Kirk-Othmer Encyclopedia of Chemical Technology.

LIQUID LEVEL MEASUREMENT

Level gauging has existed at least as long as written history; markings on the walls of Egyptian temples show that as early as 3000 years ago humans tracked the level of water for hydrologic data. These nilometers are some of the first recorded uses of systems to measure level (1).

The four process control parameters are temperature, pressure, flow, and level. Modern process level detection systems are varied and ubiquitous; in modern chemical plants there are thousands of processes requiring liquid level indication and liquid level control. From accumulators to wet wells, the need for level devices is based on the need for plant efficiency, safety, quality control, and data logging. Unfortunately, no single level measurement technology works reliably on all chemical plant applications. This fact has spawned a broad selection of level indication and control device technologies, each of which operates successfully on specific applications.

1. Measurement vs Control

Level devices can be divided into two broad groups: those that indicate level and those that provide means to control level. Indication devices report where the level is at any given point in the process. Control devices provide supervision of the process and can be used to initiate other devices to control process levels.

1.1. Sight Glass Gauges

These indication devices provide visual indication of the process level by means of a clear, nonmetallic, vertical tube piped to the vessel at top and bottom. As the level rises in the vessel, it maintains the same level in the sight glass (Fig. 1**a**). For elevated temperatures and pressures, reflex and refractive-type sight glasses are available (Fig. 1**b**). Increased solids and dense liquids can restrict movement of the liquid in and out of the glass making these sight devices unreliable. Clean liquids with no color can cause a problem determining if the glass is full or empty if no intermediate level is apparent.

1.2. Dip Stick Indicators

Visual level indication can be obtained by dropping a weighted cable or rigid dip stick into the media until it reaches the bottom of the vessel. Graduations are marked on the cable or stick. Upon retrieval the operator looks for the point of dry vs wet indicating the depth of the media. This method of level indication is useful in ambient/atmospheric applications in nonhazardous environments. It is not recommended for other applications. Measurements are accurate only to the extent of the skill of the operator.

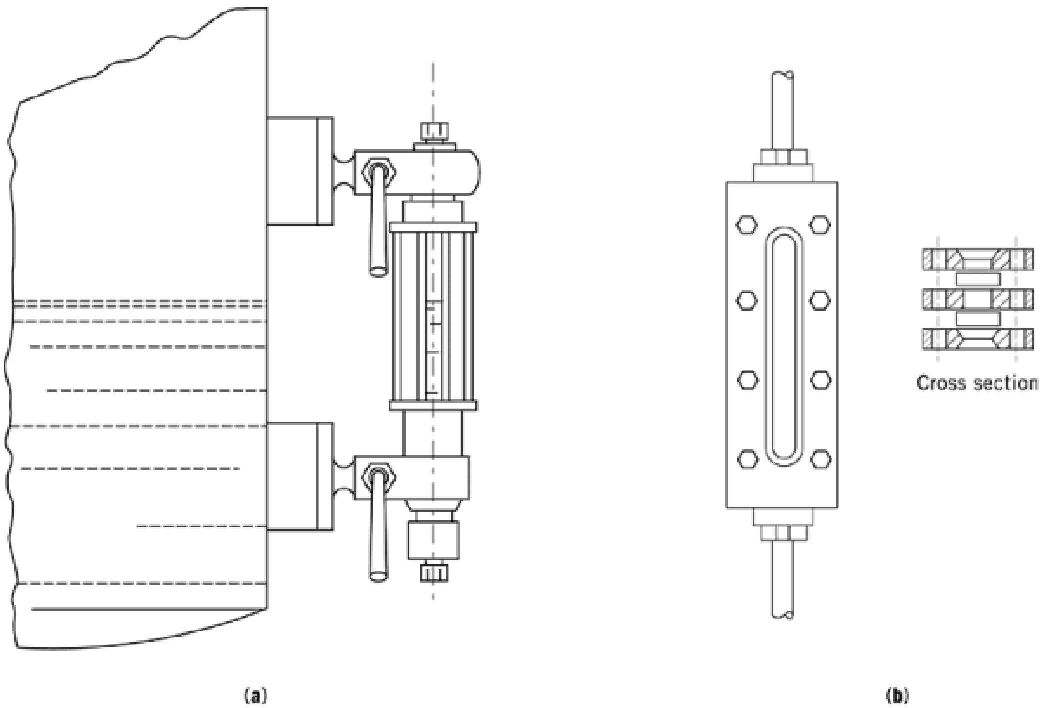

Fig. 1. Sight glass gauges: (**a**) tubular, (**b**) reflex. Courtesy of John C. Ernst Co.

1.3. Magnetic Liquid Level Indicators

Where it is necessary to isolate the process due to pressure or toxic, lethal, volatile, or corrosive liquid, a magnetic level indicator is available. These devices utilize a float mounted inside a pipe which is connected to the process. The float has strong magnets internally mounted around its diameter. A sealed isolated sight glass with a magnetic indicator is mounted on the float tube. As level changes the float follows the level change and the magnetic coupling between float and level indicator keeps the level indicator equal with the process liquid. Level indicators are either shutters that flip with level change or fluorescent indicators (Fig. 2). In addition to process isolation, these devices also allow visual level detection at much greater distances than sight glasses. Solids and heavier liquids can cause float hang-up, making the units unreliable. They are available in a variety of metals, plastics, and connection arrangements. Options for magnetically coupled level switches and transmitters are also available.

2. Level Control Devices

There are three basic requirements that liquid level control devices are designed to satisfy: alarm functions, pump/valve control, and transmitted output signal to track level continuously. Alarm devices provide warning or shutdown functions when process levels pass a predetermined point in the vessel; pump/valve control devices turn on/off pumps or open/close valves at predetermined levels in the vessel; and transmitters provide a proportional output signal over a predetermined span to send to a local meter or signal back to a control room.

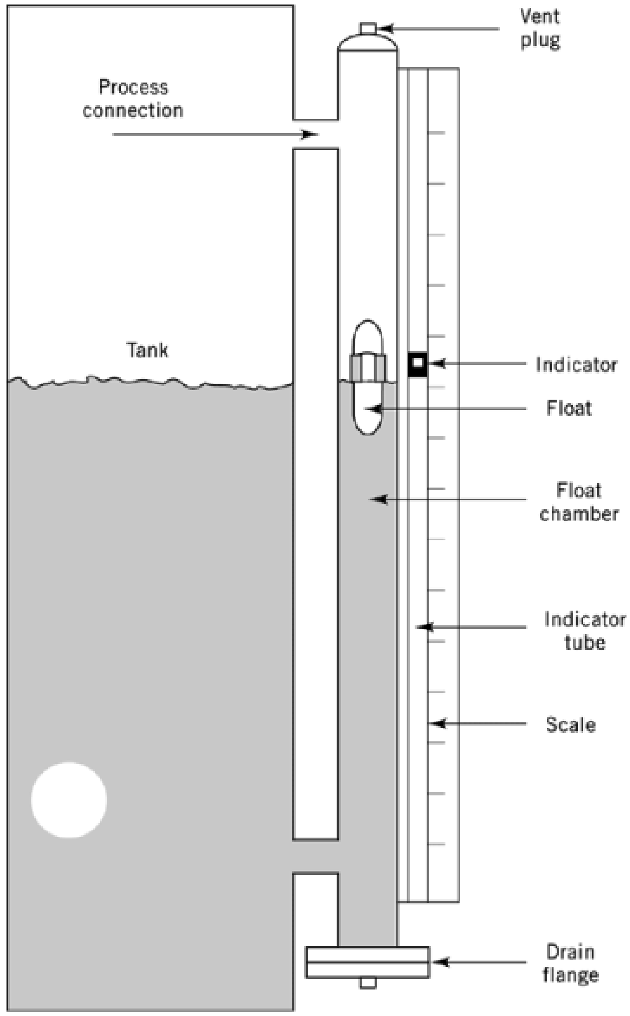

Fig. 2. Magnetic level gauge. Courtesy of ProMag.

In a discussion of the various level technologies, it is important to know the differences between the various level requirements. The implementation of a particular technology, such as ultrasonic, is different for a single alarm device than it is for a transmitter.

