emitted from the sensor, and the time it takes for the pulse to travel to the surface of the material and bounce back to the sensor is used to calculate the level. Here's a clearer explanation of how an ultrasonic level sensor works with an example:

Principle: An ultrasonic level sensor relies on the measurement of the time it takes for an ultrasound pulse to travel to the surface of the material and back to the sensor. This time-of-flight (TOF) measurement is used to calculate the level of the material in the vessel.

Components:

1. **Ultrasonic Transmitter:** The ultrasonic sensor emits a high-frequency ultrasound pulse (typically between 10 to 70 kHz) directed towards the surface of the material in the tank.
2. **Reflected Signal (Echo):** When the ultrasound pulse hits the surface of the material, it reflects back to the sensor. This reflected signal is often referred to as the "echo."
3. **Transmitter Electronics:** The transmitter electronics process the time it takes for the echo to arrive back at the sensor.
4. **Total Height of the Vessel:** The transmitter also has information about the total height of the vessel, which is typically programmed or set manually.



Operation: Here's how an ultrasonic level sensor works with a practical example:

1. Imagine you have a tank filled with a liquid, and you want to measure the liquid level using an ultrasonic level sensor.
2. The ultrasonic sensor emits a high-frequency ultrasound pulse directed towards the liquid's surface.
3. When the ultrasound pulse reaches the liquid surface, it bounces back as an echo to the sensor.
4. The sensor's transmitter electronics measure the time it takes for the echo to return to the sensor. This time measurement is used to calculate the distance from the sensor to the liquid surface.
5. Using the formula for calculating distance based on TOF ($d = (t \times v) / 2$), where "d" is the distance, "t" is the time of flight, and "v" is the speed of sound in the medium, the sensor determines the distance to the liquid surface.
6. With the distance to the surface known, the sensor's transmitter can now determine the level inside the vessel. It subtracts the distance to the surface from the total height of the vessel.
7. The result is an accurate measurement of the liquid level in the tank, which can be displayed and used for control and monitoring purposes.

Ultrasonic level sensors are versatile and can be used for measuring both liquids and solids. They are commonly employed in various industries, including water treatment, agriculture, chemical processing, and manufacturing, where non-contact and accurate level measurements are essential. These sensors are suitable for applications where the liquid or solid material may be corrosive, hazardous, or subject to extreme temperatures, as they do not require direct contact with the material being measured.

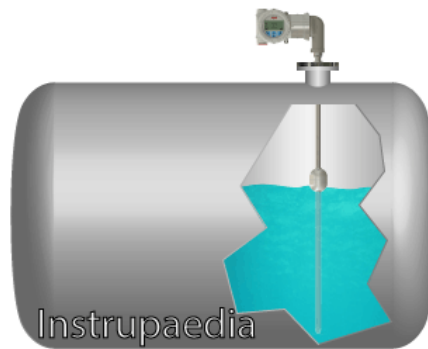
12. Magnetostrictive principle

A magnetostrictive level sensor is a device used to measure the level of a liquid in a tank or vessel. It operates based on the Wiedemann effect, one of the four effects related to magnetostriction in ferromagnetic materials. This technology involves a float that slides along a vertical ferromagnetic rod (waveguide) during changes in liquid level. By measuring the time it takes for a pulse to travel down the waveguide and back, the sensor can accurately determine the position of the float, and thus the level of the liquid. Here's a clearer explanation of how a magnetostrictive level sensor works with an example:

Principle: The Wiedemann effect is one of the magnetostrictive effects associated with ferromagnetic materials, where a change in magnetic field induces mechanical strain in the material. In the case of a magnetostrictive level sensor, this effect is used to measure the position of a float inside a tank, which corresponds to the liquid level.

Components:

1. **Float:** The sensor consists of a float that moves along a vertical ferromagnetic rod (waveguide) during changes in liquid level. A permanent magnet is located inside the float at a specific position, representing the level of the liquid.
2. **Waveguide:** The vertical ferromagnetic rod or waveguide serves as the medium for transmitting and receiving signals in the sensor.
3. **Transmitter:** The transmitter is responsible for generating the excitation signal and measuring the time it takes for the signal to travel along the waveguide and return.
4. **Pick-Up Coil or Piezo Crystal:** At the top of the waveguide, there is a pick-up coil or a piezo crystal that detects the acoustic torsional wave and converts it into an electrical signal.



