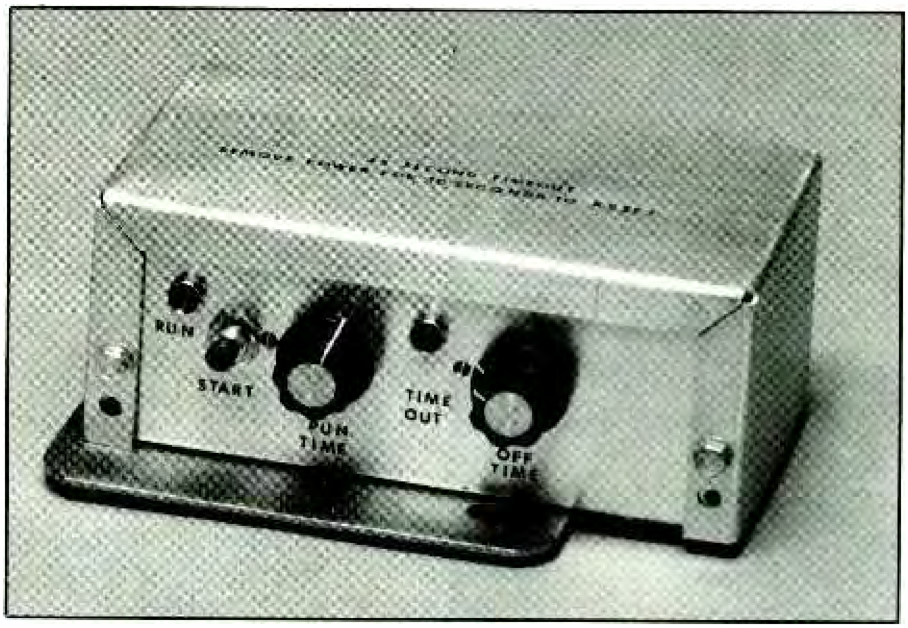
An Advanced Oil-Furnace Controller

This all-electronic furnace controller replaces the old existing one to conserve fuel and handle timing control

By Duane M. Perkins



You can easily reduce the amount of fuel you use with an oil-fired furnace by replacing the existing unit with the advanced controller to be described. The new all-electronic unit takes command of timing the heating cycle without eliminating existing temperature control. With its shorter burn time and longer interval between burns, the controller can reduce the amount of heat lost up your chimney.

Although this will result in a somewhat longer time to raise the temperature on a cold morning, depending on the timing-cycle setting, you can expect the temperature to be maintained at the thermostat setting once it has been reached. (A fuller explanation of the reasoning behind this improved efficiency was given in "Heating Costs Too High? Try a Fuel Miser," *Modern Electronics*, October 1984. Unlike the Fuel Miser, the controller described here replaces the existing unit on your oil burner and performs all tasks the existing unit performs, plus controlling the timing.)

The Oil Burner

A standard home-heating oil burner has two temperature sensors and one light sensor. The usually low-voltage, low-current thermostat senses ambient room temperature and signals the controller when heat is needed. A similar device (called the "limit control") in the furnace opens a switch when the temperature of the heat exchanger reaches a preset level. This is a high-voltage, high-current switch that controls the 117 volts ac to the burner motor and igniter. When the thermostat calls for heat, the limit control cycles the burner. Another switch, similar to the limit control, turns on and off the blower motor but is independent of the burner itself.

The light sensor is usually a small cadmium-sulphide (CdS) cell mounted in the burner tube, where is can "see" the flame. Its purpose is to signal the controller to shut down after a preset time if the burner does not ignite. Without this very important safeguard, the burner motor would continue to run indefinitely in the event of ignition failure, pumping fuel into the firebox and posing a serious fire hazard.

Figure 1 shows how these components are usually wired. The controller contains a relay with heavy contacts to carry the current required by the burner motor and igniter. The igniter includes a step-up transformer that generates a high voltage to pro-

