Solar heating temperature controller

Differential circuit gives precise control of a pump motor

by A. J. P. Williams Gwent College of Higher Education

This solar heating controller uses a recently introduced sensor to accurately detect the temperatures of a solar panel and a water tank. The circuit allows an electric pump to be controlled at precise selectable temperatures for optimum heat exchanger efficiency. The circuit is easily calibrated, and is not affected by interference form local mains wiring.

In the basic system of Fig. 1, a heat transfer fluid, usually water, is pumped through the solar collector where it gains heat. The fluid then passes through a heat exchanger coil where most of the heat gained previously is transferred to the stored water. The outputs from a temperature sensor attached to the collector output, and a second sensor attached to the storage tank operate a differential temperature controller. This controller switches the pump motor on when sensor 1 is hotter than sensor 2, which transfers heat to the stored water, and off when sensor 1 is cooler than sensor 2, thus preventing the stored water from being cooled during the night or when the weather is dull.

Because solar collectors are more efficient when they are operated at low temperatures, it is beneficial to run the system at the minimum temperature which will allow energy to enter the stored water and justify the pump operating.

For example, if the average rise in temperature of the stored water is 40 deg C, and the stored water is increased by only a further 2 deg C with precise control, this represents a 5% increase in efficiency, or an extra 348Whr for each 150 litres of water heated.

Circuit details

The complete circuit in Fig. 2 is based on the Analogue Devices AD590K temperature transducer which is a constant current temperature sensor. The current through the device is almost independent of the voltage across it within the range of 4 to 30V. This characteristic ensures that any mains induced voltages in the leads cause negligible 50Hz current through the sensors. Connections to the sensors can be by an unscreened twisted pair of wires of up to 50m in length if required, provided that they are well insulated. It is essential that the connections to the sensors are well insulated and dry so that all of the sensor current is detected by the control unit. The current through each sensor is directly proportional to the absolute temperature of the sensor. Therefore, at 0 deg C or 273 deg K the nominal current is 273μA, and at 100 deg C or 373 deg K the current is 373μA. This relationship also makes the device suitable for measuring temperature.

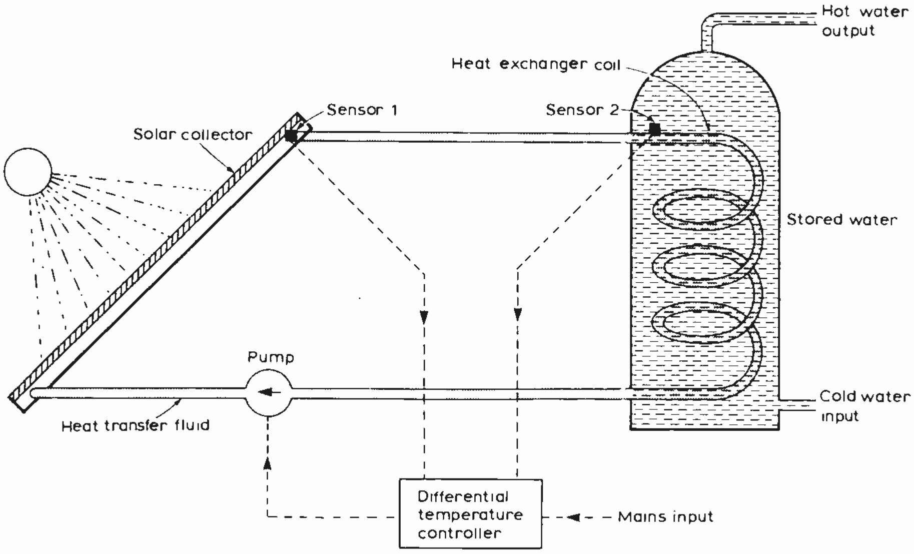

Fig. 1. *Basic solar heating system. The pump only operates when the collector temperature is above that of the stored water.*

Because IC$_2$ has a high input resistance, the difference between the currents through the two sensors, I_1—I_2 mainly flows through R$_4$. When the temperature of the stored water is greater than that of the collector, I_1 is greater than I_2, and V_1 is positive. This causes pin 2 of IC$_2$ to become positive and the output at pin 6 to move close to ground. At this point D$_5$ cannot conduct and Tr$_1$ switches off the pump motor via the relay. When the temperature of the collector is greater than that of the stored water, I_2 is greater than I_1, so V_1 is negative which drives pin 6 of IC$_2$ close to the positive rail. This in turn switches the relay and pump on via Tr$_1$ and D$_5$.

