3.9 Conductivity and Field-Effect Level Switches

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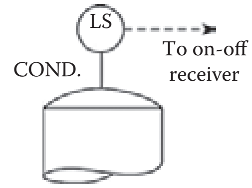

Flow sheet symbol

Applications	Point level detection of conductive liquids or slurries having dielectric constants of 20 or above. For electric switches, the maximum fluid resistivity is 20,000 Ω/cm; electronic types can function on fluids with higher resistivity. Field-effect probes are used on both solids and liquids which can be either conductive or nonconductive.
Design pressure	Typical pressures up to 3000 psig (21 MPa) for conductivity probes, 100 psig (6.9 bars, or 0.69 MPa) for field conductivity probes.
Design temperatures	Typical operating ranges for conductivity-type level switches are from –26°C (–15°F) to 60°C (450°F) for units with integral electronics and from –26°C (–15°F) to 982°C (1880°F) for units with remote electronics. Field-effect probes can operate at up to 100°C (212°F).
Materials of construction	Conductivity probes are typically made out of type 316 stainless steel, Hastelloy®, titanium, or Carpenter 20 rods with Teflon®, Kynar, or PVC sleeves. Housings are often made of corrosion-resistant plastic or aluminum for NEMA 4 and NEMA 12 services. The field effect probes are available with a Ryton™ probe with aluminum housing.
Probe lengths	Conductivity probes of solid rods having 0.25 in. (6 mm) diameters are typically available in lengths up to 1.8 m (6 ft); 1/16 in. (2 mm) diameter stainless steel cables can be obtained in lengths up to 30 m (100 ft). The length of field-effect probes is usually 8 in. (200 mm).
Sensitivity	Adjustable from 0 to 50,000 Ω.
Typical inaccuracy	0.125 in. (3 mm).
Cost	From $200 to $750. The typical price of an industrial conductivity switch is about $400.
Partial list of suppliers	AMETEK Drexelbrook http://www.drexelbrook.com/Other-Systems/Conductivity-Switches.aspx B + B http://www.directindustry.com/prod/b-b-thermo-technik/conductive-level-switches-multiple-electrodes-19452-896373.html Caché Instrumentation LTD http://www.cacheuk.com/cgi-bin/cache.cgi?Command=ShowProduct&db_pid=107 Endress+Hauser Inc. http://www.endress.com/en/products/level/detecteur-niveau-conductif-FTW31 Hawk http://www.hawk.com.au/productdetail.asp?id=17 HiTech http://www.hitechtech.com/conductivity.htm Level Guard Products http://levelguardproducts.com/sump/Field_Effect_Technical_Overview.php Omega Engineering Inc. http://www.omega.com/pptst/LVCN_LVCF_LVCR_LVCP.html Profimess http://www.profimess.com/conductive%20level%20switches/conductive%20level%20switches.htm Vega http://www.vega.com/en/Level_switch_conductive.htm

INTRODUCTION

Conductance is expressed as the inverse of resistance ($G = 1/R$). The conductivity of a substance is defined as the conductance (G) of cylindrical column of that substance, which is 1.0 cm long and 1.0 cm^2 in area. The units of conductivity are in siemens per centimeter (S/cm) or in mhos (which is ohm spelled backwards. Siemens and mhos are different terms for the same unit). The ability of a liquid to conduct electricity is a function of the number of charged ions in that solution. Deionized pure water has very high resistance, but liquids such as sewage water, sea water, and city water are quite conductive. In fact, the conductivity of most liquids is much higher than that of air. Therefore, if an electrical circuit is closed by the substance surrounding the tip of a probe, the resulting current flow will be much higher when the probe is submerged in the liquid than when it is in the air space above it. Conductivity-type level switches discriminate between air and liquid by using this principle.

CONDUCTIVITY-TYPE LEVEL SWITCH

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In a conductivity-type level switch installation, it is the process fluid itself which is the conductor that closes the electric circuit when the liquid comes in contact with the level probe. Figure 3.9a illustrates a conductivity-level probe installed in a grounded tank. One electrode is shown above the liquid level on the left side of this figure. The circuit on the left, therefore, is open, no current is flowing through the relay coil, and the load contact is open. When the liquid level rises, a conductive path is established between the electrode and the grounded tank closing the circuit through the relay coil. Energizing the relay closes the load contact, which, in the left of Figure 3.9a actuates an alarm and on the right operates a pumps. In this system, the liquid in the tank acts as a switch in the relay circuit. The use of electromechanical relays are shown on the left side of Figure 3.9a, but as implied on the right side, solid-state relays are more commonly used today.