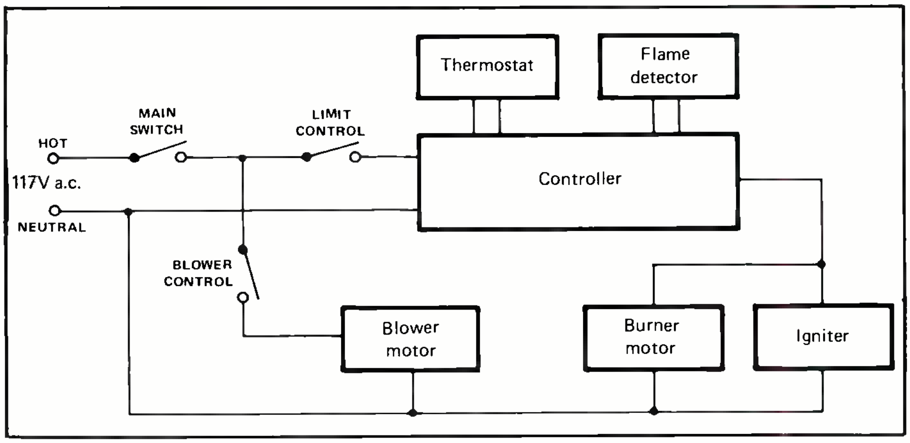


Fig. 1. Hot-air oil furnace components will usually be wired as shown.

duce an arc across the tips of two electrodes at the nozzle of the burner.

Circuit Description

Figure 2 is the schematic diagram of the controller circuit. It uses two timers, both contained in a single 556 IC. One timer, *IC1A*, is held reset by *R7* when the thermostat is open. The low output from *IC1A* holds timer *IC1B* at reset. Relay *K1* is deenergized and the burner does not operate. During this time, *C1* is held discharged by *IC1A*, and *C2* and *C3* will be discharged if *IC1A* has been off long enough for the charges on them to decay through the circuit resistances.

When the thermostat closes, the reset input at pin 4 of *IC1A* goes high through *R11* and causes the output at pin 5 to go high, sending the reset input of *IC1B* at pin 10 to high. With the firebox dark, the flame detector has a very high resistance. The voltage at the anode of *D2* will be at ground potential and this diode will not conduct. Since *C3* is discharged, the trigger input at pin 8 will be held low through *R14*, causing *IC1B* to turn on. The output at pin 9 will then go high, *Q3* will conduct, *LED2* will light, *K1* will energize and the burner will start. Capacitor *C3* will begin to charge through *R3* and *R6*. If the burner ignites, the resistance of *LDR1* will go very low and cause *Q2* to conduct, discharging *C3* and preventing *IC1B* from turning off as long as there is a flame in the firebox and *IC1A* is on.

With *IC1A* on, *Q1* conducts and charges *C2*. Capacitor *C1* begins to charge through *R1* and *R4*; when the charge rises to 8 volts, *IC1A* turns off and resets *IC1B*. At this point, *Q3* will cut off and deenergize *K1*, and the burner will shut down and *C1* will discharge. Also, *C2* will begin to discharge through *R2* and *R5*.

