Injection Molding Machine Temperature Controller

By R. G. Sparber

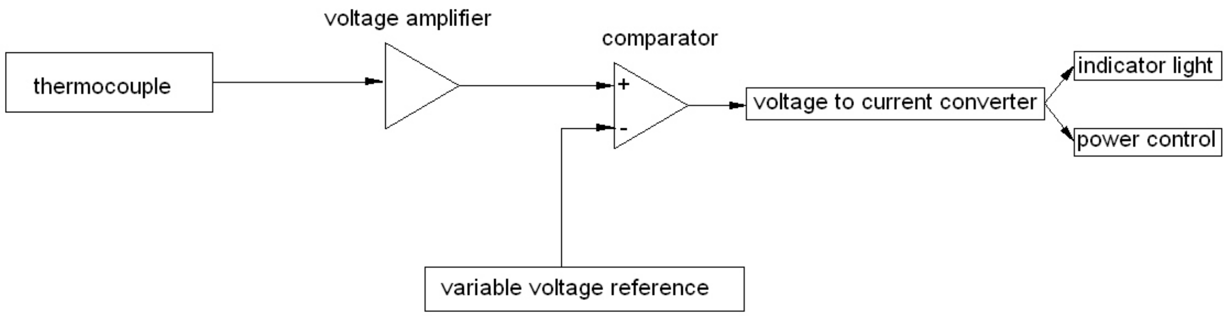
Due to a bug between Word and Open Office, I am unable to turn off this highlighting. Hopefully it is still readable to you.

Scope

This article describes the temperature controller that I use on my modified Gingery Injection molding machine. The original design used a thermal/mechanical temperature controller which sensed the surface of the heater block. My controller monitors the temperature closer to the melting chamber. If you were to buy all new parts, I suspect that the thermal/mechanical controller costs less money and is certainly easier to assemble. But what's the fun in that?

[1] You are free to copy this document but please do not modify it.

Block Diagram

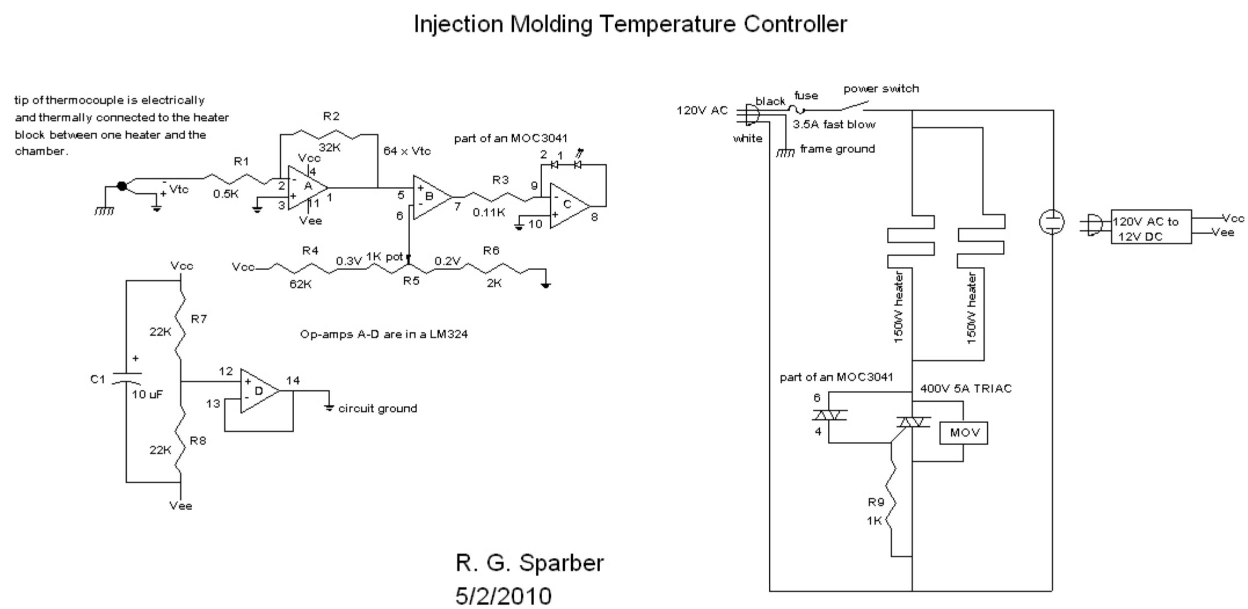


The controller is a simple "bang-bang" analog feedback system. This means that when the temperature is below a threshold, power is applied to the heaters. When above the threshold, power is removed.

