Cryogenic Liquid Level Controls

By WALTER W. SCHOPP
University of California, Lawrence Radiation Lab.

Electronic controls are taking the place of mechanical devices to regulate the coldest liquids known to man.

ALMOST everyone is familiar with some sort of liquid level control. The device that controls the valve in the automatic washing machine and keeps the hot water from spilling over the floor is a liquid level control. So is the float valve in the bathroom water closet. When the liquid being controlled is water at room temperature, a float valve is usually sufficient. When the temperature of the liquid is below —321° Fahrenheit, using the float-valve approach leads to problems. Moisture from the surrounding air freezes on moving parts, eventually encasing the mechanism in ice. Condensation moisture trapped in a small crevice and frozen and thawed many times can exert great pressure on anything periodically immersed in this liquid. These were some of the problems that had to be surmounted by electronic cryogenic liquid level controls.

The control circuits to be described were developed for use at —321° F with liquid nitrogen, which is one of the most commonly encountered cryogenic fluids. Control circuits for other cryogenic fluids operating at different temperatures would be similar, although some changes in circuit components might be necessary. An understanding of the pros and cons of these basic control circuits can aid any technician whose work involves industrial electronic controls.

The uses of liquid nitrogen vary from quick-freezing of fruits and vegetables to heat-treating razor blades. Liquid nitrogen is also useful in biology as a blood preservative and in medicine for treatment of skin disease. It is often imperative that reservoirs of this super-cool fluid be maintained at a constant level. The liquid level control must sense a drop in the surface level of the liquid in the reservoir and replace the liquid that has evaporated. Sophisticated models add a timer to fill the reservoir for a predetermined period, raising the liquid level above the sensing device and thus cutting down the number of times that the control unit cycles. The transfer pipes have to be cooled less frequently, conserving liquid consumption somewhat. Other models use an upper and lower sensing device and maintain the level of the liquid between these two points. Variations in models and modes of operation are as numerous as the types and sizes of the reservoirs that are available.

Early Control Methods

Illustrated in Fig. 1 is one of the early methods of liquid nitrogen level control. Consisting of a metal bulb and capillary tubing, this control is classed as electro-mechanical. The bulb, capillary tubing, and diaphragm housing contain a refrigeration gas. As the liquid in the reservoir drops, exposing the bulb, the gas inside warms and expands. This expansion exerts pressure through the capillary tube on the diaphragm, pushing the sensitive switch closed. Closing the switch activates a solenoid valve in the transfer line, allowing the cryogenic fluid to enter the reservoir from the supply. As the liquid again covers the bulb, the gas in the bulb condenses, relieving the pressure on the diaphragm. This opens the switch and closes the valve from the liquid supply.

Operation was simple and effective for many years until deeper and deeper reservoirs began to be used. This revealed a certain problem: the undisturbed layer of nitrogen gas just above the liquid surface was found to be only a few degrees warmer than the liquid itself. So cold was this layer of gas that unless a sizable amount of heat from the room crept down the capillary tubing and helped warm the

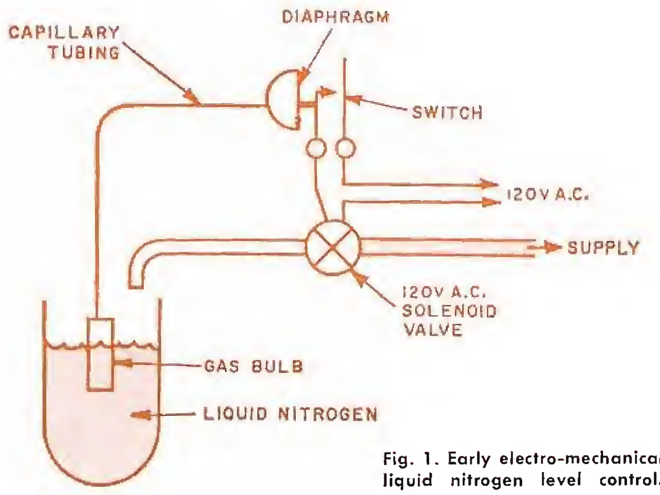


Fig. 1. Early electro-mechanical liquid nitrogen level control.

Fig. 2. Balanced bridge sensor uses composition resistor.

