Measurement 101:

Temperature, Pressure, Level and Flow

Endress+Hauser
People for Process Automation

Flow Measurement Guide 101

Product overview for applications in liquids, gases, and steam

Reasons for Flow Measurement

Precision flow meters are used to accurately monitor and/or control flow. Different industrial applications require different levels of precision as well as different levels of accuracy.

Industrial flow measurement is becoming increasingly important based on the benefits of consistent product quality, safety, process optimization, and environmental protection. Industrial processes involving store water, natural gas, steam, mineral oil, and other chemicals need to be measured each and every day.

There is no single technology suitable for across-the-board measurement. There are a number of flow measurement systems depending on your needs, and as such, there are a number of flow measurement methods.

Flow Meter Terminology

Repeatability—The ability of a flow meter to indicate the same value for an identical flow rate more than once. This should not be confused with accuracy.

Turn down—Also known as **Turn Down Ratio**, this describes the range of flow rates between maximum and minimum flow over which a flow meter will work well, depending on the accuracy limits and tolerance specifications.

Flow meter accuracy—The amount of error that can occur with the flow meter's measurements.

Percent of flow rate (%R)—The error in the measurement of flow rate when the accuracy of the meter is presented as a percent of flow rate; **error = % flow rate x measurement**

Percent of full scale (%FS)—The error in the measurement of flow rate when the meter's accuracy is presented as a percent of full scale; **error = %full scale x full scale flow**

Percent of calibrated span (% CS)—The error in the measurement of flow rate when the meter's accuracy is presented as a percent of calibrated span; **error = % calibrated span x calibrated span**

Percent of Upper Range Limit (%URL)—The error in the measurement of flow rate when the meter's accuracy is presented as a percent of the upper range limit; **error = %URL x upper range limit**

Coriolis Flow Measurement

The Coriolis Principle allows the flow of mass to be directly measured. Coriolis flow meters work based on this principle. These meters contain a constantly-oscillating tube inside them that run the length of the meter. If there is no flow, the tube oscillated evenly. Two sensors located at either end of the tube precisely measure the oscillation.

As liquid flows through the tube, it oscillates in a snake-like motion, causing the two sensors to measure the oscillations in different directions. The higher the velocity of the flow, the greater the defection of the oscillating measuring tube.

A Coriolis flow meter can also measure the density of a liquid. A tube filled with water, for example, will oscillate faster than a tube filled with honey. The oscillating frequency directly measures the density of the liquid. Endress+Hauser is a pioneer in adapting the Coriolis flow technology for multiple processes, such as measuring mass flow, volume flow, density, temperature, and even viscosity, all of which can be measured simultaneously.

Ultrasonic Flow Measurement

Ultrasonic flow meters use ultrasound and differential transit time to measure the flow of substances. Inside ultrasonic flow meters, pairs of sensors are fitted across from each other in the measuring tube, each of which can emit and receive ultrasonic signals. The transit time between these sensors are measured to obtain a reading. More sensors provide a more accurate reading.

When there is no flow, the transit time of the ultrasonic signals are the same. Once the liquid starts moving, ultrasonic signals are accelerated in the direction of the flow (taking less time to reach the opposite sensor), and decelerated against the flow (taking more time to reach the opposite sensor). The differential transit time between the sensors is directly proportional to the flow velocity in the pipe. The greater the flow velocity, the greater the time difference between the sensors.

Endress+Hauser is also the innovator behind the clamp-on sensors in these systems, which can be fitted outside the pipe, regardless of its size, and measure flow velocity and volume by sending ultrasonic signals through the liquid.

Ultrasonic flow measurement is cost effective, has more flexibility in mounting, and is safer for a number of processes.

Electromagnetic Flow Measurement

Electromagnetic flow meters contain two fueled coils on opposite ends of the meter. These coils generate a constant electromagnetic field along the cross section of the measuring tube. Two electrodes which can pick up electrical voltages are installed at right angles from the coils on the tube walls.

