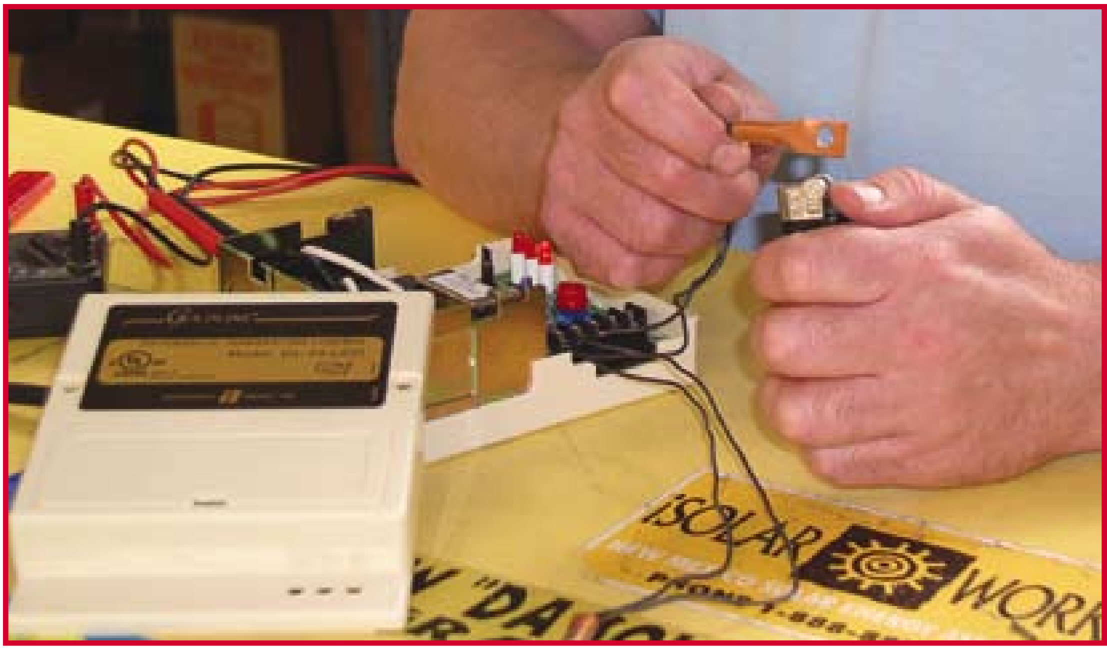
Troubleshooting Solar Water Heating Systems

Part 1: Differential Controls

Chuck Marken



Smitty from AAA Solar uses a lighter to test a sensor connected to a Goldline GL-30 control.

Drainback, closed-loop antifreeze, and direct-pump solar water heaters all use the same type of electronic controller. More than half the time, a malfunction in an active solar water heating system is in the controls. What happens when these control systems malfunction? What can you do if they fail or get out of kilter?

A differential control and sensors (*What the Heck?* #3 and #8 in *HP94* and *HP97*) are used in all solar water heating systems that use AC pumps. *HP94* covered the installation of differential controls, and if you're not familiar with them, a quick review of that article would be helpful.

In the last boom cycle of solar heating, during the 1980s, more than two dozen manufacturers made differential controls in the United States. Today, there are only two major manufacturers. Heliotrope Thermal and Goldline (formerly known as Independent Energy) are very similar in their function and design, and they both use 10 K-ohm (10,000-ohm) thermistors for sensors. We'll concentrate on these two controls in this article. The diagnostic techniques used are similar for nearly all differential controls ever made.

Take a look at the five troubleshooting steps in the sidebar. Recognizing the symptom of any problem is the first step in fixing a malfunction. Control troubleshooting is pretty straightforward. Usually a control problem will be very noticeable—the most common symptom is that the thing doesn't work at all. We'll look at a few other less likely symptoms later.

First the Obvious—Power to the Control

If there is no electricity to the control, the symptom most often will be the pump or pumps in the system not coming on. You will first need to ascertain where the control is and be able to recognize it. Sometimes it can be hidden in clever locations (like under a covered module with other system components). But most of the time, it will be out in the open and will look like one of the controls in the photo (page 63).

Most of these controls have one or more light emitting diode (LED) lights. If they have a single light, it will normally mean that the control has power. Two lights will usually mean "power" and "on (pumping)". Sometimes a third light is used to indicate a special condition.

If the power light (or single light on controls with one light) is not on, you may have found the problem. Is the control plugged in or getting power to the input terminals? Is a breaker tripped or a fuse blown? If so, did resetting the breaker, replacing the fuse, or throwing a switch energize the LED? If it still doesn't work, but you are sure the control has power and the LED is still off, an LED is probably burned out or the control is just not working. (See the troubleshooting logic tree.)