2.1. Floats

Float level switches are suitable for clean liquid applications, primarily for alarm function (Fig. 3). A float follows level change moving a stem and magnetic attraction sleeve within a nonmagnetic enclosing tube. When the attraction sleeve enters the field of the magnet, the magnet pulls in actuating a switch mechanism. The magnetic coupling allows complete isolation of switch mechanism from process. Float level switches must be mounted at the desired set point. No field calibration is required. Units can be mounted outside of the vessel in a separate cage or can be mounted directly to the vessel at top or side. A broad selection of mounting arrangements, switch mechanisms and housings, and materials of construction are available to

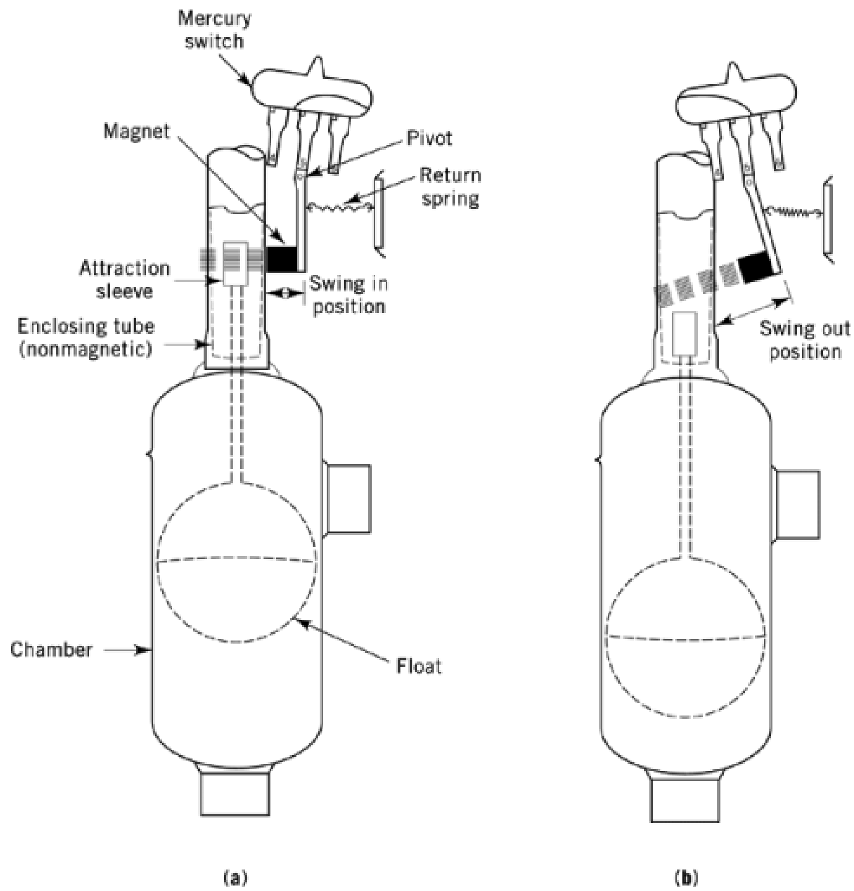

Fig. 3. Float level switch. Courtesy of Magnetrol International, Inc.

provide compatibility with clean liquid processes. Float switches provide total isolation of switch mechanism from process, require no power to operate, are intrinsically safe, and are accurate to 0.5 cm. Float level switches can also monitor interface between two immiscible fluids using specially weighted floats that sink in the upper fluid and float in the lower fluid. The float must be covered with liquid at all times to maintain calibration.

2.2. Displacers

Displacer level switches are suitable for clean and dirty fluids and are used principally to control sump pumps where shifting specific gravity, turbulent surface, and foam are common problems. Displacer(s) are suspended from a range spring connected to a stem and attraction sleeve. With change in level the spring senses the change in buoyancy causing the stem and attraction sleeve to move within a nonmagnetic enclosing tube. When the attraction sleeve enters the field of the magnet the switch mechanism is actuated. The enclosing tube totally isolates the switch mechanism from process (Fig. 4). A magnetic coupling exists between the attraction sleeve and switch mechanism. Units can be mounted in the vessel top or externally mounted in a separate cage piped to the vessel.

Displacer units are tolerant of specific gravity shifts within their range, require no power to operate, are intrinsically safe, and can be easily field calibrated. A single displacer unit can control up to three alarm set

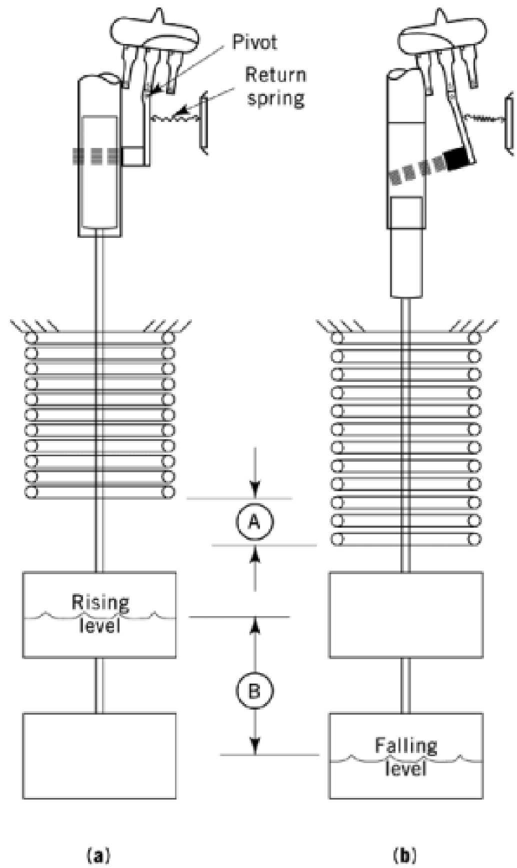

Fig. 4. Displacer level switch. Courtesy of Magnetrol International, Inc.

points or up to three pumps with different spans. They can be calibrated for set points or pump spans from 0.15–30 m from the top of the vessel mounting.

2.3. Buoyancy

Buoyancy level controllers are used to control a process having continuous flow through the vessel. The primary application is in reactors, feedwater heaters, deaerators, and similar processes having boiling and turbulent conditions. A hollow cylinder (displacer) is suspended from a range spring or torque tube. Change in level causes a change in buoyancy which creates a force–balance shift which is transmitted through a metallic seal into the control housing (Fig. 5). Level change causes the controller to increase or decrease the output signal to a proportional control valve. The valve is opened or closed to control flow through the vessel, thus maintaining level within a predetermined span. Units are available with a pneumatic 21–103 kPa (3–15 psi) or electronic (4–20 mA d-c) output. Spans are available from 36 to 305 cm. Mounting arrangements include top, side, and external cage with selections of process connection size, style, and materials.

Buoyancy level controllers/transmitters are tolerant of turbulent level and can effectively control high temperature and high pressure applications. Specific gravity shifts within the unit range do not reduce the unit's ability to maintain control of the process. Pressure changes are ignored and temperature shifts within

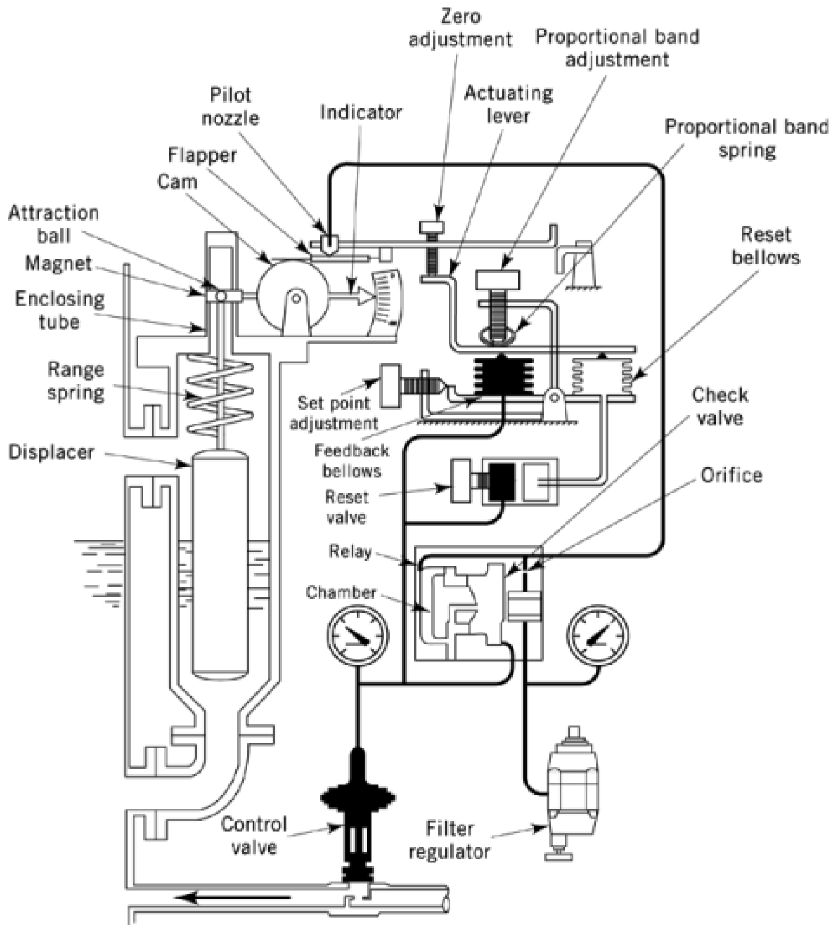

Fig. 5. Buoyancy level controller. Courtesy of Magnetrol International, Inc.

the unit range produce minimal shifts of span. Range spring models have a more stable output signal on turbulent level, and can be field calibrated without moving process level.

2.4. Conductivity

Conductivity level switches are generally limited to applications with low pressure, conductive fluids (high pressure models are available). They are alarm or pump control devices. Metal rods are inserted into the vessel with low level a-c voltage applied (Fig. 6). The conductive liquid serves to complete the electrical path from probe to ground. Multiple set points may be obtained by insertion of multiple rods. Set point is determined by rod length. Conductance level switches are not recommended on applications with volatile fluids or explosive atmospheres. Contamination of the rods can cause the unit to malfunction. Materials forming a conductive coating between the two rods cause the unit to continually show a high level. Nonconductive materials coating the rods insulate the rods from the process level causing the units to fail in a low level condition.

