June 22, 1954 T. J. MESH ET AL 2,682,026

ELECTRONIC LEVEL-SENSITIVE APPARATUS

Filed April 22, 1953

4 Sheets-Sheet 1

Fig. 1.

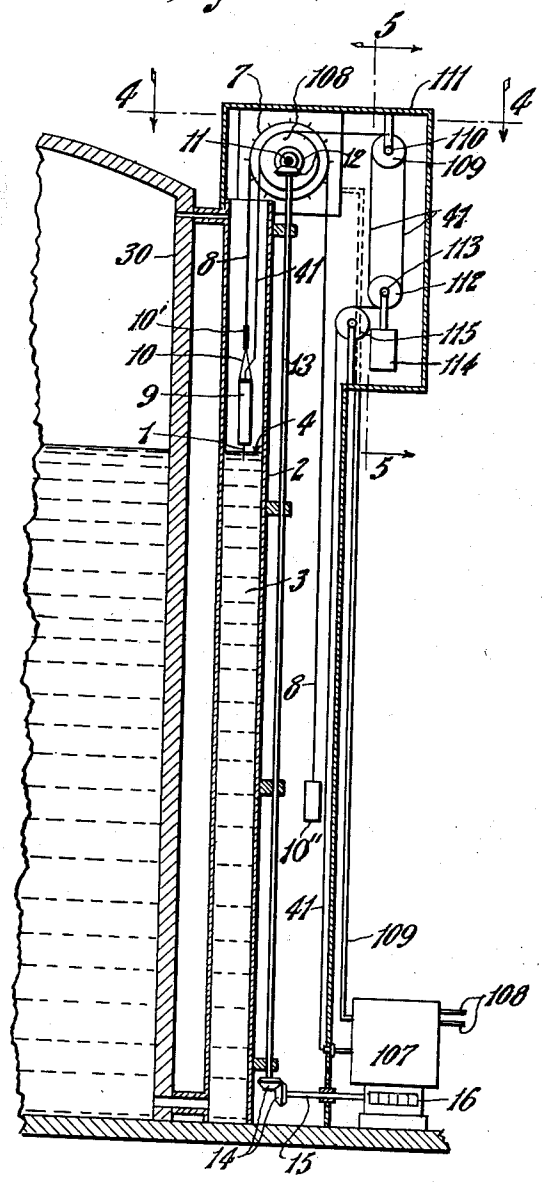


Fig. 2.

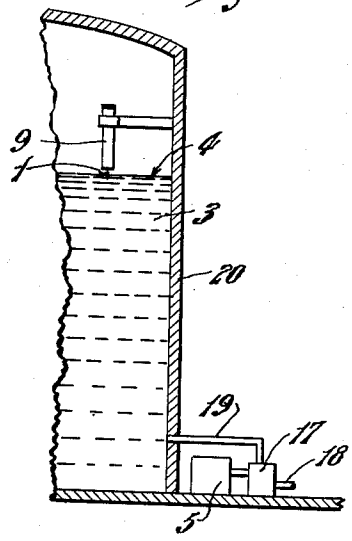
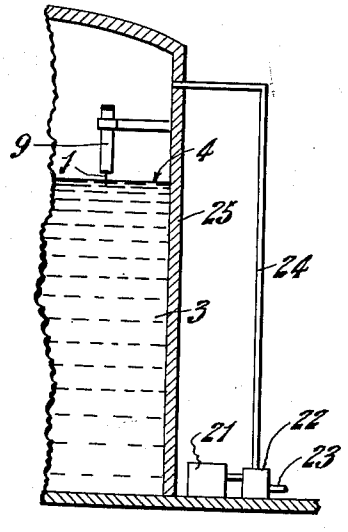


Fig. 3.



INVENTORS,
Theodore J. Mesh and
Harry F. Tapp,
BY
Chapin & Neal
Attorneys.

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4 Sheets-Sheet 2

Fig. 4.

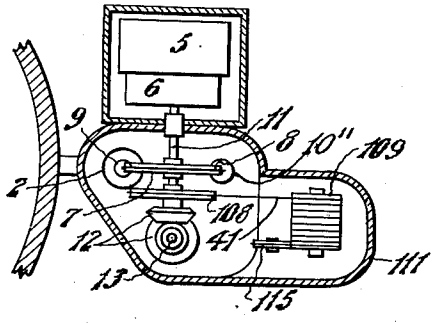


Fig. 6.

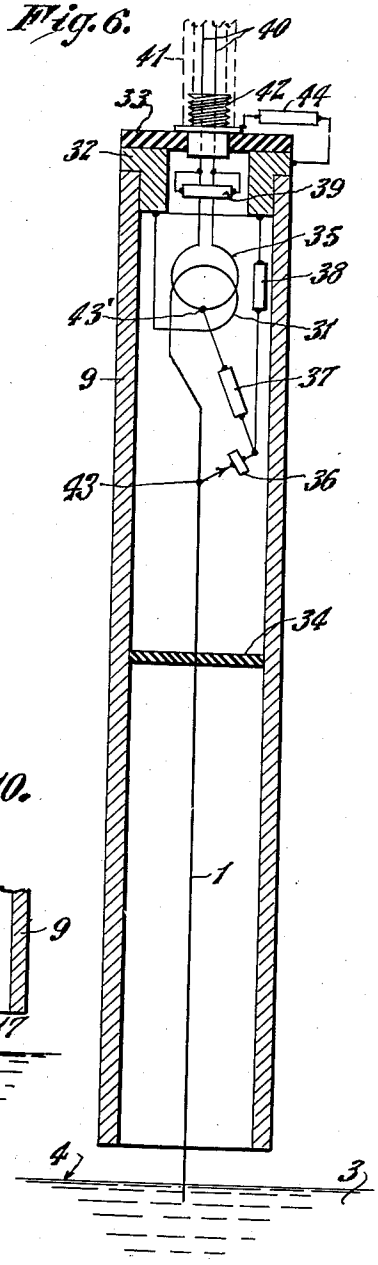


Fig. 5.

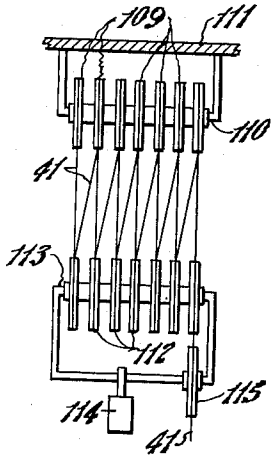


Fig. 10.