If the power light is on but the pumps don't come on when there is ample sunshine available, it's a good indication that the control system has a problem. It could be the control itself, one or both of the sensors, or a problem with wiring. In rare cases, it might be more than one thing wrong. First we'll look at the control itself, since that is the most likely problem.

The Differential Control

Both the Heliotrope Delta-T and Goldline GL-30 controls have an on-off-auto switch. The Delta-T has two lights and the GL-30 has three. First look at the switch—it must be in the "auto" position to function normally. It must also be in that position to troubleshoot the control. Without the switch in the auto position, the pumps would run all the time if the switch is in the "on" position, and the controller would never turn the pumps on at all if the switch is in the "off" position.

Now, apply a little logic about these controls. Resistance differences at the sensor terminals will cause the control to turn pumps or blowers on and off. Shorting a set of terminals gives the control a signal that the input is very hot—infinitely hot. Open terminals mean just the opposite—very cold. The thermistors (sensors) used with these controls vary their resistance with temperature. When the temperature goes up, the resistance goes down. See the table at the end of this article to match resistances with temperature.

Make sure that the control has power, and that the switch (if it has one) is in the auto position. Sensor wires should be disconnected at the controller. With a modified paper clip, short the two terminals marked "collector." On some older controls, these terminals might be labeled "solar." *Use caution: Make sure you are shorting the sensor terminals only. If you short the 120-volt terminals, you could burn your fingers or shock yourself.*

The Diagnostic Tools

- Differential control and sensors
- Your eyes, ears, and sense of touch
- Multimeter
- Small screwdrivers
- A good thermometer
- System schematic

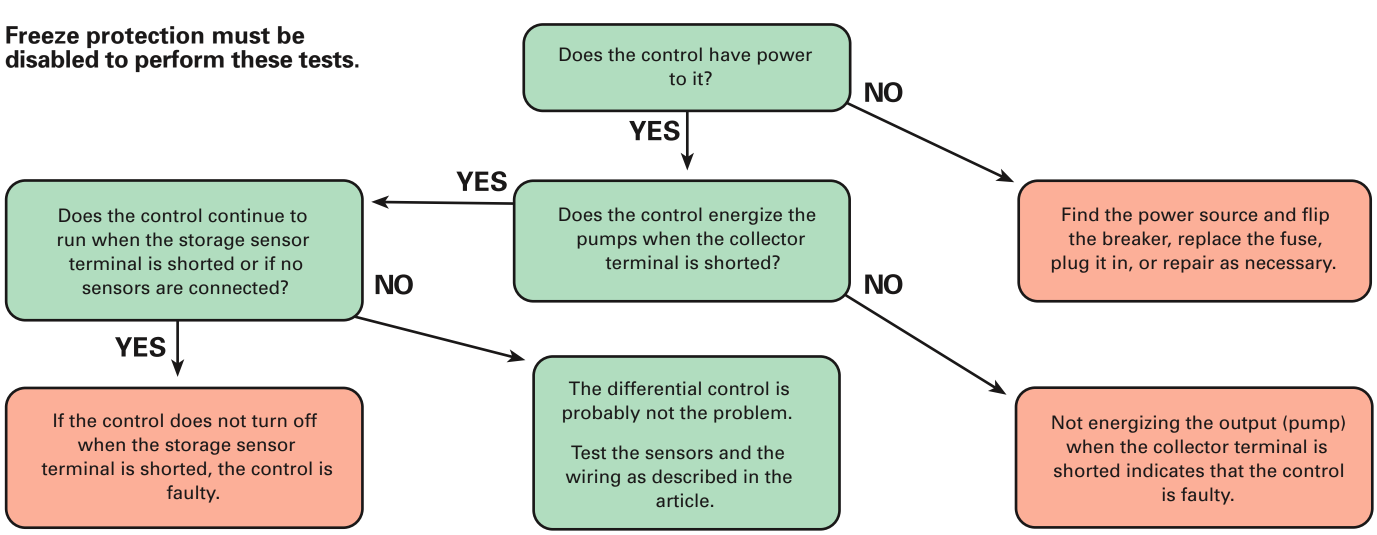
5-Step Control Troubleshooting

1. Symptom recognition
2. Symptom elaboration
3. Listing of probable faulty functions
4. Localizing the faulty function
5. Failure analysis

Thanks to David Sweetman and the U.S. Navy Basic Electronics School for this approach.