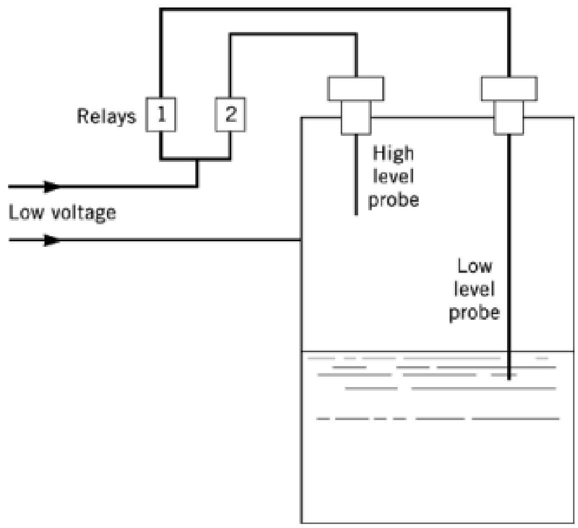

Fig. 6. Electrode system for detecting high and low levels in a conductive field.

2.5. Capacitance

Capacitance-based measurement devices, like conductivity devices, utilize the electrical properties of the medium to derive its measurement. Unlike conductivity devices, capacitance can be used to measure either conductive or nonconductive media (dielectric value: $\text{nonconductive} < 10 > \text{conductive}$). Capacitance is developed when an oscillator impresses a high frequency a-c signal across two conductive plates separated by an insulating material, or dielectric (Fig. 7). The amount of capacitance generated is dependent on the frequency of the a-c signal, the size of the conductive plates, the distance between the conductive plates, and the dielectric value of the insulating material. In industrial process measurement, a metal probe is one plate of the capacitor while the metal tank wall is the other plate, or ground reference (Fig. 8). When a tank is empty it is actually full of air which has a dielectric value of 1. All materials on earth have a dielectric value greater than 1; therefore, as the tank is filled with material having a dielectric greater than air, the amount of capacitance developed by the system increases. This increase or decrease in capacitance, proportional to the level change, can then be used with on/off or analogue devices.

When the process medium is electrically conductive ($\text{dielectric values} > 10$), the capacitor developed above does not work; the insulating material needed between the two conductive plates is lost. The conductive liquid surrounding the probe acts as a short circuit to the tank wall (second plate of the capacitor). To reestablish the dielectric (insulating material), the probe can be insulated with a nonconductive material such as tetrafluoroethylene (TFE), poly(vinylidene fluoride) (PVDF), poly(vinyl chloride) (PVC), etc. The capacitor exists between the probe rod, through the thickness of the insulation (dielectric), to the conductive liquid which is now acting as the second plate of the capacitor, or ground reference (Fig. 9).

In nonmetallic vessels, the second plate of the capacitor is missing and must be supplied. A stillwell probe, one with a concentric metal tube, is utilized. The concentric tube supplies the second plate. Stillwell probes have numerous other uses. In applications of nonconductive media, a stillwell probe is more sensitive and supplies a greater amount of capacitance because the ground reference is so close to the probe. Further, if a tank wall offers a ground reference that is a varying distance to the probe, eg, a horizontal cylinder, the stillwell offers a much more consistent (linear) ground reference.

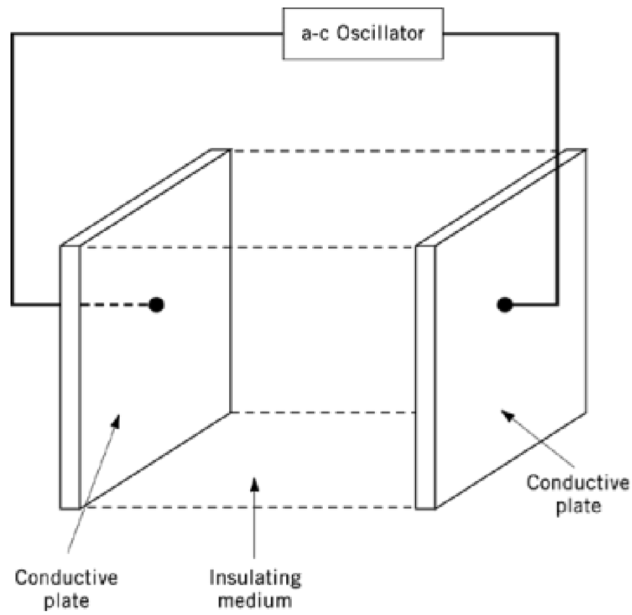

Fig. 7. Basic capacitor.

Capacitance is an extremely flexible level measurement technology. Although the approach is electronic, the sensing probe is a mechanical object serving an electronic function in the circuit. Because it has no electronic parts, it can be constructed to withstand extremes of temperature, pressure, corrosive media, etc. Temperatures of 538°C (1000°F) and pressures of 35 MPa (5000 psi) are not uncommon. Probes can be constructed as rigid rods to lengths of 3–6 m, and as flexible cables to lengths of many hundreds of feet.

Capacitance-based systems can be utilized in hazardous environments in two ways, explosion-proof housings and intrinsically safe circuitry. Explosion-proof housings can be used to contain an explosion that might ignite inside the enclosure. These electronics are usually qualified with certain probes so any explosion does not escape the housing into the atmosphere or back into the vessel. Intrinsically safe circuitry precludes an explosion from occurring by limiting the energy impressed on the probe. At these low energy levels, there is not enough energy to cause ignition. An approved intrinsically safe barrier is installed in the loop in a nonhazardous location to preclude dangerous energy levels from entering the hazardous area even during component failure.

There are two general weaknesses associated with capacitance systems. First, because it is dependent on a process medium with a stable dielectric, variations in the dielectric can cause instability in the system. Simple alarm applications can be calibrated to negate this effect by calibrating for the lowest possible dielectric. Multipoint and continuous output applications, however, can be drastically affected. This is particularly true if the dielectric value is less than 10. Secondly, buildup of conductive media on the probe can cause the system to read a higher level than is present. Various circuits have been devised to minimize this problem, but the error cannot be totally eliminated.

2.6. Static Pressure

The static pressure system offers an inferential method of measuring liquid level that is flexible and convenient, especially when there is considerable change in level. It is based on the fact that the static pressure exerted

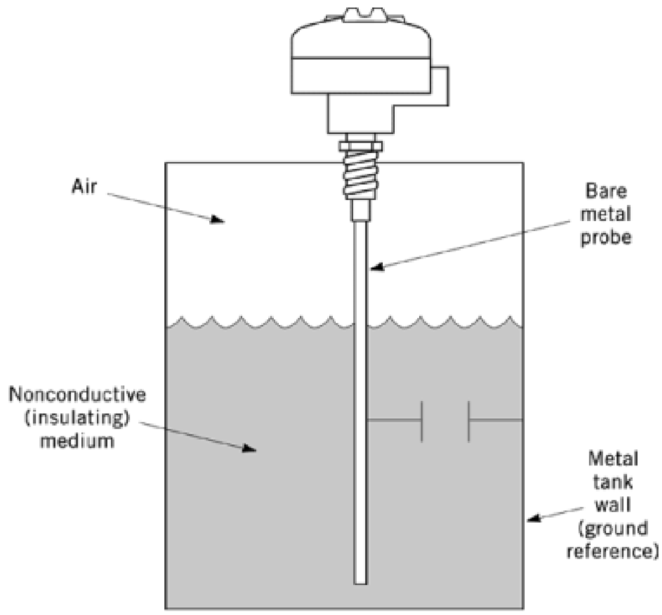

Fig. 8. Capacitance-based level measurement, nonconductive media.