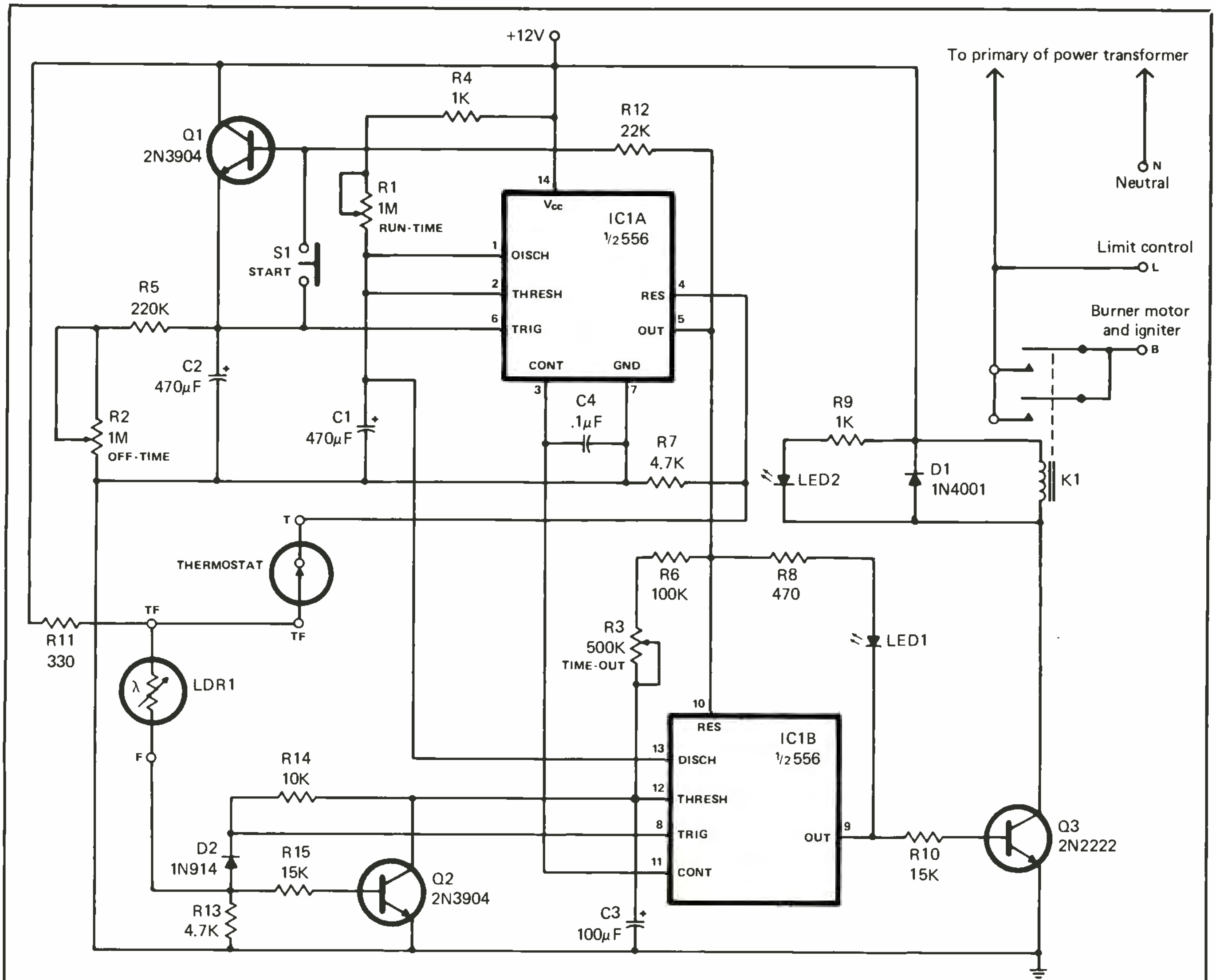
When the charge on *C2* falls to 4 volts, *IC1A* turns on. Since *C3* is discharged, *IC1B* will also turn on and the cycle will repeat indefinitely as long as the thermostat is closed. When room temperature rises above the thermostat setting, it will open and the controller will reset until the temperature drops below the thermostat setting.

In the event of ignition failure, the flame detector will have a very high resistance and *Q2* will not conduct. Capacitor *C3* will charge through *R3* and *R6*. When the charge reaches 8 volts, *IC1B* will turn off, *LED1* lights, *LED2* turns off, *K1* deenergizes and the burner shuts down. Now *IC1B* discharges *C1*, holding *IC1A* on. The controller will remain in this state until either the thermostat is turned down or power is removed. Either of these actions will reset the controller if it remains off for about 10 seconds, but the burner will not start immediately because *C2* will remain charged until the off-time portion of the cycle has elapsed. Pressing START button *S1* will cause *C2* to discharge faster and start the burner in just a few seconds.

The safety feature of the flame detector cannot be foiled by a shorted or open CdS cell, nor will the burner start if for any reason there is a flame in the firebox when *IC1A* turns on. If *LDR1* is shorted or has a low resistance when the burner is off, *D2* will conduct and hold the trigger input at pin 8 high, preventing *IC1B* from turning on. When *IC1A* turns on, *LED1* will light immediately and the circuit locks up until it is reset.

Potentiometers *R1* and *R2* allow you to set the run-time and off-time independently of each other such that changing the setting of one does not affect the other. To be useful, these times should be set so that the burn time is shorter than the time it takes for the limit control to open and the interval between burns is longer than the time it would take for the limit switch to close after the end of a burn. You can time these intervals with RUN-TIME control *R1* set to maximum and OFF-TIME control *R2* set to minimum and then adjusting them to decrease burn time and increase the interval between burns. RUN-TIME control *R1* will have a range of about 0.5 second to 10 minutes, OFF-TIME control *R2* will range from about 1.5 to 7.5 minutes. The timeout interval is adjustable, via TIMEOUT control *R3*, from about 16 seconds to 1.6 minutes but should be set for about 45 seconds.