Operation: Here's how a magnetostrictive level sensor works with a practical example:

1. Imagine you have a tank filled with a liquid, and you want to measure the liquid level using a magnetostrictive level sensor.
2. The sensor consists of a float that moves along a vertical ferromagnetic rod (waveguide) inside the tank. The float contains a permanent magnet positioned at a specific height to represent the level of the liquid.
3. To initiate the measurement, the transmitter sends a short current pulse down the waveguide and starts a timer from the moment the pulse leaves the transmitter.
4. As the current pulse travels through the waveguide, it generates a small circular magnetic field around the rod.
5. When the pulse reaches the float, its circular magnetic field interacts with the magnetic field of the permanent magnet inside the float. This interaction induces a mechanical torsional force in the waveguide, as if the rod is locally twisted.
6. This torsional force is propagated along the waveguide as an acoustic torsional wave and travels back to the transmitter at a constant speed, which is close to the speed of sound.

7. At the top of the waveguide, a pick-up coil or a piezo crystal detects the torsional wave and converts it into an electrical signal.
8. Simultaneously, the timer is stopped, and the time delay from the excitation of the waveguide to the reception of the corresponding acoustic wave is measured.
9. Knowing that the acoustic wave traveled at a constant speed, the system can now calculate the position of the float inside the tank.
10. By subtracting this position from the total height of the vessel, the sensor accurately determines the level of the liquid in the tank.

Magnetostrictive level sensors are commonly used in industrial applications where accurate and reliable level measurements are required, such as in storage tanks, process vessels, and petrochemical industries. These sensors are known for their precision and suitability for harsh environments.

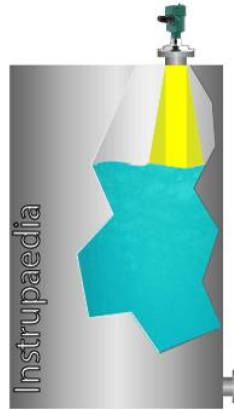
13. Non-contact radar principle

A non-contact radar level sensor is a device used to measure the level of a liquid or solid material in a tank or vessel without physical contact with the material. It utilizes radar technology and operates based on the principles of either Frequency Modulated Continuous Wave (FMCW) or Pulsed Time-of-Flight (ToF or PToF). Both technologies are highly effective for accurate level measurements in a wide range of industrial applications. Here's a clearer explanation of how non-contact radar level sensors work with both FMCW and PToF principles:

Principle: Non-contact radar level sensors use radar technology to measure the distance between the sensor and the surface of the material in the tank. The two primary radar technologies are FMCW and PToF, and both are based on the measurement of time delays or frequency differences to calculate the distance to the surface.

Components:

1. **Transmitter:** The radar sensor includes a transmitter that emits radar waves toward the surface of the material.
2. **Antenna:** The sensor is equipped with an antenna for both transmitting and receiving radar signals.
3. **Microprocessor:** The sensor has an onboard microprocessor that processes the received signals and calculates the distance to the material surface.
4. **Tank Height:** The height of the tank or vessel is typically programmed into the sensor to enable level calculations.



Pulsed Time-of-Flight (PToF) Principle:

1. In PToF radar systems, the radar antenna emits a high-frequency electromagnetic pulse (a short burst of radar waves) toward the surface of the material.
2. This pulse travels at the speed of light and reflects from the material's surface due to a change in the dielectric constant.
3. The reflected pulse returns to the radar sensor, and the sensor measures the time delay between the emitted and received pulse, known as the "time of flight."
4. Using the formula: $\text{Distance} = (\text{Speed of Light} \times \text{Time of Flight}) / 2$, the sensor calculates the distance to the material surface.
5. With the tank height programmed into the sensor, it can determine the level by subtracting the calculated distance from the tank height.

