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TWO AUTOMATIC SIRUP DRAWOFF CONTROLLERS

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TWO AUTOMATIC SIRUP DRAWOFF CONTROLLERS

J. A. Connelly
Eastern Utilization Research and Development Division*
Philadelphia, Pennsylvania 19118

In preparing foods, such as sirups, jellies, and confections that are concentrated by boiling off water under atmospheric conditions, it is difficult to determine when the desired concentration has been achieved. The evaporation must be stopped at the correct concentration, either by removal of the heat or removal of the food from the evaporator.

In sirups, one of the best means of determining when the desired concentration has been reached is by comparing the temperature of the boiling sirup with that of boiling water under the same atmospheric conditions. This is especially true in the processing of maple sap to sirup.

In making maple sirup, 30 to 40 gallons of water must be evaporated to produce 1 gallon of sirup. The concentration of the finished sirup must be held between 66° and 67° Brix. This solids content of the sirup corresponds to a fixed elevation of its boiling point above that of water. The boiling point of water varies so much with atmospheric conditions that unless a correction is applied for this the solids content of a sirup may be higher or lower than the desired 66° to 67° Brix range.

While these variable conditions can be compensated for by hand-controlled instruments, these require the constant attention of an operator to note changes in the temperature of boiling water and to correlate this with the temperature at which evaporation should be stopped. This procedure is an expensive use of manpower and frequently does not produce the desired control of the solids content of the resulting maple sirup. An automated controller that would cause a valve to open and discharge the sirup from the evaporator when the temperature of the boiling sirup reached specified number of degrees above the boiling point of water would serve two purposes. It would be constantly at work resulting in the production of sirup of uniform density and would eliminate the waste of manpower.

In 1960 C. O. Willits, Head of Maple Investigations at this laboratory, contacted several instrument makers and inquired whether such an instrument was available or whether they would manufacture one according to his specifications. He met with no success. It was then decided to try to develop such an instrument in our own electronics laboratory. This paper describes two automatic sirup drawoff controllers which we have developed and which have been field-tested. One instrument employs a Wheatstone bridge and meter relay that gives a visual display of the temperature differences, whereas the other instrument is built around an operational amplifier and does not provide a temperature difference readout. Both instruments use thermistors to measure temperature differences. The thermistors used have

* Agricultural Research Service, U. S. Department of Agriculture

resistance changes of approximately 100 ohms for each degree Fahrenheit temperature change in the boiling point range of water and sirup.

To measure temperature with a thermistor, one need only measure the resistance of the thermistor and then use a calibration table supplied by the manufacturer to convert resistance to temperature. A part of the temperature-resistance data for the thermistors used is shown in Table 1.

Table 1.--Nominal resistance values for YSI No. 44011 thermistors at temperatures encountered in maple sirup production

C°	R_T	F°
98	6393	208.4
99	6195	210.2
100	6005	212.0
101	5821	213.8
102	5643	215.6
103	5472	217.4
104	5307	219.2
105	5147	221.0
106	4993	222.8

CONTROLLER EMPLOYING WHEATSTONE BRIDGE WITH METER RELAY

The first instrument developed was based on the classical Wheatstone bridge method for measuring resistance. If a thermistor is placed in boiling sirup and connected to the bridge so that it becomes one arm of the circuit, its resistance can be measured and the temperature of the boiling sirup can be determined. If a second thermistor is placed in saturated steam at atmospheric pressure and is connected so that it becomes a second arm of the bridge, the difference in resistance between the two thermistors and consequently the temperature difference between the steam (boiling water) and the sirup can be measured. Thus by using two thermistors the boiling temperature of the sirup can be continuously referred to the boiling temperature of water regardless of changes in the boiling point of the water because of changes in barometric pressure. The detection of bridge unbalance resulting from the difference between the boiling temperatures of sirup and water is used to control a solenoid drawoff valve. The meter relay on the instrument will activate the solenoid drawoff valve causing it to open when the temperature difference; that is sirup density, reaches the desired level and remains open until the temperature difference falls below this level.