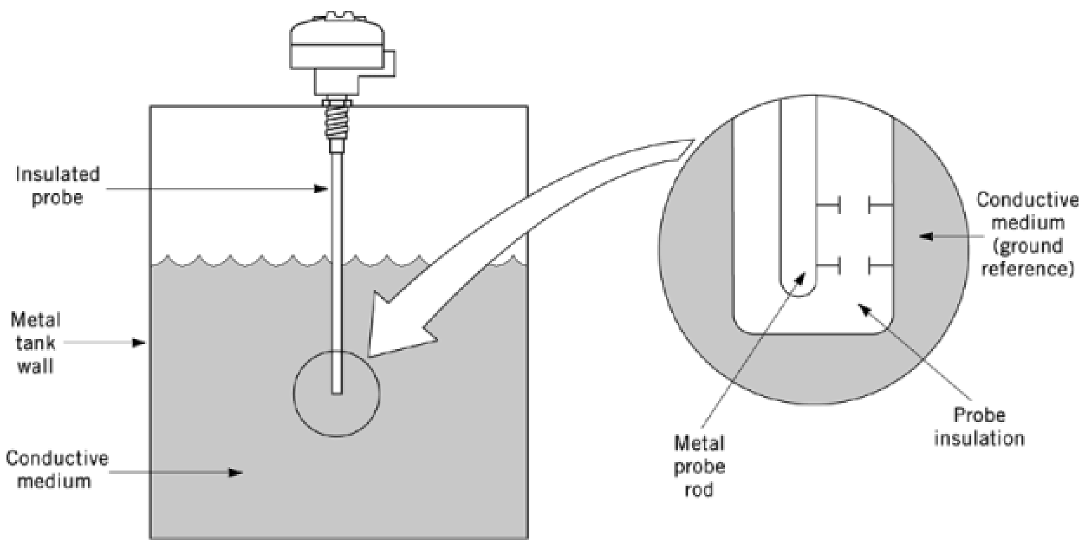

Fig. 9. Capacitance-based level measurement, conductive media.

by a liquid is directly proportional to the height of the liquid above the point of measurement regardless of the volume in the tank, provided that the specific gravity remains constant. For a given type of liquid, the specific gravity is a function of the temperature; therefore, in using the static pressure method a correction must be made for the temperature of the liquid before the exact height can be determined. However, if the mass of the liquid above the point of measurement is desired, it is necessary only to multiply the pressure measurement by the average cross-sectional area of the vessel. Any measurement, then, that measures pressure

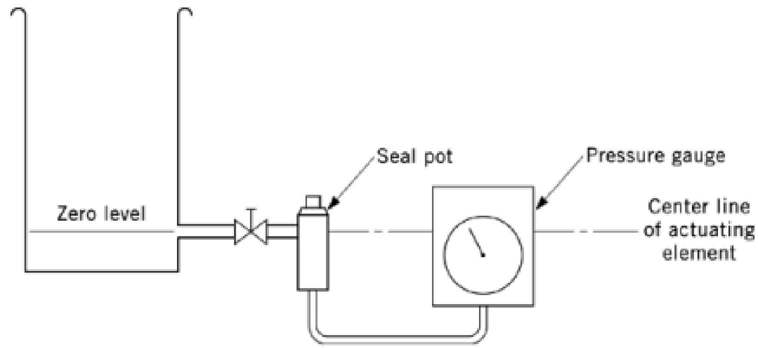

Fig. 10. Pressure gauge, calibrated in terms of liquid height, for measurement of level in open tanks.

can be calibrated in terms of the height or mass of a given liquid and can be used to measure either of these variables in vessels under atmospheric pressure (see Pressure measurement). Differential pressure measuring instruments should be used when the liquids are in closed vessels and under nonatmospheric pressure.

2.6.1. Open Vessels

When a pressure gauge is used to measure liquid level in a vessel under atmospheric pressure, the pressure tap is located at the approximate minimum level line of the vessel. If the gauge is not at the same elevation as the pressure tap, it can usually be recalibrated to compensate for the head effect on the gauge line. If the liquid being measured contains entrained solids or would have a corrosive effect on the gauge, a seal pot can be used, as shown in Figure 10. The sealing liquid should have a higher specific gravity than the liquid that is being measured. When an instrument measuring the level in an elevated, open tank is located at ground level, the total hydrostatic head at the instrument is the sum of the head of the liquid in the elevated tank plus the elevation head of the tank above the ground. For such applications, instruments are available with pressure elements designed to compensate for the elevation head and to measure only the liquid head in the tank. For example, a measuring element can give full-scale indication for a level change of 6 m of water at an elevation of 30 m.

When the pressure gauge cannot be located at the minimum tank level, a diaphragm box is used. It contains a relatively large amount of air compared with that in the pressure measuring element. The pressure exerted against the underside of the diaphragm by the liquid head compresses the air within the box until the air pressure is equal to the liquid pressure. The gauge measures the air pressure, but is calibrated in terms of liquid level. Figure 11 shows the open and closed diaphragm box. The open type is immersed in the liquid in the vessel, and the closed type is mounted externally and connected to the vessel by a short length of piping. The former is used with liquids containing some suspended material, whereas the latter is for clear liquid only. Neither type should be located more than 15 m from the gauge.

An air purge or bubbler system used for corrosive liquids or slurries where the gauge can be located up to 30 m from the point of measurement is shown in Figure 12. Corrosive liquids and those with relatively large amounts of suspended material can be handled. As shown in the diagram, an air line is immersed in the liquid to the minimum level, whereas the pressure and volume of air supply are controlled by a regulator to give a small bubbling of air when the vessel is full. The pressure in the air line is then equal to the back pressure exerted by the hydrostatic head of the liquid. The measurement of this air pressure is, therefore, equal to the measurement of the static pressure of the liquid, and thus of the liquid level. The air–purge supply should always be connected at or near the point of measurement, not at the gauge, in order to minimize error caused by friction loss in the air flow through the connecting tubing. The use of a differential regulator and a rotometer

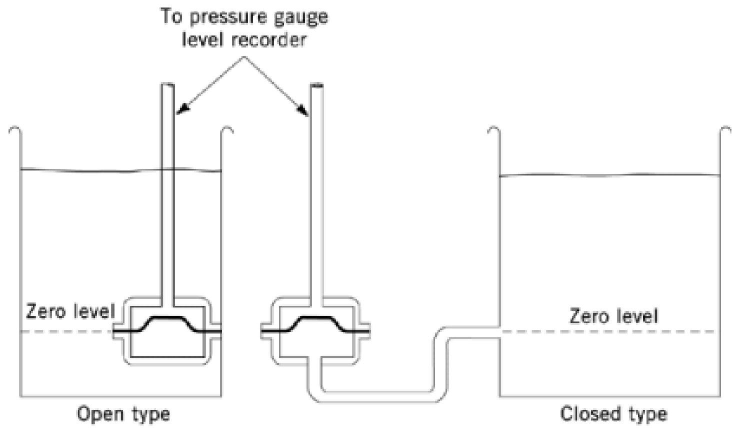

Fig. 11. Diaphragm-box systems, open and closed types, used where pressure gauges cannot be located at the minimum tank level.

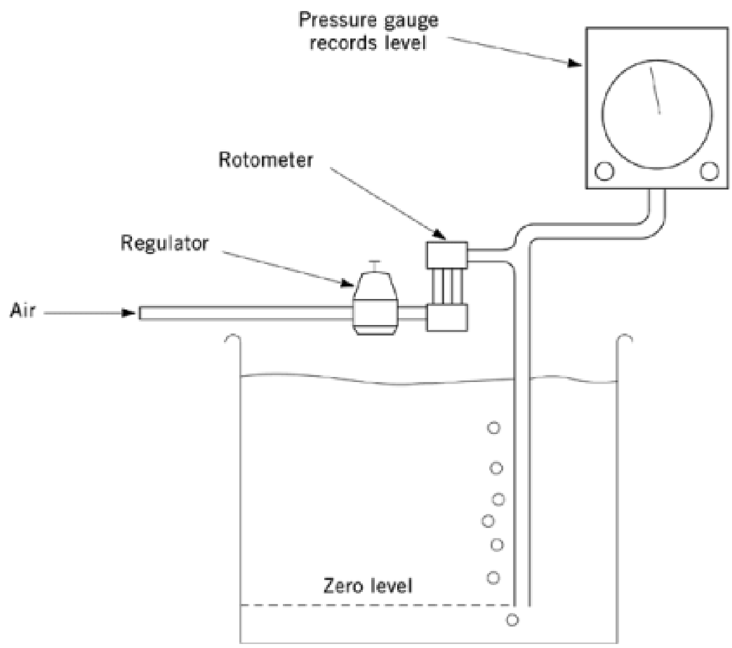

Fig. 12. Air–purge or bubbler system.

is recommended to obtain the same rate of flow regardless of level. A high flow rate can cause errors through friction losses.

2.6.2. Closed Vessels

Liquid level can be measured by the static pressure method also at nonatmospheric pressures. However, in such cases the pressure above the liquid must be subtracted from the total head measurement. Differential pressure measuring instruments that measure only the difference in pressure between the pressure tap at the bottom of the tank and the pressure in the vapor space are used for this purpose. At each tap, the pressure