Frequency Modulated Continuous Wave (FMCW) Principle:

1. In FMCW radar systems, the radar antenna emits a continuous wave of radar signals with a linear frequency sweep at a fixed bandwidth and sweep time.
2. The emitted frequency continuously changes between two fixed values, creating a triangular waveform pattern.
3. When the radar signal encounters the material surface, it bounces back to the sensor as a reflection.
4. The reflected signal is received by the antenna and sent to a mixer to be compared with the transmitted signal.
5. The difference in frequency between the emitted and received signals is directly proportional to the time of flight and, consequently, to the distance to the material surface.
6. The onboard microprocessor calculates the distance to the surface and determines the level by subtracting this distance from the programmed tank height.

Non-contact radar level sensors can be equipped with various types of antennas and can operate at different frequencies, making them suitable for a wide range of applications where accurate and non-invasive level measurements are required. These sensors are used in industries such as petrochemical, water treatment, food and beverage, and many others, where reliable and real-time level data is crucial for control and monitoring purposes.

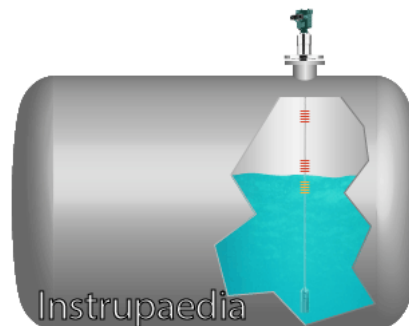
14. Guided wave radar principle

Guided wave radar (GWR) level measurement is a radar-based technique used to measure the level of liquids or solids in tanks or vessels. GWR has its origins in time-domain reflectometry (TDR), which was initially developed for detecting fractures in underground cables. In GWR, this technology is used to measure the distance from the sensor to the surface of the liquid or solid material. Here's a clearer explanation of how guided wave radar level sensors work:

Principle: Guided wave radar level sensors utilize radar technology, specifically time-domain reflectometry, to measure the distance between the sensor and the surface of the material in the tank or vessel. The sensor's antenna is designed as a probe, often referred to as the "waveguide," and it is immersed in the process medium to make the measurement.

Components:

1. **Waveguide Antenna:** The sensor's antenna has the shape of a probe, which is referred to as the waveguide. The length of the waveguide determines the measurement range.
2. **Transmitter:** The radar transmitter emits a high-frequency electromagnetic pulse that is sent down the waveguide toward the surface of the measured product.
3. **Microprocessor:** The sensor includes an onboard microprocessor that processes the reflected signals and calculates the distance to the material's surface.



Operation: Here's how a guided wave radar level sensor works:

1. The guided wave radar level sensor is installed in the tank or vessel with the waveguide antenna immersed in the process medium.

2. To initiate a measurement, the radar transmitter emits a high-frequency electromagnetic pulse that travels down the waveguide toward the surface of the material.
3. As the pulse approaches the surface of the material, part of it is reflected back up the waveguide, while the other part penetrates the material.
4. The reflected wave is received by the sensor's antenna, and the microprocessor calculates the time delay between the generated pulse and the reflected pulse. This time delay is known as the "time of flight."
5. The sensor uses the time of flight to calculate the distance from the sensor to the surface of the material, using the formula: $\text{Distance} = (\text{Speed of Light} \times \text{Time of Flight}) / 2$.
6. The result of this calculation provides the exact distance to the material's surface, allowing the sensor to determine the level of the material in the tank or vessel.

Guided wave radar level sensors are known for their accuracy and reliability in various industrial applications, including those with challenging process conditions, such as high temperatures, high pressures, or aggressive chemical environments. They are suitable for both liquid and solid level measurements and are commonly used in industries like oil and gas, chemical processing, food and beverage, and water treatment, among others, where precise level data is essential for control and monitoring purposes.

15. Laser level transmitter principle

A laser level transmitter is an advanced level measurement device that utilizes laser technology to accurately determine the level of liquids or solids in a tank or vessel. Laser level transmitters use pulsed lasers for industrial applications due to their ability to penetrate dust and steam. The principle behind laser level measurement is based on the time-of-flight technique, which measures the time it takes for a laser pulse to travel to the material's surface and back to the sensor. Here's a clearer explanation of how a pulsed laser level transmitter works:

Principle: A pulsed laser level transmitter uses a laser diode to emit a highly focused laser pulse with a very sharp beam angle (typically less than 0.3 degrees). This laser pulse is directed toward the surface of the process medium in the tank.

