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# DUTY-CYCLE SEQUENCE REFLOW CONTROLLER

This reflow controller executes a sequence of mains-power duty-cycle stages for reflow soldering of PC boards with surface mount components. A schematic and an Arduino Nano sketch are included. The duty cycle is defined as the percent ON time during each two-second period. So a 50% duty cycle would be one second fully ON and one second OFF, which would repeat for the duration of the specified stage. A solid state relay is used to switch power ON and OFF only at zero crossing points.

## No Feedback

The controller does not employ any temperature feedback, and no thermocouple is required. It simply executes the selected profile's stages the same way each time. Controllers which employ feedback are prone to errors in user placement of the thermocouple, or inadequate tuning of the PID controller for a particular heating device, either of which can result in temperature overshoots and scorched or fried boards and components. By contrast, the method used here requires initial trial and error to arrive at a profile that works well, with no overshoots, but then uses that exact profile each time, requiring only that it begin at room temperature. Results should be more consistent, with more gentle treatment of boards and parts.

## Not Needed for Hot Plate Reflow

This controller was developed for a simple open-element hot plate reflow device with a circular saw blade on top. That device is described in the "Hotplate" folder of this repo. However, in the end it was found that no controller was needed. The hot plate could simply be turned ON at 100%, then OFF, at two specific times during the reflow process, and that was sufficient to reproduce the manufacturer's standard temperature profile for reflowing leaded solder paste, providing a soak phase and a reflow phase with no overshoots. The curve produced was essentially the same as the more granular version with oddball duty cycles for which this controller was created. But since the work had been done to implement duty-cycle sequences, that work is documenmted here in case it might be useful for other projects. In addition, some may prefer to use the controller with the hotplate setup so they don't have to monitor a stopwatch on each session.

If the controller is used with other heating devices, a new profile will have to be developed, but something similar to the sequences defined in the sketch may be a good place to start.

## Controller Operations

A "profile" is defined in the Arduino sketch as a sequence of stages consisting of the number of seconds in the stage and the duty cycle to be in effect during that period. The sketch provides for multiple profiles, including the default profile for leaded solder paste plus any others the user may wish to define. Each such profile has a two-character "name" and a number beginning with #1. The default profile is the granular hot plate version. It is #1 and is named "Pb". A prospective lead-free profile is #2 and is named "LF", but stages for that profile are defined only as place holders since no lead-free profile was developed. Finally, the simplified two-stage profile for the hot plate described above is included as profile #3, named "P2". Pb and P2 produce essentially the same result.

The controller powers up in Manual Mode with the duty cycle at zero. In that Mode, the currently-selected profile name is displayed on the two-digit 7-segment display, and the green LED will blink out that profile's number. A **short** press on the rotary encoder's momentary switch will cycle through the defined profiles to select the profile to be used. Then a **long** press on the momentary switch puts the controller into Auto Mode, which begins executing the selected profile. The green LED will go solid ON at that point.

While still in Manual Mode, turning the encoder knob will set the duty cycle to any desired level. That level is displayed on the 7-segment display, and the red LED also lights up during that portion of each two-second interval during which the power is ON, which will give a rough approximation of the current duty cycle. The encoder knob can also be used during Auto Mode to modify the duty cycle of the current profile stage, and the modified setting will remain in effect for the remainder of that stage, so there will be no change in the duration of that stage or the overall sequence.

A long press on the momentary switch while in Auto Mode will temporarily suspend the profile sequence and put the contoller back into Manual Mode, with the current duty cycle remaining in effect. Another long press will put the controller back into Auto Mode, and it will pick up where it left off. These actions will have the effect of extending the total time of the sequence.

A buzzer sounds, and the green LED goes out, when board temperature is expected to have reached a maximum, which is approximately 100 seconds after the power was last turned OFF. If reflow has not completed by then, it is very unlikely that it will complete, and the board should be removed.

The process can be terminated at any time, and AC power turned off, by pressing the Arduino's reset button.

## Simplified Circuit

Since the green LED indicates which profile is selected, and which Mode the controller is in, and since the red LED indicates the current duty cycle, it is not strictly necessary to implement either the 7-segment display, the rotary encoder or the buzzer. However, a momentary switch of some kind is needed to select a profile and to switch into Auto Mode. So the minimum controller configuration would be a breadboard or PC board, a Nano with a power source, a momentary pushbutton switch, two LEDs with their resistors, a solid state relay, and the AC mains connection setup.