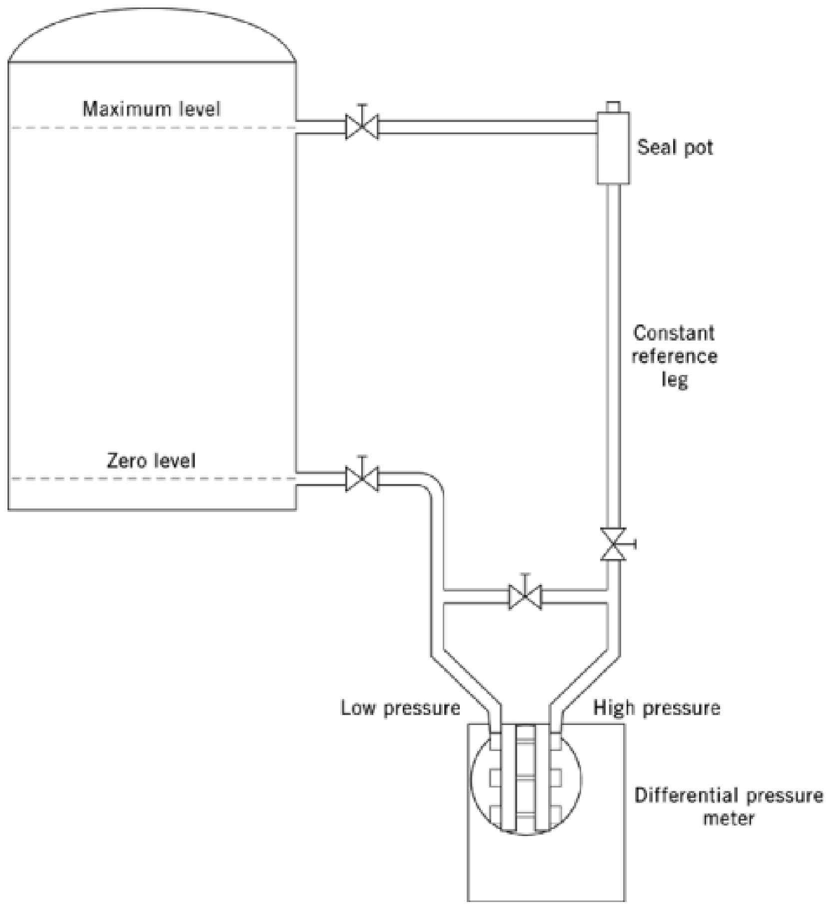

Fig. 13. Differential pressure gauge system.

detected equals the liquid head pressure plus the vapor pressure above the liquid. Since the pressure above the liquid is identical in both cases, it cancels out. Therefore, the change in differential pressure measured by the instrument is due only to the change in head of liquid in the vessel. It is independent of the pressure within the tank and is an accurate measure of the level.

Figure 13 shows a typical installation of a differential pressure instrument for closed tanks. Connections from the instruments are made to taps in the vessel at minimum and maximum levels. Between the instrument and the maximum level tap is a constant reference leg. This leg is filled with liquid until its head is equivalent to the head of the liquid in the vessel at maximum level. The reference leg must remain constant, with no formation of vapor under varying ambient conditions. On some applications it may be necessary to fill the reference leg with a liquid, such as water or a light oil, that remains stable. If the liquid used in the reference leg has a higher specific gravity than the liquid in the tank, the resulting difference in head must be corrected for in the instrument. Most differential pressure measuring instruments are equipped mechanically to suppress this difference.

For applications where a second liquid cannot be used in the constant reference leg, a self-purging system can be installed, as shown in Figure 14. Here the piping is filled with the vapor of the measured liquid instead of the liquid itself. The differential pressure transmitter is located at the upper vessel connection. The pressure

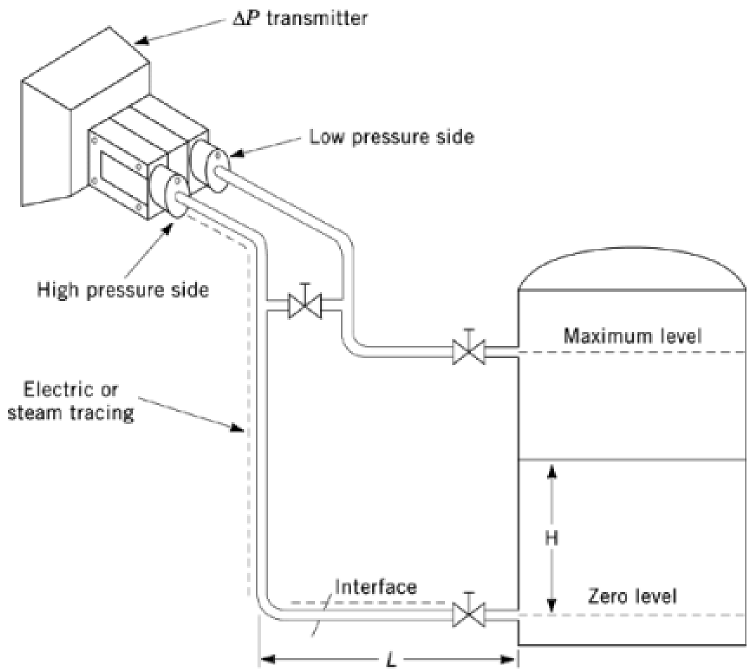

Fig. 14. Self-purging system with the differential pressure (ΔP) transmitter located at the upper level connection.

at the high pressure side is now the vapor pressure in the vessel plus the head of the liquid; that at the low pressure is the vapor pressure alone. The difference between the two pressures is equal to the liquid level. The horizontal pipe, L, must be long enough to prevent a liquid head from forming in the vertical connection to the transmitter, as this would result in a low reading. If ambient temperature causes a head of liquid to accumulate, in spite of the length L, the connecting piping requires steam or electric tracing.

A differential pressure transmitter with remote diaphragm seals offers another convenient method of measuring liquid level in closed tanks (Fig. 15). A sensing diaphragm at the upper flange connection transmits the vapor pressure at the tank top through a liquid-filled stainless steel capillary to one side of the differential meter. Another sensing diaphragm at the flange near the bottom of the tank transmits the total vapor pressure plus the variable liquid head $H1$ through another oil-filled capillary to the other side of the differential meter. The meter measures the difference between these two pressures, which is the variable head $H1$. The high pressure side of the meter is connected to the upper flange and, when the tank is empty, an elevated zero adjustment on the meter is used to balance out the fixed-liquid reference leg $H2$ in such a way that the output of the meter reads zero. When the liquid rises in the tank, the actual differential pressure across the meter body decreases. However, the electronic circuit of the meter is arranged for reverse action and, therefore, the output increases as the level rises. The advantage of this system is that no seal pots or heat-traced lines are required and there is no chance for solid materials, such as in a slurry, to plug up the connecting lines to the meter.

2.7. Differential Pressure

Differential pressure transmitters designed for liquid level measurements use solid-state electronics and have a two-wire 4–20 mA d-c output.

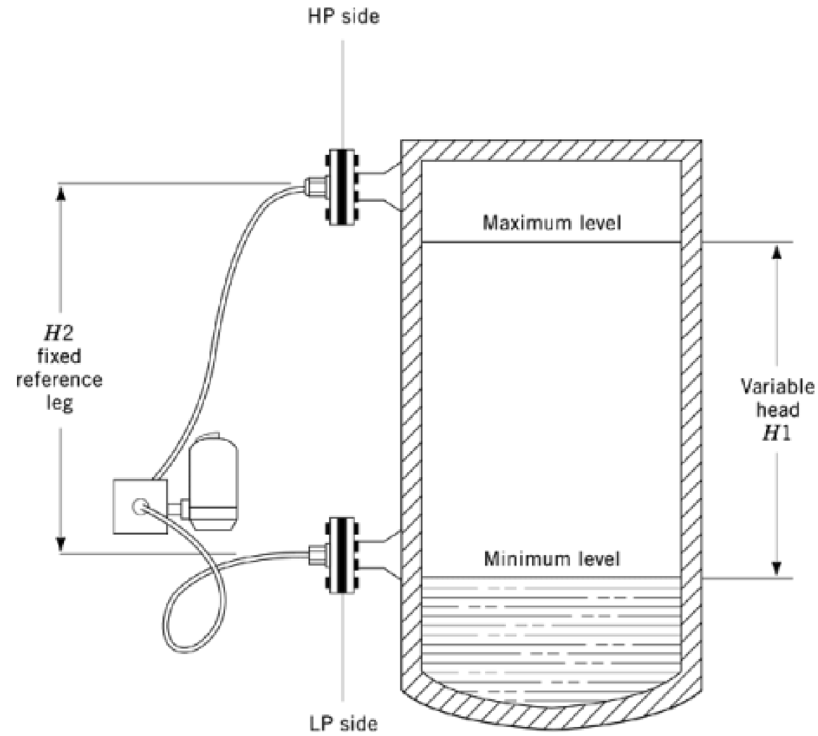

Fig. 15. Differential pressure transmitter with remote seals.

The Series 1151 differential pressure transmitter manufactured by Rosemount (Minneapolis, Minnesota) uses a capacitance sensor in which capacitor plates are located on both sides of a stretched metal-sensing diaphragm. This diaphragm is displaced by an amount proportional to the differential process pressure, and the differential capacitance between the sensing diaphragm and the capacitor plates is converted electronically to a 4–20 mA d-c output.

Foxboro's Model 823 transmitter uses a taut wire stretched between a measuring diaphragm and a restraining element. The differential process pressure across the measuring diaphragm increases the tension on the wire, thus changing the wire's natural frequency when it is excited by an electromagnet. This vibration (1800–3000 Hz) is picked up inductively in an oscillator circuit which feeds a frequency-to-current converter to get a 4–20 mA d-c output.

The Honeywell ST 3000 transmitter contains a solid-state sensing element. A Wheatstone bridge resistance circuit is diffused into a single-crystal silicon chip, creating an integrated piezoresistive sensor. An area on the back side of the chip is etched out to a precise thickness, in such a way that a given differential process pressure across the chip gives the desired bridge output change. The bridge output is amplified and converted to a 4–20 mA d-c output signal.

All these devices are filled with silicone oil and have low gradient, corrosion-resistant barrier diaphragms on both the high and low pressure sides of the sensor.

