Automation of a 3-Phase AC Motor and Assembly Line Using Allen-Bradley MicroLogix 1000 Programmable Logic Controllers (PLCs)

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Abstract

The automation of factory machines is commonly done using programmable logic controllers (PLCs). Hands-on PLC training stations are helpful to train students how to use and program PLCs. Two different PLC training setups have been designed, one automating a 3-phase AC motor-generator set and the other automating a portion of an assembly line. Both of these machines are automated using Allen-Bradley MicroLogix 1000 PLCs which have been programmed with ladder logic control programs.

1. Introduction

Programmable logic controllers (PLCs) are widely used in industry for the industrial automation of factory machines. To give students hands-on experience wiring and programming PLCs, laboratory setups involving a 3-phase motor and an assembly line machine are designed. Once these lab setups are built and tested PLC training labs will be developed so these setups can be integrated into the laboratory curriculum at SDSM&T. For the automation of these machines Allen-Bradley 1761-L20AWA-5A MicroLogix 1000 Analog PLCs will be used. The 3-phase motor-generator set is being used as a test instrument that is relatively easy to understand and work with. This electric machine consists of a 3-phase AC motor that drives a DC generator. The PLC will be used to turn on and off the relay contactor which provides the AC power for the motor. This test instrument will serve as a training and experimentation platform for learning how to wire and program a PLC and to gain understanding about how each of its various types of inputs and outputs work. The assembly line machine is an IC board component lead cutter that was used in an assembly line in industry. The implementation of PLC control on this machine makes for a perfect PLC training station as it demonstrates how a PLC can be used on an actual machine from industry.

The Allen-Bradley 1761-L20AWA-5A MicroLogix 1000 Analog PLCs have 12 discrete AC inputs and 8 AC/DC outputs. The inputs will be used to read the position of a switch and the outputs are used as relays which are programmatically energized and de-energized. They also have two analog voltage inputs, two analog current inputs and one analog output that can be configured as an analog voltage or current output. The goal in the control programs and wiring is to make use of as many of the different types of inputs and outputs as possible. This is to demonstrate the many capabilities of this PLC and to give students practice using all them.

2. Broader Impact

The broader impact of this project is to have effective laboratory setups for the hands on teaching of PLCs. Both the 3-phase motor and assembly line machine will be used as PLC training instruments used in multiple classes at SDSM&T. The assembly line machine rewired for PLC control provides for an effective training instrument to train students how to properly wire and program a PLC while at the same time using an actual machine from industry. This will better prepare students who want to work in the industrial automation field.

3. Procedure

Materials

The main materials used for this project are Allen-Bradley 1761-L20AWA-5A MicroLogix 1000 PLCs, a 3-phase AC motor-generator set and an assembly line machine. The

Allen-Bradley 1761-L20AWA-5A MicroLogix 1000 PLC (shown in image 1) has 12 discrete AC inputs, two analog voltage inputs and two analog current inputs. It also has 8 relay outputs and one analog output that can be configured to be an analog current or analog voltage output. The 3-phase AC motor-generator set (shown in image 2) is a 3-phase motor that is connected to a DC generator so when the AC motor is powered with 3-phase power the DC generator will output a steady DC voltage. The Assembly line machine (shown in image 3) is a IC board component lead cutter that was used in industry on a circuit board production assembly line and was donated to SDSM&T by Littelfuse.

Image 1: Allen-Bradley MicroLogix 1000


Image 2: 3-phase motor-generator set


Image 3: Assembly line machine

Software/Equipment

The following free software downloads from Rockwell Automation software were made to program the PLCs: RS Logix Micro English and RS Linx Classic Lite. The RS Logix Micro English program is the ladder logic programming environment where the ladder logic programs are written and run. The RS Linx Classic Lite program is used to interface between the PLC and your PC enabling the RS Logix Micro English program to download a program onto the PLC. It is important to note that these programs were lite versions which limited the functionality of the programs, but there was enough functionality for the control programs that were written.

OrCAD Capture CIS Version 9.2 Lite circuit design software was a free software download that was used to draw up circuit schematics for the PLC control of the 3-phase motor and assembly line.

Procedures

Automation of 3-Phase AC Motor-generator Set

1. Learn ladder logic programming language
2. Learn about 3-phase power, the 3-phase motor-generator set and the breaker closet
3. Design wiring schematic for implementation of PLC control of motor
4. Wire up 3-phase motor, relay contactor circuit and PLC
5. Write ladder logic control code for the 3-phase motor
6. Turn documentation of 3-phase motor into a lab for future students

Automation of Assembly Line Machine

1. Develop an electrical schematic for original wiring of assembly line
2. Identify and determine the ratings of all electrical components on the assembly line
3. Determine what new/additional parts need to be purchased
4. Develop a new electrical schematic for PLC control of assembly line
5. Build mounting fixtures and mount switches, relays, transformer, buzzer, wire terminal blocks, and PLC on user interface board
6. Wire up electrical components and motors on assembly line
7. Write ladder logic control programs for assembly line
8. Turn documentation for assembly line into 2 different labs for future students

4. Results

3-Phase Motor

For the 3-phase motor an electrical schematic was developed (see Appendix A) that made use of logic switches that were read into the PLC as analog voltage inputs, one relay output which drove the relay contactor for the 3-phase power and an analog voltage output which was measured by a DMM. An effective ladder logic control program was written that uses all of these inputs and outputs.

The control program Motor On/Off 30s Option (see Appendix C) consists of a main program and a subroutine program. The main program reads in the two logic switches, the first logic switch IA/0 acts as a master on/off switch for the motor. The motor will only turn on when this switch is logic high. The second logic switch IA/1 determines whether or not the 30s Pulse Subroutine runs or not. The 30s Pulse Subroutine is only active when both logic switches are logic high. The One-Shot-Rising (OSR) functions were used to ensure that the analog output voltage is zero volts whenever the 30s Pulse Subroutine is not active and to reset the timers so that when the 30s Pulse Subroutine is activated there is a full 30s pulse on the first iteration. The 30s Pulse Subroutine consists of two timers that turn the motor on for 30s and off for 30s in an endless loop while the subroutine is active. It also writes a voltage to the analog output that increases from 0-10V proportionately as the time of the 30s pulses increase from 0-30s. This analog output acts as a progress bar indicator.