Figure 1 shows a simplified schematic drawing of this instrument. T_R is the reference or master thermistor, which is immersed in saturated steam at atmospheric pressure. T_S is the sensing or slave thermistor, which is immersed in the boiling maple sirup. The meter relay in the diagram is a 0 to 10 microampere meter

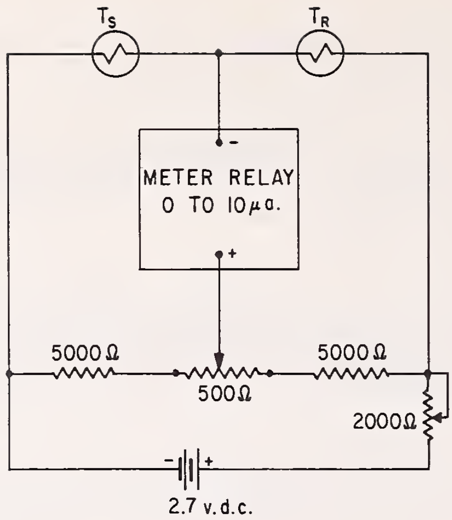

Figure 1.--Schematic drawing of Wheatstone bridge circuit and meter relay

which detects and displays the unbalance of the Wheatstone bridge. The bottom two legs of the Wheatstone bridge consist of two 5,000-ohm resistors connected by a 500-ohm adjustable potentiometer. The 500-ohm potentiometer is used only as a device to balance the bridge when both thermistors are at the same temperature. This is necessary because a pair of thermistors may not have exactly the same resistance at a given temperature. Furthermore, this arrangement helps to correct any mismatch in the two 5,000-ohm resistors. A 2,000-ohm trimming potentiometer and two mercury batteries attached in series are shown at the bottom of the diagram. The mercury batteries are used to supply currents to the bridge, and the 2,000-ohm potentiometer (which operates as a variable resistor) is used to adjust the current so that the meter will read 7 microamperes when T_S is 7° F. above the temperature of T_R.

Two steps are required to calibrate this instrument. First, place both thermistors in saturated steam at atmospheric pressure and adjust the 500-ohm potentiometer until the microammeter reads zero. Next, remove thermistor T_S from the steam bath and place it in a second bath that is approximately 7° F. above the temperature of the T_R, and measure the temperature of the two baths with a sensitive thermometer. Adjust the 2,000-ohm variable resistor until the microammeter reading is the same as the temperature difference between the two baths. The meter will then indicate how high the temperature of the boiling sirup is above that of boiling water.

Instead of the calibration procedure described above, the instrument can be calibrated using two 6,005-ohm resistors and one 5,307-ohm resistor. The two 6,005-ohm resistors are connected in place of T_R and T_S and the 500-ohm potentiometer adjusted to give a reading of zero on the meter. The 6,005-ohm resistor at T_S is replaced by the 5,307-ohm resistor and the 2,000-ohm potentiometer adjusted to give a reading of 7.2 on the meter. The listed resistances of the thermistors specified are 6,005 ohms at 212° F. and 5,307-ohms at 219.2° (see table 1).

The meter relay used in this instrument has two pointers: (1) the black pointer which indicates the bridge unbalance (temperature difference between the boiling water and sirup), and (2) the red pointer which can be set manually at any point on the meter scale. The function of the red pointer is to cause the meter relay to be energized when the black point moves upscale past it. When the meter relay is energized, it energizes a second, higher current relay which in turn activates the solenoid drawoff valve on the evaporator. As long as the temperature difference between the steam (boiling water) and sirup is equal to or greater than the temperature difference indicated by the red pointer, the drawoff system will be energized and sirup will flow from the evaporator. When the temperature difference is less than that indicated by the red pointer, the drawoff system will be deenergized and the solenoid valve will be closed.