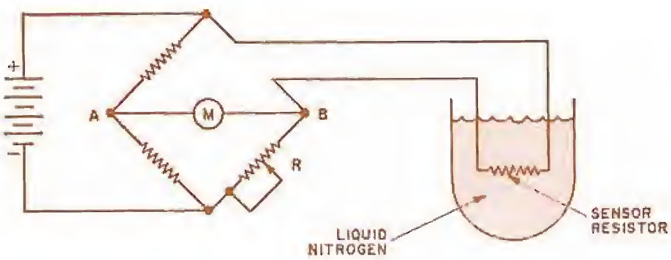
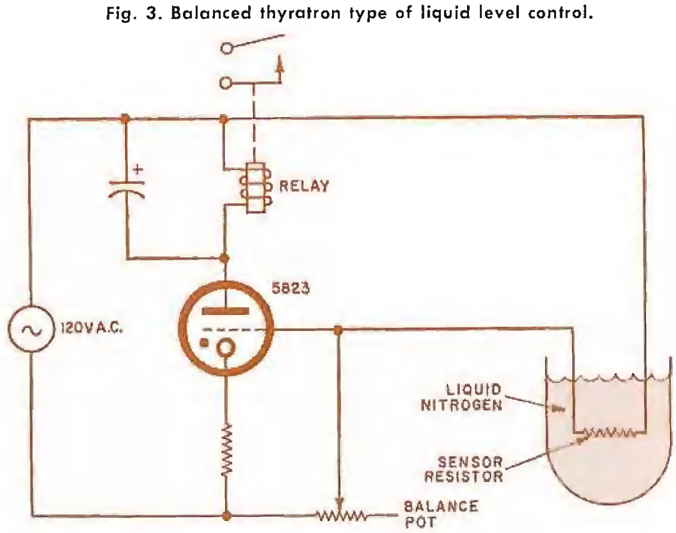


Fig. 3. Balanced thyratron type of liquid level control.



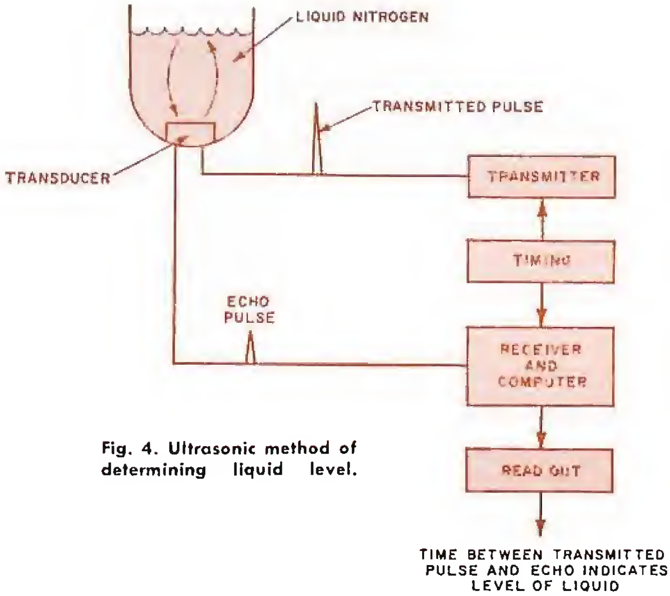


Fig. 4. Ultrasonic method of determining liquid level.

bulb, the control would not turn on until the reservoir was completely dry. One solution was to use an electric heater surrounding the sensor bulb, since the ability of liquid to carry away heat is much greater than that of gas. However, the use of a heater around an already bulky gas sensor bulb was not a desirable solution.

Balanced Bridge Circuit

At this point, electronics made its debut in this field. Why not use a balanced bridge circuit with one leg of the bridge submerged in liquid nitrogen as the sensor (Fig. 2)?

It is well known that carbon-composition resistors exhibit large increases in resistance when exposed to these low temperatures. If a low-wattage resistor were used as a sensor and operated close to its maximum heat dissipation limits, it would have its own built-in heater. Placed in the bridge circuit and immersed in liquid nitrogen, its resistance would increase to a higher than normal value. The circuit could then be balanced under these conditions by variable resistor *R* until no voltage appears across balance points *A* and *B*. As the liquid level drops and exposes the sensor, the internal heat quickly returns the resistance to its nominal value. This unbalances the bridge circuit and indicates on the meter that the liquid level has dropped below the sensor.

The balanced bridge circuit was further improved by the modification shown in Fig. 3. Here the balanced thyratron circuit directly operates a load relay when the balance between the balance potentiometer and the warming sensor resistor is upset.

The bridge circuit was a simple approach to a complicated problem. It overcame the cold sensor difficulty and distinguished positively between liquid and gas in the deepest reservoirs. However, all was not yet well as a new problem was introduced.

Small changes in applied voltage do not upset a normal bridge circuit in balance. All the voltages across all the legs increase or decrease uniformly and the net result across the balance point is zero. In the cryogenic version of this balanced bridge, however, a slight rise in applied voltage results in more internal heat being applied to the sensor resistor, driving the resistance down in this leg while not adversely changing the resistance of the other legs of the circuit. This unbalances the circuit and usually results in a large container of liquid nitrogen being dumped on the floor while the reservoir goes dry.