Assembly Line

An electrical schematic for the original wiring of the assembly line machine was created to better understand the operation of the assembly line (see Appendix A). This schematic is complete with color code and wire connectors. Once the all of the electrical components of the assembly line were taken apart, mounts were made for all of the switches, relays and other electrical hardware using scrape copper circuit board material and epoxy. This was done so that they could all be placed on a user interface in such a way that students can clearly see all of the electrical hardware and wiring. Images of all of the mounts that were made and the completed user interface can be found in Appendix B. A new electrical schematic has been created that implements the PLC (see Appendix A). The assembly line control interface (see Appendix B) consists of two circuit breakers, all of the original control switches, 1 120VAC to 28VAC transformer, a 12VDC voltage regulator circuit, 2 24VAC coil relays, 2 12VDC coil relays, a buzzer, 5 fuses, a PLC and two wire connectors, one for the emergency stop switches on the

assembly line and one for the motors. The first breaker is the master on/off switch for the PLC and is rated for a max of 5A. The second breaker is the master on/off for the power to everything else on the user interface and is rated for a max of 30A. There is also a fuse before each breaker as an additional safety precaution. Before breaker 1 there is a 1A fuse for the power to the PLC. Before the second breaker there is a 20A fuse. The start/stop push buttons, emergency stop push buttons and the two 3-position switches are powered with 120VAC and are read as discrete inputs into the PLC. All of the motors are driven using external relays. This is because they all pulled to much current for the relay contacts of this particular PLC to handle. Two different types of relays were used, two 24VAC coil relays and two 12VDC relay coils. This was done because the two 24VAC relay coils were originally on the assembly line and the only relays we were able to purchase had DC relay coils. This also demonstrates how the PLC can be wired up to drive relays or other motors that are powered with various AC and DC power sources. In order to power the two different types of relay coils the 120VAC to 28VAC transformer was used to step down the 120VAC to 28VAC for the 24VAC relay coils and so that the AC voltage to the 12VDC voltage regulator circuit is under the 30VAC maximum voltage. The 12VDC voltage regulator circuit (Shown in image 4 and 5) consists of a half wave rectifier with 100uF and 47uF capacitors making a DC input. Then a uA7812C 12VDC voltage regulator chip is used to step down the voltage to 12VDC. The output has 47uF and 1uF capacitors to keep a steady 12VDC output. The stable 12VDC power source then is used to drive the 12VDC relay coils. To connect the user interface to the assembly line two cables were made with wire connectors. This allows the user interface to be disconnected from the assembly line for ease of transport and so that programs can be tested with the PLC and relays without turning on and off all of the motors on the assembly line. There is a fuse on each motor, since they pull the most current, as added protection if there is a short in the circuit. The buzzer is wired up to the analog output which varies the intensity of a high pitch beep with the DC voltage sent to it.

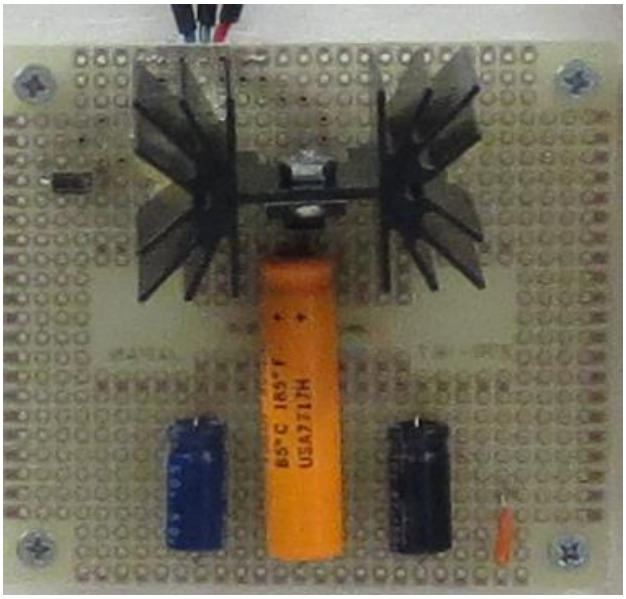


Image 4: Perfboard of 12VDC voltage regulator circuit.

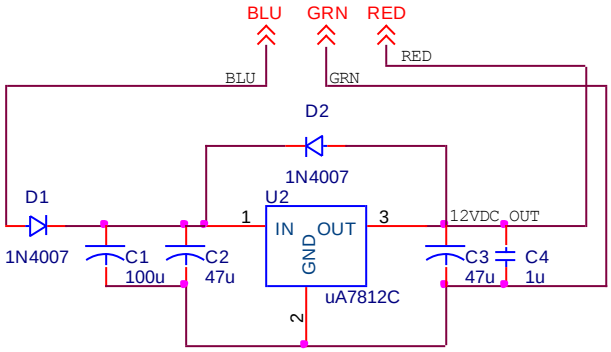


Image 5: Circuit schematic of 12VDC voltage regulator circuit.

A ladder logic control program was written for the assembly line so that it would function in a similar way to how the assembly line was originally wired, except the buzzer was used as a

warning alarm to indicate that the lid is open instead of being used as an electronic zero buzzer for the cutters. The control program, Assembly Line Control 1 (Appendix C), reads in all of the switch positions. The start push button is read in as a software latching relay, this will only allow motors to turn on after the start button is pressed. The stop button, two emergency stop panel switches and lid switch all unlatch the software latching relay turning off the motors. Since the stop buttons are placed on a lower rung then the start button they override the position of the start button. The spindle motor and post brush motor are set to turn on when the switch 8 is in the run position (up position). When switch 8 is in the setup position (down position) just the spindle motor is on. The conveyer motor is on whenever switch 9, the forward/reverse switch, is not in the neutral position. Going forward only when the switch is in the up position and going in reverse only when the switch is in the downward position. The buzzer is set to sound whenever the lid is open and the system is running, meaning the software latching relay is still latched.