In grounded metallic tanks, the level probes are usually installed vertically. If the liquid in the tank is agitated or is generally turbulent, it is desirable to employ two electrodes in detecting a single level point (Figure 3.9b). The small vertical distance between the two probes provides a dead band or neutral zone, which protects against cycling in case of splashing inside the tank. A time delay can also be employed to serve the same purpose.

When a dual-tip probe is used, the need for using a grounded metallic tank is eliminated. If the tank is fabricated

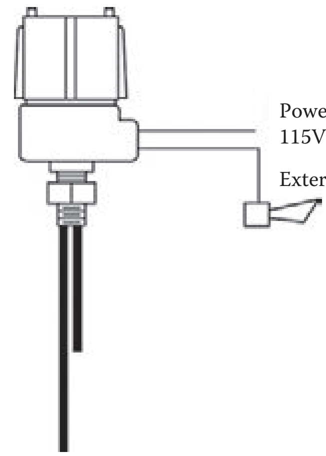

FIG. 3.9b
Dual-probe conductivity switch. (Courtesy of Endress+Hauser.)

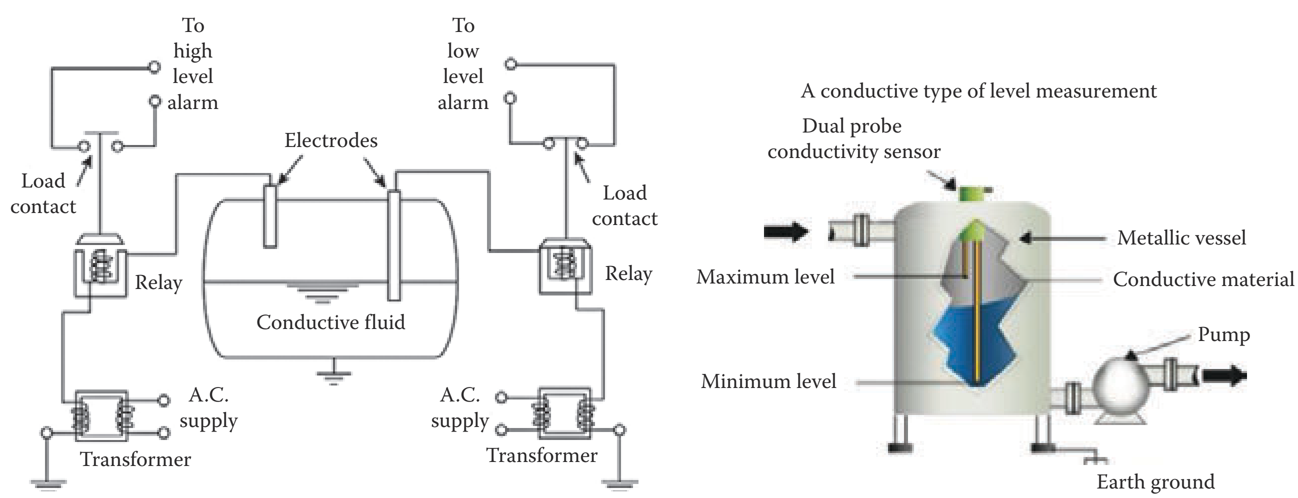

FIG. 3.9a
Illustrations of alarm (left) and pump control (right) operations using conductivity-type level switches. (Courtesy of Chipkin Automation.)

of fiberglass or other insulating material, the switching circuit is configured between the sensing probe and a reference probe. These probes can detect both total levels and interfaces between conductive and nonconductive liquids. The current flow is at the microampere level, which eliminates the hazards of shock and sparking. The sensitivity of the switch is adjusted to match the conductivity of the process liquid.

These switches are available in designs that combine switching functions, local calibration, and diagnostic communications (Figure 3.9c). In other designs, the amplifier can be separate and can be located up to 500 m away from the sensor probe. The amplifier includes relay outputs, and can also report to a supervisory control system via GosHawk, Modbus, HART, Devicenet, or Profibus DP. This allows for remote calibration, testing, or checking of the unit.

FIG. 3.9c
Smart conductivity switch. (Courtesy of Hawk.)

Conductivity-type level switches can also serve processes where tanks are filled or emptied in multiple stages. Figure 3.9d illustrates a design suited for a filling operation in four stages, using five partially insulated rod electrodes.

FIG. 3.9d
Conductivity switch with five probes can control a filling operation in four stages. (Courtesy of B + B Sensors.)