2.8. Ultrasonic

Ultrasonic level devices are based on measuring the propagation of inaudible sound waves through air, liquids, or metals at a frequency range of 20 kHz to 4 mHz. This is a mechanical process of compression and expansion

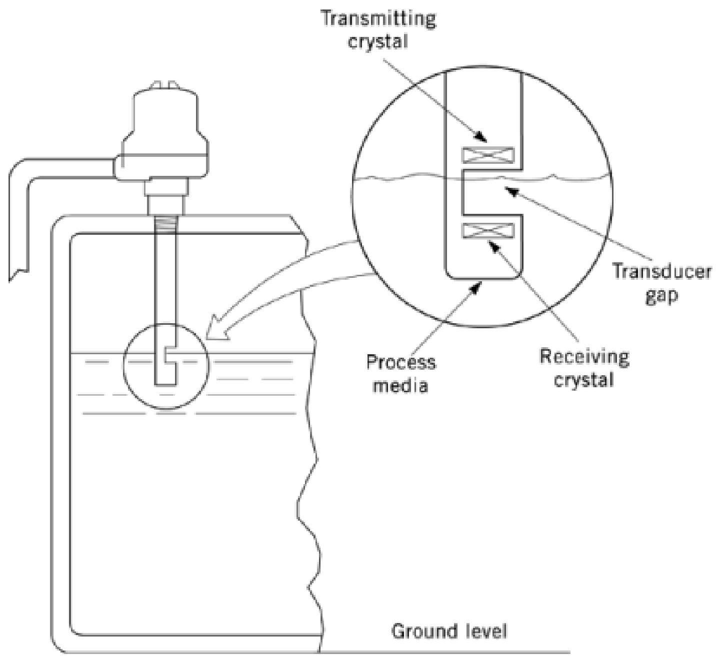

Fig. 16. Typical gap sensor application.

initiated by a vibrating material. This vibration is induced by a piezoelectric crystal with an alternating current of a frequency equal to the frequency at which the material vibrates most easily. The piezoelectric crystals are typically made from a lead zirconate or barium titanate compound which converts electrical energy to mechanical energy and vice versa.

The use of ultrasonic energy is different in on/off switches and in transmitters. Switches act on the attenuation of the acoustic signal in the gap between two crystals, while transmitters measure the time of flight of the ultrasonic pulse.

2.8.1. Switches

An ultrasonic point sensor is constructed from two piezoelectric crystals mounted opposite each other in a plastic or metallic body, and separated by a gap (Fig. 16). One crystal is connected to the input of an amplifier and transmits acoustical energy across the transducer gap, while another identical crystal is connected to the output of the same amplifier and becomes the receiver. This technique transmits the acoustical energy at frequencies from 1 to 4 mHz. At this high frequency, air becomes a deterrent to the transmission of the signal, attenuating the acoustical energy. When the gap is filled with air (or gas), the acoustical signal is not allowed to transmit, and the amplifier remains idle. Conversely, when the gap is filled with liquid, a coupling path is provided to propagate the signal. Once the receiver signal is detected, the amplifier becomes an oscillator which causes a relay circuit or current shift output to indicate a wet condition. As soon as liquid is removed from the gap, the amplifier returns to the idle state. The ultrasonic sensors are positioned in a tank at a point where level is to be controlled. The sensor design incorporates single or multiple gaps to provide optimum level control, eg, high alarm, pump control, etc. This type of measurement is unaffected by changes in temperature viscosity, specific gravity, dielectric constants, or conductivity. Installation is extremely easy and needs little calibration.

The sensors can be constructed in a wide variety of materials and lengths to suit most application conditions. These sensors can be used in almost any liquid that does not have the ability to form a crystallized coating on the sensor face. The coating can, in some instances, cause false attenuation of the acoustical signal. In addition, severe aeration, liquid temperatures above 260°C, and a high percentage of solids may also attenuate the signal to a degree that causes a false level indication. Self-test circuits can be employed to indicate the integrity of the unit.

2.8.2. Transmitters

The use of sonic or ultrasonic sound pulses to measure level on a continuous basis is known as air sonar. In its most elementary form, an electronic circuit applies multiple bursts of high voltage energy to a transducer crystal. The burst of electrical pulses causes the transducer crystal to generate an acoustical pulse at a specific oscillating frequency, typically 20 to 55 kHz. The pulse propagates through the air (or vapor) and is reflected back to the transducer from the liquid surface (Fig. 17). At the transducer, the acoustical pulse is converted back into electrical signals by the transducer and receiver circuits. Based on the microprocessor's counter/timer, the instrument knows the precise time when the crystal was charged and the elapsed time between transmission and reception of the acoustical signal. This time function is represented by the relationship $t = 2d/V_a$, where t represents time, d is the distance between the transducer and the liquid surface, and V_a is the velocity of sound in air (or gas). Solving for d, $d = V_a t/2$. The total transit time down and up through the air space is proportional to the distance from the transmitter to the liquid surface.

This method of measuring level is highly desirable because it is a noncontacting technique. There are no mechanical parts and the acoustical signal is typically not affected by the physical properties of the liquid. An adjustment must be provided in the electronic circuit to correct for the changes in temperature of the vapor space through which the signal passes. Temperature variances affect the speed (V_a) of the acoustical signal so a temperature compensation circuit is used. The circuit may be internally potted in the transducer head near the crystal or a separate temperature probe can be used which provides temperature information to the electronics. Acoustical signals transmit much faster and more efficiently at high temperatures, slower at low temperatures. This acoustical rate change caused by the varying air temperatures necessitates the need for a temperature compensation circuit. A few other considerations should be taken into account when applying this technology. Dust particles and vapors that affect the speed of sound, high temperatures, and operating pressures exceeding $\sim$700 kPa (100 psig) affect the measurement. Since the calculation in the microprocessor is based on the speed of sound in air, vapors with higher or lower densities impede the transmission of the sound wave to a certain degree. The ultrasonic signal slows down or speeds up and therefore induces some error into the measurement. If the liquid surface has foam or excessive turbulence, the acoustical signal may not have a good reflective target (this type of level measurement should not be used in mechanically operated tanks). There are certain foams that absorb the acoustical signal and others that have a good reflective surface.

2.9. Microwave

Microwave devices utilize high frequency energy to make their measurement. Microwave is defined as being electromagnetic energy in the high frequency spectrum between 1 GHz and 1 THz. One significant advantage is it can be made nonintrusive. Microwave energy has the ability to be transmitted through a nonconductive window (process seal) thereby maintaining the integrity of the vessel. The implementation of microwave energy, as with ultrasonic, is different between on/off (presence or absence) switches and transmitters (continuous measurement).

2.9.1. Switches

Microwave switches are low energy devices that send a high frequency (usually 5.8 to 24 GHz) signal at a target (process level) and measure its return. It utilizes the strength (amplitude) of the return signal as an indicator

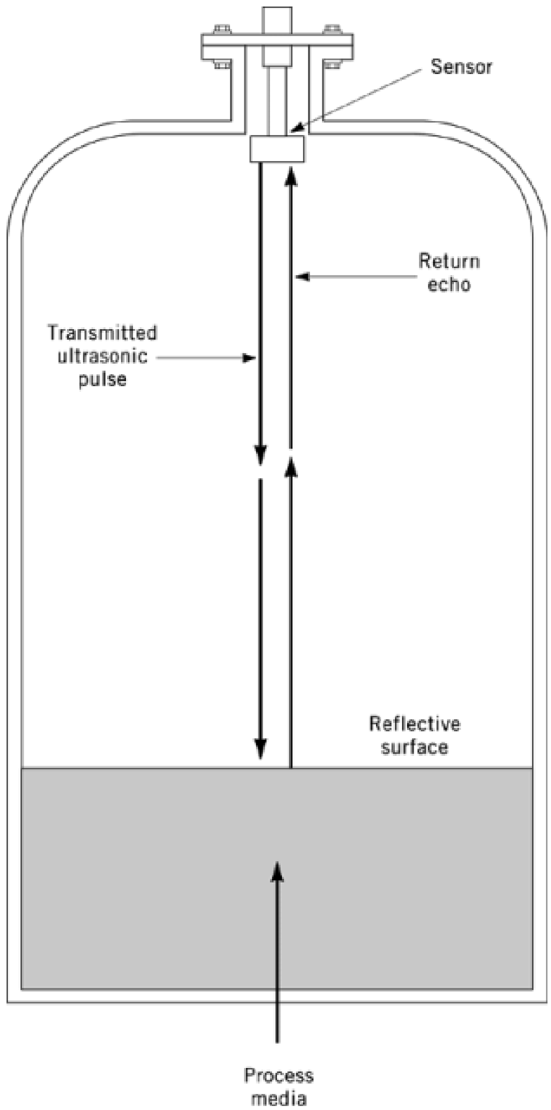

Fig. 17. Ultrasonic air sonar.

of the presence or absence of a process level. The dielectric value of the medium determines the amount of energy reflected back to the unit. Air, having a dielectric value of 1, returns very little energy. When the process is above the unit, the strength of the return signal is greater, signaling a high level condition.