Components:

1. **Laser Diode:** The laser diode is responsible for emitting the laser pulse.
2. **Receiver:** The sensor incorporates a receiver to capture the reflection of the laser pulse from the material's surface.
3. **Timing Circuit:** A precise timing circuit measures the time delay between the transmission of the laser pulse and the reception of the reflected pulse.

4. **Microprocessor:** The onboard microprocessor processes the timing data and calculates the distance to the material's surface.



Operation: Here's how a pulsed laser level transmitter operates:

1. The laser level transmitter is installed in the tank or vessel, and the laser diode emits a sharply focused laser pulse.
2. The laser pulse travels towards the surface of the material within the tank.
3. Upon reaching the material's surface, the laser pulse is reflected back towards the sensor.
4. The receiver captures the reflected pulse, and the timing circuit measures the time delay between the transmission and reception of the pulse, which is known as the "time of flight."
5. Using the formula: $\text{Distance} = (\text{Speed of Light} \times \text{Time of Flight}) / 2$, the microprocessor calculates the precise distance from the sensor to the surface of the material.
6. With the height of the tank already programmed into the sensor, the microprocessor can determine the level by subtracting the calculated distance from the tank's height.

Laser level transmitters are known for their high accuracy and reliability, making them suitable for a wide range of industrial applications. They are often used in situations where non-contact and non-invasive level measurements are required, and they excel in challenging environments where dust, steam, or other environmental factors might interfere with other measurement techniques. These sensors are commonly found in industries such as oil and gas, chemical processing, water treatment, and bulk solids handling, where precise and real-time level data is crucial for process control and monitoring.

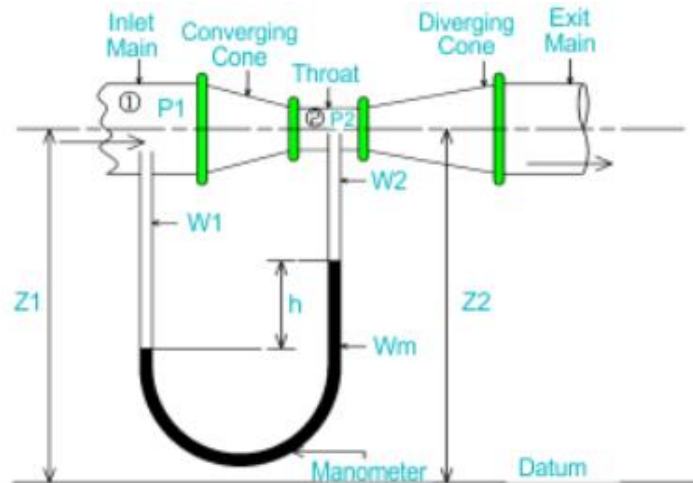
Flow Meters

Flow meters are instruments used to measure the rate at which a fluid, whether it's a gas or liquid, flows through a pipe or channel. There are various types of flow meters designed to suit different applications and measurement needs.

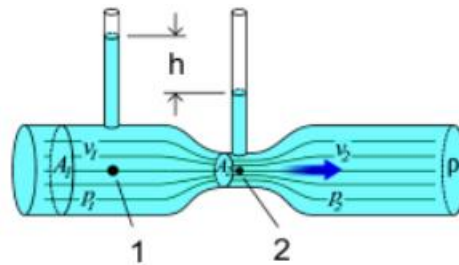
Venturi Meter

A Venturi meter is a flow measurement device that operates on the principles of Bernoulli's equation and fluid dynamics. It is commonly used to measure the flow rate of fluids in pipes. The key components of a Venturi meter include a cylindrical inlet, a converging cone, a throat, a diverging cone, and a differential manometer.