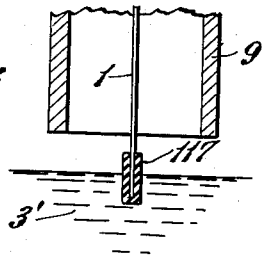
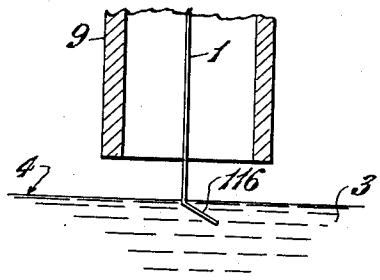


Fig. 7.



INVENTORS.
Theodore J. Mesh and
Harry F. Tapp,
BY Chapin & Neal
Attorneys.

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4 Sheets-Sheet 3

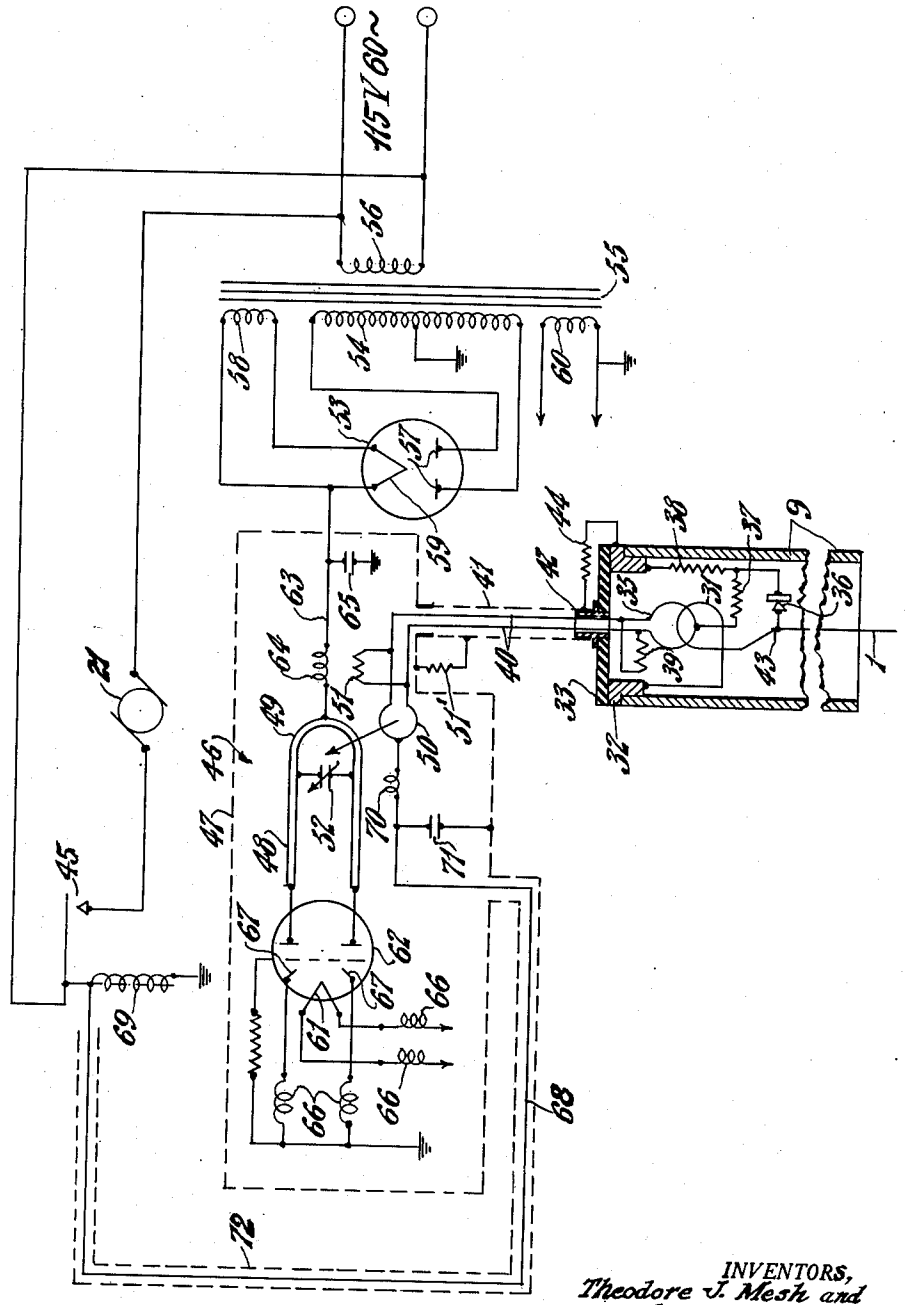


Fig. 8.

INVENTORS,
Theodore J. Mesh and
Harry F. Tapp,
BY Chapin & Neal,
Attorneys.

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ELECTRONIC LEVEL-SENSITIVE APPARATUS