On the far left is a Type K thermocouple. When heated to around 200°C, it puts out around 0.004 V. This voltage is amplified by the next stage resulting in a voltage of around 0.32V. This voltage is then fed into a comparator which outputs a negative voltage when we are below the threshold. This negative voltage feeds our voltage to current converter. The resulting current feeds both our indicator light and our power control. The light turns on and the power control applies power to our heaters. Conversely, when the temperature is above the threshold, a positive voltage is generated by the comparator causing the indicator light to go out and power to be removed from the heaters.

Full Schematic

I know this schematic is hard to read but I wanted to get it all in one place. As we go through the details, it will be easier to see.



Overview

I use two integrated circuits. The first is an LM324 which is a quad op-amp. Amplifiers "A" through "D" can be found on the left side of the schematic. The other integrated circuit is a MOC3041. It is an opto-TRIAC. Part of it is shown near op-amp "C" at the top center of the schematic while the rest is shown on the right side below the twin heaters.

In the upper left you see the thermocouple. The junction is connected to ***earth*** ground which comes into the machine via the grounding pin of the power plug. For safety reasons the metal frame of the machine is grounded. For good thermal connectivity reasons, I have chosen to ground the tip. Note that one side of the thermocouple is connected to ***electrical*** ground. This ground is just an arbitrary point as defined by a reference point in the circuit. Earth ground and circuit ground are not the same ground.

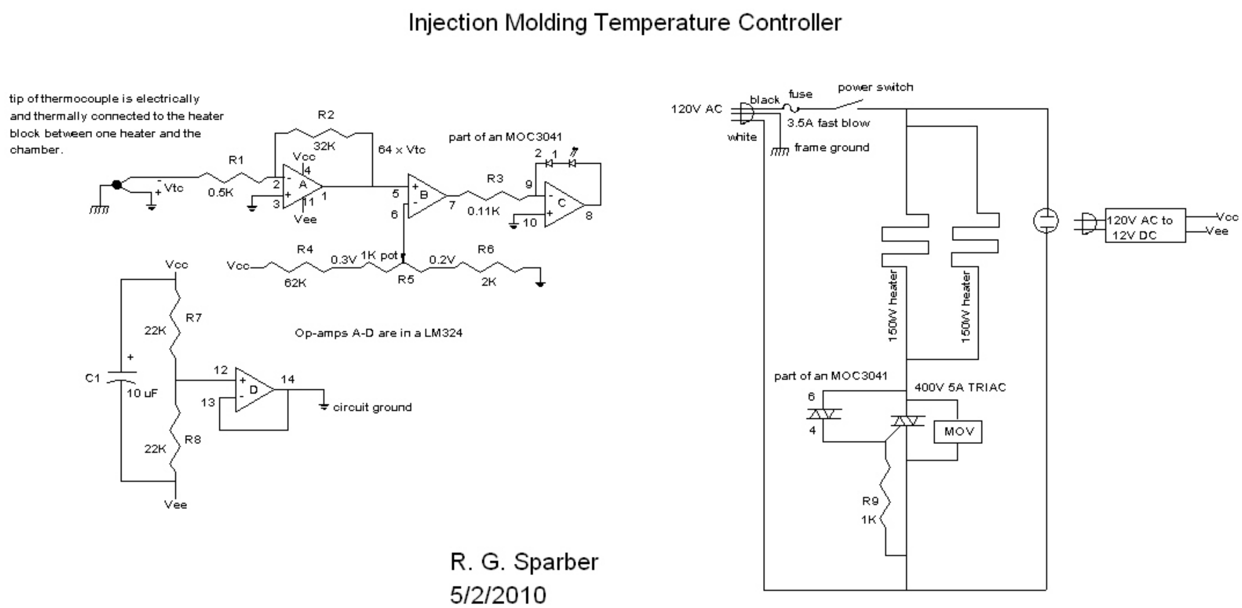
The tiny voltage of the thermocouple is fed into a times 64 voltage amplifier (A).

Note that I have not worried about the location of the cold junction[2]. My goal here is to be able to regulate a set temperature. That temperature is determined

[2] For more on cold junctions, see http://en.wikipedia.org/wiki/Cold_junction_compensation and scroll down to cold junction compensation.