Relay *K1* should have contacts rated to carry the current specified for your burner. A Radio Shack No. 275-218B with the two sets of contacts in



PARTS LIST

Semiconductors
D1,D2,D3—1N4001 rectifier diode
D4—1N914 switching diode
IC1—556 dual timer
LED1,LED2—Panel-mount light-emitting diode assembly
Q1,Q2—2N3904 transistor
Q3—2N2222 transistor

Capacitors
C1,C2—470-μF, 35-volt electrolytic
C3—100μF, 35-volt electrolytic
C4—0.1-μF disc
C5—4700-μF, 35-volt electrolytic
C6—220-μF, 35-volt electrolytic

Resistors (½-watt, 10%)
R4,R9—1000 ohms
R5—220,000 ohms
R6—100,000 ohms
R7,R13—4700 ohms
R8—470 ohms
R10,R15—15,000 ohms
R11—330 ohms
R12—22,000 ohms
R14—10,000 ohms
R1,R2—1-megohm linear-taper potentiometer
R3—500,000-ohm-flat-mount pc trimmer potentiometer

Miscellaneous
K1—12-volt dc relay with 10-ampere dpdt contacts
PC1—Cadmium-sulphide light-dependent resistor (Radio Shack No. 276-116A or similar)
S1—Normally open momentary-action spst pushbutton switch
T1—25.4-volt, 450-mA transformer
Suitable aluminum utility box (Radio Shack No. 270-238 or similar); electrical box (if needed; see text); pc board; IC socket; two control knobs; 4-lug screw-type terminal strip; rubber grommet; labeler; clear acrylic spray; ¼" spacers (3); 12-gauge stranded wire; 6-32 machine hardware; 1-lb. coffee can; switched ac lamp socket; ac line cord with plug; spst slide or toggle switch; flat black paint; wire nuts (3); solder; electrical tape; etc.

Fig. 2. This is the complete schematic diagram of the oil furnace controller, minus power supply.

parallel will have a rating of 20 amperes, which should be adequate for most burners. The power supply, shown in Fig. 3, uses a center-tapped 25-volt transformer and a 7812 voltage regulator to provide 12 volts.

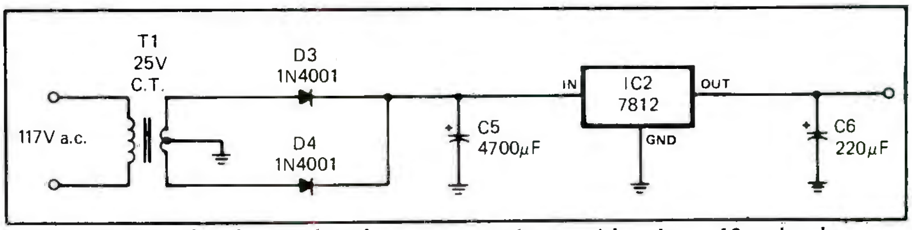


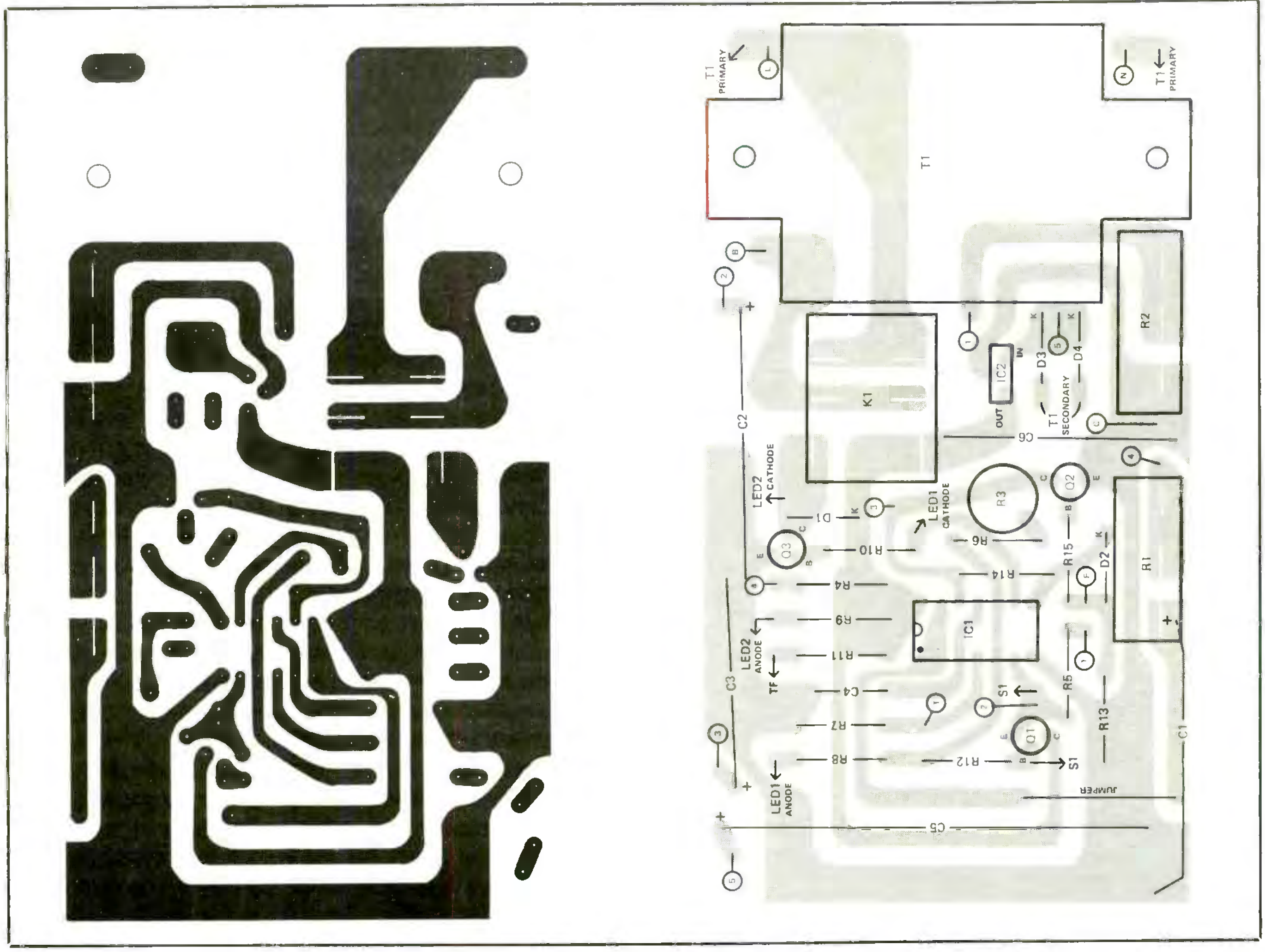
Fig. 3. This simple regulated power supply provides the + 12 volts dc required by the controller. It mounts on the same board as the controller.