Still another problem was discovered with the circuit. If the sensor resistor was out of the liquid for a prolonged time, the value of the resistor would change slightly due to overheating; thus, when the liquid level was restored and the sensor was again cooled, the circuit would not return to balance. A constant voltage source and close scrutiny would cure most of the ills of this circuit.

Ultrasonic & Transformer Controls

Ultrasonic gaging devices have been applied successfully to the level control of cryogenic liquids (Fig. 4). Application is similar to sonar principles. The surface level is determined on a readout device by the time differential between the transmitted pulse and the received echo. However, complex circuitry makes the cost very high. As the transducer is an integral part of the reservoir, versatility is not an attribute, although the system is quite reliable.

Another innovation is the variable-transformer level control. The sensor element consists of a bellows that houses a variable transformer. As the bellows expands and contracts from the liquid temperature, the inductance change due to the core movement is read with the circuit shown in Fig. 5.

The circuit in Fig. 6 illustrates how the transformer sensor can be incorporated into a transmitting level indicator. Changing frequency directly with the bellows temperature, this circuit can transmit level indications to a remote location. This control suffers the same ills as the gas-bulb sensor inasmuch as no external heat is provided.

Optical Techniques

The optical liquid level detector shown in Fig. 7 also deserves consideration. This novel approach uses light pipes

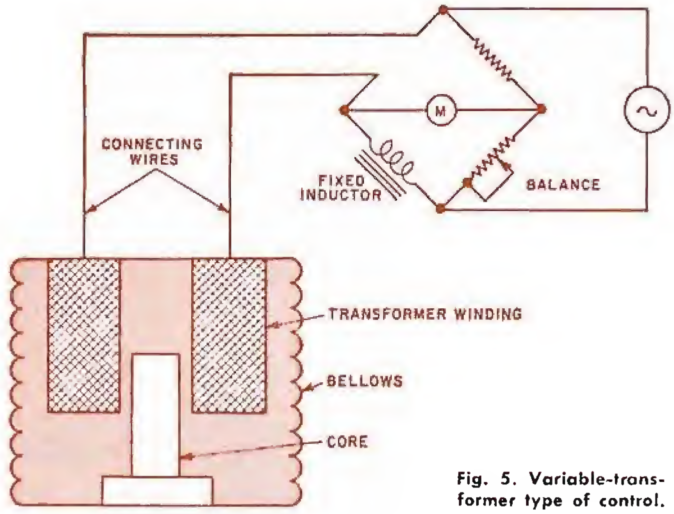
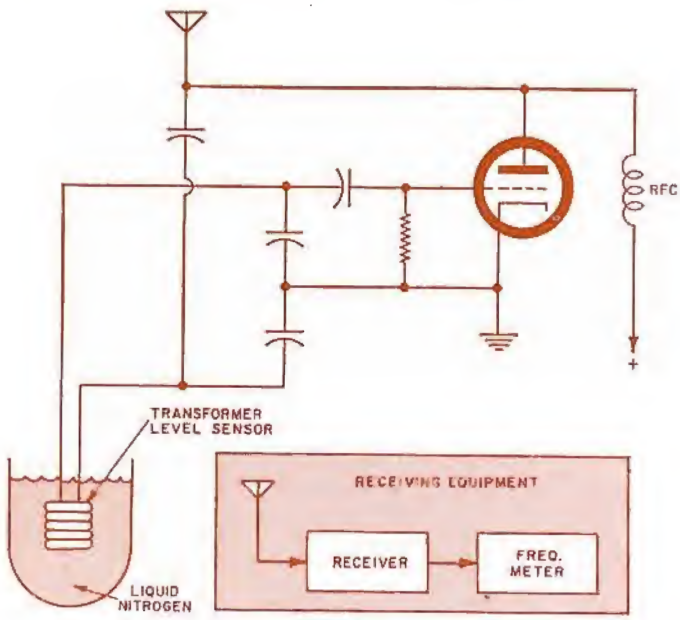


Fig. 5. Variable-transformer type of control.

Fig. 6. Frequency of the transmitter is determined by level.