If there is no flow in the tube, the two electrodes do not measure any electrical voltage. In the meantime, the electromagnetic field charges the particles in the liquid. As the liquid moves, the positively and negatively charged particles are separated and collect on the opposite sides of the tube. The resulting electrical voltage is detected by the two electrodes and measured.

The voltage is directly proportional to the flow velocity. The greater the flow velocity and the separation between the electromagnetically charged particles, the greater the voltage measured by the electrodes.

Thermal Flow Measurement

Thermal flow meters include two sensors on the inside of the tube. One of these sensors measures the temperature of the gas regardless of flow velocity. The other sensor is heated in order to constantly maintain a temperature difference between the two sensors and the material.

As the fluid moves, the heated sensor cools, and more heat has to be generated to compensate for the drop in temperature. The heating current required to maintain the difference is proportional to the mass flow in the pipe.

The greater the flow velocity, the greater the heating current required. The faster the gas flows, the faster the cooling and heat required to maintain the temperature difference, and greater the flow velocity.

Vortex Flow Measurement

Vortex flow meters work based on the vortex principle, or on the physical properties of vortexes. Each vortex flow meter has a bluff body is located in the middle of the pipe. It is used to disturb the flow of a liquid or gas. Directly above the bluff body is a sensor that can measure the smallest pressure differences in the fluid.

When there is no fluid movement, there are no forming vortexes. As the fluid starts to move and reaches a specific flow rate, vortexes appear downstream of the bluff body. The sensor measures the distance between consecutive vortexes, which corresponds to a defined volume of fluid. Total flow can be calculated by counting the vortexes that pass by the sensor.

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Level Measurement

Continuous level measurement and point level detection in liquids and bulk solids

Reasons for Level Measurement

Level measurement is the best way to keep track of inventory based on volume and weight, and a key component for accurately and reliably measuring the contents of a tank or silo.

Level measurement is also important for custody transfer, when material that is bought and sold is transferred based on level measurement. The number is converted into volume or weight, and accuracy is a major factor—even an error of 1/8 inch or 3 mm of measured level is a large error and can greatly complicate the accuracy.

Level measurement also leads to process efficiency and safety. Knowing the accurate levels leads to efficient use of storage space. Properly monitoring levels also prevents accidents and meets safety regulations.

Level Measurement Terminology

Indication —Level measurement systems with indicators require an operator to read the output and take any necessary actions. These are also known as "open-loop control systems."

Control —Level measurement systems that are automatically controlled emit signals that are received by a controller, which in turn activates any relevant processes. These are also known as "closed-loop systems."

Tank gauging systems—Tank gauging systems are used for raw materials storage, such as in pipelines, refineries, and power plants or airport fuel depots.

Continuous level transmitters —Continuous level transmitters are used in plants that are independent and automatic. These are found in chemical, oil and gas, power, pulp and paper, mining, pharmaceutical, food and beverage, and other process plants.

Bottom-up measurement —Bottom-up measurement systems are systems with level devices that use pressure transmitters. These systems typically come in contact with process fluid.

Top-down measurement —Top-down measurement systems are systems that require level measurement devices to be installed or removed without emptying the tank. These systems pose less potential for leakage.

Direct measurement —Direct measurement means that you are measuring the level directly, such as checking the oil level of a car with a dipstick.

Indirect measurement —Indirect measurement means that you are first calculating factors other than the level to then calculate the level of the contents of a system.

Measuring Principles for Various Media

Storage tanks are filled with and drained of a variety of media such as solids, liquids, and gases every day. Measuring principles vary based on these different media. Typically, storage tanks hold liquids like oils, acids, and potable water, gases like grains or powder, and gases like nitrogen. There are a number of principles behind the methods for measuring these varied media, which include continuous level measurement and point level detection in bulk solids and liquids.

Vibronic Principle in Point Level Measurement

The vibronic level measurement principle, invented by Endress+Hauser in 1967, uses the direct correlation between oscillation and damping in media. Vibronic instruments monitor point levels in tanks, silos, and pipes. This is done primarily through a tuning-fork shaped sensor attached to the instrument, which is excited to its resonance frequency.

