

Electric Furnace Controller

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Version 2

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Overview

A key element of my new electric furnace is the ability to finely control the amount of power applied to the heating element. This element can radiate up to 3600 watts when 240 volts at 15 amps is applied. It is also very fragile. Applying full power when cold causes a thermal shock that can at least reduce its life. In the worst case it can blow it open. After the furnace is at full power, it is wise to slowly bring the power down to zero for similar reasons. I have added three more requirements to this design. First of all, I want to minimize Electro Magnetic Interference (EMI). EMI can annoy the neighbors and that is not a good idea when you are operating a furnace in your backyard. My second desire is to use as much from my junk bin as possible in order to minimize cost. And finally, I wanted the fun of designing and building my own controller.

This is a very basic controller. I set a dial and can apply anywhere from about 100 watts up to 3600 watts of power. It would be easy to expand its capabilities to automatically ramp the power up and down and even regulate the temperature inside the furnace. At least for now, I'll do that manually. My last furnace was heated with charcoal so just having clean electricity as my heat source is fancy enough for me.

Background

If you just want a high power controller, you can modify a 120V AC lamp dimmer and connect it to a high power TRIAC as explained in Dan Hartman's book "An Improved electric Radiant Shop Furnace". This design has been shown to work fine but does have higher EMI levels.

My Controller

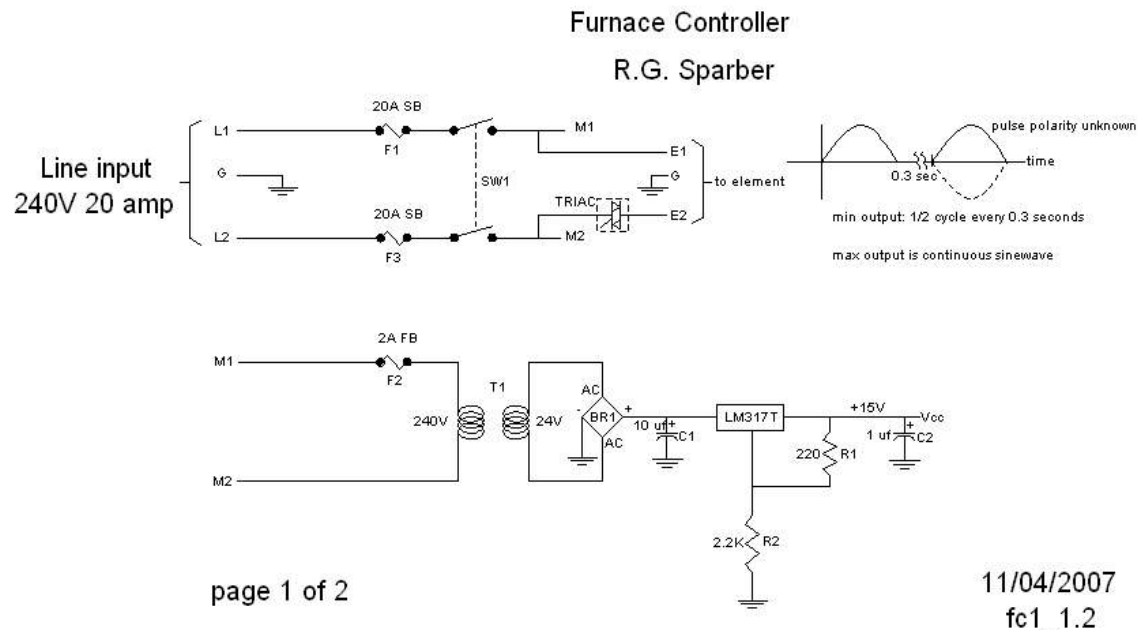


It is hard to make out much detail in the above picture so I'll give you the 5-cent tour. On the far left is a large black power plug. A 240V 35 amp extension cord connects there. To its right is a black circle. This is the output connector. The cable from the furnace plugs in here. Below it is the on/off switch. To the right of the output connector is an LED that turns on each time a pulse of power is applied to the heating element. Below the LED is the duty cycle knob. More on this later. To the right of the knob is a small fuse to protect the internal low power wiring. Inside the box is the main fuse which protects the internal and external high power wiring.



Ah, now we can see! The box is almost empty but I liked the size given the massive cables connecting to it. Starting on the right you can see the internal 20 amp slow blow (SB) fuse. Above it to the left is the on/off switch. To the left of the switch is the TRIAC. This little part, an NTE56026, can switch up to 600 volts at 40 amps yet cost me \$20 including tax. To the left of the TRIAC is my circuit board. To its left is the low current fuse. And all the way to the left is a 240V to 24V transformer.