PUMP ALTERNATOR CIRCUITS

Because these switches are available in a variety of configurations, they can be used for the on–off control of one piece of equipment or for the staged control of several pieces of equipment. When two pumps are installed in the same on–off service, it may be desirable to automatically alternate the pumps so that they will wear evenly and so that “hot starting” of pump motors is reduced. Figure 3.9e shows how one level

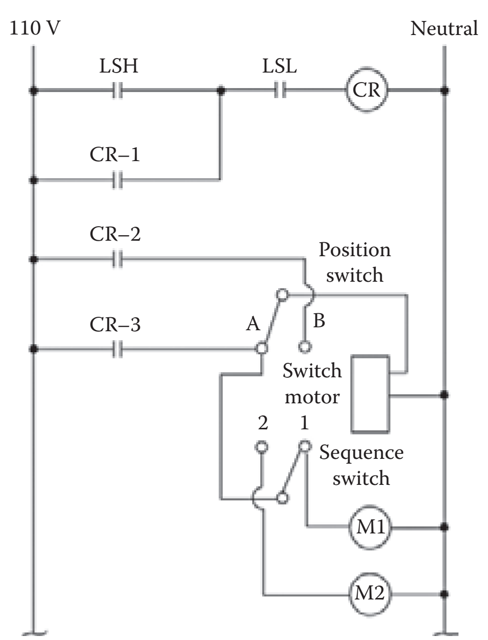

FIG. 3.9e
Pump-down alternator circuit. M1 = first pump; M2 = second pump.

switch with two conductivity probes can be used in conjunction with an electromechanical alternator to cycle the pumps.

As level rises, the low-level switch contact (LSL at top right of Figure 3.9e) of probe 1 will close, because this contact is operated by the lower probe. The control relay CR remains de-energized with its contact CR-2 closed and contacts CR-1 and CR-3 open. When the level rises to a higher level, the LSH contact of probe 2 closes, thereby energizing CR, which, in turn, closes contacts CR-1 and CR-3 and opens CR-2. The relay CR will remain energized after the level drops below and the LSH contact opens, because CR-1 is still closed. With CR energized, CR-3 is closed, and the circuits that are connected to contact A of the position switch and to contact 1 of the sequence switch are energized. The circuit connected to contact A starts the alternator switch motor, which, in turn, moves the position switch to contact B. This de-energizes the switch motor, because the CR-2 contact is held open by CR, which is energized. The circuit through contact 1 of the sequence switch energizes M1, which is the starter coil for the motor associated with the pump 1, and the first pump starts.

When the level falls below the level of the LSL probe tip, relay CR is de-energized, which opens contacts CR-1 and CR-3 and opens CR-2. Dropping out CR-3 stops the motor (M1) associated with the first pump. The closing of CR-2 energizes the switch motor, which steps to move the sequence switch to contact 2 and moves the position switch back to contact A. As a consequence, on a subsequent rise in level, M2 will be energized, and the second pump will start. This is a basic pump-down alternator circuit. A similar circuit can be designed for pump-up applications, and a wide variety of additional control requirements can be met if the numbers of probes and relays are increased.

This type of control is now implemented in solid-state controllers using multipoint probes. Multipoint probes (Figure 3.9d) are generally made out of PVC material and have conductive rings separated by equal distances. Each point is brought back to a controller to indicate the respective level. These points are then used to start and stop equipment as programed. Typical multipoint probes come in 3–10 point variations.

ADVANTAGES AND LIMITATIONS

The advantages of the conductivity switch include low cost, simple design, less maintenance, and elimination of moving parts in contact with the process material. Conductivity-type level switches can also be used to detect the level of moist bulk solids. The three-probe-element design can also provide differential level control.

The disadvantages include the possibility of sparking when the liquid level is close to the tip of the probe. Such phenomena are eliminated in the solid-state designs, which are rated for intrinsic safe operations. The conductivity switch is also limited to conductive (below 108 Ω resistivity) and noncoating process applications. One should also consider the possible harmful side effects of electrolytic corrosion of the electrode. Electrolysis can be greatly reduced, but not completely eliminated, by using AC currents.

Conductivity switches are rarely used in chemical processing applications. However, they are routinely used in the food, paper, and water/wastewater industries and in other water-level applications, including those on steam drums operated at up to 3000 psig (21 MPa). Specialized applications also include the measurement of the level of molten glass, which is a conductor at elevated temperatures.