2.9.2. Transmitters

Microwave transmitters for process level measurement are radar-type devices. Radar (radio detection and ranging) devices, like ultrasonic (air sonar) units, bounce a high frequency signal off the process level and measure its time of flight. Radar devices, however, use high frequency electromagnetic energy (in the 5.8–24 GHz range). Aviation radar simply sends a pulse of energy out at the speed of light, and times its return signal. When measuring over long distances (miles) this is a valid technique. For the relatively short distances used

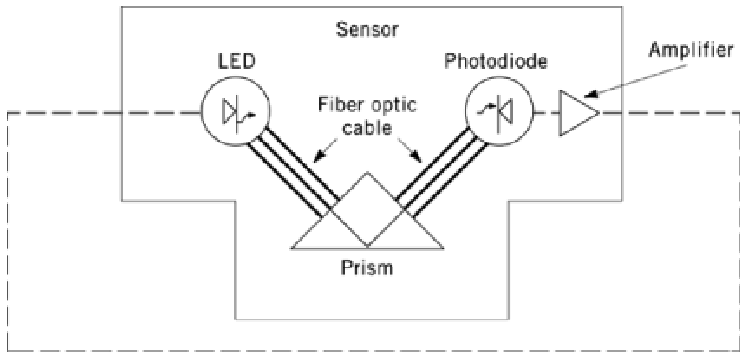

Fig. 18. Point-level device using fiber optics.

in process level measurement, the timing of such a signal is impractical. Because it is extremely difficult to measure such short time sequences, the frequency modulated continuous wave (FMCW) technique is utilized. FMCW transmits a continuous stream of energy swept across a certain bandwidth, eg, 1 GHz. The return signal cannot be measured by simple timing circuits since it will never be the exact frequency as the transmitted signal. However, if the rate of the sweep is known, distance can be derived by measuring the difference in frequency between the transmitted and received signals.

Radar transmitters have a number of advantages. Among them are the ability to sense through nonconductive process seals, operate in heavy vapors and dust, and excellent accuracy (± 1 mm). The greatest disadvantage to date (1995) is high cost. Process accuracy ($\pm 0.25\%$) devices range from \$6500 to \$10,000, while inventory accuracy (± 1 mm) is greater than \$10,000.

2.10. Fiber Optic

Fiber optic level switches are normally limited to free flowing, noncoating fluids at low temperatures and pressures. They are alarm devices utilizing nonmetallic sensors. Pulsed light signals from a light-emitting diode (LED) source are transmitted via fiber optics (qv) to a prism where they are reflected back to a photodiode receiver through another fiber optic cable (Fig. 18). When a liquid with a refractive index higher than 1.4 starts to cover the prism, the pulsed light is refracted rather than reflected by the prism, preventing the light pulses from reaching the photodiode (see Light generation, light-emitting diodes). This change is detected by a control monitor actuating a switch.

2.11. Thermal Dispersion

Thermal dispersion level switches are used on applications where multiple shifts in liquid characteristics are present. The unit is responsive only to a change in the thermal conductivity of the liquid and ignores shifts in specific gravity, dielectric, density, temperature, and pressure. Units are used for alarm signal; however, pump control may be obtained using two units with a latching relay.

The thermal switch consists of a dual element-sensing assembly wired to an electronics package. Each element of the sensor assembly contains a miniature resistance temperature detector (RTD) tightly encased in a tube. One element provides a reference to the process conditions thus providing temperature compensation over the operating range. The second element is internally heated to establish a temperature differential above the process temperature. When the sensors are dry, the temperature differential is greatest. A cooling effect on the heated RTD, caused by the presence of level, decreases the differential temperature between the two elements. This temperature is converted to actuation of the switch by the electronics package (Fig. 19).

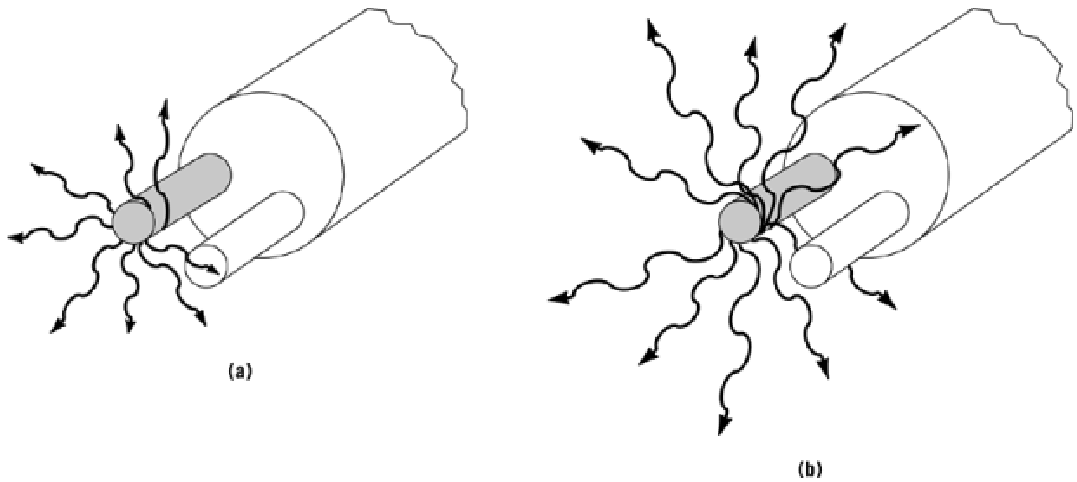

Fig. 19. (**a**) Low level sensor. In the absence of media, the heated sensor tip causes a temperature differential between the two sensors. (**b**) High level sensor. As media contacts the sensing assembly, heat is dissipated and temperature differential decreases.

Units must be mounted at the set point location. Calibration of the unit is required after installation. Thermal switches also provide for self-checking to verify functionality and also include a time delay relay to prevent switch chatter on a turbulent level. Thermal switches may also be used to monitor the interface of two immiscible fluids. Units must be calibrated to the lower thermal conductivity fluid.

2.11.1. Continuous Level Monitoring

The thermal dispersion technique can also be utilized as a continuous level monitor providing an analogue output of the level in the vessel. This is accomplished utilizing an insertion probe as indicated in Figure 20 along with a separate electronics section. The probe consists of two separate sections: the level measuring section and the dry compensator section. This probe contains a reference sensor and an active sensor. The reference sensor is a continuous RTD which detects the temperature in the vessel providing self-compensation for changes in process temperature. The active sensor consists of a continuous RTD and a heater which is energized with a constant current. Both sensors extend the entire length of the probe. When the active sensor is dry, the heater increases the temperature and the resistance of the active RTD creating a high temperature difference relative to the reference sensor. As the probe is immersed in fluid, heat is dissipated into the fluid media reducing the temperature and resistance of the active RTD. This reduction in resistance is proportional to the insertion depth of the sensor. The electronics measure the difference in resistance between the active and reference sensors and convert this to an analogue output signal. Cooling of the active RTD can also occur due to changes in the thermal conductivity of the air above the liquid level. The thermal conductivity of the air is dependent on various factors including temperature, pressure, and humidity. The dry compensator section of the probe compensates for changes in the thermal conductivity of air ensuring that the measured change in resistance is due only to immersion in the fluid.

2.12. Magnetostrictive

When a ferromagnetic material is subjected to a magnetic field, it expands or contracts in a predictable fashion. This phenomenon is the basis for magnetostrictive measurement. The liquid level gauge consists of three primary parts: a ferromagnetic waveguide protected by a solid outer rod, an electronics assembly that

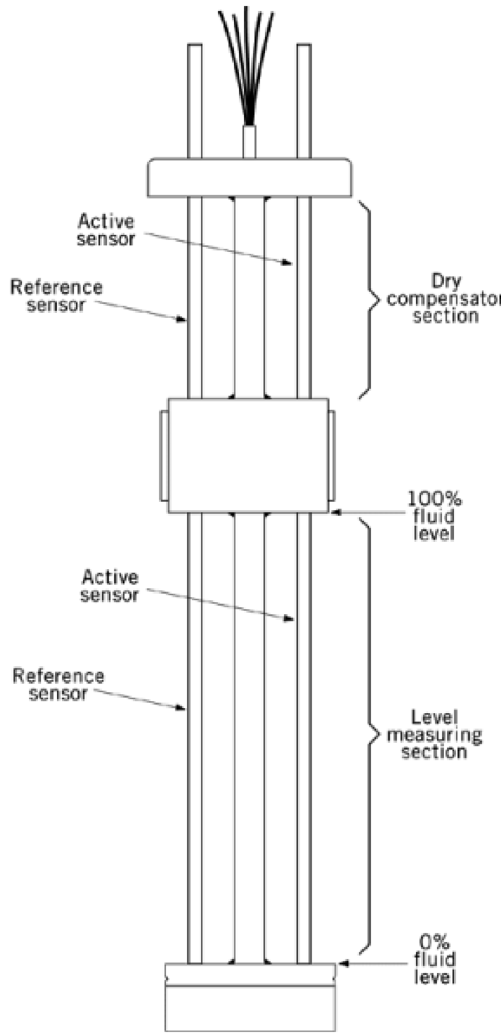

Fig. 20. Monitor assembly construction. Courtesy of Fluid Components.

determines the product level based on the waveguide behavior, and a float containing a set of magnets that ride the outside of the gauge's outer rod.