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4 Sheets-Sheet 4

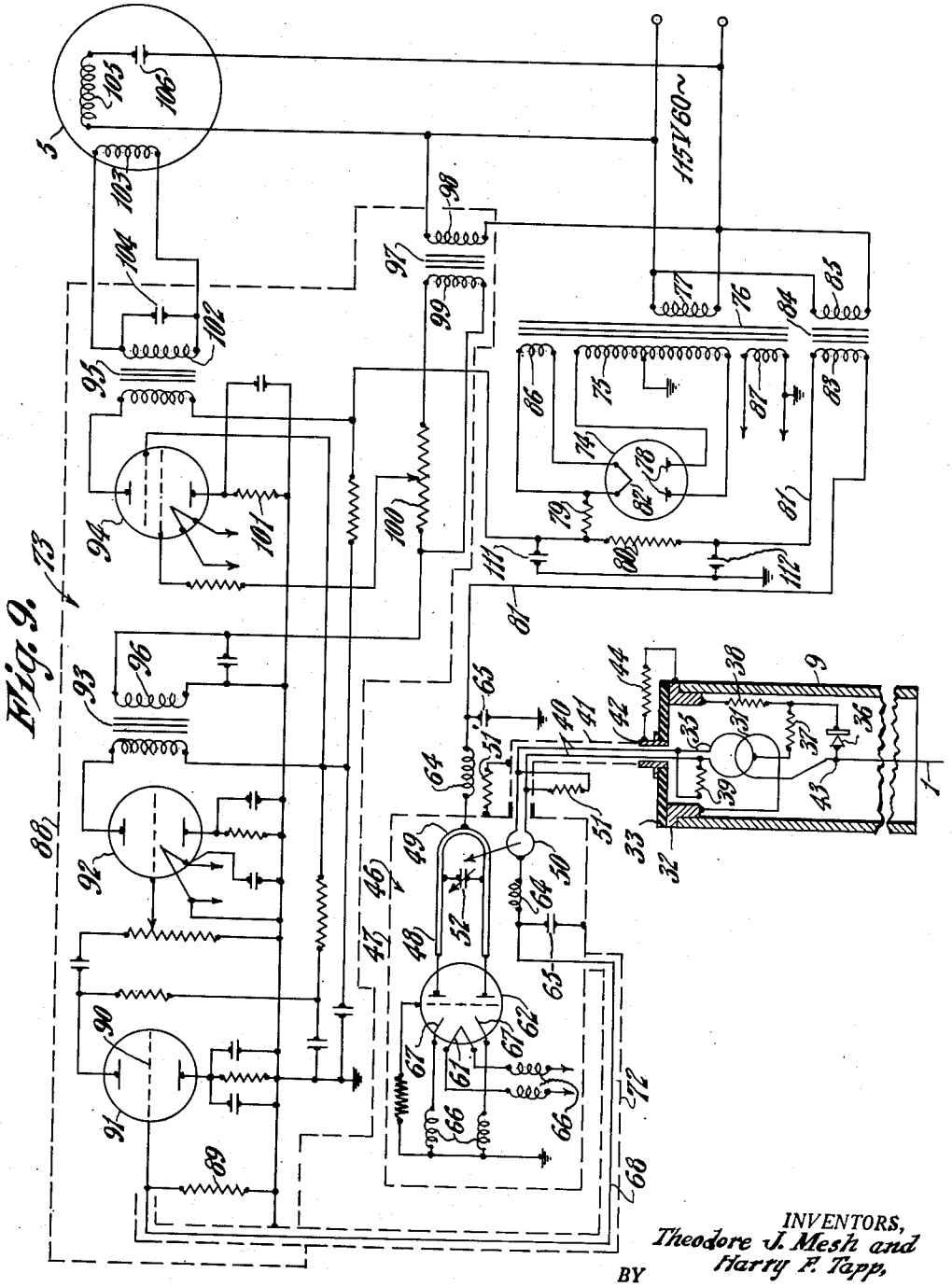


Fig. 9.

INVENTORS,
Theodore J. Mesh and
Harry F. Tapp,
BY Chapin & Neal,
Attorneys.

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UNITED STATES PATENT OFFICE

2,682,026

ELECTRONIC LEVEL-SENSITIVE APPARATUS

Theodore J. Mesh, Easthampton, and Harry F. Tapp, Longmeadow, Mass., assignors to Gilbert & Barker Manufacturing Company, West Springfield, Mass., a corporation of Massachusetts

Application April 22, 1953, Serial No. 350,485

13 Claims. (Cl. 318—31)

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This invention relates to an improved electronic level-sensitive apparatus for use with containers of liquid either for the purpose of indicating the level of liquid in the container or for the purpose of maintaining the liquid at a predetermined level in the container.

The invention is capable of use with liquids of any kind, both electrically non-conductive and electrically conductive. However, the invention has one advantageous use in connection with storage tanks, such as are used at refineries, to store various petroleum products, and these are generally electrically non-conductive.

The invention is an improvement on that disclosed in the U. S. Patent No. 2,619,620 of Harry F. Tapp and Theodore J. Mesh, granted November 25, 1952. The apparatus of this patent utilizes as a level-sensing element, a wire which is electrically resonant at a predetermined frequency and the sensitive portions of which are located horizontally and spaced above the surface of the liquid in the container. Whenever there is a change by a small increment in the spacing between such portions and surface of the liquid, a corrective relative movement is produced between such portions and surface for the purpose of restoring the desired predetermined spacing. Control of such movement depends on a change in signal voltage in the resonant wire caused by detuning it and this is effected primarily by variation of the capacity of dielectric air path between the sensitive portions of the sensing element and the surface of the liquid. The desired condition of substantially constant spacing between said sensitive portions and the surface of the liquid necessitates substantially constant signal voltage in the resonant circuit.

In the practical operation of this apparatus in storage tanks of petroleum products, variations in signal voltage can occur from various causes other than relative movement between the sensitive portions of the level-sensing element and the surface of the liquid and these produce inaccuracies in measurement. One such cause is the presence of oil on the sensitive portions of the resonant wire. While these portions are spaced above the liquid and contained wholly within a protecting shield, nevertheless, oil can and often does lodge on them. For example, where as often happens, the contents of the tank are stirred up by any means which causes churning of the liquid, as by introducing compressed air into the tank or by the use of nozzles which circulate the liquid, splash or

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spray will reach the wire and hang therefrom in a multitude of drops. Sometimes, a drop in temperature will condense saturated vapor above the liquid in the tank and cause drops to be deposited on the wire. Also, on a power failure, movement of the wire will stop while liquid may continue to be forced into the tank, whereby the wire will become wet with oil. If the liquid is relatively light, the drops will soon fall off but if the liquid is relatively heavy, the drops may remain for a long while. These drops on the resonant wire cause detuning of it and lowering of its signal voltage. Line voltage fluctuations, ageing of the various electronic tubes and variations in the temperature of the diode will likewise change the signal voltage in the resonant wire without detuning it. In general, the decreases in signal voltage, which occur from the causes described, are of substantial amount as compared to those which are effected by changes in capacity of the dielectric air path, caused by variation in the length of the air space between the sensitive portions of the wire and the surface of the liquid and therefore affect the gauging accuracy to an extent such as to require recalibration of the apparatus. Varying field conditions affect the accuracy of the apparatus in various ways. Varying conditions in the same installation cause changes which require frequent checking and recalibration.

The invention has for an object to provide an improved apparatus of the class described in which the difficulties above described are overcome.

This invention has for another object to provide an electronic level-sensitive apparatus which will determine the liquid level in a container with close accuracy and substantially independently of variations of signal voltage which occur from causes other than variation in relative movement between the sensitive portion of the resonant wire and the surface of the liquid.

More particularly, the invention has for an object the provision of a level-sensing element in the form of a wire which is electrically resonant at a predetermined frequency and which is mounted in upright position in a container of liquid with the lower end of the wire immersed in the liquid to a predetermined depth. Variations of signal voltage in the wire, effected by slight changes in the depth of its immersion, are utilized to produce a small corrective relative moment between the lower end of the wire and the surface of the liquid for maintaining the

depth of immersion of the wire, within close limits, at a predetermined value.

The invention has for a further object the provision of a non-hunting level-sensitive apparatus, comprising a two-phase low-frequency alternating-current electric motor for effecting relative movement between the level-sensing resonant wire and the surface of the liquid in the container, either by raising and lowering the wire itself or by raising and lowering the level of the liquid; a high-frequency low-power oscillator inductively coupled to the resonant wire and tuned to resonance therewith, when the wire is not immersed in the liquid, said oscillator being modulated with alternating current of the same low frequency as the motor and producing a signal in the resonant wire; and means for deriving from said signal a low frequency signal, which is amplified and transmitted to the motor to oppose the alternating current supply to various degrees, according to the depth of immersion of said wire, and cause the motor to turn in one direction or the other, as necessary to maintain the wire and level in said predetermined relationship and to stop when such relationship is attained.