5. Discussion

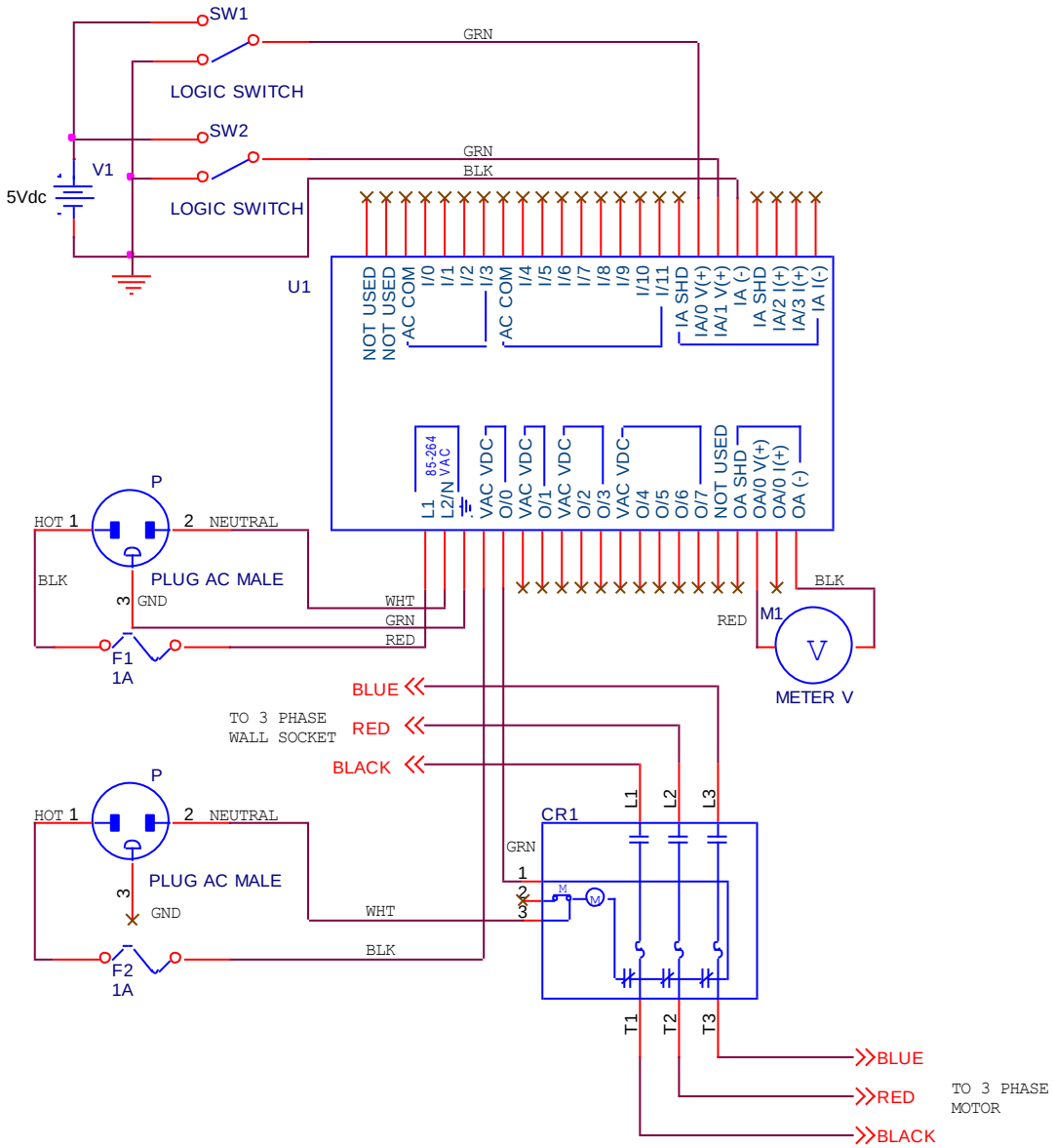
Successful automated control of the 3-phase motor-generator set with the PLC consists of a program that can turn the motor on and off with a logic switch and a second logic switch which activates a subroutine to pulse the motor on/off in 30s increments. This mini demo makes use of the analog voltage inputs, the relay outputs and the analog output. Successful automated control of the assembly line has also been accomplished with a PLC control program that simulates how it could actually be used on an assembly line in industry. The assembly line machine makes use of the discrete AC inputs, the relay outputs and the analog output. This means between the two machines all of the different types of inputs and outputs of the PLC will be used except for the analog current inputs and output.

6. Conclusion

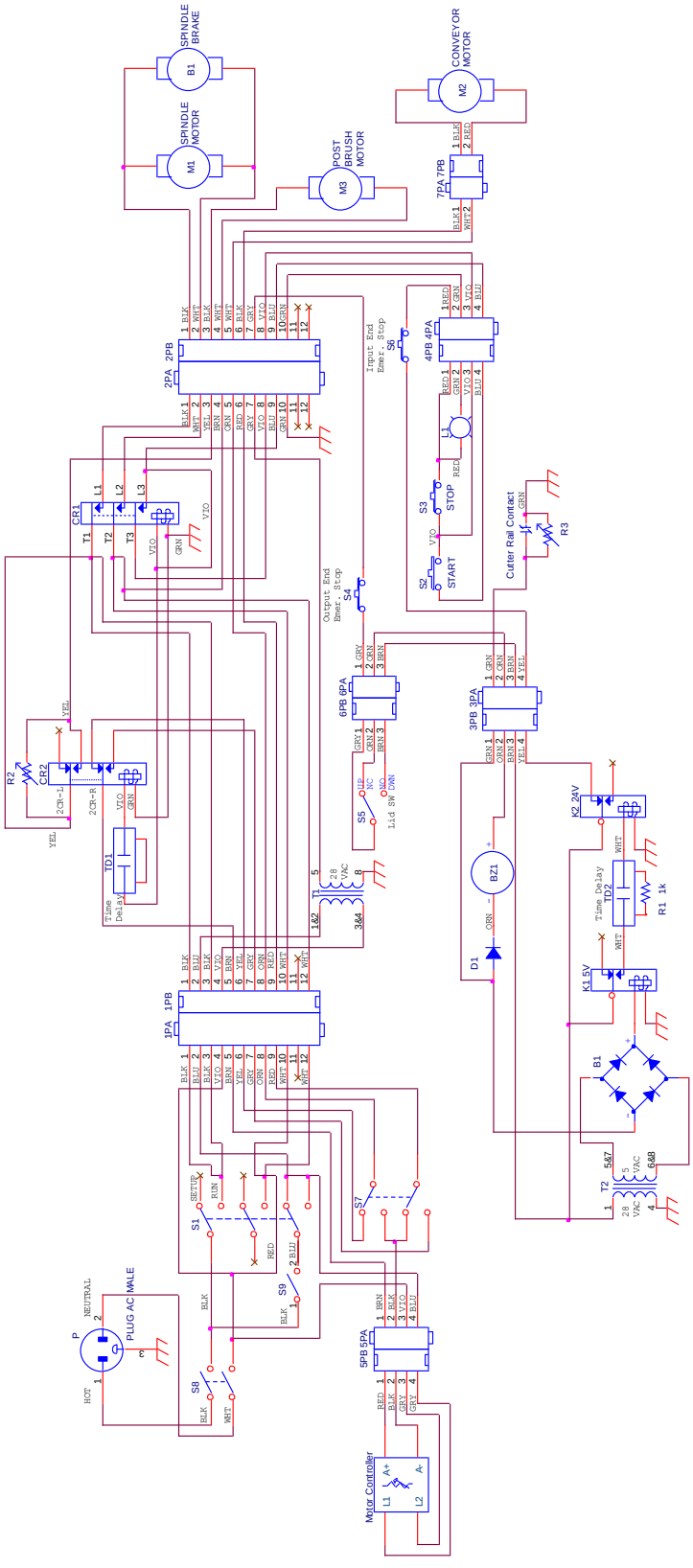
The construction and testing of the 3-phase motor-generator set and assembly line is complete and ready for implementation in the fall. The PLC wiring schematics were chosen to give students experience programming with each type of I/O on this PLC. The wiring schematic for the assembly line includes multiple types of power sources to give students experience working with the various types while wiring and programming the PLC. In the future control labs will be written for both machines to train students how to program in ladder logic and to give them hands on experience with wiring and programming PLCs. For the assembly line, the implementation of the speed controller through the analog inputs and outputs will be designed.