Magnetostrictive gauges typically operate in the following manner. (*1*) The electronics assembly initiates a short, low current pulse onto a wire that runs through the center of the waveguide material. A timer starts simultaneously. (*2*) The pulse, along with the magnetic field it generates, travels the length of the gauge. (*3*) When the pulse reaches the float, the magnetic field from the pulse interacts with the magnetic field generated from the float (Fig. 21) and initiates a torsional twist in the waveguide material. (*4*) The physical twist creates a sonic wave that travels along the waveguide in both directions and is detected by the strain gauge in the electronics assembly. The timer is stopped as soon as this return signal is detected. The distance from the float (magnet) can be determined accurately based on the time and on the signal transmission properties of the individual waveguide material. (*5*) If a second float is present on the gauge, a second twist can be detected and recorded as the interface level.

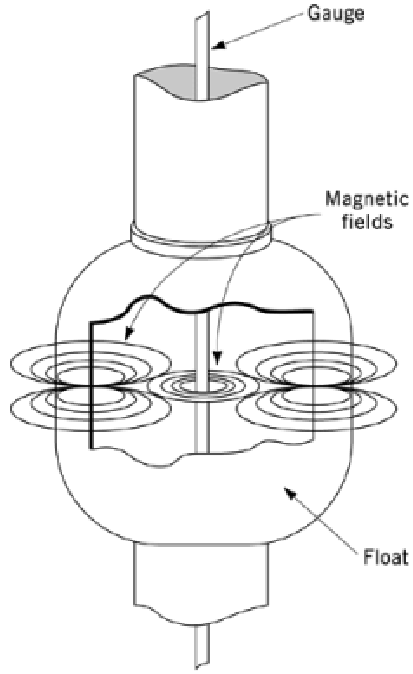

Fig. 21. Magnetostrictive level sensors measure the intersection of two magnetic fields: one in the float, the other in the gauge.

2.13. Phase Tracking

The principle of phase tracking uses a high frequency transmission line as a sensor. The sensor is comprised of two parallel conductors and hangs vertically in the tank. The electronics transmit a high frequency electrical sine wave down the sensor. This wave creates an electromagnetic field which simultaneously travels around both conductors. The signal travels at a constant velocity to the surface of the stored product. At the surface, the signal is reflected and travels back to the sensor at the same constant velocity.

The signal is reflected from the product surface because there is an abrupt impedance change in the sensor at the air–product interface. Because the electromagnetic field extends outside the two sensor conductors, the sensor impedance depends on the dielectric constant of the surrounding medium. In air (or vacuum) the dielectric constant is unity (1). In all other materials the dielectric constant is always greater than unity. Hence, there is always an echo at the air–product interface because of the difference in dielectric constant. The minimum difference is about 0.5, ie, a minimum dielectric of about 1.5 in the product.

2.14. Servo Gauge

Servo gauges are high accuracy, electromechanical devices that are used on inventory control applications where accountability is mandated for custody transfer of liquids. The large, million barrel, bulk terminal vessels are where these devices originally found a niche.

Servo gauges use a displacer as a primary element. The displacer is critically sized and weighted for optimum detection of primary and interface liquids. The displacer is suspended on a cable that is wound on a precision drum located in a housing at the top of the vessel (Fig. 22). The drum is magnetically coupled to the drive shaft. An isolation barrier separates the process from the electronics housing protecting the components from the tank vapors. Within the servo housing, a precision stepper motor is contained in a beam assembly. The

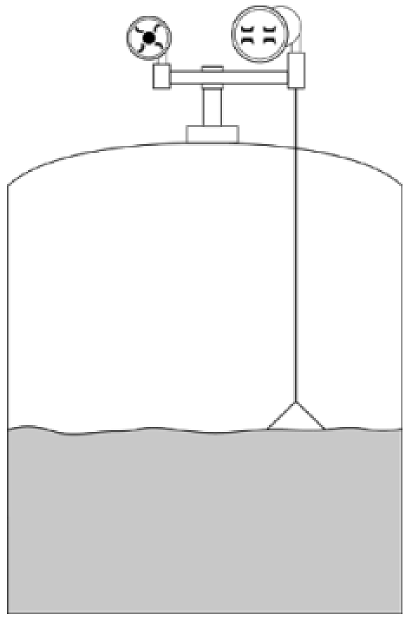

Fig. 22. Servo gauge.

beam counterbalances the apparent weight of the displacer in air and in the various products being gauged. As the level changes, the corresponding change in the weight of the displacer causes the beam to rotate and reestablish equilibrium. An optical encoder senses the rotational location of the beam and transmits this information to the microprocessor. The level is calculated from the length of the wire in the vessel which is determined from measuring the drum circumference.

In many applications temperature compensation is added to calculate level (or volume) to an industry standard value, usually the American Petroleum Institute (API).

Some servo gauges also have the ability to measure interface. This can be very important when water accumulates in the bottom of the vessel over time (water bottoms). In this way, the user receives information on the accumulation of water (which will eventually need to be pumped out), and also gets a more accurate reading of the real level of the product being stored.

2.15. Radiation

Nuclear radiation level switches and level transmitters are primarily used where process contamination is not allowed, process media prohibits use of other technologies, or where high temperatures prohibit use of other devices. The chief advantage of the nuclear unit is that all elements are completely external to the vessel. Radiation cell(s) are positioned outside of the vessel at the set point. A detecting cell is positioned outside the vessel opposite the radiating cell (Fig. 23). The gamma rays emitted by the radiation cell are partially absorbed by rising liquid. The radiation received by the detecting cell decreases proportionally to the change in level and the unit electronics convert the change to a switch action or a proportional output signal. Calibration of the unit is required after installation. Cobalt-60, cesium-137, and radium-226 are the source materials normally used. Source decay can cause signal shift unless automatic compensation is provided. There are many considerations required prior to selecting radiation level devices. The device manufacturer should be consulted for all applications. A license from appropriate federal and state agencies is normally required.

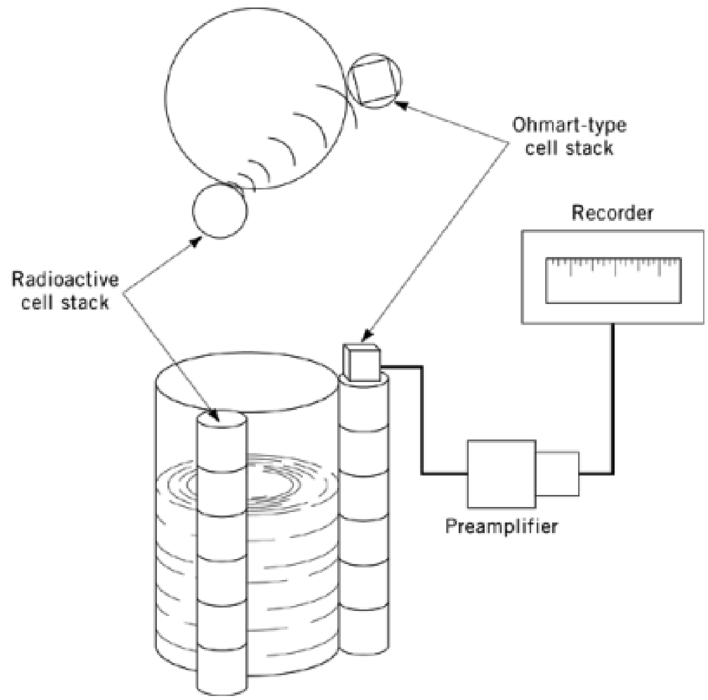

Fig. 23. Nuclear radiation level gauge, using an Ohmart-type cell stack.

3. Economic Aspects

Following is a list of suppliers for level sensing technologies.

Technology	Supplier	Technology	Supplier
sight glasses	John C. Ernst Co. Penberthy Inc.	ultrasonic	Bestobell-Mobray Endress & Hauser Magnetrol International, Inc.
dip sticks	B&K, Inc. Bagby Gage Pole Co.		Milltronics Sensall
magnetic liquid level indicators	Champ Tech K-Tek	microwave	Endress & Hauser Krohne Magnetrol International, Inc.
floats	Magnetrol International, Inc. SOR, Inc.	microwave	Saab TN-Canonbear Vega
displacers	Magnetrol International, Inc. SOR, Inc.	fiber optic	Besta Genelco (Bindicator)
buoyancy	Fisher Controls. International, Inc. Magnetrol International, Inc.	thermal dispersion	Honeywell Microswitch Moore Technologies FCI Kurz
conductivity	B&W Controls Warrick Controls Yarway		Magnetrol International, Inc. Sierra
capacitance	Bindicator Drexelbrook Endress & Hauser Magnetrol International, Inc. Princo Robertshaw Controls	magneto-strictive phase tracking servo gauge	MTS-Temposonics Magnetek Petrovend CTI-Celtek Enraf-Nonius L&J
pressure/differ-ential pressure	Foxboro Rosemount Smar Honeywell	radiation	Whessoe-Varec KayRay-Sensall Ohmart Ronan Texas Nuclear

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