THERMOELECTRIC COOLER F.R.S.C.A.

Grayson Carpenter

Submitted to:
Paul I. Lin, Professor of ECET 491 Senior Design II
To Fulfill B.S. Electrical Engineering Technology Degree Requirements

Advisor and Course Professor: Professor Paul I-Hai Lin
Department of Electrical and Computer Engineering Technology
College of Engineering, Technology, and Computer Science
Indiana University-Purdue University Fort Wayne, Indiana

Overview

- Deliverables
- Costs
- Technical
- WBS
- Schedule
- Risk
- Charter

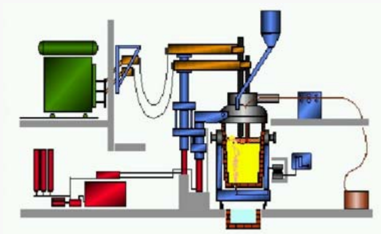
Deliverables

- Prototype
  - *Fully functional and tested circuit prototype with enclosure.*
- PLC Program
  - *The handling and display of data collected during the steel product cooling cycle. The program should be able to control the cooling cycle automatically.*
- Final report
  - *Compilation of all project information*
- Presentation
  - *Convey information about the project.*

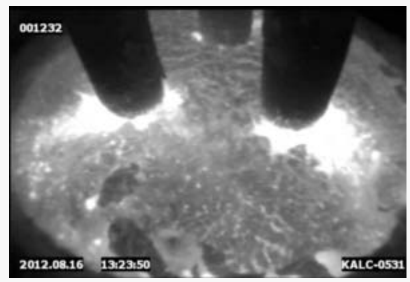
Costs

Material/Tool Cost				
Item	**Qty**	**Cost Each**	**Total Cost**	**Comments**
Voltage Transducer	1	$ 117.00	$ 117.00	
Current Transducer	1	$ 153.00	$ 153.00	
Heat Sink	1	$ 9.99	$ 9.99	
12V 0.35 Fans	2	$ 15.00	$ 30.00	
40mm x 40mm Peltier Device	2	$ 11.00	$ 22.00	
Hoffman Enclosure	1	$ 123.00	$ 123.00	
Panel Back Pane	1	$ 12.00	$ 12.00	
3/4" Cord Grip	1	$ 8.00	$ 8.00	
Siemens 3 Terminal Blocks	10	$ 3.99	$ 39.90	
Siemens 3 Terminal Jumpers	6	$ 2.99	$ 17.94	
Adhesice Wire Label Roll	1	$ 24.00	$ 24.00	
Schnieder 7A Breaker	1	$ 111.00	$ 111.00	
12V Ice Cube Relay	2	$ 4.99	$ 9.98	
Dell Power Supply	1	$ 25.00	$ 25.00	
12V/30A Power Supply	1	$ 21.00	$ 21.00	
Misc (Wire, Ferruls, Bolts, Aluminum, ect)	1	$ 100.00	$ 100.00	
Din Rail	1	$ 6.00	$ 6.00	
Switch	1	$ 0.99	$ 0.99	
	Material Total		**$ 830.80**	

Purpose



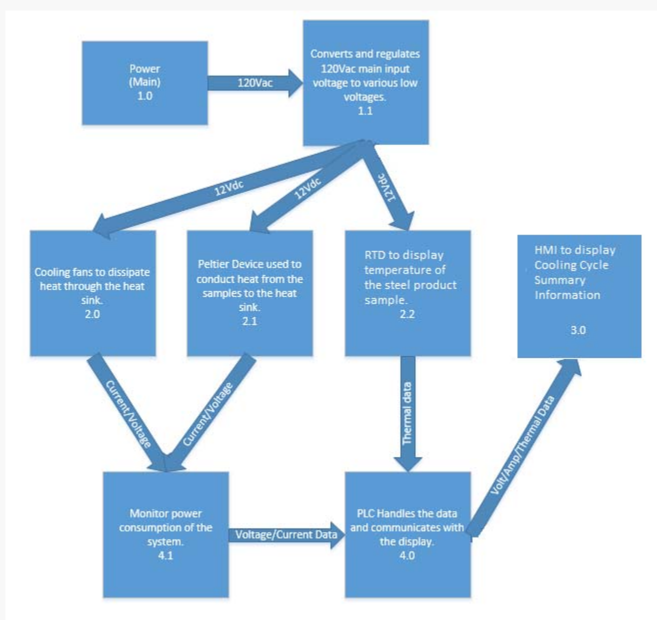
Ladle Metallurgical Furnace (LMF)



- SDI SRD produces structural and rail steel products
- LMF Process Costs Approximately $1000/minute
  - *Labor hours*
  - *Power Consumption*
  - *Material (Alloys)*
- Customer Quality Requirements
  - *Material Chemistry and Temperature*
  - *Material Strength*
  - *Material Quality Standards*