If the pump comes on when the collector terminals are shorted and turns off quickly after you remove the short, the control is undoubtedly functioning properly. You should have the pumps connected normally when you perform this test, since the LED light might come on and there will be no real output power if they are disconnected. You might find that the control comes on and powers the pump, but the pump doesn't run. In this case, you probably have a problem with the pump. We'll look at pumps and other system malfunctions in the next article in this series.

Differential Control Troubleshooting Logic Tree



If the control does not energize the pumps when the collector sensor terminals are shorted, the control is bad. It will need repair or replacement, and with the rare exception of multiple problems at the same time, you have found the problem. Pat yourself on the back—troubleshooting is at the top of the pyramid in the world of field technicians.

The Collector Sensor

Assuming the sensor terminal short test worked, and you feel that the control is OK, the sensors are the next thing to check. Use a multimeter to check resistances. The best place to check the resistances is at the ends of the wires while they are still disconnected from the control. The other ends of the wires still need to be connected to the sensors themselves. In most cases, you won't need a thermometer—approximations are good enough for this check.

For one person to do the test at the end of the wires, the pumps will need to be able to be powered. If the control has an on-off-auto switch, they can be powered by flipping the switch to "on." If not, they can be powered with an extension cord from another electrical receptacle. Set the multimeter for ohms, attach the probes to the collector sensor wires, and note the reading.

There is no polarity with thermistors or an ohm meter, so either multimeter probe can go to either wire. In bright sunshine, the collector will be 200 to 300°F (90–150°C), and maybe higher in hot climates. Looking at the resistance chart, a 10 K sensor at 200°F plus will measure less than 1,000 ohms. Turn on the pumps while looking at the meter. When the relatively cold collector loop fluid circulates through the collector, it will begin to cool the sensor. You should see the resistance rise.

If the resistance reading indicates a short (short circuit) or open (open circuit), there is a problem with this sensor circuit. Infinite resistance indicates an open circuit, and extremely low resistance of a few ohms indicates a short circuit. If the sensor's resistance reading is very high when it should be low, or if the sensor does not change when circulation of the collector loop fluid is cooling the sensor, there is a problem.

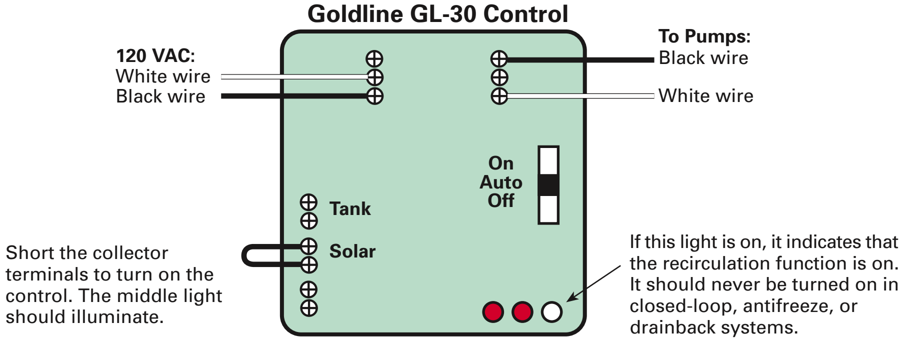
Most often, a sensor not changing resistance with a known temperature change, or a vastly different resistance reading from a good approximation, indicates that the sensor needs replacing. A short or open can also mean a bad sensor, but just as likely there could be a problem with the wiring going to the sensor. In any of these conditions, the next step is to test the sensor at its internally connected leads. We'll go over that procedure with the storage sensor.