- **Pipe or Cylindrical Inlet:** This end of the meter is attached to the pipe through which the fluid flows.
- **Converging Cone or Part:** A short pipe that converges from a diameter that is equal to that of the pipe to a smaller diameter is known as a converging cone or portion. The converging cone has an angle of $21 \pm 2^\circ$.
- **Throat:** It is a small cylindrical section. Typically, the diameter of the throat ranges between $\frac{1}{12}$ and $\frac{1}{4}$ of the diameter of the cylindrical inlet and is equal to its length. Here, pressure is reduced while velocity is increased.
- **Diverging Cone or Part:** The tube diameter steadily increases at this point. As a result, the pressure is increased again to its initial inlet pressure. The diverging cone angle ranges between 5° to 7° .
- **Differential Manometer:** The manometer is a device for measuring the pressure exerted on a fluid column. Pressure differences are typically measured using differential manometers.
- **Capillary Tubes:** These tubes are made of glass or other hard materials like steel, fitted on top of the venturi tube to which the fluid at high pressure flows. These are used to reduce or control pressure.



Working Principle: The working principle of a Venturi meter is based on the application of Bernoulli's equation, which relates the pressure, velocity, and potential energy of a fluid along a streamline. Here's how a Venturi meter operates:



The apparatus is generally preceded by a straight pipe through which the fluid, whose rate of flow is to be measured, flows. It enters the cylindrical inlet of area A_1 with velocity V_1 and pressure P_1 . If the pressure is high, the fluid flows into the capillary tubes. As it passes through a smaller area A_2 , there is a reduction in the pressure. This is called the “venturi effect”.

The velocity increases as pressure decreases in this section. This is because the volume of fluid entering at V_1 and P_1 should pass through that smaller area A_2 at the same time. Again, the fluid flows into the capillary tube past section 2 to equalize pressure throughout the fluid as it flows.

But the fluid in the capillary tube in section 1 is less than that of section 2. This creates a differential pressure head ‘ h ’. These are the effects of Bernoulli's principle which states that “an increase in the velocity of a fluid is followed by a reduction in static pressure or the potential energy of the fluid”.

These values are then recorded to measure the coefficient of discharge of venturimeter which is followed by the calculation of actual Q_{act} and theoretical discharge Q_{th} through the pipe. Let us understand the discharge by a simple derivation.

Derivation of Equation for Discharge

The fluid is assumed to be ideal while deriving the formula for discharge which is also known as the venturimeter formula. The theoretical flow rate of the meter is derived by applying the continuity equation. Let us refer to Figures 2 & 3 for notations of the formula.

Let,

ρ = Density of fluid to be measured, in kg/m^3

g = Acceleration due to gravity, in m/s^2

Z_1 & Z_2 = Distance from the bottom or datum head at section 1 and 2, in m

We studied that the venturimeter works on Bernoulli's principle. Applying the principle to both the sections,

$$\frac{P_1}{\rho g} + \frac{(V_1)^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{(V_2)^2}{2g} + Z_2$$

Both the datum heads or the distance from the ground is the same. So,

$$\begin{aligned} \frac{P_1}{\rho g} + \frac{(V_1)^2}{2g} &= \frac{P_2}{\rho g} + \frac{(V_2)^2}{2g} \\ \implies \frac{P_1 - P_2}{\rho g} &= \frac{(V_2)^2 - (V_1)^2}{2g} \end{aligned}$$

The LHS of this equation is called the differential pressure head and is denoted by 'h' i.e. $h = \frac{P_1 - P_2}{\rho g}$... (a).

By continuity equation, $A_1 \cdot V_1 = A_2 V_2$

$$\implies V_2 = \frac{A_1 V_1}{A_2}.$$

Thus, substituting the value of V_2 in equation (a) and evaluating the value of V_2 , we have

$$(V_2)^2 = 2gh \left[\frac{(A_1)^2}{(A_1)^2 - (A_2)^2} \right]$$

$$\implies V_2 = \left(\frac{A_1}{(A_1)^2 - (A_2)^2} \right) \sqrt{2gh}$$

Now, the discharge 'Q' is defined as the product of area and velocity of flow. Mathematically, "Q = A . V"

This is measured along section 2. Hence, the equation becomes $Q = A_2 \cdot V_2$.