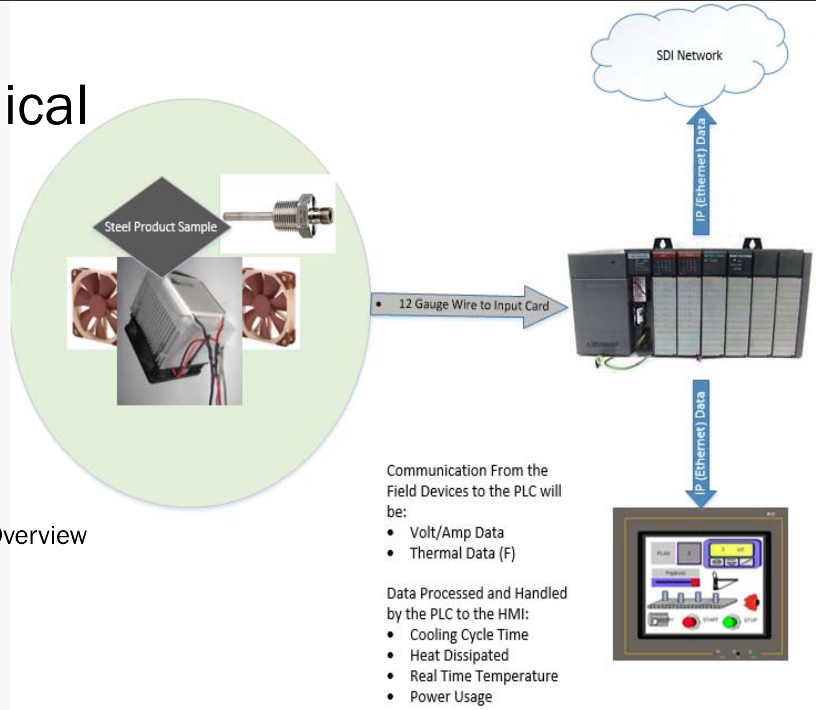
Technical

- Functional Block Diagram



Technical

- System Overview



Technical

- System Requirements

Requirement Data			Verification Planning		
ID	Requirement Type	Requirement (Shall or Should statements)	Verification Method	Date Verific	Verification Report
1	Operational	The system shall reduce the temperature of the Steel Product Sample.	Analysis	4-Dec-16	Final Report
2	Operational	The system shall dissapate the heat between 45 seconds and 1 minute, slew rate of 25 °F / 1 minute	Analysis	4-Dec-16	Final Report
3	Functional	The system shall utilize Peltier Devices for the cooling application.	Inspection	4-Dec-16	Final Report
4	Functional	The system shall utilize fans to dissappate heat.	Inspection	4-Dec-16	Final Report
5	Operational	The system shall have a power supply that supports 12 Volt to 24 Volt to power the smaller equipment for the cooling application.	Inspection	4-Dec-16	Final Report
6	Functional	The system shall display thermal data from the sample.	Demonstration	4-Dec-16	Final Report
7	Operational	The system shall display Voltage and Current usage information during operation.	Demonstration	4-Dec-16	Final Report
8	Functional	The system shall utilize a Programmable Logic Controller (PLC) to control the system functionally.	Demonstration	4-Dec-16	Final Report
9	Functional	The system shall scale the collected data in the PLC to display the data on a screen.	Demonstration	4-Dec-16	Final Report
10	Functional	The system shall utilize a RTD (resistive temperature device) to read the temperature values with the ability send an output analog/digital signal to the PLC.	Inspection	4-Dec-16	Final Report
11	Functional	The system shall have a PLC to calculate the heat dissapated.	Demonstration	4-Dec-16	Final Report
12	Functional	The system shall display when the cooling cycle is running and complete.	Demonstration	4-Dec-16	Final Report
13	Functional	The system will have analog signals communicate to the PLC through an Analog Input card.	Analysis	4-Dec-16	Final Report
14	Physical	The system terminals shall not be exposed during operation.	Inspection	4-Dec-16	Final Report
15	Physical	The system shall fit in the requested 3 foot by 2 foot operating space in the lab area.	Inspection	4-Dec-16	Final Report
16	Environmental	The system shall use input power of 110VAC to 130VAC at 57hz to 63Hz.	Inspection	4-Dec-16	Final Report
17	Operational	The system shall have a PLC to calculate power consumption.	Analysis	4-Dec-16	Final Report
18	Performance	The system shall have the ability to operate manually without PLC control.	Demonstration	4-Dec-16	Final Report

Calculations

3.3 Calculations

Power Supply Sizing Calculations:

Peltier Device Specifications = 12V/7.66A
Cooling Fans Specifications = $12V/0.35A$
Max Heat Pump = 260 Watts
Max Temperature = 154.4°F
Power needed per Peltier Devices = P=IE= 12V * 7.66A = 91.92 Watts
2 Peltier Devices = 91.92W * 2 = 183.84W (used to size Power Supply)
4 Peltier Devices = 91.92W * 4 = 397.68W (used to size Power supply)
Peltier Device Specifications = 12V/7.66A
Cooling Fans Specifications = $12V/0.35A$
Power needed per Cooling Fan P=IE = 12V * 0.35A = 4.2W
2 Cooling Fans = 4.2W * 2 = 8.4W

Watts per Hour Calculation: Watts * hour

Max Mode:

Measured= (14.6A * 15V) * 0.01hr $= 2.19 \frac{W}{hr}$ note: no load
Ideal = (15.3 * 15V) * 0.01hr $= 2.295 \frac{W}{hr}$

Efficient Mode:

Measured= (13.6A * 12.2V) * 0.01hr $=1.66 \frac{W}{hr}$ note: no load
Ideal= (14A * 12V) * 0.01hr $=1.68 \frac{W}{hr}$

Define the Temperatures: [2]

T_c = Cold Side of the Peltier Device — Avg T_c = 70.5°F 28.66°F heat dissipation
T_s = Heat Sink side of the Peltier Device — Avg T_s = 99.166°F
ΔT = Difference between T_c and T_s — Avg ΔT = 28.66°F
Qmax = Thermal load = 28.66°F
Qc = Thermal Load = Avg 28.66°F
I_{max} = 7.6A per Peltier Device; 30.4A of system (4 Peltier Devices)
Efficient Mode Input Power
Max Mode Input Power = 15.4v *

Calculations Cont'd

Max Mode Coefficient of Performance (COP) = $\frac{\text{Thermal Load(Qc)}}{\text{Input Power}} = \frac{28.66\ F}{235.93\ W}$ = 0.121 Watts

Efficient Mode Coefficient of Performance (COP) = $\frac{\text{Thermal Load(Qc)}}{\text{Input Power}} = \frac{0}{142.8W}$ = 0.202 Watts

Calculating Peltier Efficiency = [3]

- Input Power = Watts to joules = 1 Watt = 1 $\frac{\text{Joule}}{\text{second}}$
- Input energy @ time (in seconds) = $\frac{\text{Joules}}{\text{second}}$
- Average Temp calculated above
- BTUs used for cooling = (weight) * (Average Temperature change) * (1 $\frac{\text{BTU}}{\text{lbF}}$)
- Energy used for cooling = (BTU's used for cooling) * 1055 $\frac{\text{joules}}{\text{BTU}}$
- Efficiency = $\frac{(\text{Energy used for cooling})}{(\text{Input energy})}$

@ Efficient Power mode (1/2 Power)

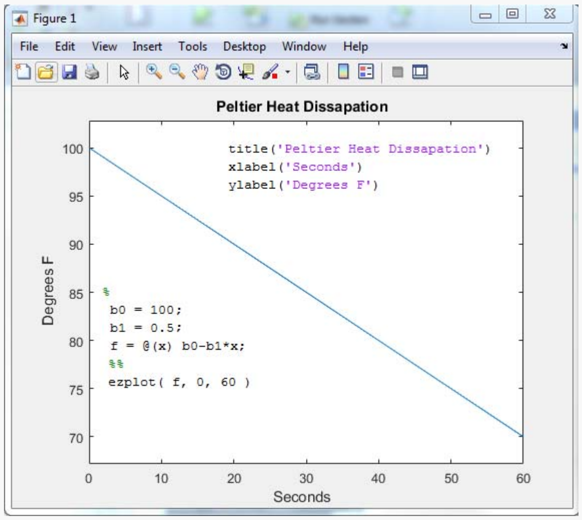
- Input Power = 183.84 Watts = 183.84 joules/second
- Input Energy @1 minute = 183.84 $\frac{\text{joules}}{\text{BTU}}$* 60 seconds = 10,980 joules
- Average Temperature Change = 28.66°F
- BTUs used for cooling = 0.75lb * 28.66°F *1BTU/lbF = 21.495 BTU
- Energy used for cooling = 21.495 BTU * 105.5$\frac{\text{joules}}{\text{BTU}}$ = 2263.92 joules
- Efficiency = $\frac{2{,}263.92\ joules}{10{,}980\ joules}$ = 0.206%

@ Full Power Mode

- Input Power = 397.68 Watts = 397.68 joules/second
- Input Energy @1 minute = 397.68 $\frac{\text{joules}}{\text{BTU}}$* 60 seconds = 23,860.8 joules
- Average Temperature Change = 28.66°F
- BTUs used for cooling = 0.75lb * 28.66°F *1BTU/lbF = 21.495 BTU
- Energy used for cooling = 21.495 BTU * 105.5$\frac{\text{joules}}{\text{BTU}}$ = 2263.92 joules
- Efficiency = $\frac{2{,}263.92\ joules}{23860.8\ joules}$ = 0.094%

Peltier devices are approximately 5% efficient

Calculations Cont'd



Testing Data

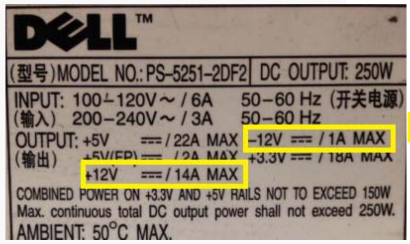
Heat Dissipation Data Collected each at 1 minute; Refer to Figure 30 & 31 for System used.