These and other objects will more particularly appear from the following description of illustrative examples of the invention in the accompanying drawings, in which:

Figs. 1, 2, and 3 are small-scale, fragmentary, sectional-elevational views illustrating various ways of mounting the level-sensing element of the apparatus in a container of liquid;

Figs. 4 and 5 are sectional views taken on the lines 4—4 and 5—5 respectively of Fig. 1;

Fig. 6 is a sectional elevational view showing the level-sensing element and its mounting in its shield together with the coupling loop, detector and associated elements, which are mounted in the shield;

Fig. 7 is a fragmentary view, taken similarly to Fig. 6 and showing a modification in the shape of the level-sensing element;

Fig. 8 is a diagrammatical view of one form of apparatus used to operate a control switch;

Fig. 9 is a diagrammatical view of another form of apparatus used to operate a reversible alternating current motor; and

Fig. 10 is a fragmentary view showing a modification in the resonant wire.

Referring to these drawings and first to Figs. 1 to 3 thereof, the invention makes use of a level-sensing element 1, which is suitably mounted in upright position in a container 2 of liquid 3 of any desired kind. The lower end of this element is immersed in the liquid in the container being spaced slightly below the surface 4 of the liquid. The spaced relationship of the lower end of element 1 and surface 4 is maintained by suitable means, actuated by a signal derived, as will be later described in detail, from the sensitive element 1. Such means may, for example, consist of an electric motor 5 (Fig. 4) driving, preferably through suitable gear-reduction mechanism indicated at 6, a sprocket or pinwheel 7 (Fig. 1), carrying a chain or tape 8, from one end of which the sensitive element 1 and its enclosing shield 9 are suspended as by a bail 10 and an interposed insulating link 10'. The shield consists of a metal tube having its upper end closed and its lower end, which is spaced above but adjacent the surface 4 of the liquid, normally open. The other end of tape 8 carries a counterweight 10. The shaft 11 of sprocket 7 drives by bevel gearing 12 a vertical shaft 13, which in turn drives by bevel gearing 14 a shaft 15, which operates a suitable indicator 16, as for example one of the number wheel type, showing the level of liquid in the tank. The motor 5 will turn in one direction or the other to respectively raise or lower the sensitive element 1, as may be required to maintain the predetermined spaced relationship between the lower end of element 1 and the surface 4 of the liquid. Alternatively, the motor 5 may, as shown in Fig. 2, drive a pump 17 which is connected by a pipe 18 with a supply of the liquid and by a pipe 19 with the lower part of a tank 20 in which the element 1 is stationarily mounted. The pump can force liquid into or draw it out of the tank to respectively raise or lower the level 4 of the liquid in the tank as required to maintain the desired predetermined spacing between the surface of the liquid and the lower and immersed end of the stationary sensing element 1. The signal derived from the latter may also be made, as shown in Fig. 3 and as will later be described in detail, to start and stop a non-reversing motor 21, which operates a pump 22 to draw in liquid from a suitable supply through a pipe 23 and force it through a pipe 24 into a tank 25, in which the sensitive element 1 is stationarily supported. As the liquid in the tank is used up and its level falls, the motor 21 will operate the pump to restore the liquid to its normal level.

In Fig. 1, the container, in which the sensitive element is mounted, is a vertical tube 2, connected like a gauge glass, at top and bottom to a larger tank 30, while in Figs. 2 and 3 the sensitive element is mounted directly in the tank itself.

The sensitive element 1 and its associated elements are mounted as shown in Fig. 6. The sensitive element itself consists of a suitable length (in this case about 20 inches) of wire, which is electrically resonant at some predetermined high frequency, as for example, 160 megacycles. This wire, which may be of any desired cross sectional shape, is disposed substantially vertically within its tubular metallic shield 9, with the lower and sensitive end of the wire extending beyond the lower end of the shield and adapted to be immersed in the liquid 3. The lower end of wire 1 is maintained, within close limits, a predetermined distance below the surface 4 of the liquid, such predetermined spacing, termed the normal working spacing, being maintained by means, such as described in connection with Figs. 1, 2 and 3. The wire 1 has a coupling loop 31 formed near its upper end and such end is connected to a metallic bushing 32, which is suitably fixed in the upper end of the tubular shield 9 and has attached thereto an insulating disc 33 which closes the upper end of the tube. The suspension means, such as the described bail 10, is usually attached to the bushing 32. The wire 1 may if desired also be supported intermediate its ends by a disc 34 of insulating material, suitably fixed in tube 9. In the upper end of the tube 9, is a wire loop 35, mounted in fixed coupling relation with loop 31; a rectifier or detector 36, which is preferably of the crystal diode type, such as a silicon diode for example; resistors 37, 38 and 39 and certain electrical connections. The ends of coupling loop 35 connect with the wires 40 of a two-conductor, radio-frequency cable, having a shield 41, which is shown in the diagrams later to be described and the lower end of which is connected to a metallic fitting 42 fixed to disc 33. The detector 36 has one terminal electrically connected to the resonant wire at the

point 43. Its other terminal is electrically connected through a coupling resistor 37, having in this case a resistance of 20,000 ohms, to the midpoint 43' of coupling loop 35 and through a load resistor 38, having in this case a resistance of 4700 ohms, to the bushing 32 and shield 9. When a signal is impressed on the resonant wire 1, by means to be later described, a fraction of the signal voltage is transmitted to the detector 36. The resistor 39 is an ordinary terminating resistor of 100 ohms resistance coupled across the wires 40 of the radio frequency cable for the purpose of damping out standing waves on these wires. A resistor 44, also of 100 ohms resistance, is connected to bushing 32 and to fitting 42, which is electrically connected to the shield 41 of the radio frequency cable, is used to damp out standing waves on such shield. The values given are illustrative of some that have been found suitable and not as imposing limitations.