Substituting the values and equating for Q,

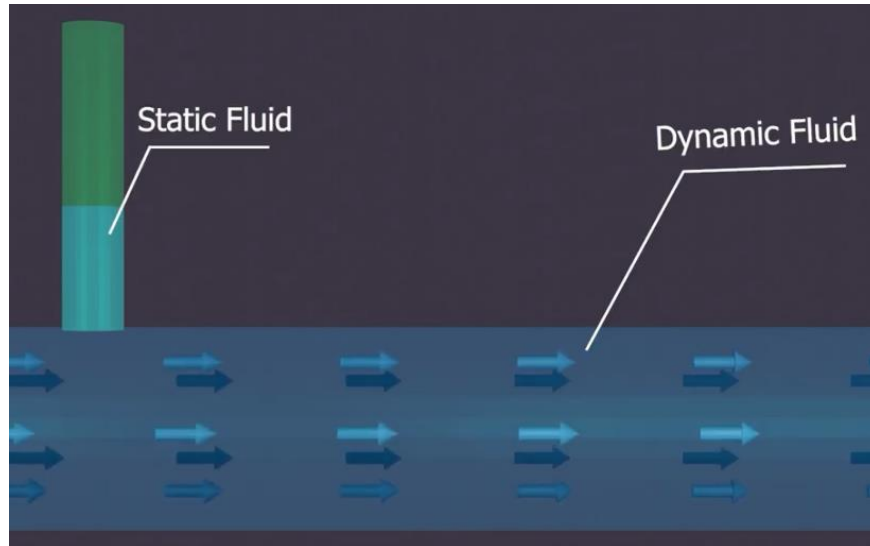
$$Q = \frac{A_1 A_2}{\sqrt{(A_1)^2 - (A_2)^2}} \sqrt{2gh} \dots (b)$$

Equation (b) is known as the theoretical discharge. To calculate the actual discharge, we need to understand the coefficient of discharge of venturimeter C_d . It is defined as the ratio of actual discharge to the theoretical discharge of the venturimeter i.e. $C_d = \frac{Q_{act}}{Q_{th}}$.

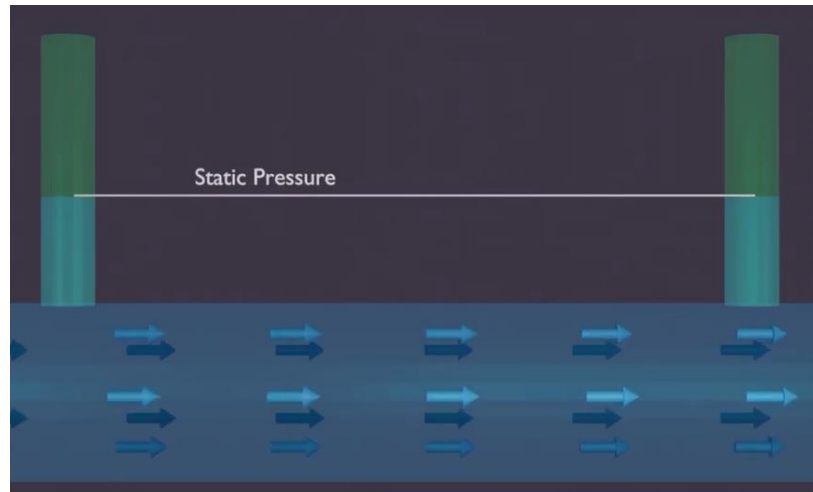
Thus, the actual discharge is given as $Q_{act} = C_d \times \frac{A_1 A_2}{\sqrt{(A_1)^2 - (A_2)^2}} \sqrt{2gh}$.