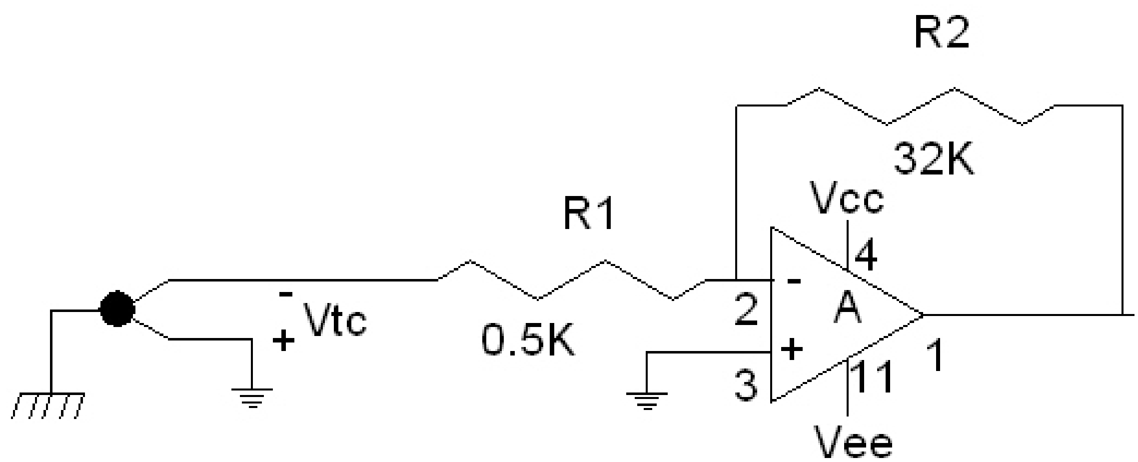
external to this circuit. I calibrated this controller by directly measuring the temperature of the plastic inside the melting chamber. Then my threshold dial was marked to roughly show the temperature. In critical situations, I will use this external thermometer to precisely set the threshold.

The voltage amplifier is one quarter of a quad op-amp. The second quarter is used as my comparator (B). The third quarter is my voltage to current converter (C). The last op-amp generates my circuit ground reference voltage (D).



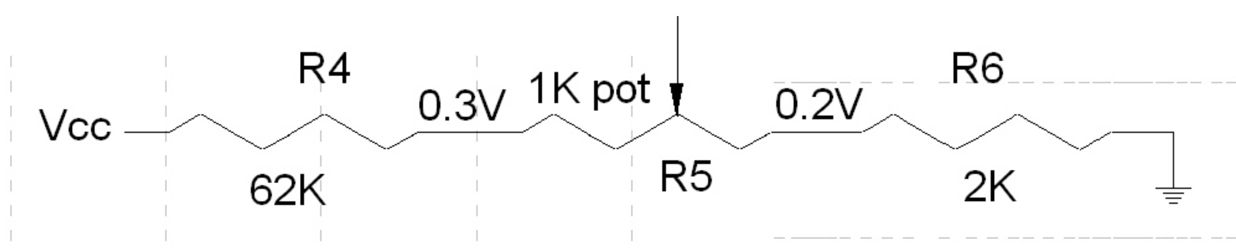
The output of the voltage to current converter feeds an opto-TRIAC via pins 1 and 2 and a common LED. The opto-TRIAC via its pins 4 and 6 controls a power TRIAC which supplies power to my two 150W heaters shown on the right.