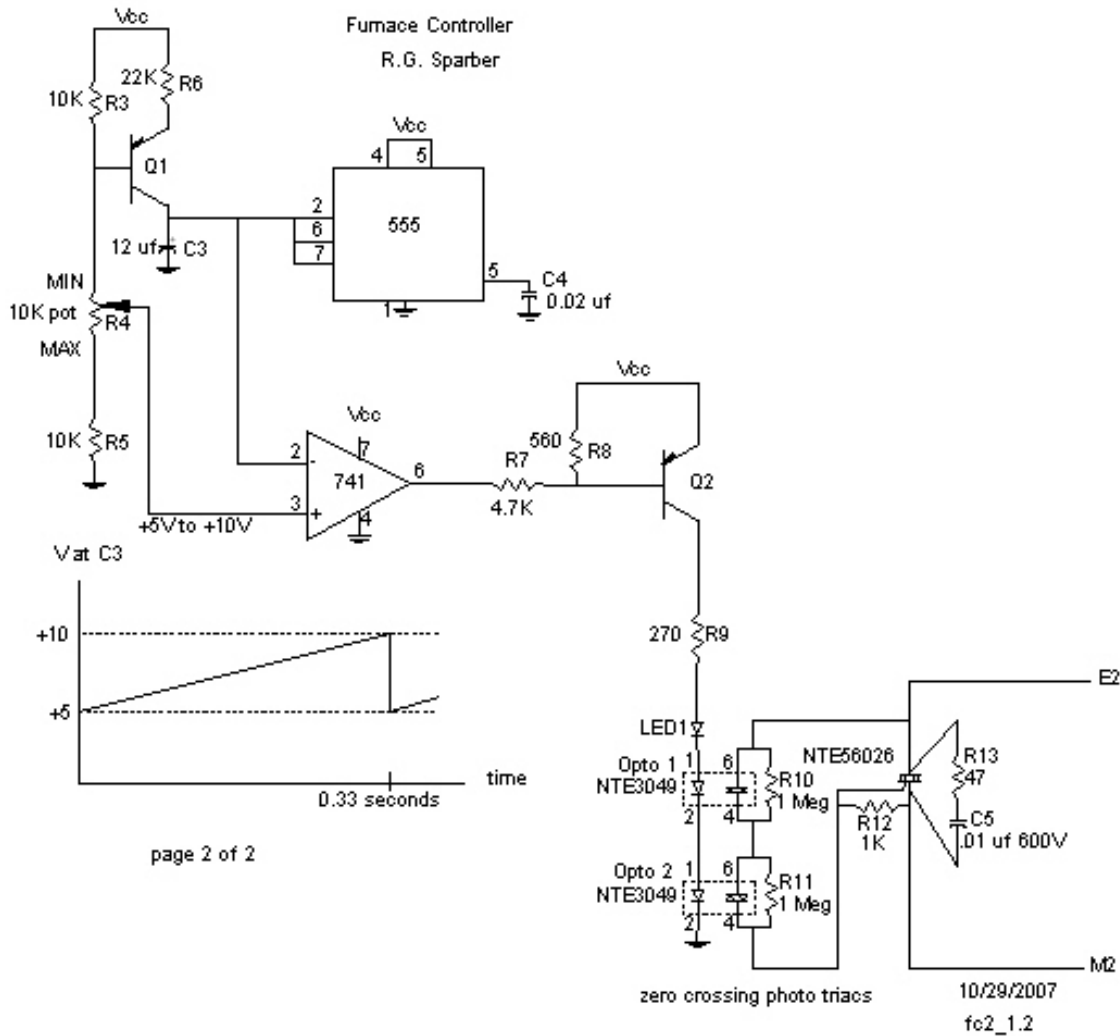
The Schematic



Line power plus ground comes in from the upper left. Both Line 1 (L1) and Line 2 (L2) are fused because faults out at the element can be between L1 and L2 or between either L1 or L2 and ground. The above picture does not show fuse F3 as it was added later. Power is then fed through a DPST power switch. Both L1 and L2 are hot with respect to ground so it is essential that both conductors pass through the switch. The switched power is fed to the transformer to power the electronics and to the TRIAC plus furnace element.

The transformer draws far less than 2 amps so under normal conditions the fuse will hold. The fuse is there to protect the wiring. No thermal fuse can protect electronics.

I come out of the transformer into a diode bridge to fully rectify the AC. This feeds into a standard power supply circuit which outputs around +15V DC. Not much exciting here.



The fun part of the circuit is shown above. Nothing creative here, just simple and clean. Q1 generates a constant current, which feeds timing capacitor C3. The 555 timer starts to dump the charge on C3 when the voltage gets above 10V and lets go when it falls below 5V. The result is a voltage ramp that starts at 5V, rises to 10V, and then drops back down to 5V. It takes about 0.3 seconds for one cycle. Q1 can be any small PNP transistor.