Fig. 8 shows a form of the apparatus, which can be used to actuate a switch, such as 45, which in turn may control a motor such as the pump-actuating motor 21, described in connection with Fig. 3 and shown herein as supplied from a 115 volt, 60 cycle alternating current source. Here the sensing-element 1 is mounted stationarily in its tank. A high frequency signal is impressed on the element 1 by any suitable means, such as the oscillator 46, which is of well known form and the parts of which are entirely enclosed within a suitable shield, indicated by the dotted lines 47. This is a low-power oscillator having a frequency range sufficient to include the natural frequency at which wire 1 is resonant. The plate circuit coil of the oscillator consists of a piece of copper tubing 48, the semi-circular end of which forms a coupling loop 49. This loop is loosely coupled by an adjustable loop 50 to the transmission wires 40, above described, and thus to loop 35, which is coupled as heretofore described, to the loop 31 of the resonant wire 1. 51 is an ordinary terminating resistor of 100 ohms bridged across the wires 40 to eliminate standing waves on the wires and 51' is a resistor of 100 ohms connected between the shield 41 and the grounded shield 47 to eliminate standing waves on the shield. The tank circuit of the oscillator includes a variable condenser 52, by means of which the oscillator can be tuned to resonance with the sensitive element 1. Power for the oscillator is derived from a full-wave rectifier 53, supplied from the secondary 54 of a transformer 55, the primary 56 of which is connected as shown to the above mentioned alternating current source. The mid point of secondary 54 is grounded and its ends are connected one to each of the plates 57 of the rectifier. The transformer also has a secondary 58 to supply current at 5 volts to the cathode 59 of the rectifier and a secondary 60 to supply current at 6.3 volts to the heating filament 61 of the oscillator tube 62. The rectifier 53 supplies direct current at 200 volts to the oscillator through a connection 63, which includes a small radio frequency choke 64 and is connnected to one side of a by-pass condenser 65, the other side of which is grounded. Similar small radio-frequency chokes 66 are inserted in the supply wires of filament 61 and in the ground connection of cathodes 67. The oscillator is tuned to resonance with the wire 1, before the lower end of the stationary wire becomes immersed in the liquid. A minute amount of power, say for example of the order of $\frac{1}{100}$ of a watt, is transferred to wire 1, when the latter is in resonance, and at a low voltage, say for example in the neighborhood of one volt. This unimmersed position, in which wire 1 is tuned to resonance, is not a normal working position but merely a preliminary tuning position, which is followed by immersion of the wire as the liquid rises until the lower end of the wire has penetrated into the liquid. Then, the liquid causes substantial decrease in signal voltage chiefly by detuning the resonant wire and also by its presence in the field of the wire. The signal will decrease in value approximately in direct proportion to the extent of immersion of the wire in the liquid, until a certain limit is reached (at about ⅛ inch) when the signal completely disappears. A portion of the signal passes through the detector 36, through the transmission wires 40 to coupling loop 50 and thence by a wire 68 to one terminal of the coil 69 of a very sensitive relay which actuates switch 45, closing the latter, when the depth of penetration of the wire in the liquid is less than a predetermined amount, say for example about $\frac{1}{16}$ inch. Then the motor 21 will be energized to drive pump 22 and force liquid into the container 25 to restore the liquid to the desired level, when the signal will have decreased sufficiently to cause the relay to drop out and open switch 45 to stop the motor and pump. Of course, the value of the signal initially impressed on the coil 69 of the relay, during tuning of the wire, while the latter is unimmersed, will be abnormally great but the relay can readily be designed to withstand the abnormal signal for the short time necessary. The level of the liquid will change as necessary to maintain the predetermined penetration of wire into the liquid within small limits say plus or minus one thirty-second of an inch.

The wire 68 has a small radio-frequency choke 70 therein and is connected to one side of a by-pass condenser 71 the other side of which is grounded. This choke 70 and condenser 71 are both located within the shield 47 and are for the purpose of excluding the high frequency current from the wire 68. The wire 68 has a shield 72, which is connected to the shield 47 of the oscillator.

Fig. 9 shows another form of the invention which affords an exceedingly sensitive anti-hunting control for a reversible motor, such as the above mentioned motor 5. A high frequency signal is produced by the same oscillator 46, but the signal is modulated with 60 cycle alternating current. The coupling between the resonant wire 1 and the oscillator is the same as described in connection with Fig. 8; the same kind of detector is used and the signal derived is transmitted in the same manner through the shielded wire 68 to a suitable amplifying means 73, to be later described, which amplifies the low-frequency 60 cycle signal sufficiently to control the movement of the alternating current motor 5. As before, power for the oscillator is derived from a full-wave rectifier 74, which is supplied from the secondary 75 of a transformer 76, the primary 77 of which is connected to a 115 volt 60 cycle alternating current source. The mid point of the secondary 75 is grounded and its ends are connected one to each of the plates 78 of the rectifier. This rectifier supplies the 300 volt direct current needed for the amplifying means to be described and this voltage is reduced to the 200 volts, needed for the oscillator, by resistors 79 and 80, included in series in a wire 81, which connects the cathode 82 of the rectifier to the plate loop 49 of the oscillator. Also included in series in

this wire 81 is the secondary 83 of a transformer 84, the primary 85 of which is connected to the above-mentioned alternating current source. This secondary supplies 60 cycle current at 70 volts to effect a fifty per cent modulation of the high frequency signal produced by the oscillator. The transformer 76, as before, has other secondaries 86 and 87 to respectively supply current at five volts to the cathode 82 of the rectifier and current at 6.3 volts to the heating filament 61 of the oscillator and the heating filaments of the amplifier tubes to be described.

The detector 36 derives a portion of the signal from the resonant wire 1 and transmits it as before to wire 68, the high frequency components of the signal being excluded, as before, by a choke 64 and a by-pass condenser 65. The wire 63, in this case, is connected to an amplifying means 73, comprising the elements represented within the shield enclosure indicated by dotted lines 88. Wire 68 is connected to one terminal of the input control resistor 89 and to the grid 90 of an amplifier tube 91. The other terminal of the resistor 89 is grounded to the shield 88. The amplifying means is of conventional form, designed for amplification of 60 cycle current with maximum efficiency. Only the alternating current component of the detected signal is amplified. The amplifying means comprises two triode stages, using the tube 91 and a tube 92, an interstage transformer 93, a power amplifier tube 94 and an output transformer 95 and is supplied with 300 volt direct plate current from the full-wave rectifier 74. A gain of about 2000 is effected, providing across the secondary 96 of transformer 93 a 60 cycle signal of approximately 50 volts when the wire 1 is in resonance. A transformer 97, the primary 98 of which is connected to the 115 volt 60 cycle alternating current supply, has its secondary 99 connected to a potentiometer 100, from which a 60 cycle voltage is derived and applied in series with the secondary 96 in the grid circuit of the power amplifier tube 94. The transformer 84, which supplies the 60 cycle alternating current modulation for the oscillator, and the transformer 97, which supplies adjustable 60 cycle alternating current bias for the power amplifier grid are so connected that the signal across the secondary 96 is opposite in polarity to the alternating current derived from secondary 99. The signal across secondary 96 may, for example, vary from a maximum of about 50 volts, when the sensitive element 1 is in resonance, to zero when the element is immersed to the predetermined depth in the liquid. The voltage derived from secondary 99 may, for example, be constant at say 15 volts. The differential voltage is amplified, say 20 times, in tube 94 and reduced one-half in transformer 95, appearing in the secondary 102 thereof as at least 150 volts, when the wire 1 is in resonance. The secondary 102 is connected to one winding 103 of the two-phase motor 5, and has bridged across it a power-factor correction condenser 104. The other winding 105 of the motor is connected to the 115 volt, 60 cycle alternating current supply through a condenser 106. When the wire 1 is in resonance, the 60 cycle current applied to winding 103 will cause the motor 5 to turn in the direction necessary to lower the wire 1. As the wire 1 is lowered toward the surface of the liquid it is immersed therein to various degrees and the signal, derived and amplified as described, will decrease and eventually the signal voltage across secondary 96 will equal the voltage derived from transformer secondary 99 and the differential voltage becomes zero, when the motor 5 will stop with the wire 1 immersed to the predetermined extent in the liquid. Now, if the level of the liquid rises, the voltage across secondary 96 will become less than that derived from secondary 99 and the differential voltage applied to winding 103 will be in an opposite direction, whereby the motor will reverse and lift the wire 1 until a balance is again obtained.