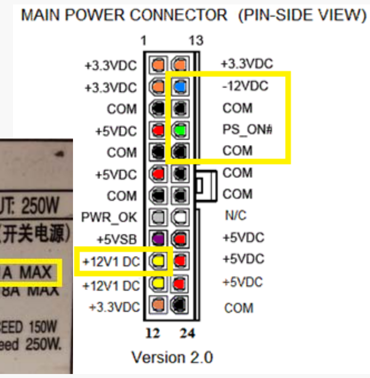
Trial 1:	101°F	69°F	= 32°F
Trial 2:	98°F	73°F	= 25°F
Trial 3:	99°F	71°F	= 28°F
Trial 4:	96°F	72°F	= 24°F
Trial 5:	99°F	68°F	= 31°F
Trial 6:	102°F	70°F	= 32°F
Average:	99.166°F	70.5°F	28.66°F

Cooling Fans		
	Voltage	Amperage
	11.98	0.4
	11.97	0.4
Peltier Device		
	Voltage	Amperage
Efficient Power Supply Output	11.4	12
Peltier Device 1	11.24	2.8
Peltier Device 2	11.31	3.1
Peltier Device 3	11.23	2.9
Peltier Device 4	11.23	3
Max Power Supply Output	14.86	15
Peltier Device 1	14.46	3.75
Peltier Device 2	14.5	3.74
Peltier Device 3	14.46	3.67
Peltier Device 4	14.47	3.76

Technical-Power

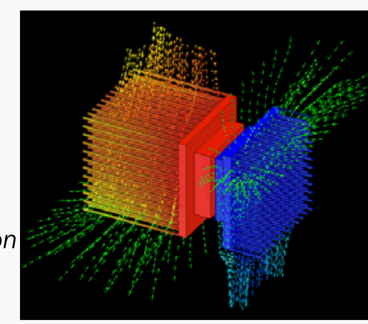
- Main 120Vac System Input
- 9V 14A for Peltier Efficient
  - -Dell, PS-5251-2DF2



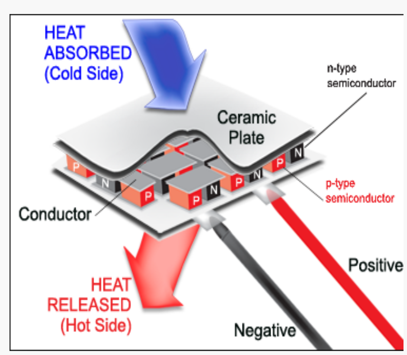


- 9V-15V 30A for Peltier Max
  - eTopxizu 12v 30a Dc Universal Regulated Switching Power Supply

Technical



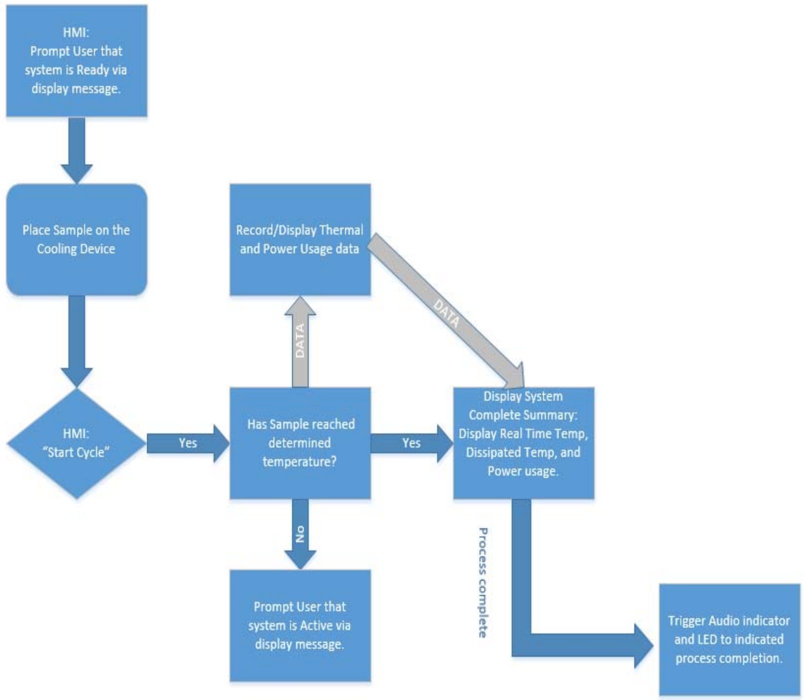
- *Cooling Application*
  - Peltier Devices
  - Cooling Fans
  - Heat Sink