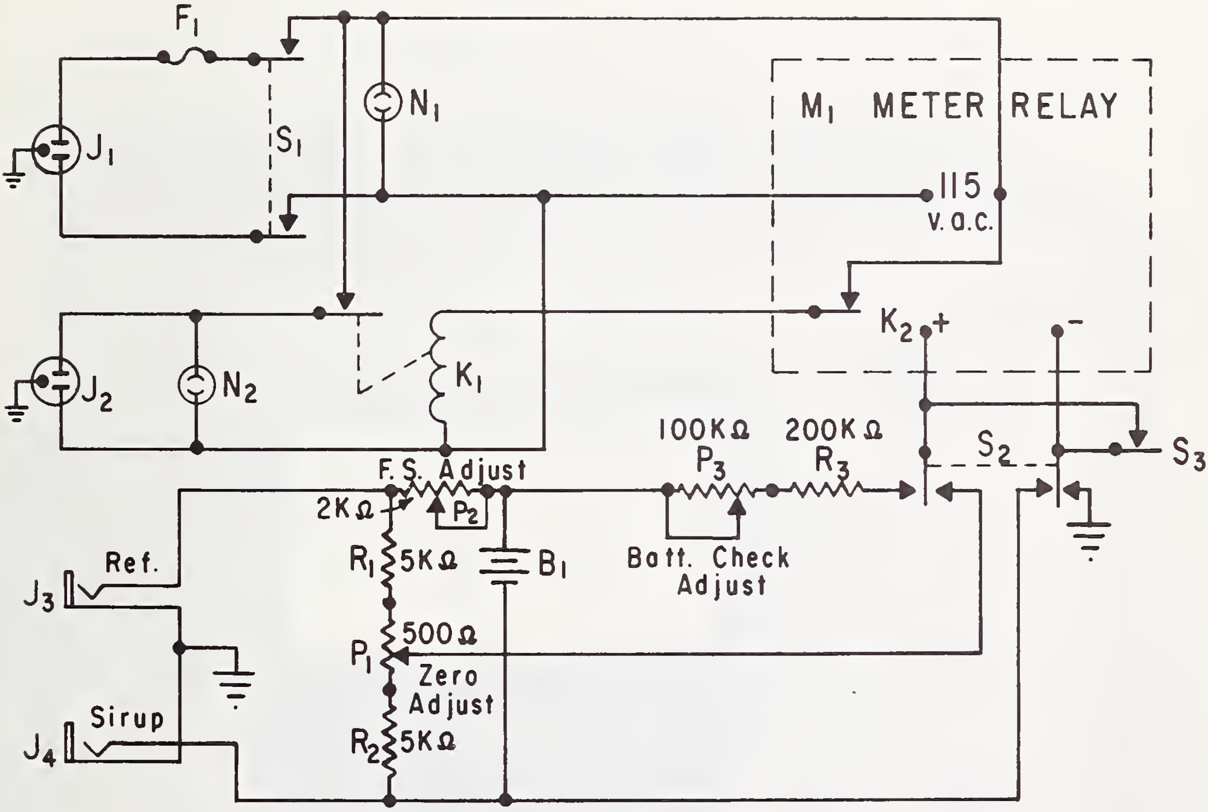

Figure 2.--Wiring diagram for automatic controller employing Wheatstone bridge and meter relay.

Figure 2 shows a complete schematic drawing of the instrument that was successfully tested by Lloyd H. Sipple at his central evaporator plant near Bainbridge,

N. Y. This drawing will be described from left to right and from top to bottom. J_1 is a connector for the incoming 115 v., a.c., F_1 is a fuse holder and fuse (nominally 5 amperes), S_1 is an on-off switch and N_1 is a neon pilot light to indicate when the 115 v., a.c. has energized the instrument. The manufacturer's literature on the meter relay, M_1, describes which terminals should be attached to the 115 v., a.c., which to the Wheatstone bridge circuit, and which terminals are available for operating relay K_1. J_2 is a receptacle for attaching the solenoid valve, N_2 is a neon pilot light, and K_1 is a relay which is energized when contacts in relay K_2 in the meter are closed. J_3 and J_4 are symbolic representations of standard telephone jacks. The thermistors as purchased are equipped with telephone plugs. Reference thermistor, T_R, is attached at J_3 and sensing thermistor, T_S, is attached at J_4. R_1, P_1, R_2, P_2, and B_1 are all components shown in figure 1 and previously described. S_3 is a switch that short-circuits the meter and protects the meter movement when the instrument is being moved or when it is not in actual operation. A photograph of this instrument is shown in figure 3.