The motor 5 may, of course, as above described, operate to raise and lower the level of the liquid instead of raising and lowering the wire 1.

The transformer 55, oscillator 46, full-wave rectifier 53 and relay 69 of the Fig. 8 apparatus or the oscillator 46, transformers 76, 84 and 97, full-wave rectifier 74, and amplifying means 73, of the Fig. 9 apparatus may be housed, as shown in Fig. 1, in a box 107 into which lead the alternating current supply wires 108 and from which lead wires 109 to connect with motor 5. The shielded radio-frequency cable 41, indicated in Figs. 1, 4 and 5 by a single line, extends from the top of the shield 9 to the housing 107 and may be mounted in any suitable way to pay out the cable as the shield, and the sensitive element housed therein, descend in the container and to take up the slack as such shield and element rise. An illustrative example of one mounting, suitable for the purpose, is shown in Figs. 1, 4 and 5. The cable extends upwardly from shield 9 in the container 2 and part way around a pulley 108, fixed to the shaft 11. From the pulley 108, the cable passes part way around the first of a series of seven sheaves 109, all loosely mounted on an arbor 110, suitably supported from a housing 111. The cable then passes downwardly around the lower part of the first of a series of seven sheaves 112, all loosely mounted on an arbor 113, which is pulled downwardly by a weight 114. The cable then passes upwardly and over the second sheave 109, then downwardly around the second sheave 112 and so forth until it finally leaves the seventh lower sheave 112 and passes horizontally across to a pulley 115 and then downwardly to the housing 107. It will be clear that, as the sensitive element 1 and its shield 9 move downwardly, the arbor 113 will rise toward arbor 110 and provide the cable necessary and that when this element and its shield rise, the weight 114 will draw arbor 113 downwardly to take up slack in the cable.

In Fig. 7, a variation in the level-sensing element is shown. Here, the lower end of the resonant wire 1 is bent at an obtuse angle, as indicated at 116, and it is this bent portion only that is normally intended to contact the liquid in the tank. The mid portion of this bent portion is adapted to lie at the predetermined depth. For any given depth of immersion, the Fig. 7 level-sensing element provides a greater surface area in contact with the liquid than does the Fig. 1 level-sensing element. While additional area for contact with the liquid might be otherwise provided, as for example, by a flat horizontally-disposed disc fastened on the lower end of the wire 1 and engaging the liquid with its lower face only, this would be objectionable because, when the wire moves upwardly, it will draw the liquid upwardly to a certain extent because of surface tension and then, when the liquid breaks away, the disc will be left out of contact with the liquid causing a quick and large variation in signal voltage which is undesired because it causes hunting.

The invention provides for close gauging accuracy, which is not substantially affected by variations in signal voltage, which occur from causes other than variations in the depth of immersion of the wire in the liquid. The upright arrangement of the sensing wire 1 avoids the trouble from oil drops described in connection with the apparatus of the prior patent. Any changes in signal voltage that are produced from causes other than variation of the depth of immersion of the wire, are relatively small in comparison to the changes produced by variation in the depth of immersion of the wire. For example, when the wire 1 is lowered toward the surface of the liquid, no significant change in signal voltage occurs until the wire touches the liquid, when there is a large and sudden decrease due to detuning and losses as above described. These decreases in signal voltage are much greater than those which occur in the apparatus of the prior patent because of the elimination of air from the dielectric path between the resonant wire and the surface of the liquid and the use in its place of liquid having a dielectric constant several times that of air. The decrease in signal voltage varies with the area of the sensing wire that is in contact with the liquid and thus with the depth of immersion of the wire. The rate of decrease in the signal voltage, measured at the output of the amplifier in the particular example disclosed in Fig. 9, is about 50 volts for each one-tenth of an inch of penetration of the wire into the liquid. With the sensing element of the prior patent, the signal variation, also measured at the output of the amplifier, was about five volts for each one-tenth inch of relative movement between the surface of the liquid and the sensing wire, within the operating range of such movement. Thus, assuming that a signal variation of five volts causes the gauging error, this error will be only one-tenth as great with the present apparatus as it is with the apparatus of the prior patent. In the present apparatus the five volt change causes a gauging error of only .01 inch while with the apparatus of the prior patent, the same five volt change would cause a gauging error of .1 inch which is greater than is desired. With the present apparatus, assuming a normal signal voltage of 50 volts, a 50% variation in voltage will result in a gauging error of only .05 inch or a little less than one-sixteenth of an inch. Thus, close gauging accuracy may be had under varying conditions encountered in the field because the loss in signal voltage caused by such conditions results in an error which is so small as to be negligible. Ageing of the electronic tubes used no longer causes an appreciable error and fluctuations in line voltage, which with the apparatus of the prior patent often necessitated the use of a voltage regulator, no longer causes any material error.

This invention has been described as used in connection with containers of liquids which are insulating, such for example as most petroleum products. However, the invention may be used with other liquids, such as water or alcohol which have very high dielectric constants. For such use, it is desirable that such portion of the resonant wire as is adapted to contact with the electric-conducting liquid 3' be covered with relatively thin insulation as shown at 11' in Fig. 10, to prevent conductive contact of the liquid with the wire. With this sleeve, the apparatus will operate satisfactorily in electrically-conductive liquid. Without the sleeve, the apparatus will operate but with hunting, the motor operating all the time because the instant the lower end of the wire 1 touches the liquid, the resonant wire is completely detuned, being short circuited by the liquid. A sudden change in signal voltage from a maximum to zero occurs which will cause the wire to move away from the liquid, producing another sudden change in signal voltage from zero to a maximum. The use of the insulating sleeve provides for changes in signal voltage which are more gradual and, as before, vary with the depth of penetration of the wire into the liquid.