Construction

Though you can use traditional point-to-point wiring or Wire Wrap techniques to assemble the controller circuit, a printed-circuit board is much the safer and easier approach. You can fabricate your own pc board with the aid of the actual-size etching-and-drilling guide shown in Fig. 4.

Once the board is etched and drilled, it will be necessary to cut long, narrow slots for the lugs of relay *K1* and potentiometers *R1* and *R2*. If you have a Moto-Tool or similar tool, you can use a thin abrasive wheel to do this. On the other hand, if you don't have such a tool, it will be necessary to drill a hole at each end of each slot and use a coping, jeweler's or keyhole saw fitted with a fine-tooth blade to make the slots.

Fig. 4. Shown at left is the actual-size etching-and-drilling guide for the pc board on which the controller and power supply circuits mount. Wire components to the board as shown in the parts placement/orientation diagram at right.



All components except the LEDs, pushbutton switch and four-screw terminal strip mount on the pc board. The conductors to the relay contacts must be wide and have as much insulation between them and other conductors as possible to safely carry the high current and voltage. Wire the pc board as shown in the components-placement diagram in Fig. 4. Start with the smallest components and work up to the electrolytic capacitors, potentiometers and relay. Do not forget the jumper wire between the *R1/C1* junction and pins 1, 2 and 13 of *IC1*; install this jumper *before* you mount *C1* and *C5*. Also, use a socket for *IC1*.

Before mounting the relay, carefully cut off the lugs to the normally closed contacts (the two nearest the edge opposite the coil connectors) and file them flush with the surface. Cut the potentiometer shafts to ⅜" before mounting these components on the board. Temporarily mount the transformer with 6-32 hardware. Connect and solder its leads to the indicated points on the board (the center-tap goes to the point labelled C). Use insulated wire to interconnect like-numbered points, leaving these until last so that the wires can be routed around the components.

Use 12-gauge stranded wire for the connections to the points labelled L (limit control) and B (burner). Red insulation for the L and black for the B wires is recommended so that it conforms to the standard color coding for house wiring. The wire used for the N (neutral) lead can be as small as 20 gauge, since it carries only the current to power the controller. Cut all three of these wires to the lengths needed to reach the leads to which they will connect when the controller is installed in your furnace. Drill holes in the pc board adjacent to the connecting points and run these wires through the holes so that they can be routed through a hole in the bottom of the utility box. Cut seven 12" lengths of stranded hookup wire and solder them to the points labeled F, T, TF, *LED1* and *LED2* (both anode and cathode).