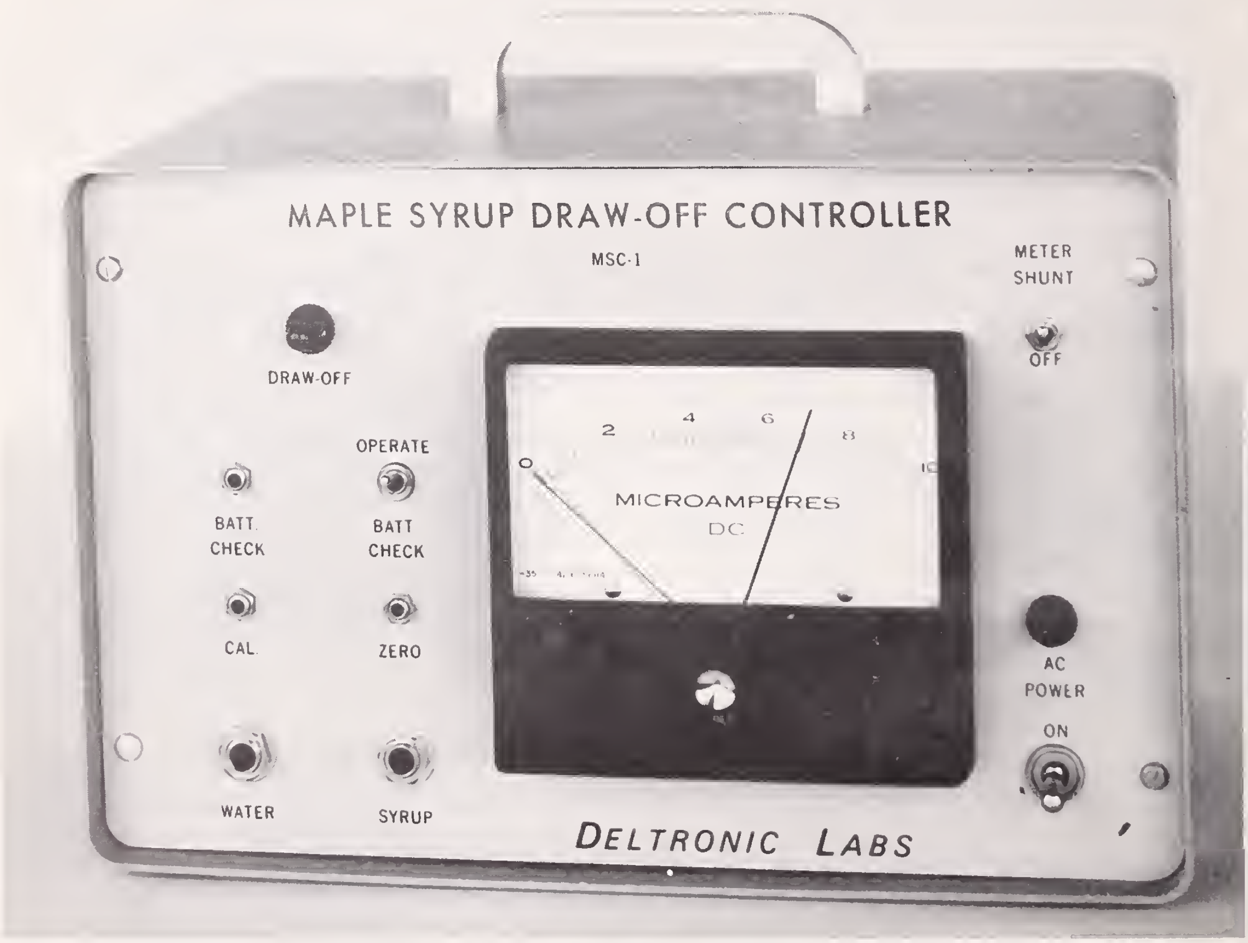

Figure 3.--Photograph of automatic controller with meter relay

The successful performance of this instrument depends on the two mercury cells maintaining a constant voltage. Provisions are made through switch S_2, potentiometer P_3, and resistance R_3, for determining that the battery voltage has not changed since the instrument was last calibrated. After the calibration procedure described above has been completed, S_2 should be switched to its alternate position and P_3 adjusted until the microammeter reads exactly 10. A battery check should be performed each day this instrument is used. To do this, merely throw S_2 to its alternate position and read the meter. If the reading is less than 9.9 or greater than 10.1 microamperes, the batteries should be replaced and the instrument recalibrated.

To test the instrument in the laboratory, a 6,005-ohm resistor was connected at J_3 instead of the reference thermistor. The sensing thermistor was attached at J_4 and placed in an oil bath and the bath heater was connected at J_2. The red pointer on the meter relay was set at 7.2 microamperes and the instrument was then used to control the oil bath temperature. The temperature (219.2° F.) was maintained constant to $\pm$ 0.05°. It can be shown by network analysis that the temperature differential between the steam bath and sirup should be maintained to $\pm$ 0.1° or better even under conditions of major barometric change.