The invention thus provides a level-sensitive apparatus for the control of the level of liquid in a container or for the determination of such level. This control is characterized by the use of a resonant wire located in upright position in the container and on which a high-frequency low-power signal is impressed. Such wire is tuned to resonance while wholly unimmersed in the liquid, but in normal operation it is partially immersed in the liquid and the latter operates to partially detune the wire decreasing the signal to an extent which varies with the depth of immersion of the wire. This change in signal voltage on the wire is utilized to actuate a suitable control, which causes a corrective relative movement between the surface of the liquid and the lower end of the wire for restoring such end and surface in the desired predetermined spaced relation.

What is claimed is:

1. In combination with a container of liquid, a level-sensing element consisting of a wire electrically resonant at a predetermined frequency and mounted in upright position in the container above the surface of the liquid therein, means for effecting relative movement between the lower end of said wire and the surface of the liquid operable to vary the spacing therebetween first from a preliminary spacing in which such end is out of contact with the liquid to a normal working spacing in which such end is immersed in the liquid to a predetermined depth and subsequently from other working spacings in which such end is immersed to other depths to said normal spacing, a high-frequency low-power oscillator coupled to said wire near its other end and tuned to resonance with the wire when the latter and the surface of the liquid are separated by said preliminary spacing for producing in the wire a high-frequency low-voltage signal, a detector, an electrical operator, and a circuit including said detector and operator and coupled to said wire through said detector to receive a portion of the signal from the wire and transmit it to the operator for actuating the same, said signal gradually varying in amplitude on changes in the working spacings and substantially in proportion to the area of contact between the liquid and the wire, the amplitude of said signal when the wire is immersed above or to said predetermined depth being respectively sufficient and insufficient to cause actuation of said operator.

2. In combination with a container of liquid, a level-sensing element consisting of a wire electrically resonant at a predetermined frequency and mounted in upright position in the container above the surface of the liquid therein, means for effecting relative movement between the lower end of said wire and the surface of the liquid op-

erable to vary the spacing therebetween first from a preliminary spacing in which such end is out of contact with the liquid to a normal working spacing in which such end is immersed in the liquid to a predetermined depth and subsequently from other working spacings in which such end is immersed to other depths to said normal spacing, a high-frequency low-power oscillator coupled to said wire near its other end and tuned to resonance with the wire when the latter and the surface of the liquid are separated by said preliminary spacing for producing in the wire a high-frequency low-voltage signal, a detector, and a circuit including said detector and said means and coupled to said wire through said detector to receive a portion of the signal from the wire and transmit it to said means for actuating the same, said signal gradually varying in amplitude on changes in the working spacings and substantially in proportion to the area of contact between the liquid and the wire, the amplitude of said signal when the wire is immersed above or to said predetermined depth being respectively sufficient and insufficient to cause actuation of said means.

3. In combination with a container of liquid, a level-sensing element consisting of a wire electrically resonant at a predetermined frequency and mounted in upright position in the container above the surface of the liquid therein, means for effecting relative movement between the lower end of said wire and the surface of the liquid operable to vary the spacing therebetween first from a preliminary spacing in which such end is out of contact with the liquid to a normal working spacing in which such end is immersed in the liquid to a predetermined depth and subsequently from other working spacings in which such end is immersed to other depths to said normal spacing, a modulated high-frequency low-power oscillator coupled to said wire near its other end and tuned to resonance with the wire when the latter and the surface of the liquid are separated by said preliminary spacing for producing in the wire a high-frequency low-voltage signal, a detector, and a circuit including said detector and said means and coupled to said wire through said detector to receive a portion of the signal from the wire and transmit it to said means for actuating the same, said signal decreasing in amplitude substantially in proportion to the area of contact between the liquid and the wire, the amplitude of said signal when the wire is immersed above or to said predetermined depth being respectively sufficient and insufficient to cause actuation of said means.

4. In combination with a container of liquid, a level-sensing element consisting of a wire electrically resonant at a predetermined frequency and mounted in upright position in the container above the surface of the liquid therein, means for raising and lowering said wire operable to move the wire from a preliminary tuning position in which it lies entirely above the surface of the liquid to a working position in which its lower end is immersed in the liquid to a predetermined depth and operable on rise and fall of the liquid to raise and lower the wire sufficiency to maintain its lower end immersed to said predetermined depth, a modulated high-frequency low-power oscillator coupled to said wire near its other end and tuned to resonance with the wire when the latter is in said preliminary position for producing in the wire a high-frequency low-voltage signal, said signal varying in amplitude on changes in the depth of immersion of the wire decreasing substantially in proportion to the increase in the area of contact between the liquid and the wire, a detector, a circuit including the detector and coupled to said wire through the detector to receive a portion of the signal therefrom, and means for amplifying the signal received by said circuit and transmitting it to said first-named means to control the actuation thereof and raise or lower the wire as necessary to maintain it immersed to said predetermined depth.

5. In combination with a container of liquid, a level-sensing element consisting of a wire electrically resonant at a predetermined frequency and fixed in upright position in the container, means for raising and lowering the level of the liquid in the container operable to vary the spacing between the lower end of said wire and the surface of the liquid first from a preliminary spacing in which such end is out of contact with the liquid to a normal working spacing in which such end is immersed in the liquid to a predetermined depth and subsequently from other working spacings in which such end is immersed to other depths to said normal spacing, a modulated high-frequency low-power oscillator coupled to said wire near its other end and tuned to resonance with the wire when the latter is in said preliminary position for producing in the wire a high-frequency low-voltage signal, said signal varying in amplitude on changes in the depth of immersion of the wire decreasing substantially in proportion to the increase in the area of contact between the liquid and the wire, a detector, a circuit including the detector and coupled to said wire through the detector to receive a portion of the signal therefrom, and means for amplifying the signal received by said circuit and transmitting it to said first-named means to control the actuation thereof and raise or lower the wire as necessary to maintain it immersed to said predetermined depth.