Appendix A

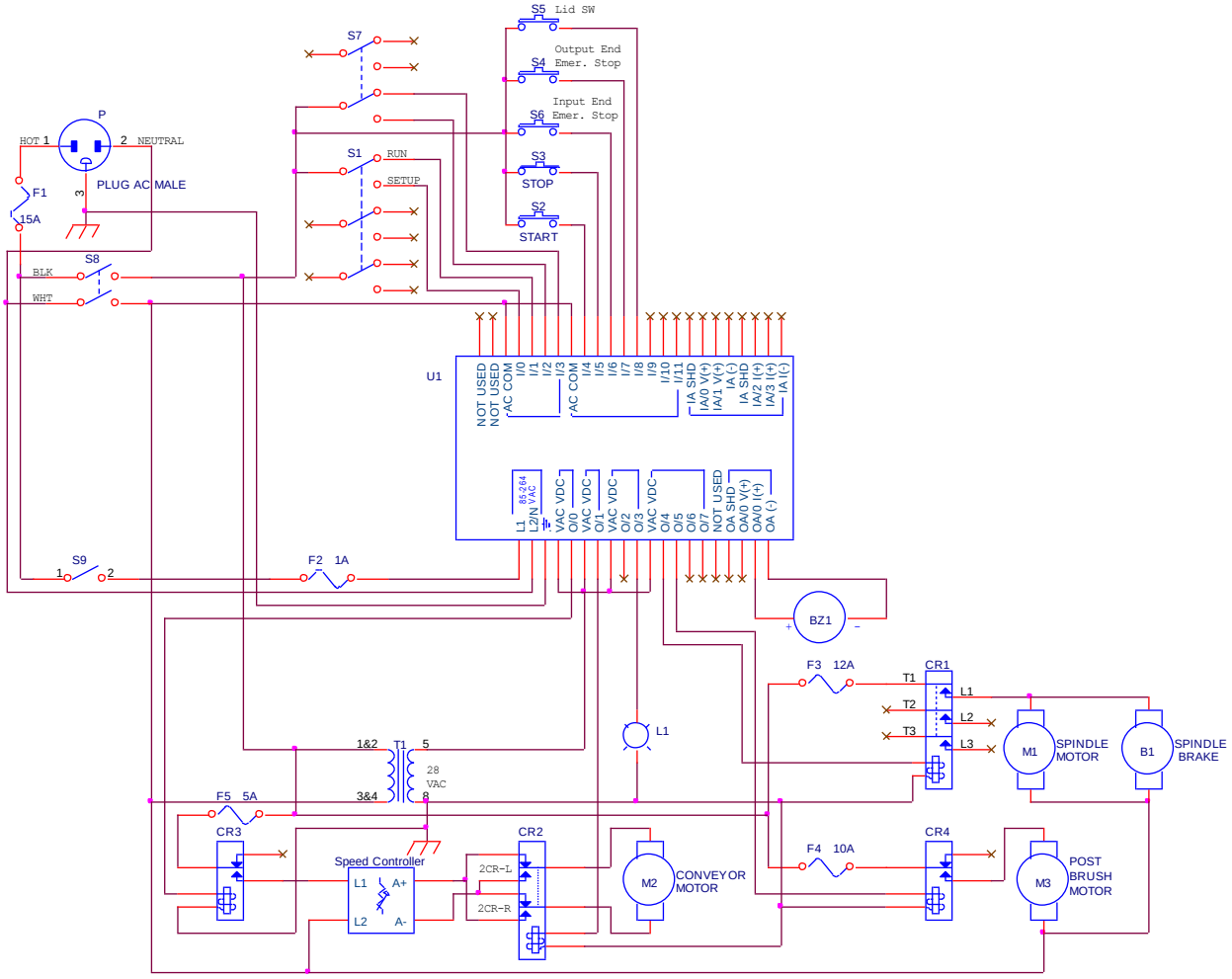
This section is reserved for electrical schematics for the 3-phase motor and assembly line.