In liquids measurement, the tuning fork sensor is placed horizontally and oscillates based on the height level of the liquid. When the sensor is not in contact with the liquid, it oscillates at a rapid pace. When it is fully submerged, it oscillates at a slow pace. This oscillation is converted into a switching signal.

In solids measurement, the tuning fork faces downward. As it is covered by solids, the oscillation is damped, and the change in amplitude is converted into a switching signal.

Endress+Hauser's vibronic measurement principle allows point level measurement regardless of the medium. It can be modified to measure a range of physical properties of the media, including conductivity, density changes, pressure and temperature. The formation of foam or bubbling liquids do not affect the detection accuracy of the system.

Time-of-Flight Measuring Principle in Point Level Measurement

The time-of-flight measuring principle for liquids is based on echolocation and the radar principle.

Endress+Hauser time-of-flight measuring instruments are placed on top of a tank, container, or silo. The instrument emits ultrasonic or radar impulses, which are reflected off the medium and sent back to the sensor. The distance between the sensor and the medium is calculated by measuring the time of flight, or the time that passes from when the sensor sends and receives the ultrasonic signal. By calculating the speed of the signal and the height of the tank or silo, it is very easy to analyze the height level of the medium. This signal can be led along by a vertical rod, or emitted freely in a tank.

The time-to-flight measuring method works equally well with both liquids and solids. Endress+Hauser time-of-flight instruments can even effectively measure media in high pressure and temperature environments. These instruments also work well on various gases and aggressive media with constantly moving liquid surfaces or foam.

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Reasons for Pressure Measurement

Pressure measurement may not be necessary in every situation, but for specific applications in the food and beverage, life sciences, oil and gas, chemicals, petrochemicals, and water industries, it is essential. Pressure devices in these environments need to be reliable, accurate, and easy to read in order to help prevent failures and ensure the success of everyday operations.

Pressure measurement is essential for measuring pressure variables in tanks, containers, and silos. It can also be used as an alternative to level measurement to analyze fluid levels in certain industries like oil and gas and petrochemicals.

Pressure Measurement Terminology

Absolute pressure —Pressure measured against a perfect vacuum, so it equals to gauge pressure plus atmospheric pressure.

Gauge pressure —Pressure measured against ambient air pressure, so it equals absolute pressure minus atmospheric pressure.

Differential pressure—The pressure difference between two points.

Hydrostatic pressure —Pressure measured in a fluid at rest.

Measuring Principles for Various Media

Storage tanks and containers store and are drained of a variety of media such as solids, liquids, and gases every day. Measuring principles vary based on these different media. Typically, storage tanks and containers hold liquids like fuel, acids, and potable water, gases like grains or powders, and gases like nitrogen. There are a number of principles behind the methods for measuring these varied media, which include continuous level measurement and point level detection in bulk solids and liquids.

Absolute and Gauge Pressure Measurement

In a pipe constantly flooded with a fluid, pressure can be measured constantly. Absolute and gauge pressure meters can both be installed on such a pipe, and produce different readings.

The absolute pressure meter is a closed system, and measures against air vacuum when pressure from a liquid is applied. It indicates the air pressure in an atmospheric environment.

In a gauge pressure meter, the system is open, and allows a comparison between the atmosphere in the environment and the inside of the gauge pressure cell. The cell measures values relative to the ambient pressure in the system. It does not measure the air pressure in the atmosphere, unlike the absolute pressure cell.

Differential Pressure Measurement

In a differential pressure measurement in a closed tank, the atmospheric pressure does not affect the pressure reading. A meter measures the pressure of the liquid on the sensor, as well as the pressure at the top of a tank, where there is no liquid. The calculator analyzes the difference between these readings, and determines the level of the liquid.

A pitot tube is also used to measure differential pressure flow. Pitot tubes are inserted perpendicularly in a tube, measuring the tiniest pressure changes in the fluid. If the fluid is not flowing, there is no pressure difference.