6. In combination with a container of liquid, a level-sensing element consisting of a wire electrically resonant at a predetermined frequency and mounted in upright position in the container above the surface of the liquid therein, means for effecting relative movement between the lower end of said wire and the surface of the liquid operable to vary the spacing therebetween first from a preliminary spacing in which such end is out of contact with the liquid to a normal working spacing in which such end is immersed in the liquid to a predetermined depth and subsequently from other working spacings in which such end is immersed to other depths to said normal spacing, a high-frequency low-power oscillator coupled to said wire near its other end and tuned to resonance with the wire when the latter and the surface of the liquid are separated by said preliminary spacing for producing in the wire a high-frequency low-voltage signal, a detector of the crystal diode type, an electrical operator, and a circuit including said detector and operator and coupled to said wire through said detector to receive a portion of the signal from the wire and transmit it to the operator for actuating the same, said signal gradually varying in amplitude on changes in the working spacings and substantially in proportion to the area of contact between the liquid and the wire, the amplitude of said signal when the wire is immersed above or to said predetermined depth being respectively sufficient and insufficient to cause actuation of said operator.

7. In combination with a container of liquid,

a level-sensing element consisting of a wire electrically resonant at a predetermined frequency, a metallic shielding casing supported in upright position in the container and in which said wire is mounted substantially vertically and which encompasses said wire except for a small end portion near its lower end, means for effecting relative movement between the lower end of said wire and the surface of the liquid operable to vary the spacing therebetween first from a preliminary spacing in which such end is out of contact with the liquid to a normal working spacing in which such end is immersed in the liquid to a predetermined depth and subsequently from other working spacings in which such end is immersed to other depths to said normal spacing, a high-frequency low-power oscillator coupled to said wire near its other end and tuned to resonance with the wire when the latter and the surface of the liquid are separated by said preliminary spacing for producing in the wire a high-frequency low-voltage signal, a detector of the crystal diode type, and a circuit including said detector and said means and coupled to said wire through said detector to receive a portion of the signal from the wire and transmit it to said means for actuating the same, said signal decreasing in amplitude substantially in proportion to the area of contact between the liquid and the wire, the amplitude of said signal when the wire is immersed above or to said predetermined depth being respectively sufficient and insufficient to cause actuation of said means.

8. In combination with a container of liquid, a level-sensing element consisting of a wire electrically resonant at a predetermined frequency, said wire having its upper end grounded and having near such end a coupling loop, a member supporting said wire in the container with the portion of the wire below the coupling loop disposed in upright position in the container with its lower end immersed to a predetermined depth in the liquid, means for effecting relative movement between said supporting member and surface to maintain the predetermined spacing of said element and surface, a high-frequency oscillator with a coupling loop, a radio-frequency cable having a coupling loop on one end related to the oscillator loop and a coupling loop on the other end mounted on said supporting member and related to the first-named loop, whereby a high-frequency signal from the oscillator may be impressed on said element, the latter being tuned to resonance with said oscillator when said portion and surface are in another and wider predetermined spaced relationship, the relative movement of said portion and surface toward said first-named predetermined spacing detuning said element and decreasing the amplitude of said signal, a detector of the crystal diode type connected to said wire at a point intermediate its ends and to the mid point of the coupling loop of said cable on said support, and a conductor connecting the other loop on said cable to said first-named means and transmitting the detected signal to the first-named means for actuating the same.

9. In combination with a container of liquid, a level-sensing element consisting of a wire electrically resonant at a predetermined frequency and mounted in upright position in the container above the surface of the liquid therein; means for effecting relative movement between the lower end of said wire and the surface of the liquid, operable to vary the spacing therebetween first, from a preliminary spacing, in which such end is out of contact with the liquid, to a normal working spacing, in which such end is immersed in the liquid to a predetermined depth, and subsequently, to other working spacings, in which such end is immersed to other depths, said means including a two-phase low-frequency electric motor having two windings, separate circuits for supplying alternating-current in proper phase relation to the windings of said motor; a high-frequency low-power oscillator inductively coupled to said wire near its other end, tuned to resonance with the wire when the latter and the surface of the liquid are separated by said preliminary spacing, and producing in the wire a high-frequency low-voltage signal; means for modulating the high-frequency oscillations with alternating-current of the low frequency used for said motor, a detector receiving part of the signal and transmitting it to one of said circuits in a direction to oppose the first-named alternating current supply thereto, the full amplified signal, when said wire and surface are separated by said preliminary spacing, being greater than the first-named alternating current supply to said last-named circuit and causing the motor to effect relative movement between the wire and surface to immerse the lower end of the wire in the liquid until the amplified signal and alternating-current balance, when said wire and surface are separated by said normal working spacing and the lower end of the wire is immersed in the liquid to said predetermined depth, further relative movement between the wire and surface in the same direction decreasing the amplified signal to less than the first-named alternating-current supply and causing the motor to effect relative movement between the wire and surface in the opposite direction until said wire and surface occupy said normal working spacing.

10. In combination with a container of liquid, a level-sensing element consisting of a wire electrically resonant at a predetermined frequency and mounted in upright position in said container with its lower end immersed to a predetermined depth in the liquid, means for moving said element up and down in the container to follow variations in the level of the liquid, said means including a two-phase low-frequency electric motor having two windings, separate circuits for supplying low-frequency alternating-current in proper phase relation to said windings, a high-frequency low-power oscillator inductively coupled to said wire and tuned to resonance with the wire before the latter is immersed in the liquid, the amplitude of the signal decreasing with increases in the area of contact of the liquid and the wire, means for modulating the high-frequency oscillations with alternating-current of the low-frequency used for said motor, a detector receiving part of the signal from said wire, and means for amplifying said part of the signal and transmitting it to one of said circuits in a direction to oppose the first-named alternating-current supply thereto, the full amplified signal when the lower end of said wire is above said predetermined depth being greater than the first-named alternating-current supply to the last-named circuit and causing the motor to lower the wire until the amplified signal and first-named alternating-current supply balance when said lower end is at said predetermined depth, further lowering of the wire decreasing the amplified signal to less than the first-named alternating-current supply and causing the motor

to raise the wire until its lower end is at said predetermined depth.

11. In an electronic level-sensitive control adapted for use with containers of liquid and of the type, wherein the level-sensitive element consists of a wire that is electrically resonant at a predetermined high frequency, is tuned to resonance while out of contact with the liquid and has a high-frequency low-power signal impressed thereon, and wherein the sensitive portion of the wire is maintained within close limits in a predetermined spaced relation with the surface of the liquid, and a differential variation in the level of liquid causes change in the amplitude to the signal to effect a corrective relative movement between such portion of the wire and the surface of the liquid to restore the predetermined spaced relationship; the improvement consisting in mounting said wire in upright position in the container with its lower end immersed to a predetermined depth in the liquid.

12. The combination as claimed in claim 11, in which the wire, the major portion of which is adapted to lie normal with the surface of the liquid, has its lower portion which is adapted to be immersed in the liquid, bent to lie in inclined relation with the surface of the liquid.

13. The combination, as claimed in claim 11, for use with liquids that are electrically-conductive and wherein the lower portion of the wire, that is adapted to be immersed in the liquid, has a relatively-thin insulating covering.

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