Circuit Details

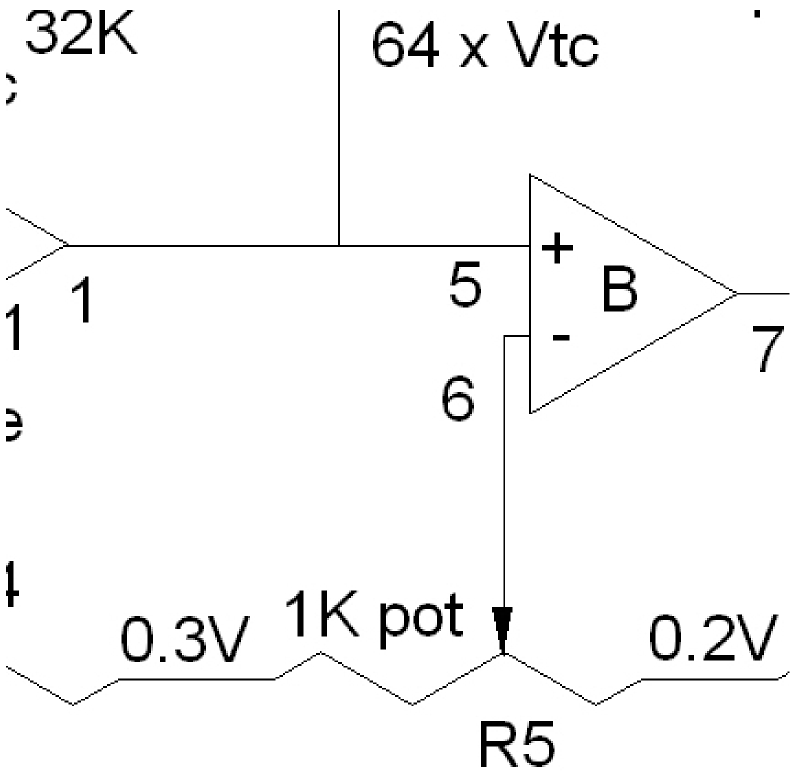


The gain of the voltage amplifier equals R2 divided by R1 or 64. The exact gain is not that important because of the external calibration. There is also a voltage inversion but this has been taken care of by my definition of the input voltage, Vtc. As Vtc gets larger, the voltage at pin (A1)becomes become proportionally larger and of the same polarity.

While the thermocouple puts out around 0.004V when at 200°C, we see 0.004V x 64 = 0.25V at the voltage amplifier's output. This larger voltage is far above the input offset voltages of the op-amps so is more predictable.

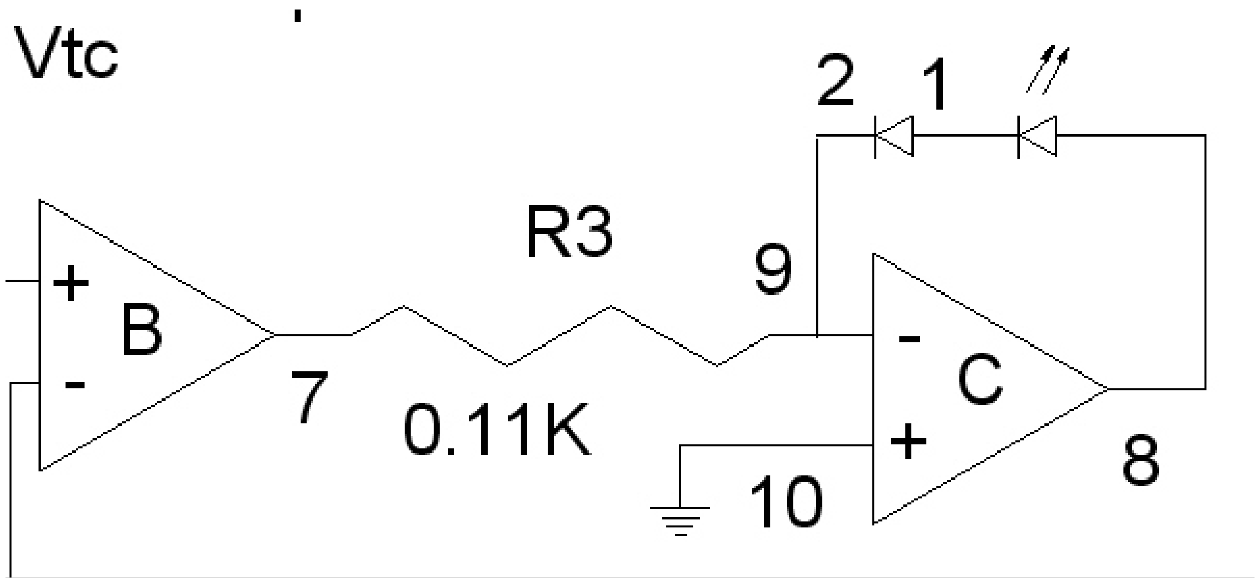


Below the comparator (B) is a voltage divider formed by R4, R5, and R6. One end is connected to Vcc, our most positive power rail. The other end is connected to circuit ground. R5 is a 1K potentiometer. When turned all the way counterclockwise, the wiper reads about 0.2V. Turned all the way clockwise the wiper reads 0.3V. R4 and R6 were selected to give the pot this very narrow range



of wiper voltages. This arrangement enables me to use the entire range of the pot to set all useful temperatures. The center of this range and the limits were found empirically once I got the circuit controlling the temperature. In my particular circuit, Vcc is about +6.67V.