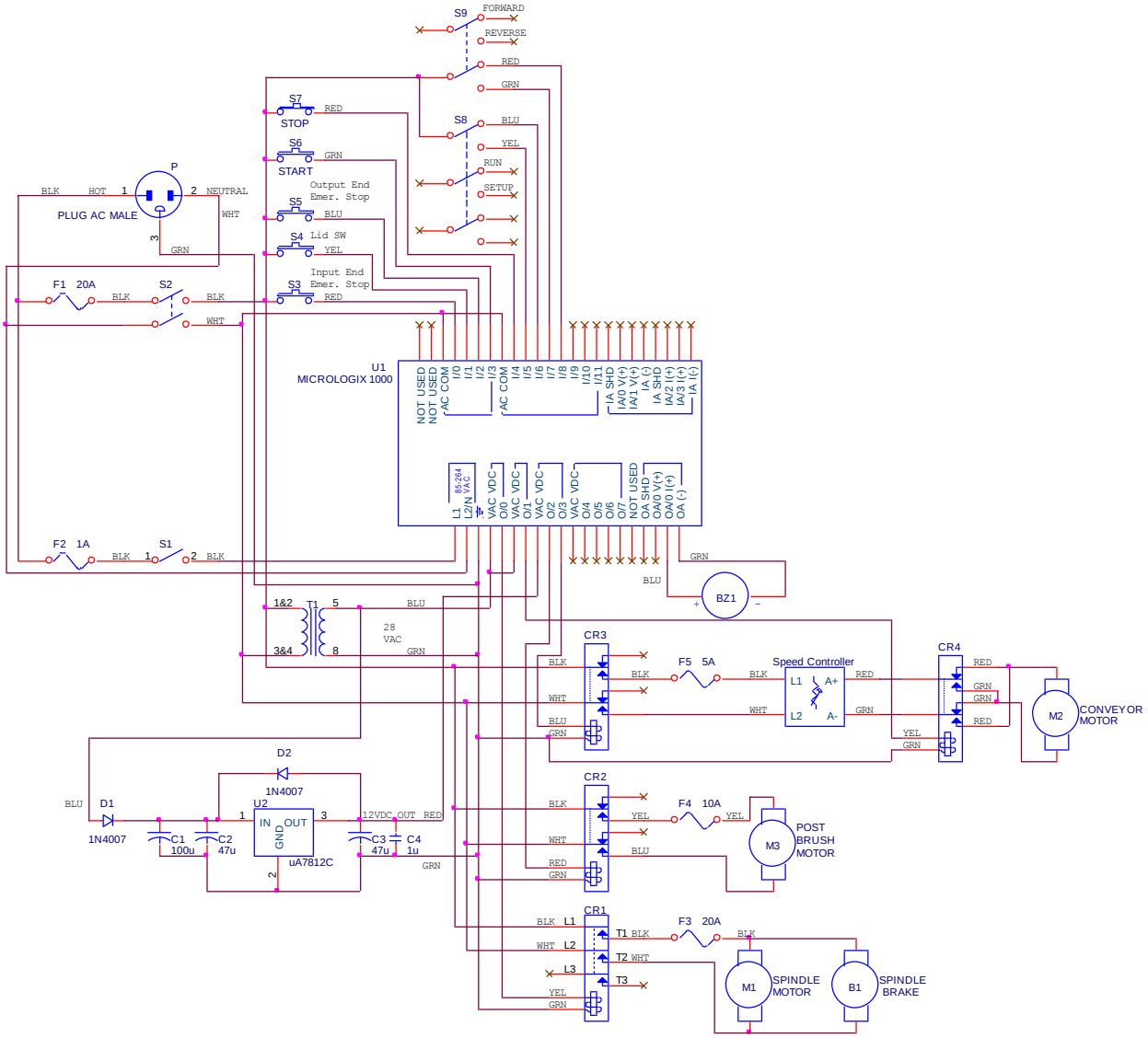
Electrical schematic for PLC control of 3-phase motor-generator set



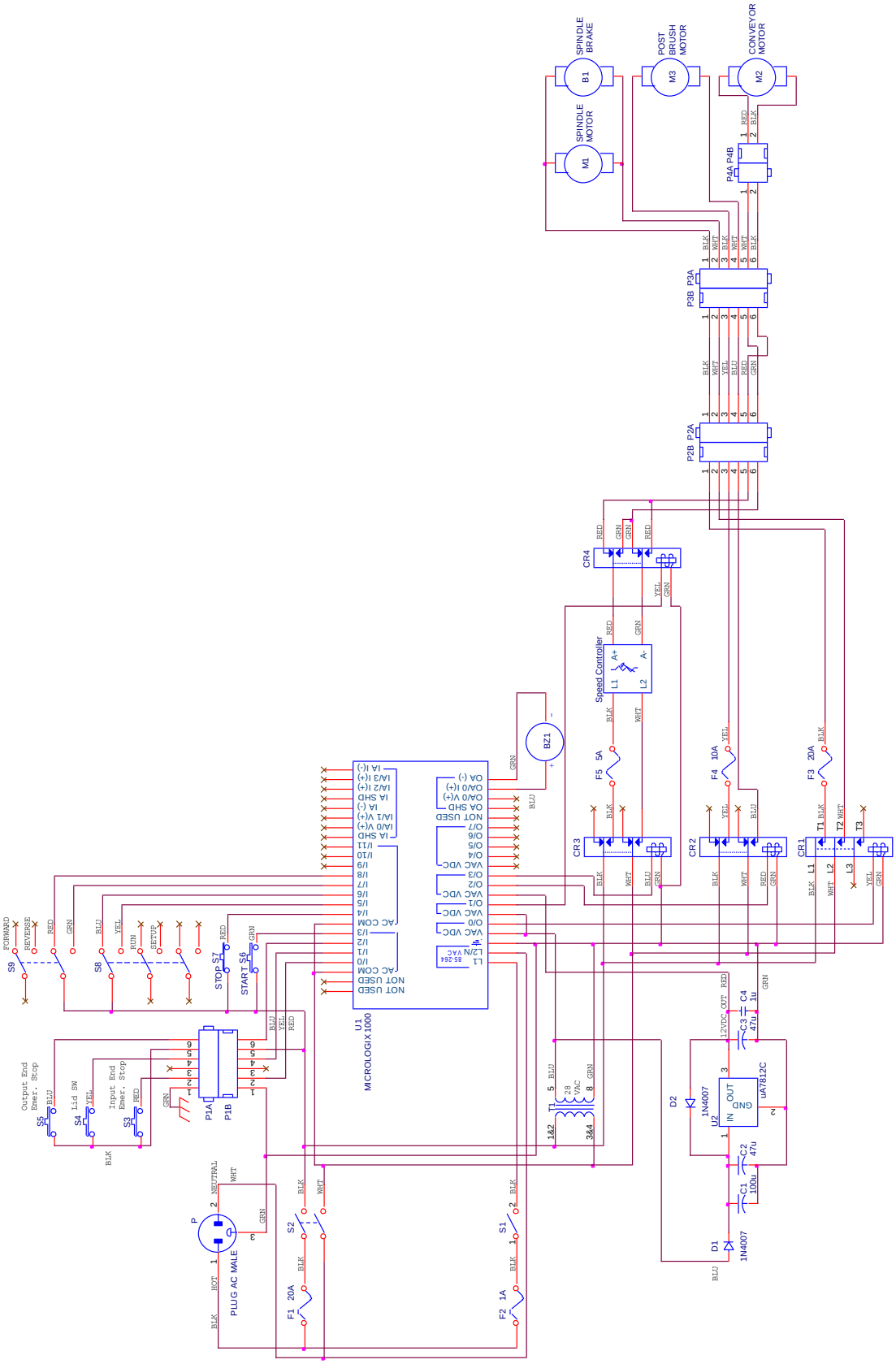
Electrical schematic for original wiring of assembly line machine



First design of the electrical schematic for PLC automation of the assembly line



Final electrical schematic for the PLC control of the assembly line



Final electrical schematic for the PLC control of the assembly line with wire connectors

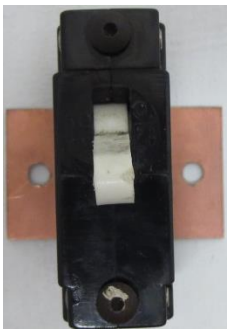
Appendix B

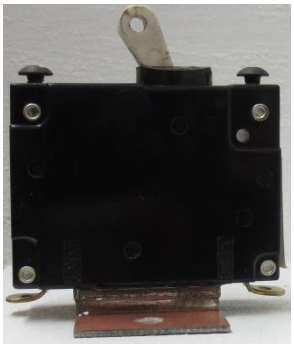
This section is reserved for images of constructed electrical component mounts, user interfaces and laboratory setups.