FIELD-EFFECT LEVEL SWITCHES

As illustrated in Figure 3.9f, the field-effect probe creates a field between a metallic cap cast into a Ryton probe and the metal in the tank or in the probe gland and probe housing. When a conductive or nonconductive liquid, slurry, or solid material (with electrical characteristics different from that of air) breaks the field lines, the high-frequency current increases, and the relay trips. The probe should be installed horizontally (as shown in Figure 3.9f), with a small downward angle, if installed on slurry services.

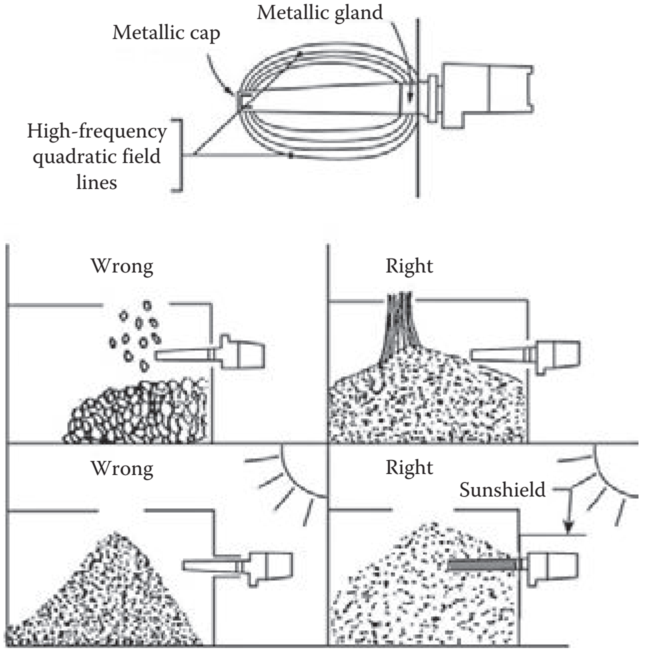

FIG. 3.9f
The field-effect level switch and its installation. (Courtesy of Endress + Hauser Inc.)

The Ryton probe material is unaffected by solvents if the operating temperature is under 100°C (212°F). The probe is 8 in. (200 mm) long and requires a 1.5 in. NPT tank connection. It is advisable to protect the probe form the impact of the flowing solids and to protect the electronics from direct sunshine.

The field-effect sensors can be digital, solid-state electronic devices using an integrated circuit (IC) that switches its output state when a conductive target is sensed. A field-effect cell is comprised of three main elements: the IC, a sensing electrode, and two tuning resistors (Figure 3.9g). When 5 VDC is supplied to the sensor, a low-power field is created which emanates directly through any protective dielectric barrier such as plastic or glass that may surround or cover the sensor. When water or another conductive fluid enters the field, the sensor detects the change and generates an output signal which, for example, can start a sump pump.

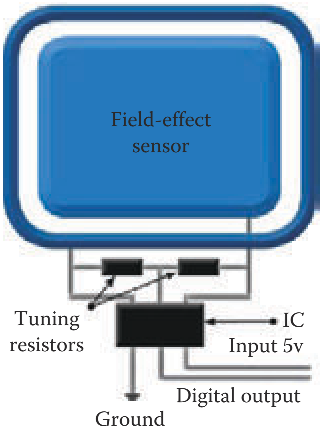

FIG. 3.9g
Field-effect sensor components. (Courtesy of LevelGuard Products.)

Definitions

Conductance: is the degree to which an object conducts electricity, calculated as the ratio of the current that flows to the potential difference present. This is the reciprocal of the resistance, and is measured in siemens or mhos. Symbol: G.

NEMA enclosures: NEMA defines standards for various grades of electrical enclosures typically used in industrial applications. Each is rated to protect against designated environmental conditions. A typical NEMA enclosure might be rated to provide protection against environmental hazards such as water, dust, oil or atmospheres containing corrosive agents.

RYTON is Solvay Specialty Polymers' trade name for Polyphenylene sulfide.

Abbreviation

PPS Polyphenylene sulfide

Organization

NEMA National Electrical Manufacturers Association

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3.10 Diaphragm Level Detectors

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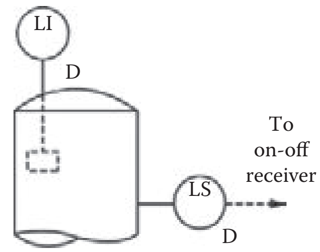