Peltier Device

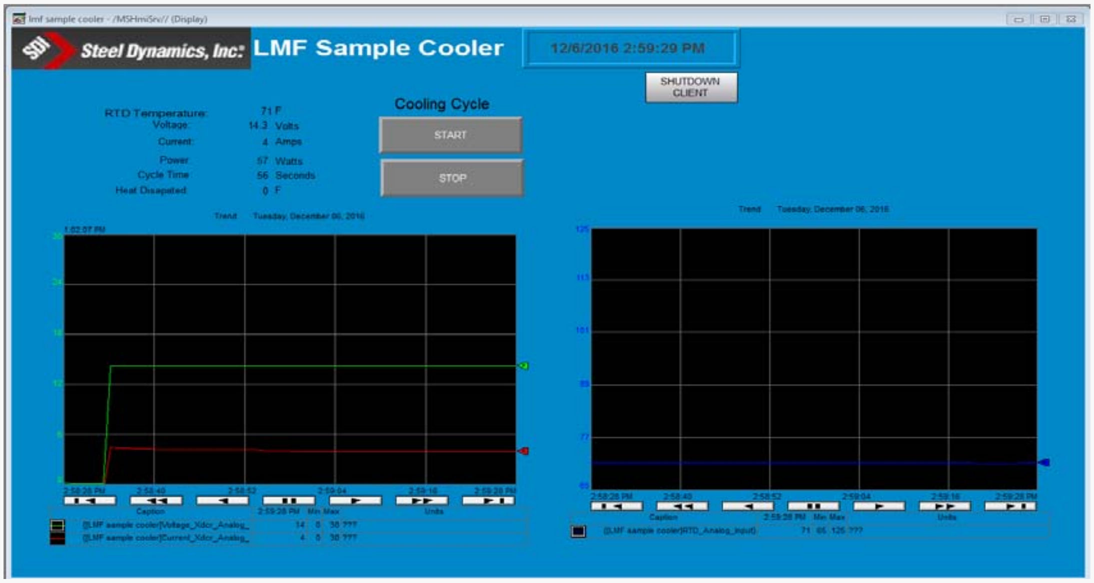
Technical

- SW Flow Chart



Technical-Logic

HMI



LMF_Peltier_Sample_Cooler - Module Properties Listing

Page 9
11/18/2016 3:49:46 PM
C:\Users\grayson.carpenter\Documents\Studio 5000\Projects\LMF_Peltier_Sample_Cooler.ACD

1756 Backplane, 1756-A10 : Local Modules

Local: [0] 1756-L62 LMF_Peltier_Sample_Cooler

Senior Design Project. Controls the max and efficeint modes of the Cooling Device.

Type:	1756-L62 ControlLogix5562 Controller	Parent:	Local
Vendor:	Allen-Bradley	Vendor ID:	1
Slot:	0	Electronic Keying:	Exact Match
Revision:	20.15	Status:	Standby
Module Fault:	Offline	Inhibit Flag	Off

Local: [1] 1756-ENBT/A ENET

Type:	1756-ENBT/A 1756 10/100 Mbps Ethernet Bridge, Twisted-Pair Media	Parent:	Local
Vendor:	Allen-Bradley	Vendor ID:	1
Slot:	1	IP Address or Host Name:	10.30.65.113
Electronic Keying:	Compatible Keying	Revision:	6.4
Status:	Standby	Module Fault:	Offline
Inhibit Flag	Off		

Local: [2] 1756-IF8 Analog_Input

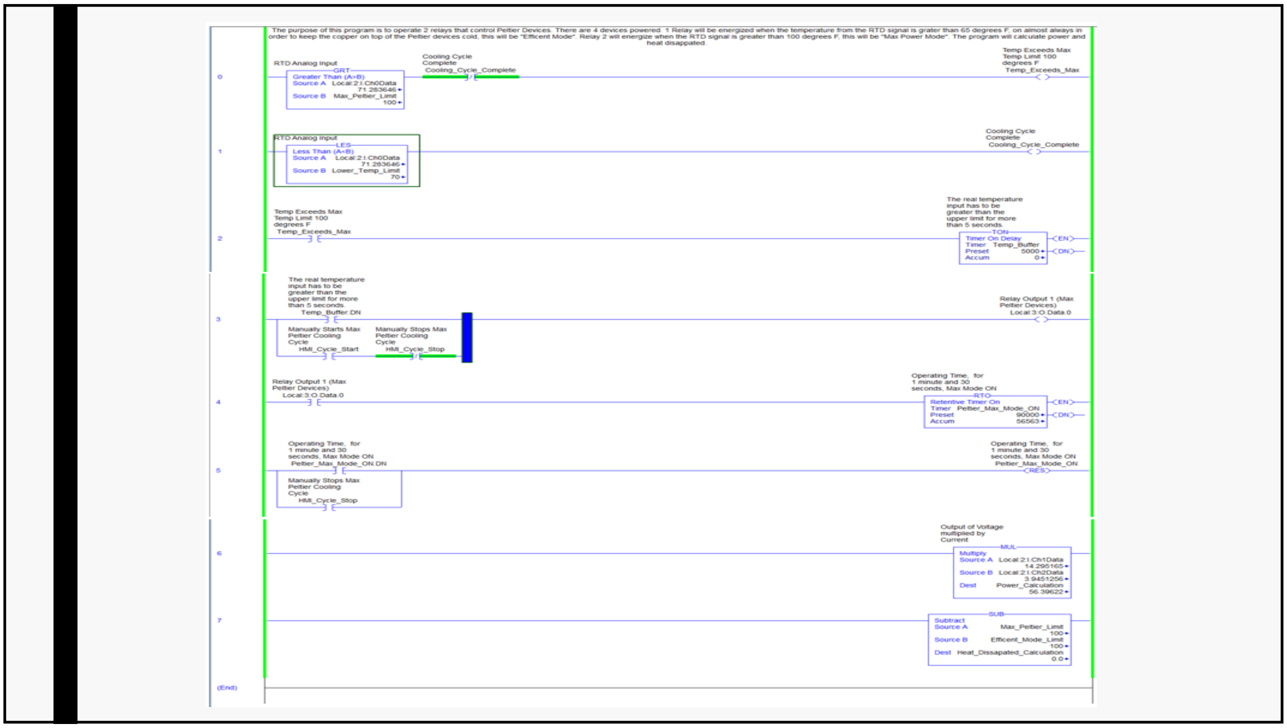
Type:	1756-IF8 8 Channel Non-Isolated Voltage/Current Analog Input	Parent:	Local
Vendor:	Allen-Bradley	Vendor ID:	1
Slot:	2	Electronic Keying:	Compatible Keying
Revision:	1.5	Status:	Standby
Module Fault:	Offline	Inhibit Flag	Off
Use Unicast:	n/a		