With a temperature difference of 1 deg C between S1 and S2, a current of 1μA will flow through R$_4$ which makesV_1 100mV. The value of V_3 is arranged to be approximately 125mV which ensures that V_2 can be varied from 0 to 100mV. AsV_2 is increased it tends to switch Tr$_1$ off therefore, I_2 must be greater than I_1 to make V_1 sufficiently negative before Tr$_1$ can be switched on. Thus, adjustment of R$_{19}$ determines the collector temperature that switches the pump on. The range of R$_{19}$ is at least 10 deg C. At 25 deg C the tolerance of the current through the temperature transducer is ±2μA, so V_1 could be ±40mV when it should be zero. To correct for any such unbalance beween the sensors, and any input offset voltage on IC$_2$, V_4 can be varied from about 0 to 75mV. Varying R$_{19}$ and R$_{21}$ only has a small effect on the total resistance between pins 2 and 3 of IC$_2$ and point C respectively. This ensures that the calibration of different control units will be similar.

Feedback circuit

Positive feedback around IC$_2$ makes sure that V_1 must be made more positive than V_5 before Tr$_1$ can be switched off. This switch-off hysteresis enables the pump to be switched on when the collector is, for example, 5 deg C higher than the stored water, and off when the collector is 3 deg C higher than the stored water. The amount of hysteresis is determined by R$_{22}$ which is a log-potentiometer. This control is wired so that the low resistance end is connected to D$_1$. The hysteresis control can be calibrated over the range 0.4 to 9 deg C,