The parts necessary to construct this instrument are listed below. Company or trade names are used solely for the purpose of providing specific information. Mention of a product does not constitute a guarantee or warranty of the product by the U. S. Department of Agriculture over similar products not mentioned.

B_1 Two Mallory mercury batteries, RM42R
One Keystone battery holder, #2176

F_1 Indicating fuse post (Littlefuse #344125)
5 ampere slo-blo fuse (Littlefuse #315005)

J_1 Amphenol 2 pole grounding type plug (#160-3 male,)

J_2 Amphenol (#160-2 female)

J_3 Phone jacks, Mallory long frame type #1

J_4 Same as J_3

M_1 Meter relay (A.P.I. Instrument Co., Chesterland, Ohio 44026) Model 603-K; 0 to 10 microamperes with single high set point

N_1 Neon pilot lite, Dialco #249-7841-0931-574, with built-in resistor

N_2 Same as N_1

P_1 Helitrim #78PR500, 500 ohm cermet pot
with bushing mounting kit 56BW

P_2 Helitrim #78PR2K, 2000 ohm cermet pot and 56 BW

P_3 Helitrim #78PR100K, 100,000 ohm cermet pot and 56 BW

K_1 Relay, Potter & Brumfield #KRP-11AG DPDT 120 v., a.c.

K_2 Relay (included as part of meter relay, M_1, A.P.I.)

R_1 Resistor, wire wound, 5000 ohms, 1/2 watt, 0.1 percent tolerance

R_2 Same as R_1

R_3 Resistor, composition, 200,000 ohms, 1/2 watt, 20 percent tolerance

S_1 Switch DPDT (on-x-on) J-B-T; JMT-223

S_2 Same as S_1

S_3 Switch SPDT (on-x-on) JMT-123

Thermistors--two needed. These are a special thermistor obtainable from Yellow Springs Instrument Co., Yellow Springs, Ohio 45387. Thermistor #CQ97 (#44011 thermistor mounted in #403 probe)

CONTROLLER EMPLOYING OPERATIONAL AMPLIFIER WITHOUT METER

After the successful field tests of the first instrument, an attempt was made to develop a second controller using less expensive components. The objective was to lower the price so that more individual maple producers could buy and use the instrument.

This new instrument was designed to use an operational amplifier instead of a Wheatstone bridge-meter relay system. This reduced the cost of the parts required by about $100. Figure 4 shows a rough schematic drawing of this device.