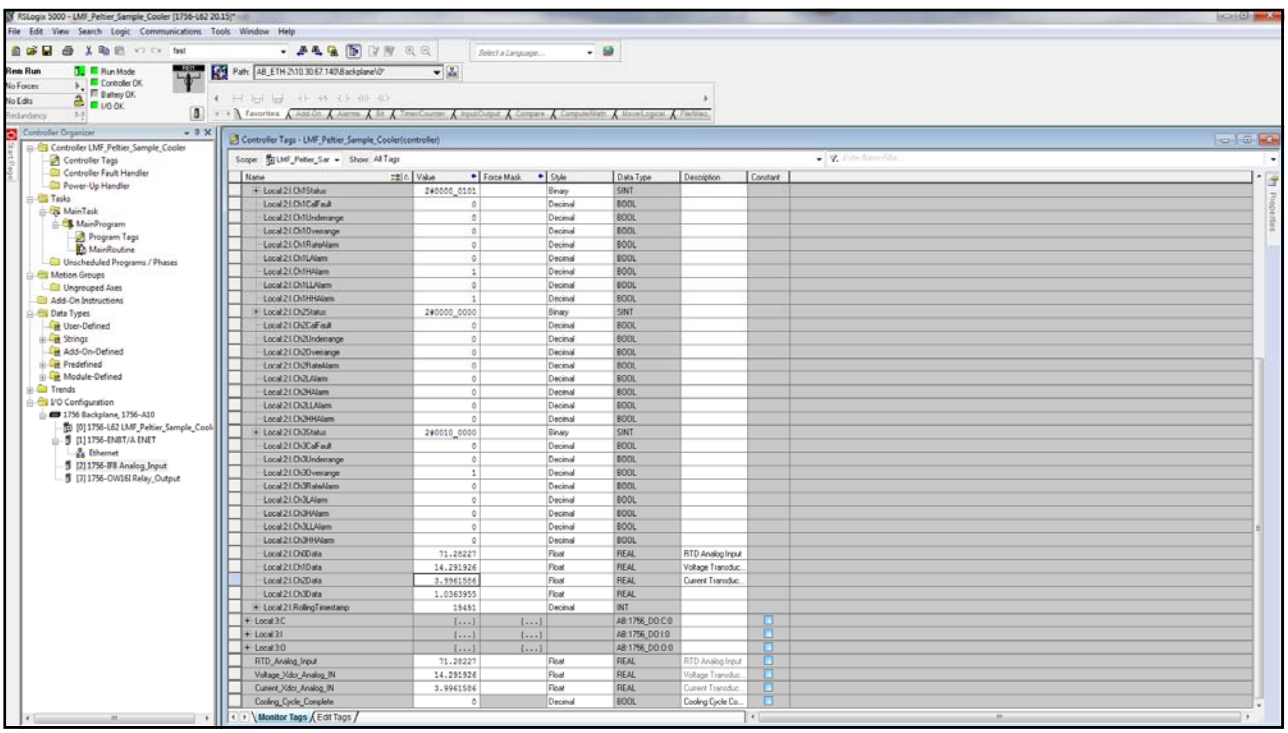
Module Defined Configuration Tag	Value	Data Type
Local:2:C		AB:1756_IF4_Float:C:0
.ModuleFilter	2	SINT
.RealTimeSample	100	INT
.Ch0Config		AB:1756_NII_Struct:C:0
.Ch1Config		AB:1756_NII_Struct:C:0
.Ch2Config		AB:1756_NII_Struct:C:0
.Ch3Config		AB:1756_NII_Struct:C:0

Local: [3] 1756-OW16I Relay_Output

Type:	1756-OW16I 16 Point 10V-265V AC, 5V-150V DC Isolated Relay	Parent:	Local
Vendor:	Allen-Bradley	Vendor ID:	1
Slot:	3	Electronic Keying:	Compatible Keying
Revision:	3.2	Status:	Standby
Module Fault:	Offline	Inhibit Flag	Off
Use Unicast:	n/a		

Module Defined Configuration Tag	Value	Data Type
Local:3:C		AB:1756_DO:C:0
.ProgToFaultEn	0	BOOL
.FaultMode	2#0000_0000_0000_0000_0000_0000_0000_0000	DINT
.FaultValue	2#0000_0000_0000_0000_0000_0000_0000_0000	DINT