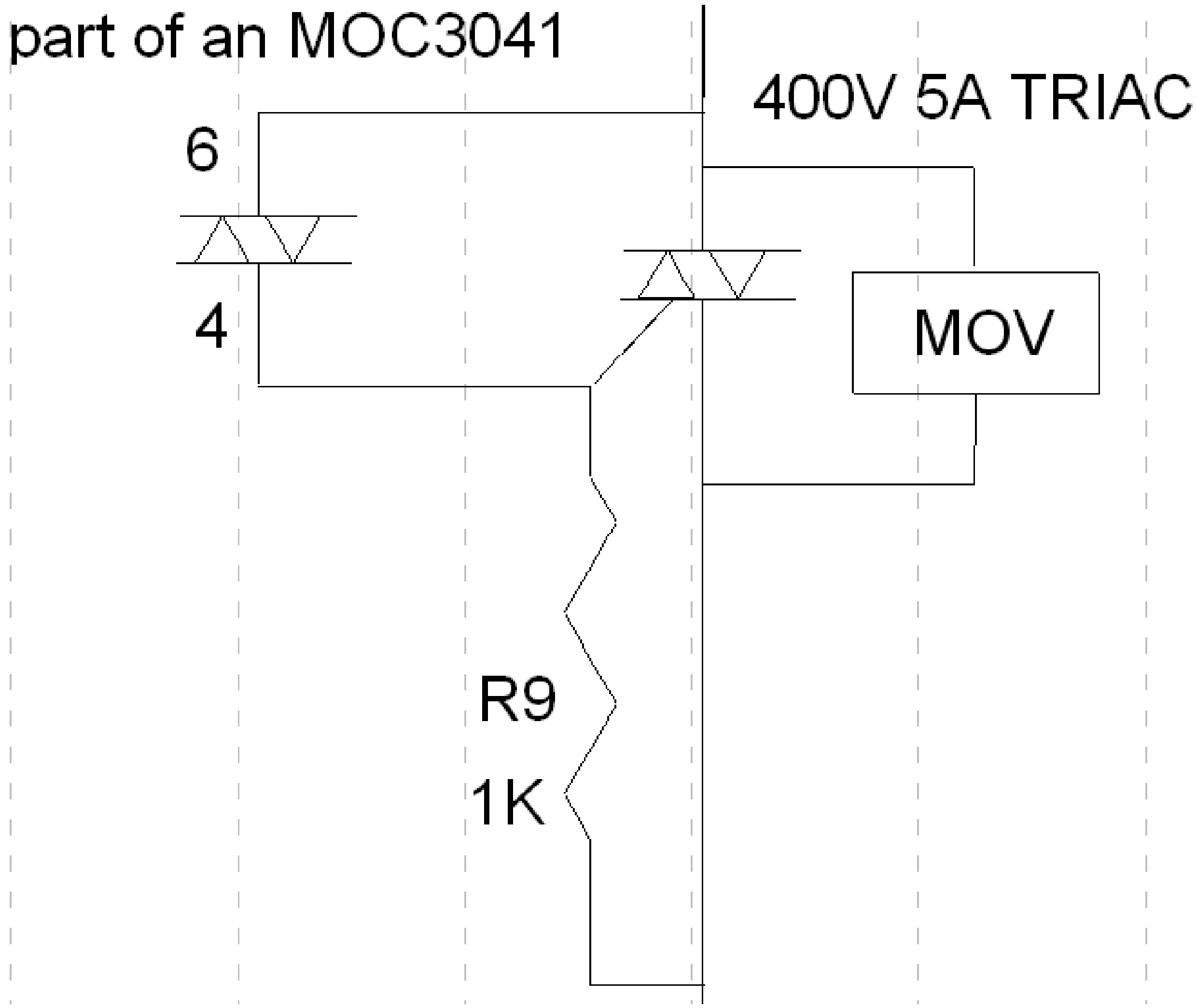
Here we have the comparator stage. The positive input comes from our times 64 voltage amplifier. The negative input comes from our voltage divider's wiper contact on the potentiometer. When the amplified thermocouple voltage is greater than the voltage on the wiper, the output (pin B7) rises to within a few volts of Vcc. This is around 4V. When the amplified voltage is below the wiper voltage, the output falls to around -4V.