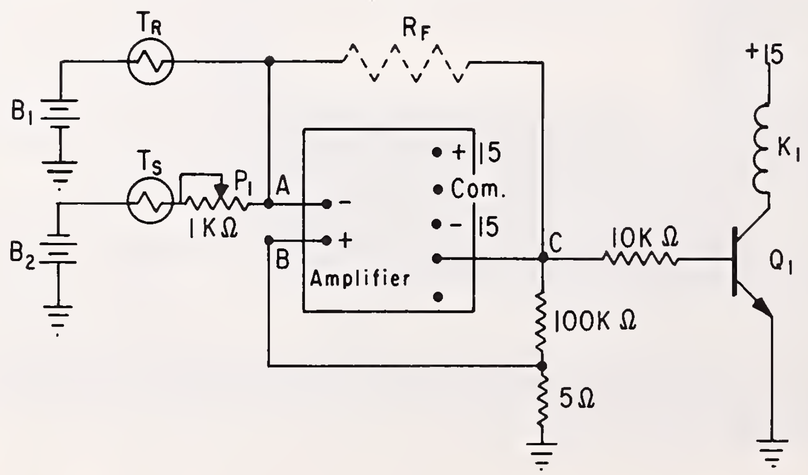

Figure 4.--Schematic drawing of operational amplifier control circuit

The square in the center of the drawing is a symbolic representation of the amplifier which has a gain of approximately 50,000. The amplifier struggles to keep the voltage difference between A and B in the microvolt region since any greater difference would saturate the amplifier. To explain its performance, it is necessary to imagine that there is a feedback resistor R_F connected between points C and A. If R_F has a value of 10,000 ohms and the current flowing into junction A is unbalanced by 1 ma., then the output of the amplifier will reach 10 v. When 10 v. is impressed across 10,000 ohms a current of 1 ma. will flow causing the unbalance to be satisfied. In the actual instrument, R_F is left out so that when there is a current unbalance at A the amplifier can only saturate. In other words, when there is a negative unbalance of current, the amplifier's output goes to approximately +12 v.; and conversely, when point A sees a positive unbalance of current, the amplifier's output goes to -12 v. When the sum of the resistances of T_S and P_1 is less than the resistance of T_R the voltage at point A will be negative and cause the amplifier's output to be approximately +12 volts (providing B_1 and B_2 have the same voltage). This voltage turns on transistor Q_1, causing current to flow through the coil of relay K_1 which then causes contact closures with the resultant transfer of 115 v., a.c. to the external solenoid that releases the maple sirup from the evaporator. The action of the voltage divider consisting of the 100 K and 5 ohm resistors is to cause the output of the amplifier to snap from the negative to the positive voltage or vice versa. This prevents relay chattering.

Figure 5 shows the complete schematic drawing of this instrument. The top

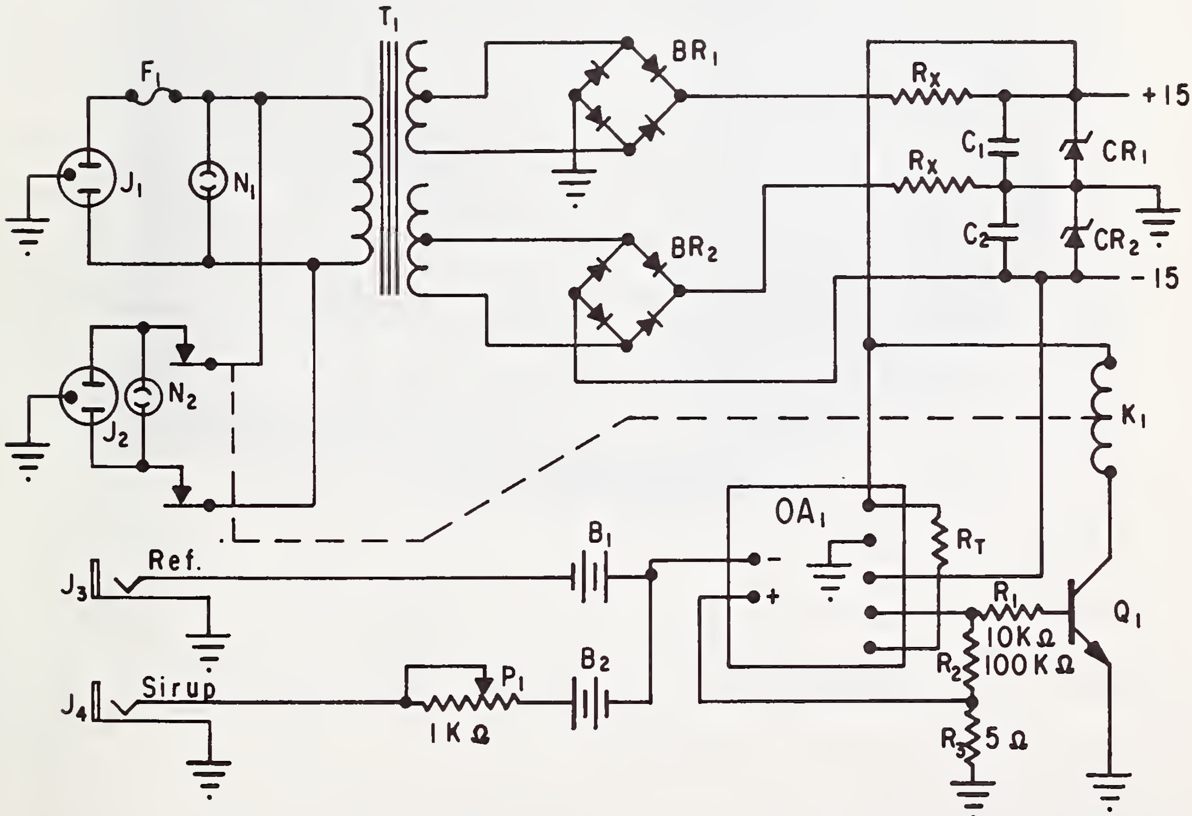

Figure 5.--Wiring diagram for automatic controller employing operational amplifier