Image of setup for PLC control of 3-phase motor.

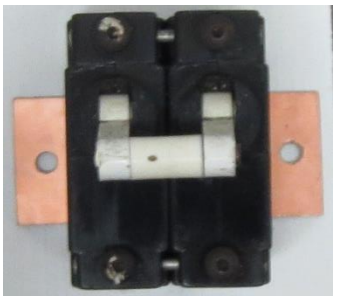
Electrical Component Mounts for Assembly Line

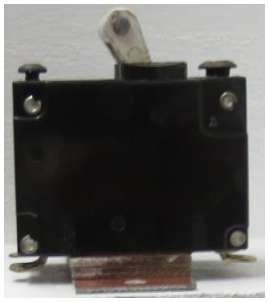
Breaker 1:



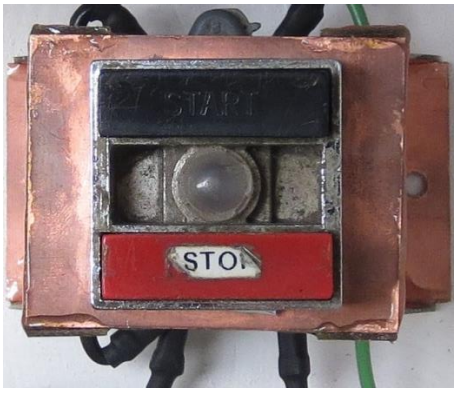


Breaker 2:



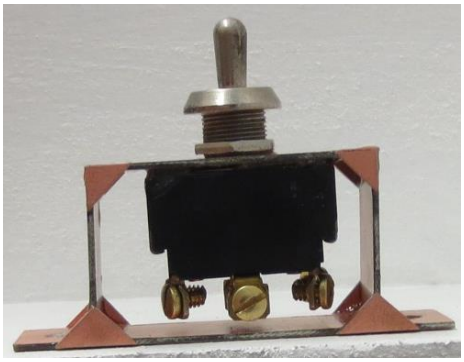
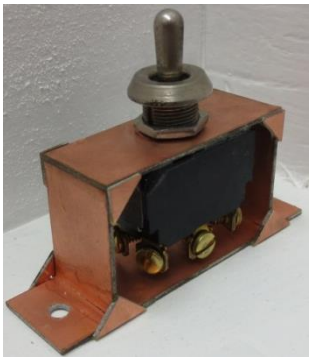


Start/Stop Buttons:

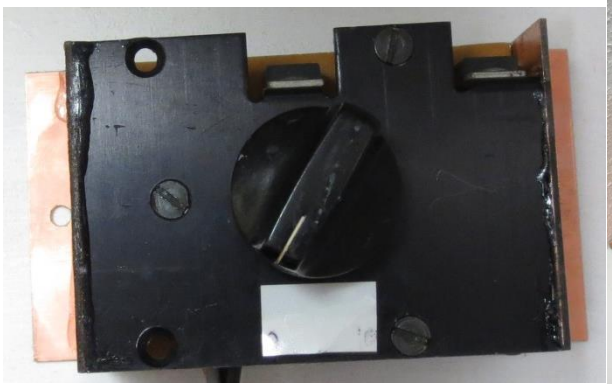
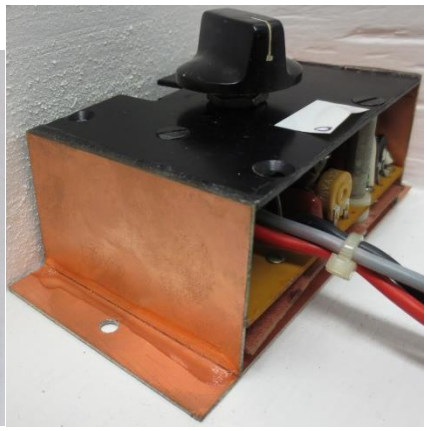


Run/Setup Button:

Forward/Reverse Button:

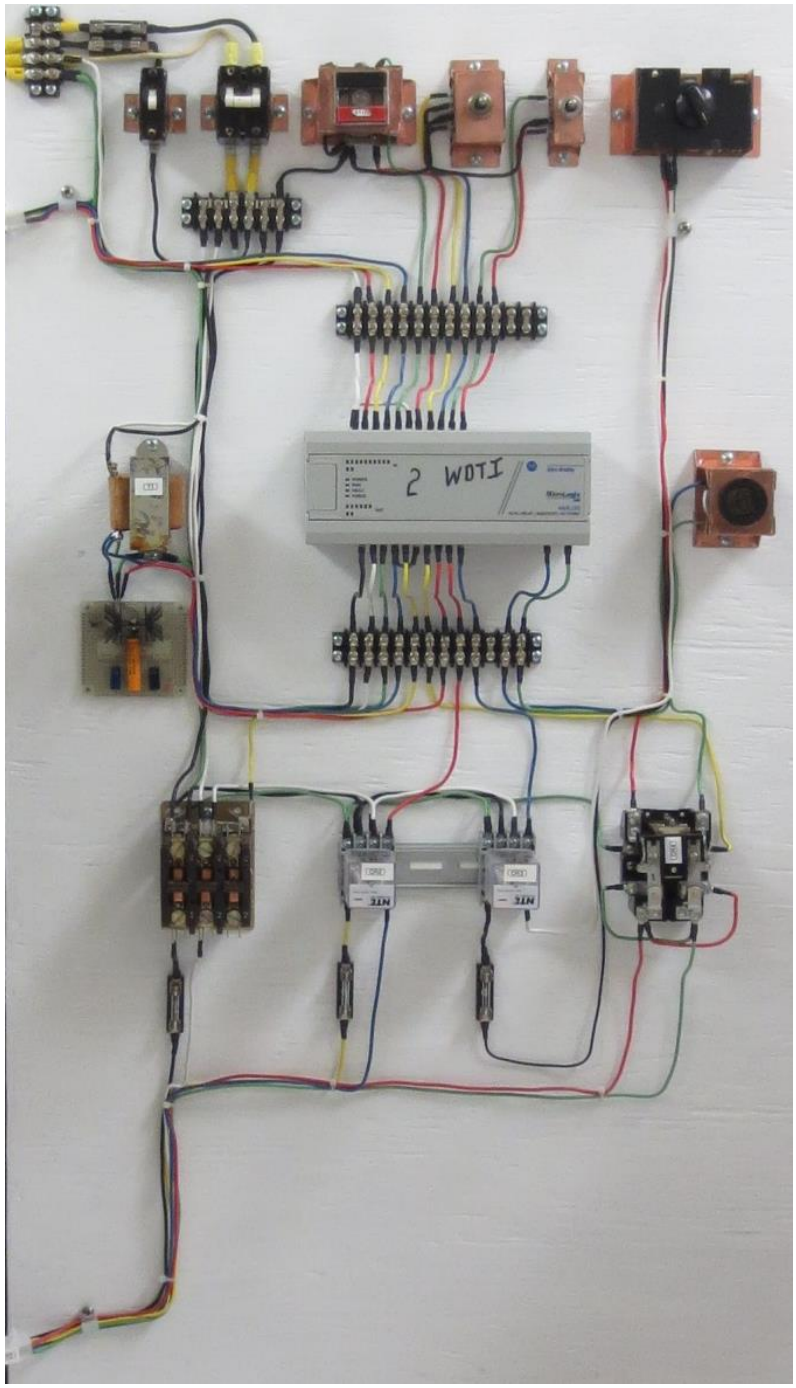
Speed Controller:

Buzzer:



Assembly Line Control Interface

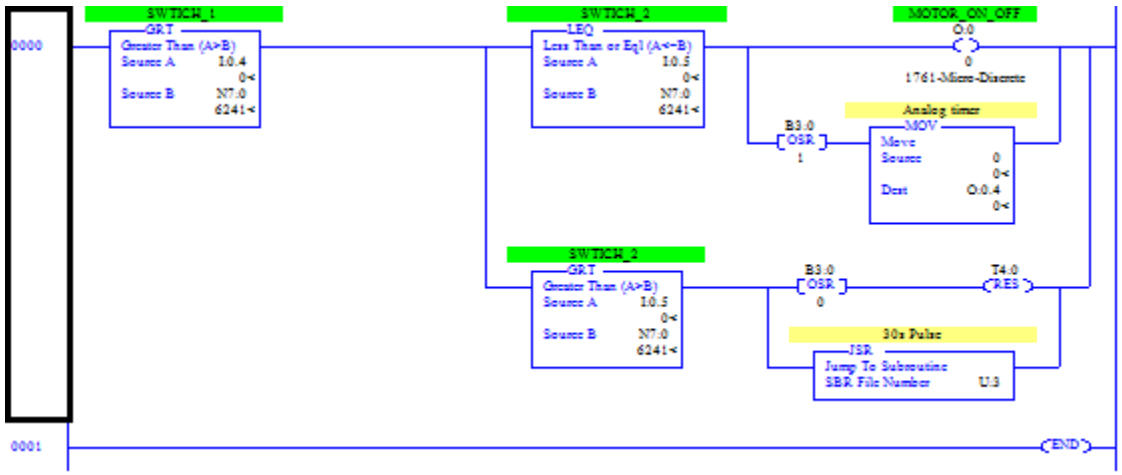


Assembly Line Machine

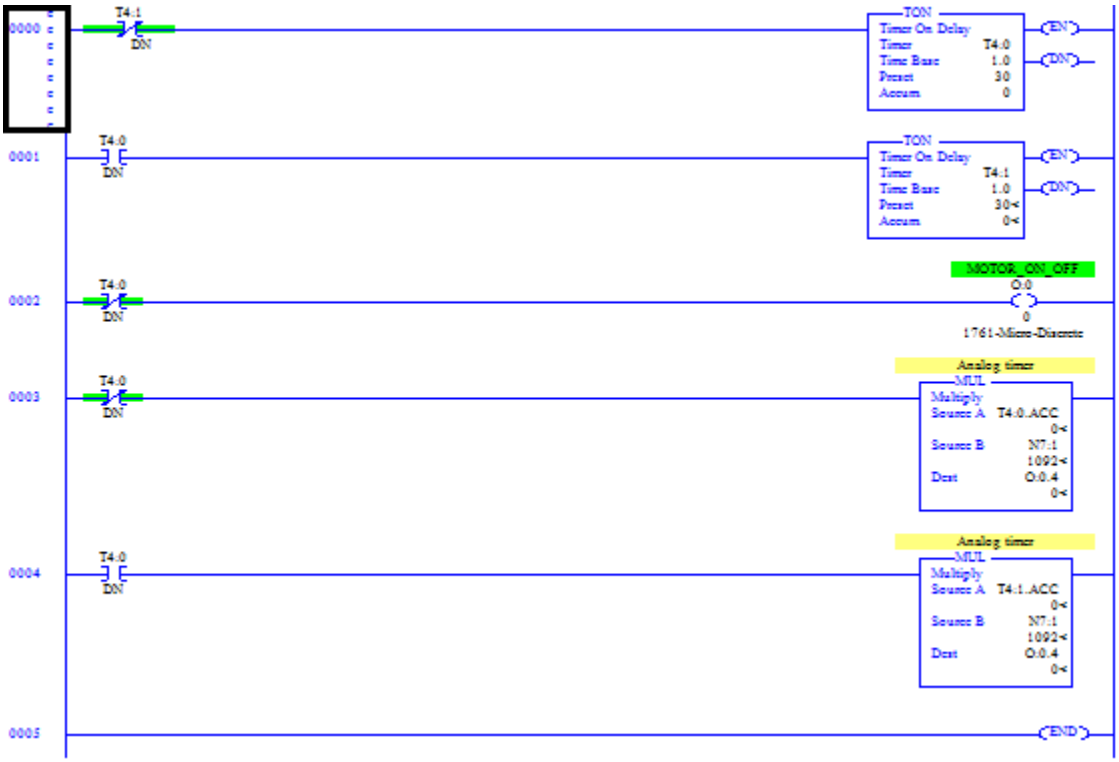
Appendix C

This section is reserved for images of ladder logic code and code descriptions.