The comparator (B7) feeds the voltage to current converter made up of R3 and op-amp C. The current converter's output is between pins C8 and C9. When the comparator's output (B7) is at -4V, op-amp C is able to hold pin C9 very close in voltage to what it has on pin C10. This puts 4V across R3 so the current through R3 is 4V/0.11K = 36 mA. This current flows through the LED (marked with the double arrows) and the input of the opto-TRIAC (marked with pins 1 and 2).

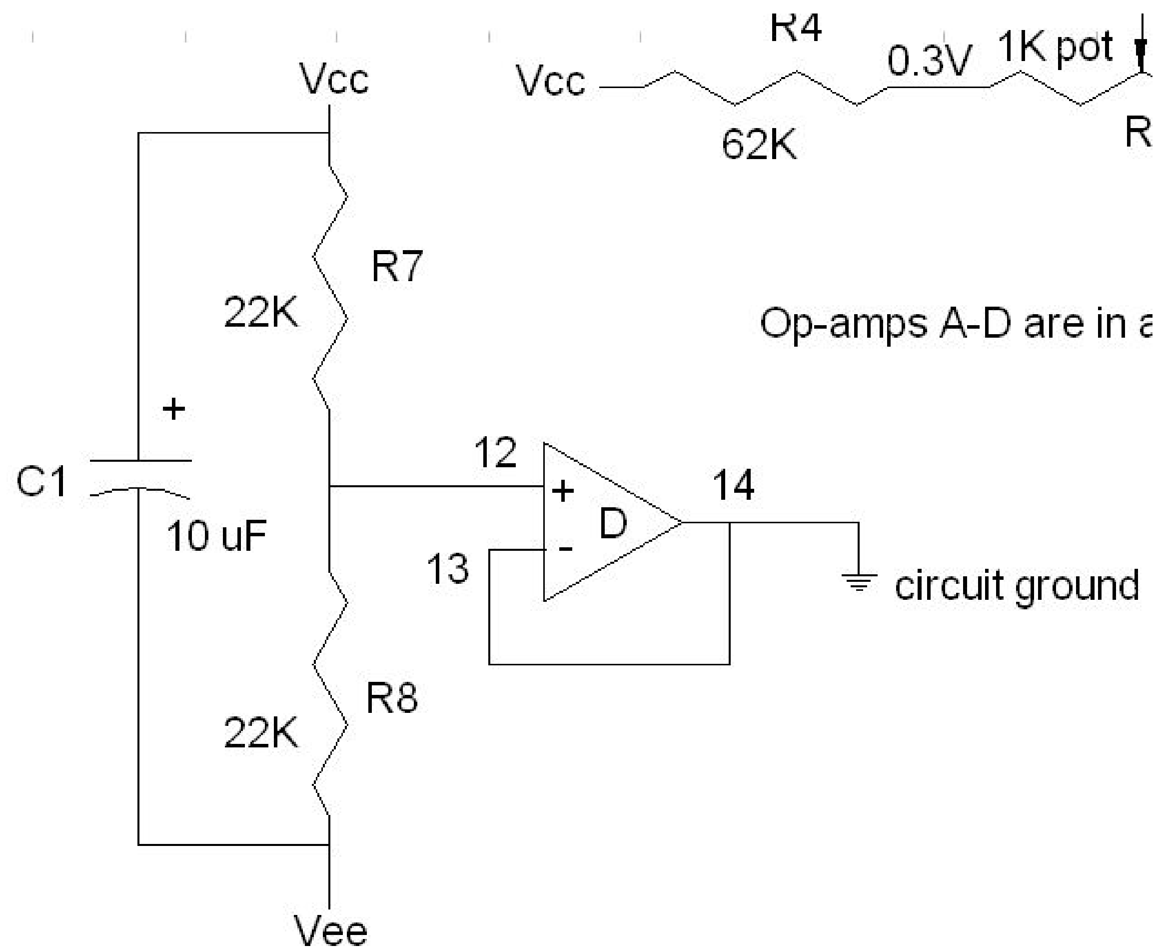
When the comparator's output voltage is at +4V, op-amp C tries to sink current but the diodes in the feedback path (pin C8 to C9) block the current. We end up with C8 falling to about -4V. Essentially no current flows through R3 so the voltage at C9 is at about +4.

Note that when the opto-TRIAC's diode receives current, the LED is on. This is a simple way to indicate when the heaters are on.