part of the drawing shows the components needed to construct a power supply that proves ± 15 v., d.c. The two resistors designated R_X are selected so that 170 milliamps flows through each zener diode before the voltages are attached to either the amplifier or the relay coil. The lower part of the drawing shows a more complete illustration of the operational amplifier part of the controller shown in figure 3. The only change is that the batteries are placed adjacent to point A. The reason for this is that the thermistor probes are of stainless steel and each metal part must of necessity be a short circuit to each other. R_T is a resistor used to zero the amplifier's offset. Its value is written on the epoxy package of the amplifier proper. A photograph of this instrument is shown in figure 6.

Figure 6.--Photograph of automatic controller using operational amplifier

Below is a list of parts necessary to construct this second instrument.

B_1 Mallory mercury battery, RM 12R

B_2 Same as B_1

F_1 Same as previous list

J_1, J_2, J_3, J_4 Same as previous list

BR_1 Bridge rectifiers Motorola #MDA 1491-2

BR_2 Same as BR_1

C_1 Capacitors, computer grade, Mallory #CG152U25A1 1500 μF 25 WVDC

C_2 Same as C_1

CR_1 Zener diode, 10 watt, Motorola #IN2979

CR_2 Zener diode, 10 watt, Motorolo IN 2979R

K_1 Potter and Brumfield #KRP11DG 12 v d.c., 10 amp contacts

N_1, N_2 Same as previous list

OA_1 Operational amplifier, Philbrick Research #PP85AU

P_1 Helitrim #78PR 1K with 56 BW
OR
Bourns knobpot #3640S-1-102

R_1 10 K resistor, composition 1/2w

R_2 100 K resistor, composition 1/2w

R_3 5 ohms resistor, wire wound 20 percent tol.
OR 10 ohms

Q_1 Transistor, Motorola 2N 1711

T_1 Transformer, signal transformer Brooklyn 11212, Model 80 - 1/2 secondary 0 - 20 - 40 - 60 - 80 V.

R_X Resistors, 2w, composition (selected for optimum current through zener diodes)

R_T Resistor, 1/2w, composition (value noted on amplifier package)

The calibration of this instrument requires only one adjustment. Although it can be calibrated by immersing T_R in saturated steam at atmospheric pressure and T_S in boiling maple sirup and measuring the temperature of the two, it is easier to use fixed resistors. Two resistors with 0.1 percent tolerance are used, one with a value of 6,005 ohms and the other 5,307 ohms. They are attached to phone plugs and plugged into phone jacks J_4 and J_3, respectively.

The nominal value of the thermistors at 212° F. is 6,005 ohms; and at 219.2°, it is 5,307 ohms (see table 1). When these two resistors are plugged into their appropriate jacks the 1,000 ohm potentiometer, P_1, is adjusted until N_2 (the neon

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light indicating that the outlet receptacle is energized) is lit. When making this adjustment, P_1 is turned until the light goes off and then very slowly turned in the reverse direction until the light goes on again. If the more expensive Bourns knobpot is used (instead of the Helitrim), there is a convenient relationship between the trip point of the relay and the number of turns on the knobpot. By chance one turn of the knobpot increases the trip point by approximately 1°. If the knobpot reads 5:00, the pilot light N_2 will go on when the sirup is boiling at a temperature of approximately 5° above the boiling point of water. If the knobpot is then adjusted to 6:00, the trip point will be raised to approximately 6°. It must be emphasized that these settings are only approximate and that the resistors should be used for a more accurate calibration.

COMMENTS ON CONTROLLER OPERATION

The controller with the meter relay is more expensive; however, its distinct advantage is that the operator can see at a glance the exact temperature difference and changes therein. A neon pilot light on the controller without the meter is lit when the temperature difference exceeds the desired value but the degree of overshoot or undershoot is not indicated.

The use of the automatic drawoff controller in the maple sirup making process has been discussed by Willits.[2] He recommends that when the automatic controller is used the sirup produced should be checked occasionally for density (degrees Brix) to make certain that the system is functioning properly.

ACKNOWLEDGEMENT

I express my appreciation to C. O. Willits of this Laboratory for his help and encouragement in the development of these instruments.

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[2] Willits, C. O. A completely automatic sirup drawoff. Maple Syrup Digest 7(1): 12-13. 1968.

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