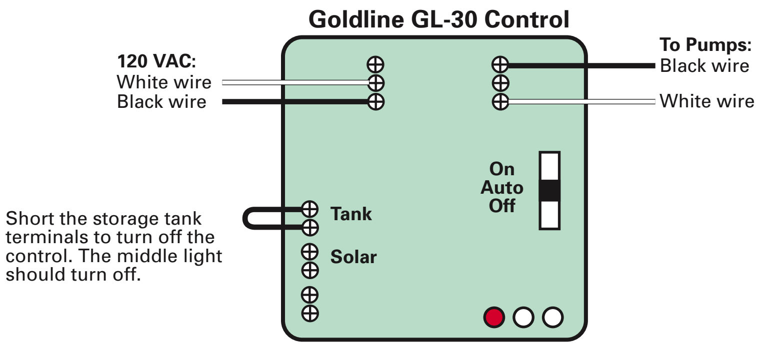
The Storage (Tank) Sensor

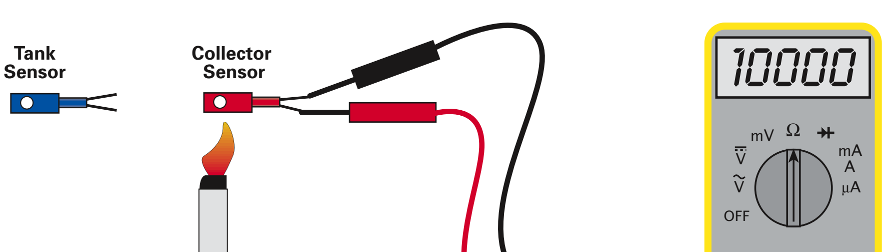
The storage sensor usually will be bolted to the bottom of the tank or attached to a pipe near the bottom of the tank. Because of its location near a large mass of water, the resistance will not change quickly when you circulate the collector fluid. It is best to test this sensor with fire and ice.

Once again, the meter probes should be connected to the sensor wires. Using a butane lighter or match, heat the sensor up while observing the resistance reading. If you have an ice cube, you can cool it down quickly, too. Did the sensor's resistance change

Differential Control Troubleshooting







Set the multimeter to a resistance scale that will read in the thousands of ohms, and test each sensor by gently heating it with a match or lighter.

Ten differential controls used in solar water heating systems over the last 20 years.


A Goldline GL-30 on the left and Heliotrope Delta-T on the right with the covers off. Note the diagrams and explanations on the covers.

when you changed the temperature? Does the resistance reading approximate what the chart gives? If so, this sensor is probably OK. If the resistance is way off, open, or shorted, the sensor is bad. If the sensor is OK, a short or open in the circuit is very possibly a wiring problem.

A Test of All the Components

The above troubleshooting procedures will identify the problem almost all of the time. If you wish to perform a more accurate test without the wiring in the circuit, connect both sensors to the control using only the short leads on the sensors. Make sure that the control has power and the switch is in the auto position.

If both sensors are the same temperature, the pumps or load should not be energized. Using a lighter, heat the collector sensor. It should energize the pumps fairly quickly. Take the heat away when the control comes on. Using the lighter, heat the storage or tank sensor. Keep applying heat until the control shuts off. If all is well with the components, this cycle should work every time, and energize and shut off quickly.

System Runs All the Time or at Odd Times

Two other, less common symptoms are the pump running all the time and running at times when the sun isn't shining. Running all the time can be caused by: the control switch in the on position, an internal relay frozen in the on position, an open tank sensor, or a shorted collector sensor.

If the switch is in the auto position and the pump runs all the time, the problem is likely with the control, sensors, or wiring. A control that runs the pumps with no sensors attached and the switch in the auto position almost always means a problem with the control itself.

A system that runs at odd times is the most difficult to diagnose. The most obvious cause is the third light on a Goldline control (the Heliotrope doesn't have this light). Both controls have the function of recirculation freeze protection. In extremely mild climates where it might freeze once every five or ten years, this function may have been enabled. The Goldline has an internal jumper for enabling this, and the Delta-T has an internal DIP switch.

Recirculation freeze protection is a bad idea in all but the mildest climates. It should never be enabled in drainback or closed-loop antifreeze systems. Check for this if the control is new, or if someone has been fooling around inside the control. The Goldline will have the light to warn you that this feature is enabled, but the real symptom is the pump running when it shouldn't be.

Internal settings can make a control run or not run when it shouldn't. The Delta-T has a series of DIP switches for adjustments in the field. The Goldline has two dials. These settings control the turn-on differential and the storage temperature high limit. Any system with a heat exchanger in the collector loop (drainback and closed-loop antifreeze) should have a higher turn-on differential than a direct pump system without an exchanger.

The Delta-T should be set for an 18:5 differential and the Goldline from 16 to 20. On the Delta-T, the first number is the "on" differential, the second the "off." The Goldline has a fixed "off" differential of 4, so the dial only controls the "on" differential. These settings are temperatures in degrees Fahrenheit.

Lower settings (9:4 on the Delta-T and about 10 on the Goldline) are for direct-pump systems without exchangers used in nonfreezing climates. High-limits should be no more than 180°F (82°C). The high-limit setting will turn the pumps off when the storage gets to that temperature. The Delta-T has two choices—160°F and 180°F. The Goldline has a dial.

What Else Can Go Wrong?