The back half of the opto-TRIAC is shown above on the left. It is an MOC3041 and a very cool part. When current is passed through pins 1 and 2 of the input, the opto-TRIAC starts to watch the voltage across pins 4 and 6. Only when the voltage is near zero does it permit current to flow between pins 4 and 6. This current feeds into the large TRIAC's gate which turns it on. This arrangement means that we are only turning on the large TRIAC when the voltage across it is small (i.e. "zero crossing"). Why does this matter? The instantaneous power dissipated in the TRIAC equals the voltage across it times the current through it. When the TRIAC is on, the voltage across it is around 2V so we are only dissipating 2V times the heater current which is around 2.5 amps or 5 watts. If the TRIAC turned on at the worst possible time, the instantaneous power would be around 75 watts[3]. That would not be so good even though the average power would be much less.

Sometimes we have very large voltage spikes on the AC power lines. The Metal Oxide Varistor (MOV) which spans the power TRIAC limits the voltage to a safe value. The excess spike voltage is dumped across the heaters which can take it.



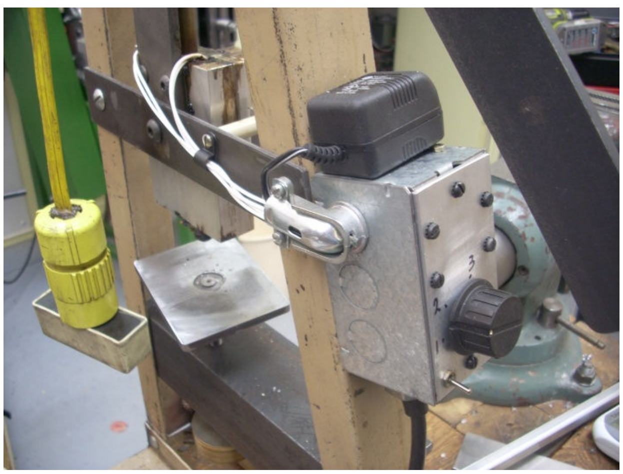
The last bit of circuit is possibly the strangest. A number of points in the temperature controller need a ground reference. In this case, "ground" simply means a voltage half way between Vcc and Vee. R7 and R8 are a voltage divider that defines this voltage. I then use op-amp D to buffer this voltage and generate

[3] This point is when the AC sine wave is at maximum of 120V and would have 60V across the heaters so they would draw about 1.25 amps. The other 60V would be across the TRIAC. 60V times 1.25 amps = 75W.

circuit ground. No matter what Vcc minus Vee is, it will always be "circuit ground". Vcc minus Vee is generated by the "wall wart" powered by 120V AC on the far right side of the full schematic. For ease of assembly, I use a two prong 120V socket.

This particular junk box wall wart puts out 13.34V which means Vcc = 6.67V and Vee = -6.67V with respect to circuit ground. Although the voltage is not regulated, the load is fairly constant so the voltage will not change significantly. Capacitor C1 reduces the low frequency noise that may be present on these supply rails.

Mechanical Considerations



The wall wart is plugged in on top of a standard duplex AC box. Power comes in from the black cord at the bottom. The lower left corner of the front plate is my on/off switch. The fuse is inside. Not visible on the lower right corner of the front plate is the LED. The dial has 1, 2, and 3 marked on it. "1" is about 175°C, "2" is about 208°C or 33°C more than "1". "3" is about 241°C.

On the side of the box is a cable clamp which passes my 4 heater wires and my wall wart's output DC.

Now you can see the LED in the lower right corner of the front plate. The white wire on the right side is from the thermocouple. This wire feeds into the square tube in the background. This tube holds the splice to solid wire that connects to the thermocouple. The thermocouple is held in a spring loaded fixture so it maintains good physical contact to the heater block.

Operational Considerations

I run polypropylene between "1" and "2". When I melt plastic coat hangers, I am closer to "2". If I need more precision, I stick my thermometer into the heating chamber to read the molten plastic. When monitored over a 10 minute interval, I can see that the temperature is held within +/- 2°C of my set point. Good enough for me.

Conclusion

If you enjoy tinkering with electronics and have a decent junk box, this project might be for you. If you just want to get your plastic molder working, then the thermal/mechanical temperature controller is probably a better choice.

Acknowledgement

My good friend Larry Gill is a newbie in electronics. As such, he was the perfect person to review this document for clarity. Thanks Larry!

Your questions and comments are welcome. All of us are smarter than any one of us.

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