The purpose of this program is to operate 2 relays that control Peltier Devices. There are 4 devices powered. 1 Relay will be energized when the temperature from the RTD signal is grater than 65 degrees F, on almost always in order to keep the copper on top of the Peltier devices cold, this will be "Efficent Mode". Relay 2 will energize when the RTD signal is greater than 100 degrees F, this will be "Max Power Mode". The program will calculate power and heat disappated.
0
RTD Analog Input
GRT
Greater Than (A>B)
Source A Local:2:I.Ch0Data
71.283646
Source B Max_Peltier_Limit
100
Cooling Cycle Complete
Cooling_Cycle_Complete
Temp Exceeds Max Temp Limit 100 degrees F
Temp_Exceeds_Max
1
RTD Analog Input
LES
Less Than (A<B)
Source A Local:2:I.Ch0Data
71.283646
Source B Lower_Temp_Limit
70
Cooling Cycle Complete
Cooling_Cycle_Complete
2
Temp Exceeds Max Temp Limit 100 degrees F
Temp_Exceeds_Max
The real temperature input has to be greater than the upper limit for more than 5 seconds.
TON
Timer On Delay
Timer Temp_Buffer
Preset 5000
Accum 0
EN
DN
3
The real temperature input has to be greater than the upper limit for more than 5 seconds.
Temp_Buffer.DN
Manually Starts Max Peltier Cooling Cycle
HMI_Cycle_Start
Manually Stops Max Peltier Cooling Cycle
HMI_Cycle_Stop
Relay Output 1 (Max Peltier Devices)
Local:3:O.Data.0
4
Relay Output 1 (Max Peltier Devices)
Local:3:O.Data.0
Operating Time, for 1 minute and 30 seconds, Max Mode ON
RTO
Retentive Timer On
Timer Peltier_Max_Mode_ON
Preset 90000
Accum 56563
EN
DN
5
Operating Time, for 1 minute and 30 seconds, Max Mode ON
Peltier_Max_Mode_ON.DN
Manually Stops Max Peltier Cooling Cycle
HMI_Cycle_Stop
Operating Time, for 1 minute and 30 seconds, Max Mode ON
Peltier_Max_Mode_ON
RES
6
Output of Voltage multiplied by Current
MUL
Multiply
Source A Local:2:I.Ch1Data
14.295165
Source B Local:2:I.Ch2Data
3.9451256
Dest Power_Calculation
56.39622
7
SUB
Subtract
Source A Max_Peltier_Limit
100
Source B Efficent_Mode_Limit
100
Dest Heat_Dissapated_Calculation
0.0
(End)


RSLogix 5000 - LMF_Peltier_Sample_Cooler [1756-L62 20.15]*
File Edit View Search Logic Communications Tools Window Help
Rem Run
Run Mode
Controller OK
Battery OK
I/O OK
Controller Organizer
Controller LMF_Peltier_Sample_Cooler
Controller Tags
Controller Fault Handler
Power-Up Handler
Tasks
MainTask
MainProgram
Program Tags
MainRoutine
Unscheduled Programs / Phases
Motion Groups
Ungrouped Axes
Add-On Instructions
Data Types
User-Defined
Strings
Add-On-Defined
Predefined
Module-Defined
Trends
I/O Configuration
Controller Tags - LMF_Peltier_Sample_Cooler(controller)
Name
Value
Force Mask
Style
Data Type
Description
Constant
Monitor Tags
Edit Tags

WBS

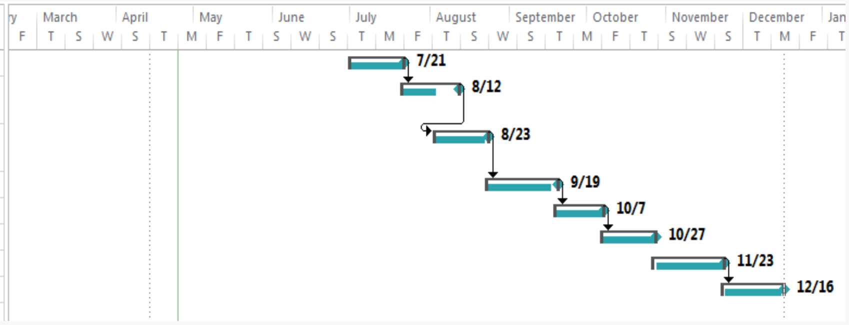
LEVEL	WBS ID	WBS Description	Status	Labor Hours
1	0000	Thermoelectric Cooler		145
2	1000	Prototype		100
3	1100	Circuit Design/Research		10
4	1110	Circuit theory of operation		
4	1120	Complete circuit design schematic		
3	1200	Circuit Construction		20
4	1210	Circuit design schematic		
4	1220	Circuit Prototype		
4	1230	Troubleshooting		
4	1240	Functional Testing		
3	1300	Encolsure Design/Construction		20
4	1310	Complete enclosure design schematic		
4	1320	Fabricate enclosure prototype		
4	1330	Enclosure drop testing		
3	1400	PLC Programming		20
4	1410	Rate Cooling Control		
4	1420	Data handling		
4	1430	Data Display		
3	1500	Integration		15
4	1510	Initial Assy		
4	1520	Hardware/PLC Software integration		
4	1530	Troubleshoot		
4	1540	Functional Test		
3	1600	Test Requirements		15
4	1610	Cools the Steel Product Sample		
4	1620	Displays Thermal Data		
4	1630	Displays System Power Data		