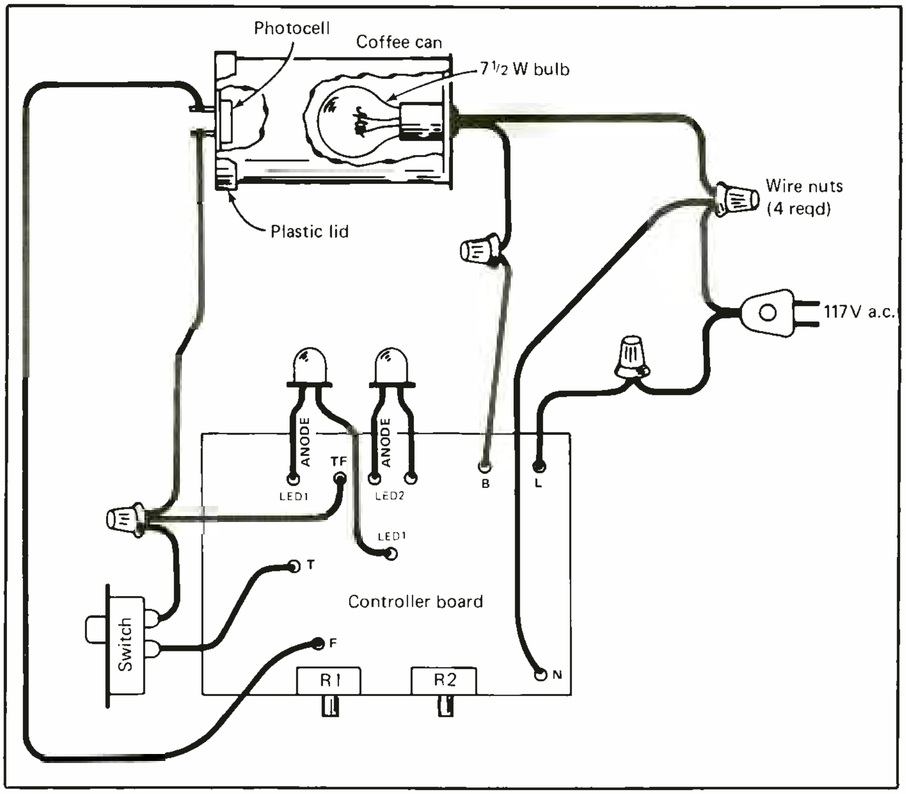


Fig. 5. Before installing your newly wired controller circuit in your oil furnace, wire it as shown here and perform the tests detailed in the text.

Initial Tests

A simple device that simulates the oil burner will greatly simplify testing of the controller. To make it, refer to Fig. 5. Mount a standard 117-volt switched lamp socket in the bottom of a 1-pound coffee can and screw in a 7½- or 15-watt bulb. Spray the inside of the can's plastic cover with a quick-drying flat black paint. When the paint dries, mount a CdS photocell in the center of the cover with its sensing surface facing inward and its leads brought out through the plastic of the cover. The lamp will simulate the flame in the firebox, the CdS cell the flame detector.

Connect the controller to this simulator exactly as shown in Fig. 5. Connect the two LEDs to the leads coming from the points labelled *LED1* and *LED2* on the pc board, making sure the anodes connect to *R8* and *R9*, respectively. Connect an spst switch to the leads from points T and TF. This switch will be used to simulate the thermostat.

Rotate *R1* and *R2* to fully clockwise. With the thermostat switch open, plug the line cord into an ac outlet. Nothing should happen. Use a voltmeter to measure the potentials between pin 14 of *IC1* and ground and between pins 3 and 11 and ground. The measurements should be +12 and +8 volts, respectively. All other pins of *IC1* should be at or near ground potential.

Set the lamp switch and then the thermostat switch to on. The relay should now pull in and the lamp should light. Also, *LED2* should light whenever $K1$ is energized. With the photocell conducting, there should be about +8 volts at point F, and the potential at pins 3 and 11 of $IC1$ should be near ground, while that at pin 1 should be slowly rising. When the potential at pin 1 of $IC1$ reaches 8 volts, $K1$ should drop out, turning off the lamp. The voltage at pin 6 should then slowly drop until it reaches 4 volts, at which point, $K1$ should energize and the lamp should turn on.