Flow sheet symbol

Types	(A) Solid level switches (bin monitors) (B) Liquid level switch (hydrostatic head detector or sump pump control switch) (C) Repeaters of hydrostatic head
Applications	Level switches and repeaters for both liquid and solids services including bins and sumps
Inaccuracy	Switches: Liquids: 1 in. (25 mm), Solids: 2 in. (50 mm) Transmitters: see Chapters 3.11, 5.5, and 5.6 Sump Pump Switches about 1 in. (25 mm) Repeaters: can repeat hydrostatic head within 1% FS
Design pressure	Switches: usually operate at gravity pressure, near atmospheric pressure Repeater: function of air or nitrogen supply
Temperature	−40°C (−40°F) to 130°C (266°F) typical
Wetted materials	Solids switches: typically aluminum, SS, neoprene, and various polymers Repeaters: SS, TFE, neoprene, Buna-N, and polyethylene Special designs: 316 SS, Hastelloy, Inconel, Monel, Titanium, and Butyl rubber
Ranges	Switches are single point Repeaters are a function of air/nitrogen supply pressure up to about 10 bars (150 psig) or to vacuum source
Cost	Switches: for sump control about $100; industrial ones about $500 Repeaters about $1000 (function of materials of construction)
Partial list of suppliers	For transmitters: see Chapters 3.11, 5.5, and 5.6 BinMaster (A); http://www.binmaster.com/search?q=diaphragm+level+switch&start=0&show=10&action=Go BulkPro Sistems LLC (A); http://www.directindustry.com/prod/bulk-pro-systems/membrane-point-level-switches-55819–689841.html Dwyer (A); http://www.directindustry.com/prod/dwyer/membrane-point-level-switches-7228–557358.html Foxboro-Eckhardt (C); http://www.foxboro-eckardt.com/en-gb/products/pneumatic/139pp/ Jayashree Solids (A) jayashree.co.in/products/level-sensing Jayce Technologies (A); http://www.jayceetech.net/diaphragm-level-switch.htm Kansai Automation Ltd. (B); www.kansai-automation.co.jp/eng/products/liquid/kf500.html KD Instruments (A); http://www.kdinstruments.com.au/index.php?id=102 Murphy Co. UK, (B); http://www.fwmurphy.com/uploaded/documents/pdfs/94124.pdf N.K. Instruments Ltd. (A, B); www.nkpressureinstruments.com/diaphlevelswitch.html Pentair (C); http://www.hydromatic.com/ResidentialProduct_diaphragmpressureswitch.aspx Plumberstock (C); https://www.plumbersstock.com/product/110785/ridgid-22803-diaphragm-switch/ SumpPumpWorld (B); http://www.sumppumpworld.com/hydromatic-dps41-diaphragm-switch-for-d-a1-sump-pump.html T. G. Rankin (C) grankin.com/content/view/42/65/ Valcom Srl. (C); http://www.pulpandpaper-technology.com/companygallery/process-automation-controls/valcom-srl/

All diaphragm detectors operate on the simple principle of detecting the force exerted by the process material against the diaphragm. The designs discussed below include diaphragm switches for liquid and solid services and diaphragm hydrostatic head repeaters for use for continuous liquid level detection in tanks, sumps, or wells.

DIAPHRAGM TYPE SWITCHES FOR SOLIDS SERVICE

For solid service, diaphragm switches (Figure 3.10a) can be installed on bins and can be selected from a number of design variations. Devices with mercury switches can be used with materials having a bulk density of more than 48 kg/m^3 (30 lb/ft^3), whereas units with microswitches are used for lower-density services. Some of the most sensitive diaphragm switches will actuate with as little as 171 g (6 oz) of force on the diaphragm. The differential of a single diaphragm can be as high as 8 in. (200 mm), meaning that the switch will close its circuit when the solids rise to the top of the diaphragm and will open the circuit when they drop 8 in. The lower the solid density, the larger the diaphragm area required. Units are available with 4–10 in. (100–250 mm) diameter diaphragms.

FIG. 3.10a
Diaphragm-type level switch designs for solid bin applications. (Courtesy of BulkPro Systems LLC, BinMaster, N.K. Instruments and Jayashree Solids.)