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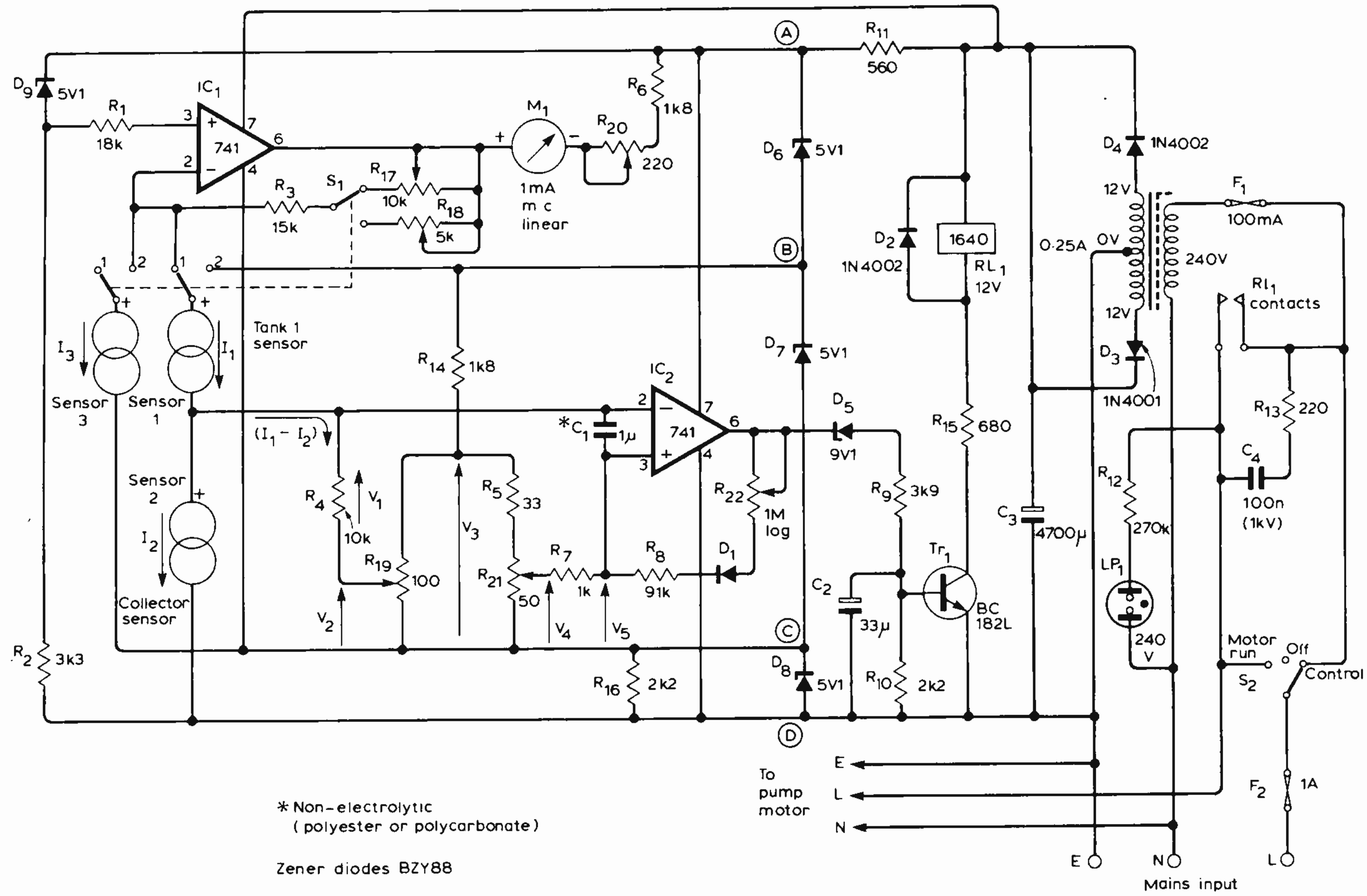

* Non-electrolytic (polyester or polycarbonate)

Zener diodes BZY88

Fig. 2. *Complete circuit for the differential temperature controller. Sensors 1 and 2 are sited as shown in Fig. 1, and sensor 3 can monitor the temperature anywhere in the system.*

but for a temperature resolution of better than 0.1 deg C, the feedback resistance may be increased to 4.7MΩ.

Measuring circuit

The measuring circuit operates as a current-to-voltage converter where the current from S1 or S3 flows through R_3 and R_{17} or R_{18}. The voltage at pin 6 of IC_1 moves sufficiently positive to maintain the sensor current through $R_3 + R_{17}$. The potential at pin 2 of IC_1 is always close to the potential at point B which ensures that S1 has the same internal power dissipation with SW1 in position 1 or 2. When the current through S1 is 273μA, and R_3+R_{17} is 18.68k, the p.d. across the two resistors will be 5.1V which holds the positive side of the meter at the same potential as point A. The meter then reads zero which represents 0 deg C. When the current through S1 is 373μA, the p.d. across $R_3 + R_{17}$ will be 6.97V with respect to point B. Therefore, the positive end of the meter will be 6.97 — 5.1V with respect to point A. The resistance in series with the meter can therefore be set to 1.87kΩ to represent 100 deg C. More sensitive meter movements may be used by changing $R_3 + R_{17}$ accordingly.

The temperature coefficient of the 5.1V zener diodes is comparatively low so that changes in ambient temperature only have a minor effect. This also applies to sensor S3 which may be used for monitoring any part of the system. A separate control for each sensor is not used because of their high linearity. The circuit may be simplified by omitting the measuring circuit and connecting the top end of S1 to point B.

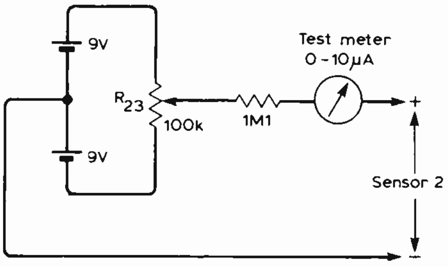

Fig. 3.