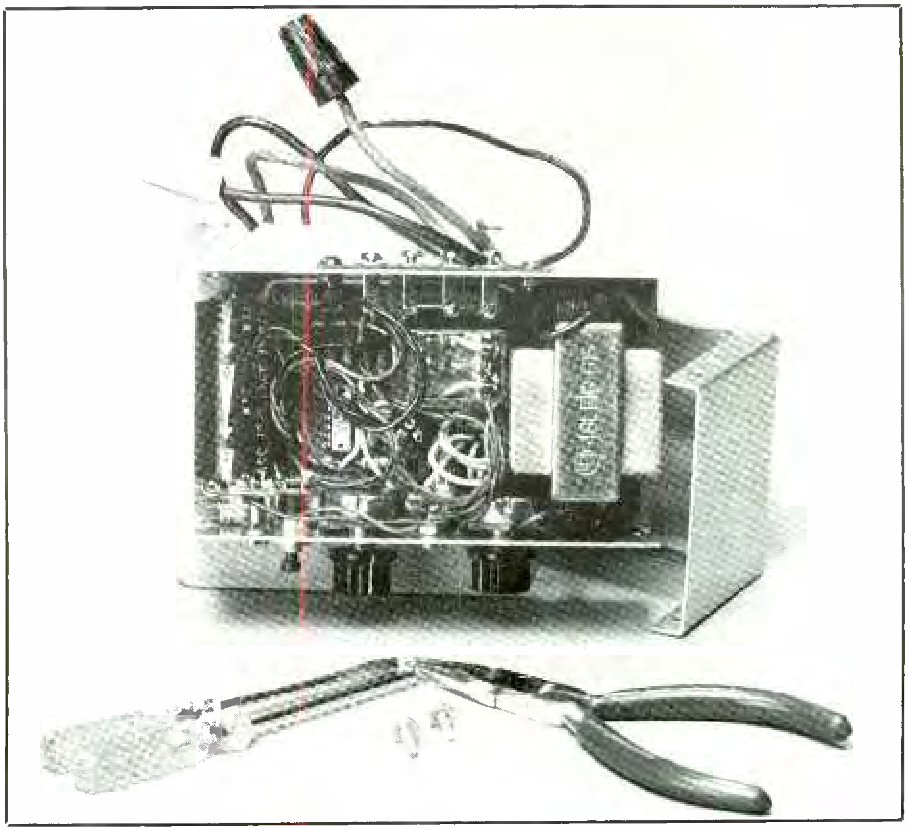
Slowly turn $R1$ counterclockwise to decrease run-time. The voltage at pin 1 of $IC1$ should rise more rapidly. When the relay drops out, rotate $R2$ to maximum counterclockwise. The voltage at pin 6 should drop more rapidly and the "off" time should be about 1.5 minutes. The unit should now cycle continuously with a "run" time set by $R1$.

Set $R3$ for minimum resistance. When the relay drops out, turn off the lamp switch and set $R1$ maximum clockwise. When the relay energizes, the CdS cell will not conduct. The voltage at pin 12 of $IC1$ should rise rapidly. When it reaches 8 volts, $LED1$ should light and the relay should not energize. The circuit should remain locked in this state until it is reset. Turn on the lamp switch and then turn off then on the thermostat switch. Normally, cycling should resume beginning with the "off" time portion of the cycle.

When the lamp is off, remove the coffee can cover and expose the CdS cell to bright light. At the end of the "off" time, $LED2$ should light immediately. Cover the CdS cell momentarily; at this point, the relay should energize.

Final Assembly

If the controller is working as described above, it is ready for final assembly. Disconnect the leads from the test setup and remove the two LEDs. Solder two short lengths of stranded hookup wire to the points labelled S1 on the pc board. The board is to be mounted on ¼" spacers. Measure the height of the centers of the potentiometer shafts from the base of the enclosure (¼" below the bottom of the board). Measure the distance from one edge of the board to the centers of the potentiometer shafts. Marks these dimensions on the front panel of the enclosure and drill the holes for the shafts.



An interior view of the controller.

Position the board in the enclosure and check that there is ¼" of clearance for the spacers. Carefully noting the positions of the components, mark the centers for the holes where the two LEDs and the pushbutton switch will be mounted. Remove the board and drill these holes.

Placement of the four-lug screw-type terminal strip on the rear panel of the box is not critical. It can be centered vertically and horizontally. Cut a slot for the strip's lugs and drill the mounting holes.

The positions of the screws that secure the two utility box halves together must be changed because the pc board is now at the height of the original holes. Therefore, drill new holes about ⅜" above the original ones, sizing them the same as the originals to permit use of the self-tapping screws supplied with the box.