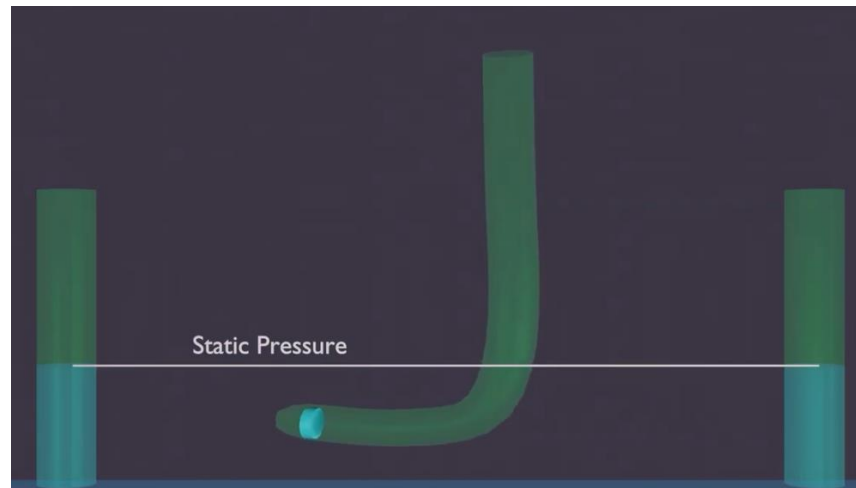
Pitot Tubes

Tube is used to calculate the static pressure by measuring the height to which a column of liquid rises against gravity.



The static pressure height would be same considering the fluid is steady and incompressible.

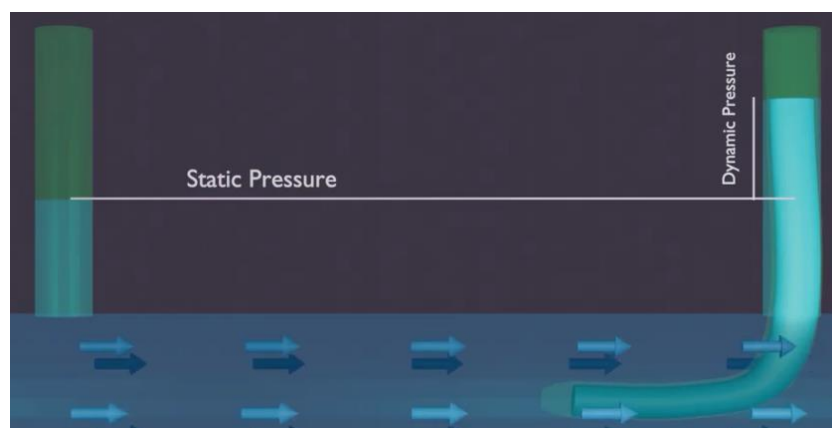




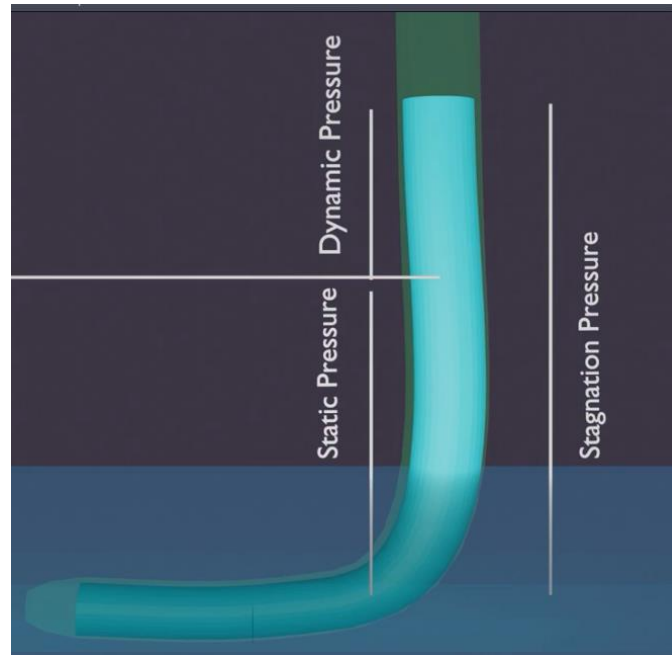
If we replace it with a pitot tube, the column of height of water will increase