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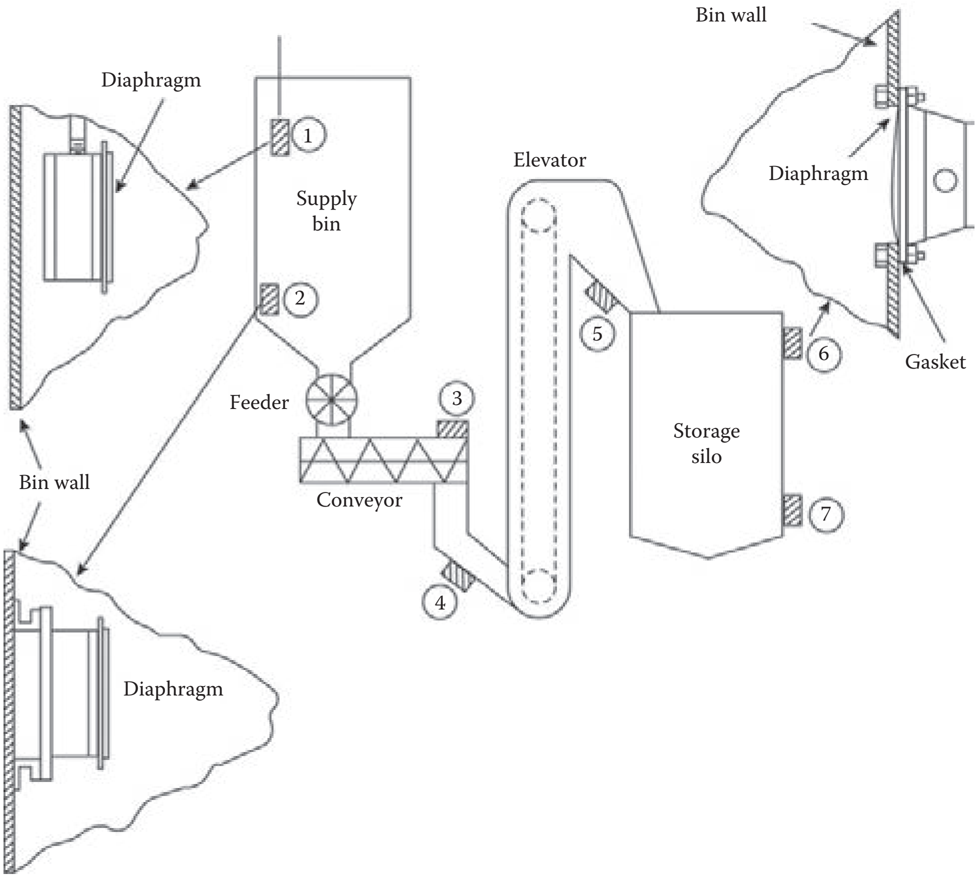

FIG. 3.10b
Use of diaphragm switches in solid services.

As illustrated in Figure 3.10b, there are three ways to install these detectors. They can be suspended on a support pipe to provide for quick adjustment of the switch position, they can be mounted on the inside wall of thick-walled silos, or, as is most commonly done, they can be externally mounted on thin-walled bins and silos. The mounting location should always be selected to guarantee the free flow of solids to and from the diaphragm area.

As shown in Figure 3.10b, diaphragm-type switches for solids can serve several purposes. Switch 1 protects against overfilling, switch 2 signals low supply level, and switch 3 indicates choke up in the screw conveyor. Diaphragm switch 4 detects overfeeding the elevator boot, and diaphragm switch 5 detects plugging of the elevator discharge spout. Diaphragm switches 6 and 7, in the storage silo, will signal extreme level conditions. Switch 6 can interlock the material feed and shut it down when the storage silo is full.

In newer designs, the diaphragm itself is vibrated by built-in piezoelectric elements and, when the solids' level rises up to the diaphragm, the resulting load on the diaphragm decreases the amplitude of vibration. This change in amplitude is used to trigger the level switch. This solids' level switch (Figure 3.10c) is smaller, lighter, and more sensitive than the earlier designs, and its stainless steel diaphragm (in an ABS resin body) is more rugged than the rubber diaphragms of the direct pressure-sensing units. The vibration of the diaphragm at 200–400 Hz reduces the probability of material sticking to the diaphragm and it also increases its sensitivity. The switch will actuate when it is 50% covered by materials with specific gravities exceeding 0.5, such as flour (0.48–0.55), polyethylene pellets (0.56), rice (0.58), PVC pellets (0.76), or wheat (0.77). On lighter materials, such as instant coffee (0.22) and copier toner (0.49), the diaphragm will actuate when it is 80% covered. To eliminate cycling, a 1–3 sec time delay is provided.