As the fluid starts to flow, higher pressure is applied on one side of the pitot tube, while the sensor on the tube in facing the direction of the flow reports a constant pressure. The difference between these levels is used to calculate the flow velocity and thus the volume and mass of the liquid in the pipe.

Hydrostatic Pressure Measurement

In hydrostatic pressure measurement, the liquid in the tank acts on a sensor with a process diaphragm. As the level of a liquid rises, the pressure on the sensor increases. The liquid column is proportional to the filling level and density of the medium.

In an open tank, there is a constant compensation of pressure in relation to ambient air. For this reason, the gas on the upper level of a tank does not affect level measurement, although the atmospheric pressure also adds to the sensor. The higher the pressure, the greater the flexion of the process diaphragm, and the greater the resulting reading.

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Thermometers and transmitters for the process industry

Endress+Hauser offers a complete assortment of compact temperature assemblies, modular temperature assemblies, thermowells, measurement inserts and accessories for a variety of industries. These include oil and gas, chemicals, food and beverage, life sciences and pharmaceuticals, primaries and metal, and power and energy. In various applications in these industries, proper temperature measurement is essential in ensuring that the fluids, whether perishables like fruit juices or petrochemicals like various fuels, are kept at the optimal temperature for storage, preservation, and transfer.

Temperature Measurement Terminology

Temperature assemblies components —Components that make up temperature assemblies and thermocouples. These include a measurement insert with a terminal head, thermowells, process connections, a neck/lagging connection, and a terminal head with cable glands.

Terminal head—The ceramic block or head transmitter fitted to the thermowell or the neck of the temperature assembly. It aids in the protection and installation for the terminal block or transmitter, allows cable entry and wiring, and can hold the display.

Neck/lagging —The connection between the terminal head and process connection or thermowell. It protects the head transmitter from overheating and guarantees access to the terminal head in case of pipe insulation.

Process connection —The connection between the process and the temperature assembly.

Thermowell—The process wetted of the temperature assembly. It protects the insert from process influence and provides mechanical stability against pressure and flow.

Multi-point thermocouples —Custom-made thermocouples made for applications in high pressure process reactors.

Endress+Hauser Temperature Assembly

The mechanical construction of Endress+Hauser temperature assemblies involves five major components. The assembly used in process plants is the same for resistance temperature assemblies and thermocouples. The five components are a measurement insert with a terminal head, thermowells, process connections, a neck/lagging connection, and a terminal head with cable glands.

Endress+Hauser Measurement Inserts

Temperature is the most frequently measured property in the process industries like oil and gas, chemicals, food and beverage, life sciences and pharmaceuticals, primaries and metal, and power and energy. There are two measurement principles that have been adopted as standards in electrical contact temperature assemblies.

Resistance sensors

In RTD resistances sensors, the electrical resistance changes along whenever the temperature changes. They are best suited to measure temperatures between -200°C (-328°F) and 600°C (1112°F), and are notable due to their high measurement accuracy and long-term stability. Resistance sensors are used in two formats: wire wound ceramic sensors and thin layer sensors.

Wire wound ceramic sensors include a double coil with capillary ultra-pure platinum wire. The tube is sealed at both ends by a ceramic protective coating. They ensure long-term stability and accurate readings for the resistance/temperature characteristic in a temperature range of up to 600°C (1112°F).

Thin layer sensors operate via a ceramic plate with a coating of very thin platinum on it. It is then photo-lithographically structured. The resulting platinum conductors form the sensor resistance, with the advantages of smaller dimensions and better vibration resistance than the wire-wound versions. Thin layers sensors are best used for measurements in temperature ranges of up to 500°C (932°F).

Thermocouples

Thermocouples are components comprised of two different metals connected to each other at one end. If connection and the free ends are exposed to different temperatures, it causes an electrical potential or thermoelectrical force. Thermocouples reference tables are used to calculate the temperature at the connection or measuring junction.

Thermocouples are best suited to measure temperatures in the range of 0°C (32°F) to +1800°C (3272°F). They have the advantage of a fast response time and high vibration resistance.

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