The utility box should be mounted on a standard square electrical box cover to keep the ac power connections safely enclosed and to facilitate installation in the furnace. Unless a suitable box is already in place, mount one in a convenient place in the furnace's enclosure. Note how the controller will best fit on the box when installed and mark the box's outline on the cover.

Drill the three mounting holes for the pc board (one for each of the transformer's mounting tabs and a third for the left-front hole in the board) through the bottom of the utility box. Set the bottom half of the box on the electrical box's cover, oriented properly in the drawn outline (the two mounting holes for the board at the *T1* tab locations should overhang the edge of the lid by at least ⅜″) and transfer the electrical box lid's outline to the bottom of the utility box. Mark the front-left board mounting hole outline on the top of the electrical box's lid and drill this hole. Fasten the two pieces together with 6-32 machine hardware.

Next, drill two more screw holes through both metal pieces for two more sets of machine hardware. Make sure you position these holes where they will not interfere with either the circuit board assembly or proper mounting of the lid on the electrical box. Secure the two pieces together with 6-32 × ¼″ machine screws, lockwashers and nuts. Flip over the assembly and drill a ¼″ hole through the bottom of the utility box, centering it within the large hole area of the electrical box lid. Deburr the newly drilled hole and then line it with a rubber grommet.

Thoroughly clean all exterior surfaces of the utility box with fine steel wool. Then use a dry-transfer lettering kit or plastic tape labeler to identify the controls, indicators and connectors. If you use a dry-transfer lettering kit, spray two or three *light* coats of clear acrylic over all exterior surfaces of the box, allowing each coat to dry before applying the next.

When the acrylic has thoroughly dried, mount the terminal strip on the rear wall of the box. Feed three 6-32 × ½″ machine screws up through the three holes in the bottom of the utility box. Drop a ¼″ spacer onto each screw.

Place electrical tape over the surfaces of the utility box adjacent to the section where the board's conductors carry ac line power. Feed the ac power leads from the board through the rubber grommet and lower the board onto the screws, making sure the shafts of *R1* and *R2* properly seat in their holes in the front panel and that no conductors are caught between the board and spacers. Set *T1* in place over the protruding screws and anchor with lockwashers and nuts. Anchor the front-left corner of the board in place with another lockwasher and nut.

Mount *LED1, LED2* and *S1* on the front panel. Tighten the board-securing hardware and check to make sure that the nut and lockwasher at the left-front corner does not interfere with *C1* or *C5*. Cut all wires on the upper side of the board to the lengths needed to complete the interconnections and, referring back to Fig. 2, connect them to the proper points.

Before you close the utility box, it is a good idea to once again check the project for proper operation. To do this, use the test setup shown in Fig. 5 once again. This time, however, connect the photocell and thermostat switch to the terminal strip. This done, repeat the tests detailed above to be certain that all connections have been made correctly.

When the lamp turns off, press START pushbutton *S1*. In just a few seconds, the lamp should turn on. Adjust *R1* and *R2* for the run and off times you want to initially try when the controller is installed and in control of your furnace. Turn off the lamp switch and adjust *R3* for a 45-second time-out. After each trial, use the thermostat switch to reset and then restart with the START switch.

Installation & Operation

Before you attempt to install the controller in your furnace, make sure all ac power is disabled, preferably at the service box. Use wire nuts to connect the 117-volt ac power leads to existing wiring. Also, ground the controller for safety, using bare 12- or 14-gauge copper wire to connect to the existing ground lead. If it is necessary to extend the connections from the project to the existing wiring, use plastic-insulated three-conductor electrical cable with a ground wire.

Connect the flame-detector and thermostat wires to the contacts on the terminal strip on the rear of the controller and turn the thermostat all the way down. Apply power to the controller. Slowly turn up the thermostat until the burner kicks on. If the thermostat momentarily breaks after it makes, the off-time must elapse before the burner will start—or you can press the START button to get things rolling.

The burner should cycle according to the times previously set. Make any adjustments necessary if the control settings were moved during installation. Remove power, disconnect the black burner lead and replace the wire nut on the lead to prevent grounding. Recheck for a 45-second time-out before *LED2* turns on; readjust if necessary. Reconnect the burner lead and close up the box, using the four self-tapping screws.

In Closing

Experience will tell if the times you set are judicious. If it takes longer than you would like to get the temperature up to the thermostat setting on a cold morning, increase the run-time or decrease the off-time. The limit to which you can go with either control is determined by the limit control cycle time. Economy is achieved by having the controller determine both portions of the cycle. The best compromise will probably be with a setting that runs the burner only long enough for the blower to start and starts the burner shortly after the blower stops. ME