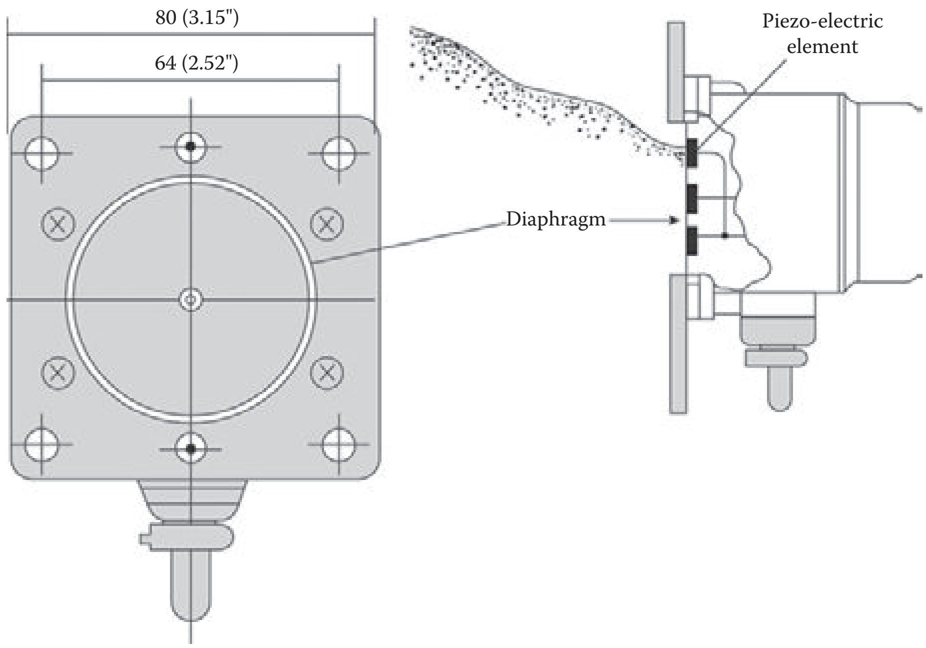

FIG. 3.10c
Vibrating diaphragm–type solid level switch.

DIAPHRAGM SWITCHES FOR LIQUIDS

Figure 3.10d shows how diaphragm switches can be used to detect liquid level by sensing the pressure of a captive air column in a riser pipe beneath the diaphragm. An 8 in. (203 mm) head of liquid above the inlet of the riser pipe generally compresses the air sufficiently for switch actuation. The unit can handle a maximum of 18 m (60 ft) of liquid. The diaphragm is in contact with the captive air but not with the process. The liquid rises in the dip pipe enough to compress the enclosed mass of gas to match the level-caused pressure outside the dip pipe minus the liquid rise inside the dip tube. Physical dimensions are important.

Sensitivity increases as the wetted portion of the dip tube increases and decreases in proportion to the enclosed air volume (Figure 3.10e). These units can be used only on atmospheric tanks and should be considered only for applications where low cost is desired and accuracy is not a critical consideration.

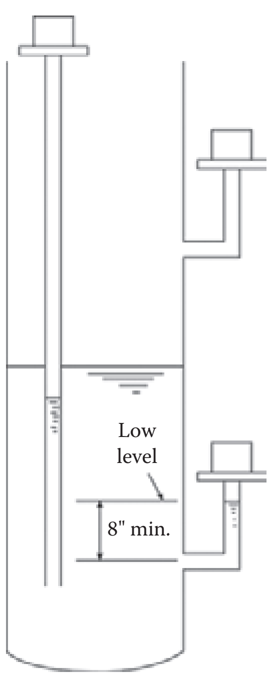

FIG. 3.10d
Diaphragm switches in liquid service.

FIG. 3.10e
Hydrostatic level switch. (Courtesy of Murphy Co., UK.)

CONTINUOUS LEVEL SENSORS AND REPEATERS

Figure 3.10f illustrates two versions of the continuous level detector, both limited to atmospheric tanks and to applications where low cost is more important than quality or accuracy of measurement. The diaphragm box unit, shown on the left side of the sketch, is similar in operation to the previously discussed riser pipe diaphragm switches except that the diaphragm isolates the captive air from the process fluid. The unit consists of an air-filled diaphragm box connected to a pressure detector via capillary tubing. Correct function depends on a large volume displacement by the diaphragm, with negligible spring constant. As the level rises above the slack diaphragm, the liquid head pressure compresses the captive air spring. The air pressure in the capillary tubing is sensed by a pressure element and displayed as an indication of level.

A one-to-one pressure repeater is illustrated on the right side of Figure 3.10g. With this unit submerged in the vessel, the static head of the liquid exerts an upward force on the diaphragm that increases as the level rises. The air supply pressure on the other side of the diaphragm opposes the upward force. The force caused by the rising level moves the diaphragm toward a bleed orifice, thus restricting its flow to atmosphere and causing the air pressure to build up until it equals the static head pressure. When the forces on the two sides of the diaphragm are equal, the unit is in equilibrium. The speed of response of the unit is changed by an adjustable restriction that, if opened, will increase sensitivity by allowing more air to flow onto the diaphragm. Air supply to the unit should be regulated at a pressure of 3–5 psig (0.2–0.3 bar) in excess of the maximum hydraulic head to be repeated.