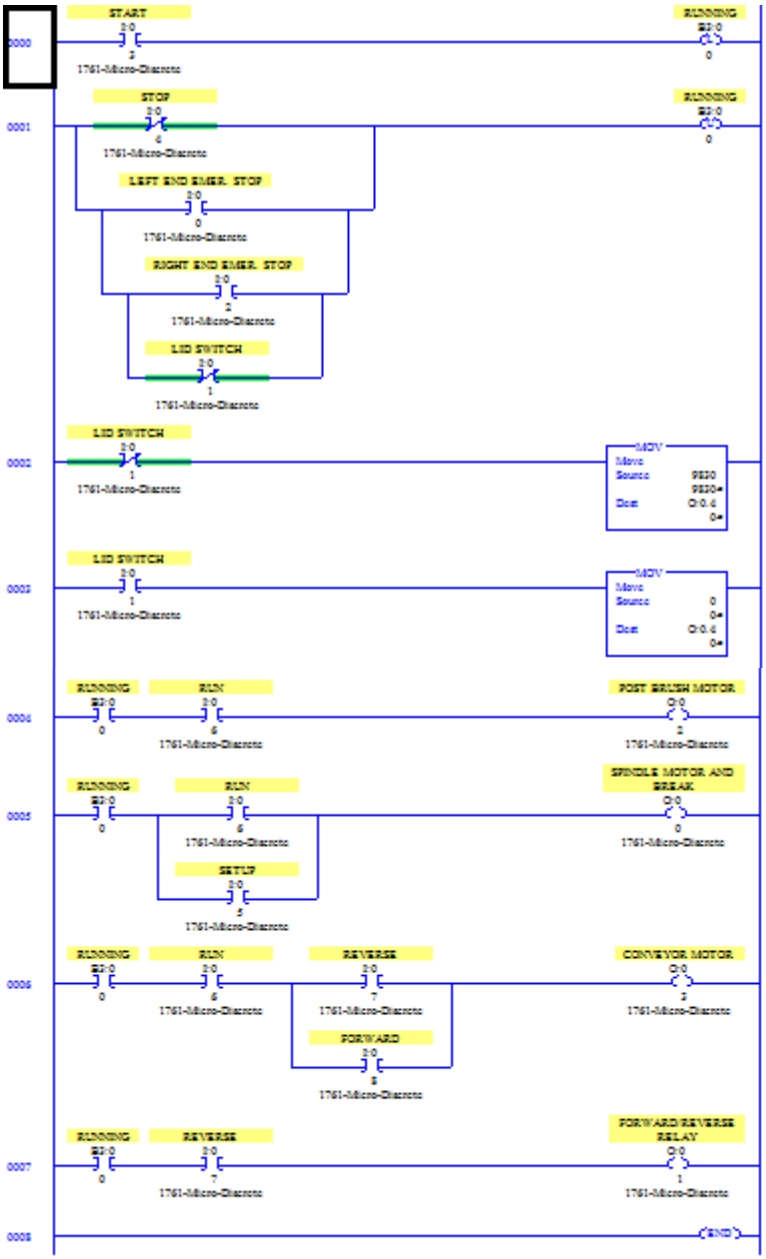
Motor On/Off 30s Option Program



Main program: Reads logic switches to turn on/off motor or to execute the 30s Pulse Sub-Routine.



30s Pulse Sub-Routine: Sends 30s on/off pulses to 3-phase motor and increases the analog output from 0-10V as time of the pulse increases from 0-30s.



Assembly Line Code: written to simulate how the assembly line could be controlled with the PLC if it were used in an actual assembly line.

References

1. Allen-Bradley. (1998). *User Manual: MicroLogix 1000 Programmable Controllers.* Retrieved from http://etidweb.tamu.edu/hsieh/ENTC410/Manual/MicroLogix1000-1761-um003_-en-p.pdf
2. Petruzella, F. D. (2011). *Programmable Logic Controllers* (4th ed.). New York, NY: McGraw-Hill.
3. Ron Beaufort Training. (2009, March 24). *1 - Problem: Mistakes & Misconceptions (AB PLC Training)* [Video file]. Retrieved from https://www.youtube.com/watch?v=T3tnXu-Eywc
4. Ron Beaufort Training. (2009, March 24). *2 - Basic Inputs and Outputs (AB PLC Training)* [Video file]. Retrieved from https://www.youtube.com/watch?v=jhLIOM1gfgk
5. Ron Beaufort Training. (2009, March 24). *3 - Introducing the PLC Processor (AB PLC Training)* [Video file]. Retrieved from https://www.youtube.com/watch?v=xywXrN6AJGs
6. Ron Beaufort Training. (2009, March 24). *4 - Fundamentals of the Scan Sequence (AB PLC Training)* [Video file]. Retrieved from https://www.youtube.com/watch?v=8qqv2M_3DeI
7. Ron Beaufort Training. (2009, March 24). *5 - Understanding Bits and Instructions (AB PLC Training)* [Video file]. Retrieved from https://www.youtube.com/watch?v=iO9UzFafUpE
8. Ron Beaufort Training. (2009, March 24). *6 - Basic Instruction XIC (AB PLC Training)* [Video file]. Retrieved from https://www.youtube.com/watch?v=HniwADNPX5A
9. Ron Beaufort Training. (2009, March 24). *7 - Basic Instruction OTE (AB PLC Training)* [Video file]. Retrieved from https://www.youtube.com/watch?v=q4JSrEVOgok
10. Ron Beaufort Training. (2009, March 24). *8 - Basic Instruction XIO (AB PLC Training)* [Video file]. Retrieved from https://www.youtube.com/watch?v=7Sf6qNRuluc
11. Ron Beaufort Training. (2009, March 24). *9 - Solution: Step-by-Step Analysis (AB PLC Training)* [Video file]. Retrieved from https://www.youtube.com/watch?v=B9HYUbyTKhU
12. Ron Beaufort Training. (2009, March 24). *10 - Which Rung Wins? (AB PLC Training)* [Video file]. Retrieved from https://www.youtube.com/watch?v=rnsQpgrByNI
13. Ron Beaufort Training. (2009, March 24). *11 - Retentive Instructions OTL and OTU (AB PLC Training)* [Video file]. Retrieved from https://www.youtube.com/watch?v=KraWAA_i9GM
14. Q Corporation. (2003). *Operators Manual: IV^B*.

Acknowledgments

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