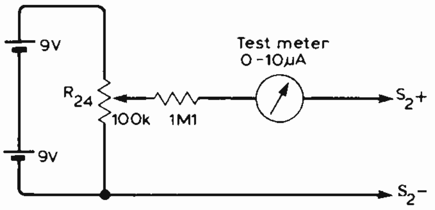

Fig. 4.

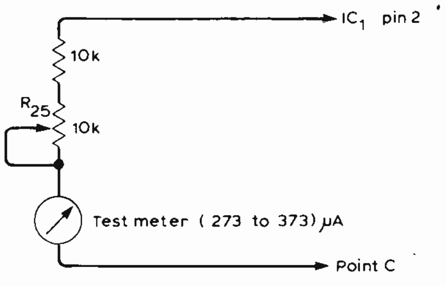

Fig. 5.

Calibration

For the differential temperature, remove S1 and S2, connect the calibration circuit of Fig. 3 in place of S2 and switch SW1 to position 2, or replace S3 by a 15kΩ resistor to prevent the meter reading backwards. Load the pump motor output with a 40W lamp so that LP_1 can turn on. Set the slider of R_{19} to within a few degrees of point C and mark as zero degrees temperature difference. Set R_{22} for minimum hysteresis, i.e. maximum resistance, and then set the current on the test meter to zero by adjusting R_{23}. Slowly adjust R_{21} until LP_1 just lights, and set R_{23} to give 1μA on the test meter. Adjust R_{19} until LP_1 goes out, and then return R_{19} slowly until LP_1 just lights. This position is marked 1 deg C on the dial of R_{19}. Reset R_{23} for 2μA and re-adjust R_{19} until LP_1 goes out. The point at which R_{19} just lights LP_1 is marked as 2 deg C. This procedure is repeated at 1μA steps to calibrate up to 10 deg C.

To calibrate the hysteresis control, connect the circuit in Fig. 4, and set the differential temperature control to zero. Set the hysteresis control to maximum, i.e. minimum resistance. Adjust R_{24} until LP_1 lights and then set R_{24} so that the meter indicates the hysteresis required, e.g. 2μA for 2 deg C hysteresis. Slowly move the hysteresis control to the point where LP_1 goes out and mark the calibration point. Repeat the procedure for temperatures from 0.5 to 9 deg C.

For the temperature measuring circuit the following method is suitable if an accuracy of ±3 deg C is sufficient, or ± 2 deg C if the more expensive AD590L sensor is used. Connect the test circuit in Fig. 5, and set SW1 to position 1. Adjust R_{25} to give 273μA on the test meter and set R_{17} so that M1 indicates zero, i.e. 0 deg C. Switch SW1 to position 2 and adjust R_{18} so that M1 indicates zero. Set the test meter to indicate 373μA by adjusting R_{25} and adjust R_{20} so that M1 reads full scale, i.e. 100 deg C. If the meter M1 is scaled 0 to 100 in 10 steps, then each step will indicate an increment of 10 deg C.

For maximum accuracy, the sensors are used directly. Keep S1 and S3 at 0 deg C, switch SW1 to position 1 and adjust R_{17} so that M1 indicates zero. Switch SW1 to position 2 and adjust R_{18} so that M1 indicates zero. Keep S1 at 100 deg C, switch SW1 to position 1 and adjust R_{20} until meter M1 indicates full scale, i.e. 100 deg C.

The linearity of the AD590K sensor is better than ±0.5 deg C over the range —55 to +150 deg C, but because all of the senors have the same general characteristic they should track within about 0.1 deg C.

It is not easy to check the accuracy of the switching-temperature differences by varying the temperature of the senors because the control is more precise than most readily available temperature measuring instruments. The overall error for differential temperature and hysteresis is generally less than ±0.3 deg C.