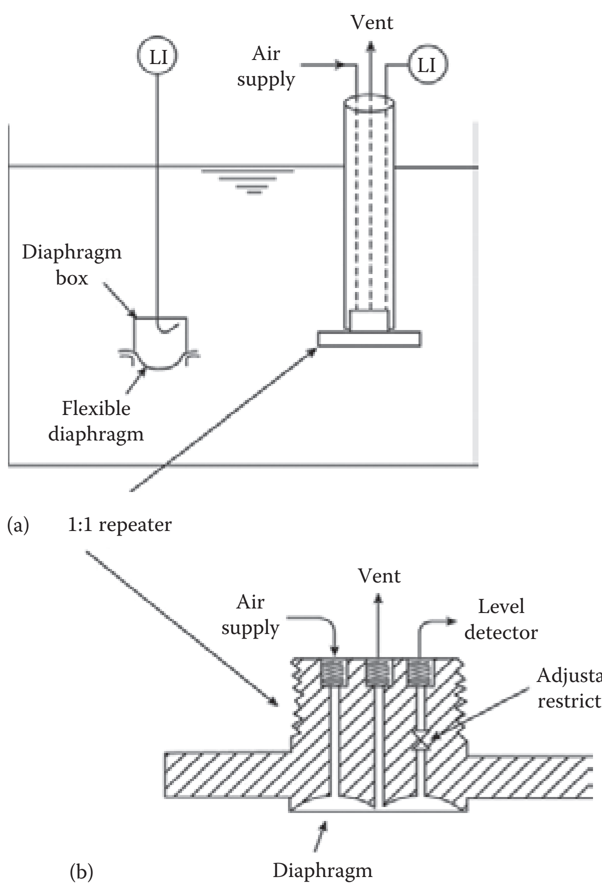

FIG. 3.10f
Diaphragm box for coupling bottom-of-tank pressure to a pressure gage (a); and 1:1 pressure repeater (b) for continuous pneumatic transmission of liquid level.

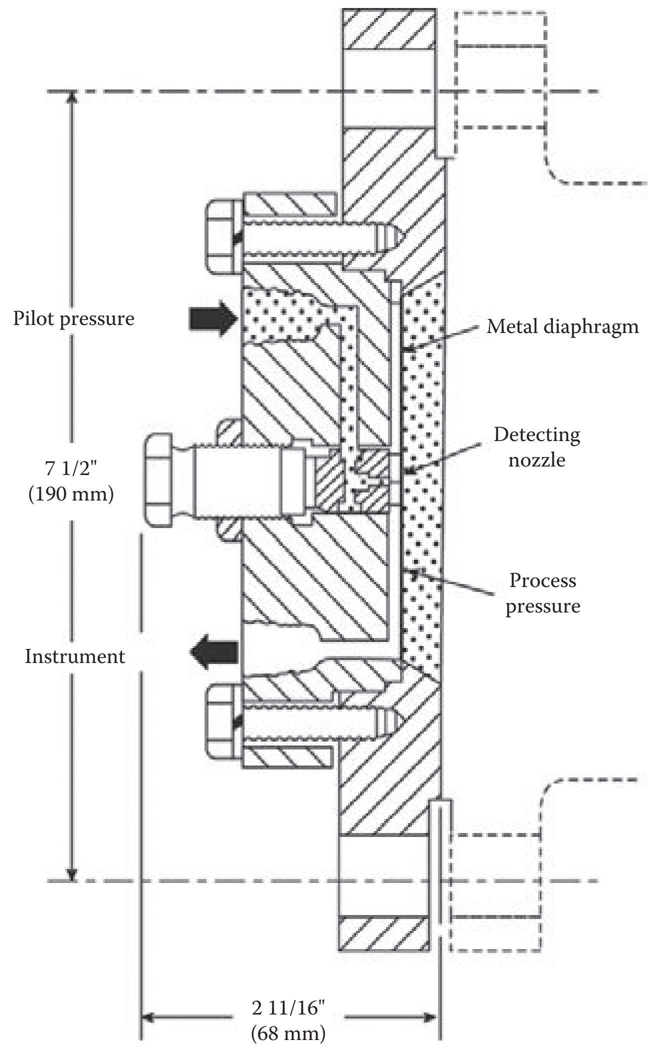

FIG. 3.10g
Pressure repeater for mounting on 4 in. (200 mm) tank nozzles.