In a few instances out of a thousand, the tests above cannot diagnose a problem. Systems that run at odd times, sporadically, or don't run sometimes when they should can be caused by faulty sensors or controls. If this seems to be the case, there are only a couple of choices. "Shotgun" the

Sensor Temperature vs. Resistance

Temperature (˚F)	(˚C)	Measured Resistance (KΩ) For 10 KΩ Sensor	For 3 KΩ Sensor
27	-2.8	39.8	11.9
32	0.0	32.6	9.8
37	2.8	28.3	8.5
42	5.6	24.7	7.4
47	8.3	21.5	6.5
52	11.1	18.9	5.7
57	13.9	16.5	5.0
62	16.7	14.5	4.4
67	19.4	12.8	3.8
72	22.2	11.3	3.4
77	25.0	10.0	3.0
82	27.8	8.8	2.7
87	30.6	7.9	2.4
92	33.3	7.0	2.1
97	36.1	6.3	1.9
102	38.9	5.6	1.7
107	41.7	5.0	1.5
112	44.4	4.5	1.4
117	47.2	4.0	1.2
122	50.0	3.6	1.1
127	52.8	3.2	1.0
132	55.6	2.9	0.9
137	58.3	2.6	0.8
142	61.1	2.4	0.7
147	63.9	2.2	0.6
152	66.7	2.0	0.6
157	69.4	1.8	0.5
162	72.2	1.6	0.5
167	75.0	1.5	0.4
172	77.8	1.4	0.4
177	80.6	1.2	0.3
182	83.3	1.1	0.3

problem (replace components in a logical fashion) or have a professional electronics technician look at the differential control and sensors. If you choose the shotgun approach, replace the sensors first. They cost about one-tenth what a good differential control costs. See the Access section at the end of this article for companies that sell, evaluate, and repair controllers.

Other Controls

Each controller is designed for sensors with a specific resistance. Differential controls that use 10 K-ohm sensors have been the standard for more than twenty years. However, there are still quite a few controls in service that are older than that and may have something besides 10 K-ohm sensors. Four that enjoyed varying degrees of popularity were Honeywell, Johnson Controls, Webb Electronics, and Delta-T. Virtually all other manufacturers used 10 K-ohm thermistors for sensors.

Some early Delta-T controls made before 1983 used 3 K-ohm sensors. These will have orange and gray wires on the control, and will almost always have a metal cover plate. Newer, 10 K Delta-Ts have plastic cover plates.

Webb Electronics used 30 K-ohm thermistors for sensors. If you find one of these and the owners know what they have, expect to pay a reasonably high price. But warranty considerations and the thought of possibly buying another expensive 30 K sensor in the future would make me lean towards just getting a whole new control with a warranty and reasonably priced replacement parts.

Honeywell and Johnson Controls also had odd duck sensors that are very tough to find. The Honeywell used a sensor that reads 3,500 ohms at 85°F (29°C). The resistance and temperature were not inverse, as they are in differential controls made today. Johnson made a control that operated with two, 1 K-ohm sensors at 70°F (21°C), and may have made a few others that were not in wide circulation.

If you have a differential control and know nothing about it, the inside surface of the cover plate is the first and best place to look for information. Delta-Ts and Goldlines made today lay out the terminal connections, switches, or dials as appropriate.

Most DC-pumped systems with a dedicated photovoltaic (PV) module for power don't use a differential control. The control is the module itself, and if it is closely matched to the pump motor, it will work well with the sun cycle. There are a few systems with DC differential controls (I know of none readily available today) and all that I have seen operate just like their AC cousins.

Fault Analysis

Once you've found the problem and corrected it, it is good to try to minimize the risk of it happening again. Most control problems seem to be caused by normal life of the components or voltage spikes. There isn't much you can do about normal wear except to replace the component with one that has a good reputation for reliability, or have the faulty control repaired by a reputable electronics technician.

Voltage spikes are not nearly the problem they used to be. Many early controls had poor surge suppression built in—some had none. With the collector sensor near the top of many homes, this was asking for trouble. Nearby lightning can cause spikes, and controls with poor or nonexistent surge suppression were easy prey. The industry seems to have solved that problem, and we see very few controls with voltage spike damage today.

A caveat on troubleshooting: some differential control manufacturers did not recommend shorting the sensor terminals on their controls. We have been told that it can cause damage. After checking thousands of controls from dozens of manufacturers over the last 25 years with the quick checks given in this article and never seeing any harm caused, we just don't pay any attention to the warning. Manufacturers may still discourage this testing procedure, and if so, you should be aware of it and check with the manufacturer if the warning bothers you.

Differential controls are used in solar domestic water heating, space heating, and pool heating systems. Typically, they will last a long time. Perhaps today they are no longer the most likely component to check when a system malfunctions. But they can fail, and I hope these troubleshooting procedures will help you if they do.

Access

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