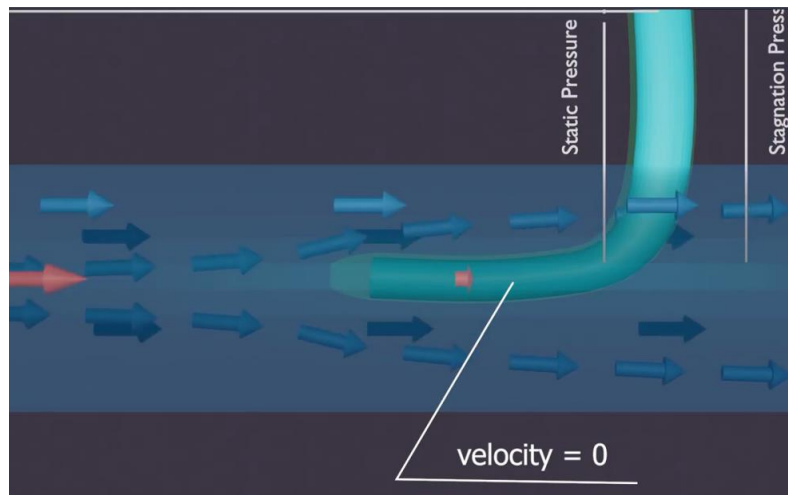
The extra height is called dynamic pressure caused due to stagnation pressure.



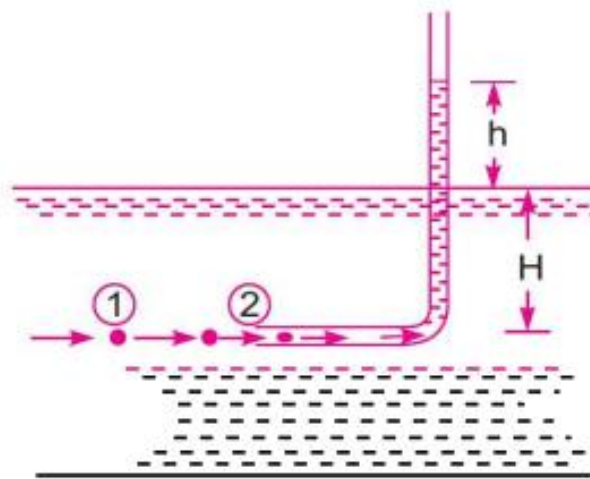
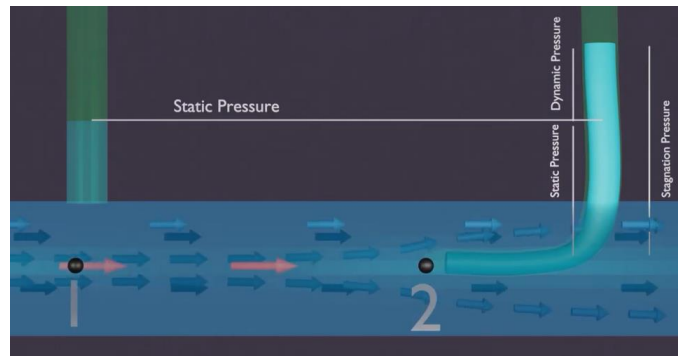
When the water particles enters the pitot tube, its velocity will convert to dynamic pressure



Stagnation pressure represents the pressure at a point where the fluid is brought to a complete stop.



- ☐ Measuring the velocity of flow at any point in a pipe
- ☐ Principle: If the velocity of flow at a point becomes zero, the pressure there is increased due to the conversion of the kinetic energy into pressure energy



Applying Bernoulli's equation at points (1) and (2), we get

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

But $z_1 = z_2$ as points (1) and (2) are on the same line and $v_2 = 0$.

$$\frac{p_1}{\rho g} = \text{pressure head at (1)} = H$$

$$\frac{p_2}{\rho g} = \text{pressure head at (2)} = (h + H)$$

Substituting these values, we get

$$\therefore H + \frac{v_1^2}{2g} = (h + H) \quad \therefore h = \frac{v_1^2}{2g} \quad \text{or} \quad v_1 = \sqrt{2gh}$$

This is theoretical velocity. Actual velocity is given by

$$(v_1)_{\text{act}} = C_v \sqrt{2gh}$$

where C_v = Co-efficient of pitot-tube

$$\therefore \text{Velocity at any point} \quad v = C_v \sqrt{2gh}$$