The 741 op amp is being used as a comparator. I chose the 741 because I had a few, not because it is the best part for the job. The op amp monitors the ramp voltage with its inverting input. Its non-inverting input is fed from a potentiometer. I can set the pot to output any voltage between 5 and 10 volts. With the pot very close to 10V, I get a narrow low pulse every 0.3 seconds. The rest of the time the output is high. With the pot at below 5V, I get a constant low output.

This output signal feeds into a pair of resistors that feed Q2. When the op amp's output is high, it can be as low as 10 volts. R7 and R8 have been partially selected to insure that Q2 is off. When the op amp's output is low, it can be as high as 5 volts. R7 and R8 have been partially selected to insure that Q2 is deep into saturation. Q2 can be any small PNP transistor.

When Q2 is in saturation, the top of R9 is essentially tied to Vcc, which is around 15 volts. I get about 30 mA of current flowing through LED1 and the two optos. These are nice little optos (NTE3049). I can apply current to their inputs at any time but they will not turn on the power TRIAC unless the voltage across the TRIAC is typically below 5 volts. This insures that the TRIAC does not switch a lot of power.

I use two of these optos because each one can only handle 120 volts but I need 240 volts. Resistors R10 and R11 insure that when the optos are off, each one sees no more than 120 volts. R12 reduces the sensitivity of the TRIAC's gate so capacitive coupled noise from the load or leakage currents through the optos do not falsely trigger the TRIAC.

R13 and C5 are intended to provide a path for an inductive kick we may have as the TRIAC turns off. The lines are drawn diagonally from R13 and C5 to the TRIAC to remind you to keep these leads as short as possible.

The heating element is mostly a big resistor but it is also coiled like a spring so will have some inductance. Doing zero crossing switching should minimize any transience but it is still wise to add this snubber circuit.

Operational View

Say R4 is set to output almost 10 volts. When the voltage at the top of C3 is below this voltage, the op amp will output a high, which must be at or above 10 volts. Q2 will be off so no current flows to the optos and the TRIAC is off. Each time the voltage at the top of C3 rises above the voltage set by R4, the op amp will change state, Q2 will turn on, and the optos will get a pulse of current. If the pulse is less than a half cycle of AC, 8.3 ms, then I will sometimes have the opto powered when we are at a zero crossing of the AC power and so the TRIAC will turn on and the heating element will get a half cycle of power. It will then be 0.3 seconds before another half cycle of power is possible. Depending on exactly when the pulse occurs, I may or

may not get this pulse. The output power will vary between zero and a half cycle every 0.3 seconds which means a power level of $(8.3 \text{ ms}/300 \text{ ms}) \times 100\% = 3\%$. That is not enough power to melt much more than butter but it will be useful during the phase of furnace construction where I must warm up the freshly mixed refractory to drive out any moisture.

As R4 is set to a lower voltage, we get a wider pulse. With the pulse width greater than 8.3 ms but less than 16.7 ms, we are guaranteed to get at least half a cycle of power and at most a full cycle of power. This translates into an output power level of between 3% and about 6%.

With R4 set to 7.5 volts, we will get a pulse with a 50% duty cycle. Assuming it is active for 150 ms, we will apply about 9 full cycles of power to the heating element and then none for the next 9 cycles.

When R4 is set to 5 volts, the op amp will output a solid low and Q2 will stay on all of the time. We will then turn on the TRIAC at every zero crossing so will be at 100% of available power.

Non-electronic power controllers also work with variable duty cycles but rather than cycle every 0.3 seconds, they are working at around 30 seconds. This means there is more thermal shock to the element since it has more time to cool off.

Future Improvements

The voltage set by R4 is the key. If I slowly lowered this voltage from 10 volts down to 5 volts in, say, 45 minutes using a circuit, I would be able to automatically bring the furnace up to heat gently. Slowly raise this voltage from 5 volts to 10 volts and I have automatic cool down.

A few years ago I gave away two Radio Shack TRS-80 model 100s. These are wonderful old computers but I just needed to clean house. Now I sort of wish I had one of those old machines. It would be possible to take an output from such a computer and drive the optos directly. Then ramping up and down plus manually setting the duty cycle would be done with simple software programs. The danger here is that if the computer freezes, the hardware must be fail safe. No free lunch here. Such a fail-safe circuit would be at least as complex as when I have designed here.

By driving the control voltage from a circuit that responds to a thermocouple and we have temperature regulation.

If you really want these nice features in the first place, I suggest you go to eBay and find a commercial furnace controller. They cost less than \$100 and have every possible feature you can think of for a home furnace.

What next?

If you find errors in this article, please contact me so I can fix them. If you decide to build some or all of this controller, I would be glad to answer any questions you have.

With my controller now operational, I can move onto building the furnace. Then the fun *really* begins!

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