## The Solid State Relay and Mains Power

The Crydom relay shown on the schematic works well for switching the 1000W hot plate used in testing - about 10 amps of U.S. 120VAC current. But this SSR is quite expensive. Some prefer to buy far less expensive SSRs on Ebay, typically SSRs bearing the "FOTEK" name. Be aware that the great majority of these SSRs are not genuine FOTEK products, but rather knockoffs of unknown origin. Various tests of these SSRs on Youtube and elsewhere show that their claimed current ratings are not valid. If one of these SSRs is used, get one rated at 40 amps or more to improve the odds that the actual current capability will be at least 10 amps. If the SSR gets materially warm, a heatsink may need to be added. The Crydom did not get warm.

No matter which SSR is used, remember that you will be switching AC mains power, and care must be taken to physically enclose and isolate all AC connections properly so that there is no risk of human contact. An outlet box powered by a three-prong power cord, and containing both the SSR and a standard power receptacle and cover plate might a good choice. Then the hot plate or toaster oven can be plugged into that receptacle. Also, the reflow process must never be allowed to run unattended. SSR triacs may fail short, which could lead to a fire if such failure is not detected. Just remember you are dealing with mains power, and proper safety practices must be implemented.

Other than the three standoff screws, no modifications were made to the hot plate, and it is expected that no modifications would be needed to a toaster oven used for this purpose. But each would need to be set to "Always On" or to maximum temperature so power will be controlled by the SSR.

## Software

The sketch was compiled and flashed to a generic Nano (old bootloader) using the Arduino IDE for Windows, v1.8.8. Various power saving measures were implemented to permit powering by a 9V battery as well as USB. Current draw through the barrel connector is roughly 5ma in Manual Mode (0% power), 10ma in Auto Mode (100% power), and briefly up to 25ma when the buzzer sounds.

The user may need to modify the sketch as follows:

1. Pin assignments must be changed if pins used differ from those shown in the schematic.

2. The user may modify the stages of the default profile, or define additional profiles. That may require changes to the following variables:

   a. **Profiles** - the total number of defined profiles
   b. **ProfileDisplay** - the array defining a two-character "name" for each profile
   c. **AutoSteps** - the array defining the sequence stages for each profile

3. **SEGON, SEGOFF, CACCON** and **CACCOFF** definitions need to be changed to the alternate commented-out versions if **common anode** 7-segment displays are used.

4. **ENCODERTYPE** should be changed to "1" if the rotary encoder selected has half the number of pulses per revolution as detents per revolution. The default type is "0",which has the same number of pulses and detents per revolution.

## **Developing Profile Stages**

To develop the stages specified in the sketch, some form of temperature readout is helpful. For this project a TM-902C device was used. It is a K-type thermocouple with LCD readout, widely available on Ebay for around $5 plus a 9V battery. But while this device seemed accurate at 100°C (boiling water), measurements at higher temperatures seemed invalid. For example, it indicated that 63/37 leaded solder paste melted at 165°C. So while it was useful to show the general progression of temperatures - the slope of the temperature curve, topping out points, etc. - the absolute values were not dependable. Some multimeters have thermocouple inputs, and they should provide better results.

But there are two known values that may be useful in creating profile stages, and those are the melting points of 63/37 solder (183°C) and 60/40 solder (188°C). The idea is to generally follow the manufacturer's profile curve, including a "soak" stage during which solder DOES NOT melt, followed by a "reflow" stage just above that during which solder DOES melt, but which doesn't get much hotter than that melting point. A successful reflow should melt all the solder, but not scorch any parts or the board, including the bottom of the board. Developing the stages is a trial and error process. Just remember than there will be significant lag in the response of the system to the application of power. The board may continue to heat up for quite a while after power has been turned off - probably moreso with hot plates than with toaster ovens with quartz heating elements.

DIY reflow devices will generally heat up somewhat more slowly than the target curve, but this should still work if significant overshoot is avoided. Cool-down is also too slow, but that can be addressed by removing the saw blade and/or the board from the hot plate, or simply opening the door of the toaster oven. This should be done very carefully because the solder will still be molten.