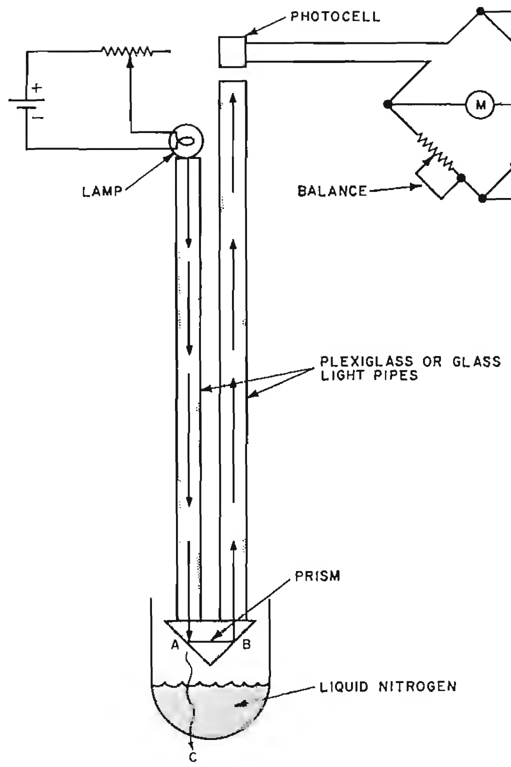


Fig. 7. An optical level control used for liquid nitrogen.

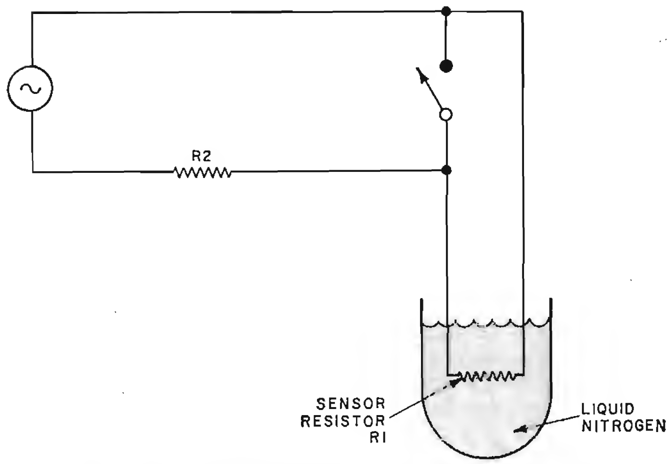
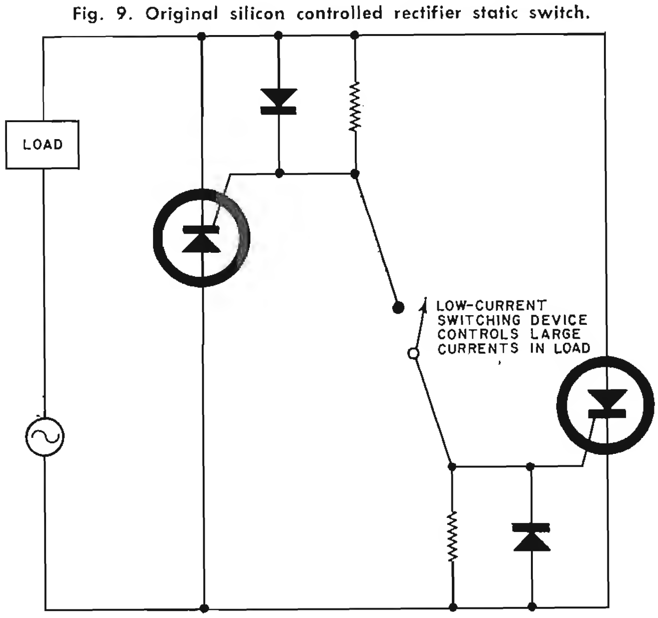


Fig. 8. The simplified electronic control circuit employed.

Fig. 9. Original silicon controlled rectifier static switch.



and a photocell along with a light source and associated circuitry. The sensing device in this system is a small glass prism. When this prism is dry or out of the liquid, light from the lamp travels down one light pipe, reflects off the two 90° prism surfaces *A* and *B*, and moves back up the other light pipe to the photocell. When the sensor prism is wet, the new light path is into the liquid towards point *C*, since the two wet prism surfaces lose their ability to reflect due to the similarity in the refractive indices of the glass and liquid nitrogen. The resulting resistance change of the photocell caused by the light variations is read on the balanced bridge.

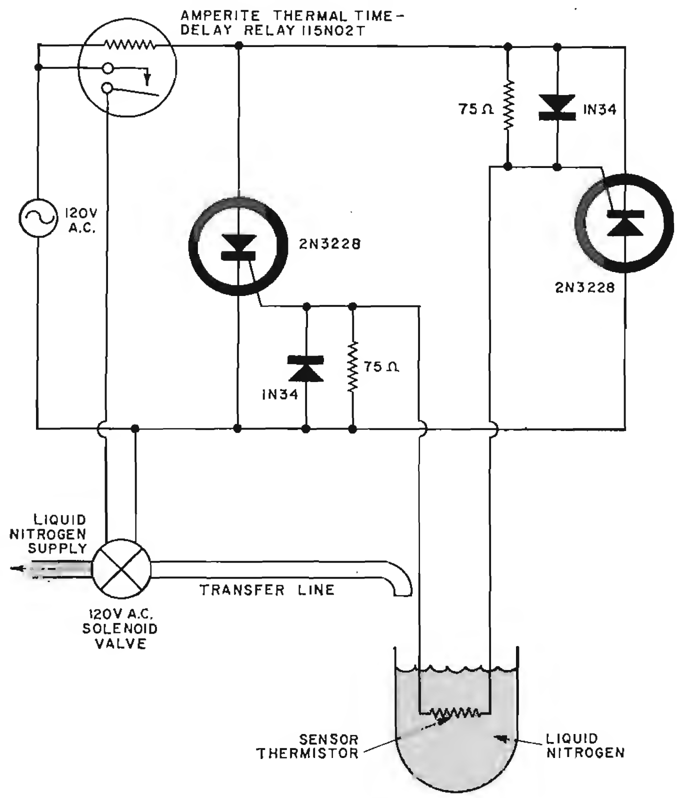
A problem with this type of sensor is that it becomes erratic due to splashing and vapor created during the liquid transfer cycle. This deposits enough liquid on the optical surfaces to falsely indicate that the sensor is immersed in liquid, which prematurely stops the liquid transfer and causes short cycling.

A definite need existed for a control that possessed the reliability of the gas-bulb sensor in a shallow reservoir and the selectivity of the internally heated sensor, without the voltage sensitivity of the cryogenic version of the bridge circuit or the troublesome resistance drift. Economy was also desired, which ruled out ultrasonic devices. What was really needed was a liquid level control that removed the heat from the sensor while it was out of the liquid but would stand by to apply it quickly as the sensor was immersed in liquid and the heat was required.

Electronic Methods

Shown in Fig. 8 is a simplified circuit illustrating a new concept of electronic liquid nitrogen level control. The basic circuit consists of a load resistance (*R*2), a switch, and a resistor representing the sensor (*R*1); also shown is a voltage source. If the load has a high positive temperature coefficient, when the switch is open, most of the voltage appears across the comparatively high resistance of sensor resistor *R*1. As the switch is closed, the full voltage now appears across the load resistance, while the heat-creating current is bypassed by the switch. This was the exact operation desired and the silicon con- (*Continued on page* 74)

Fig. 10. A.c. static switch modified for liquid level control.



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trolled rectifier a.c. static switch provided this action.

The original SCR a.c. static switch appears in Fig. 9. This circuit was designed to handle large amounts of alternating current with a low-current switching device connected across the gates of the SCR's. In the cryogenic level control modification, a thermistor was substituted for the switching device and a time-delay relay was used for the load resistance. The revised circuit appears in Fig. 10.

When the thermistor is immersed in liquid nitrogen, its resistance value increases enough to completely turn off the SCR switch circuit. Most of the a.c. line voltage appears across the sensor through the time-delay relay heater which is cool and low in resistance. A small amount of current flows through the sensor to maintain internal heat.

As the liquid level drops and exposes the thermistor, its resistance drops due to warming by internal heat, and the SCR's start to conduct. As current begins to flow through the relay heater, its resistance starts to rise, dropping an increasing amount of voltage. As more voltage is applied to the heater, less voltage is available to heat the sensor due to the bypassing of current through the SCR's. When the SCR switch is turned fully on, very little voltage is left on the sensor. As the sensing thermistor is again covered with liquid, the resistance rises sharply, turning off the SCR switch and shutting off the current to the relay heater. As the heater cools, full line voltage is restored to the sensor for heating.

The transition of the circuit from on to off is smooth and operates flawlessly; heat is applied as needed to the sensor and removed when it could be damaging. The time-delay relay changes the slow rising and falling voltage across the heater to an abrupt "on-off" signal through the relay contacts.

By careful selection of the value and temperature coefficient of the sensing thermistor, along with the proper physical size for the correct power dissipation, the circuit can be made to tolerate line-voltage variations as great as 90 to 140 volts a.c. without seriously affecting the operation and can positively distinguish between liquid and vapor without adjustments of any kind.

In this article we have seen how electronics and solid-state devices have come to the field of cryogenic liquid level control. Like so many other fields of application that were formerly dominated by mechanical devices of various types, this field is now finding use for electronic controls with their improved reliability and sensitivity. ▲