WBS

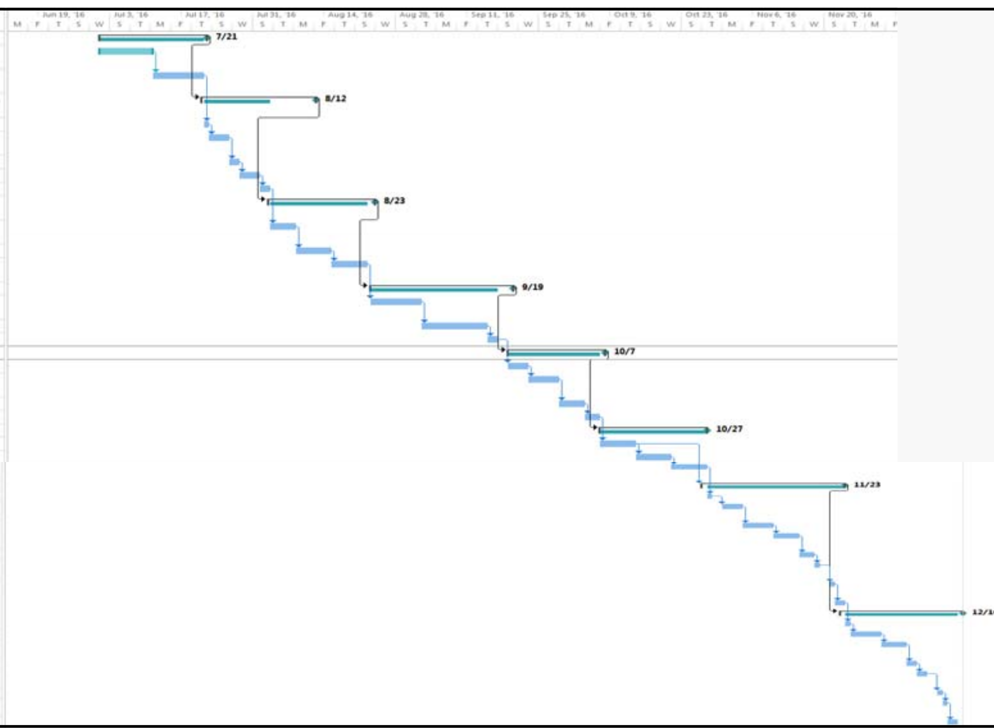
2	2000	Project Report		30
3	2100	Outline		10
4	2110	Top level project summary		
3	2200	Draft		10
4	2210	Meet Report requirements		
3	2300	Edit Draft		5
4	2310	Grammer/Formatting Check		
4	2320	Change discrepancies		
3	2400	Final		5
2	3000	Presentation		15
3	3100	Outline		3
3	3200	Draft		3
4	3210	Meet Presentation Requirments		
3	3300	Edit Draft		3
4	3310	Grammer/Formatting Check		
4	3320	Change discrepancies		
3	3400	Rehearse		3
4	3410	Meet timing requirements		
3	3500	Final		3

Schedule

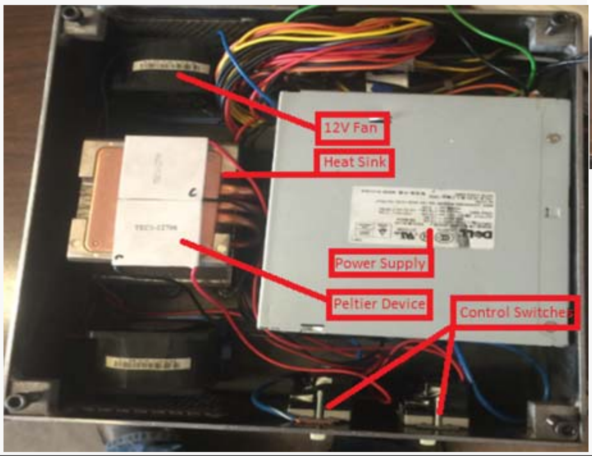
Task Mode	Task Name	Duration
	Prototype	15 days
	Circuit Design Schematic Research	16.5 days
	Enclosure Construction	15 days
	PLC Programming	20 days
	Integration	15 days
	Test Requirements	15 days
	Project Report	20 days
	Presentation	18 days



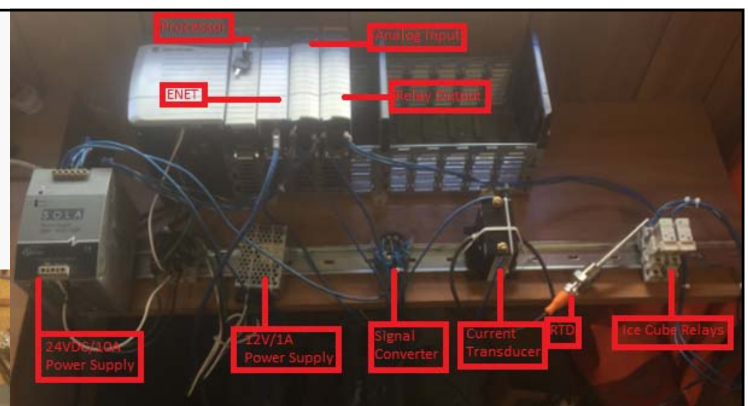
	Task Mode	Task Name	Duration
1		Prototype	15 days
2		Circuit Design/Research	7 days
3		Circuit Theory of operation	8 days
4		Circuit Design Schematic Research	16.5 days
5		Circuit constructio	1 day
6		Circuit design Schematic	2 days
7		Circuit Prototype	2 days
8		Troubleshoot	2 days
9		Functional Testing	2 days
10		Enclosure Construction	15 days
11		Enclosure Design Schematic	3 days
12		Fabricate Prototyp	5 days
13		Encolsure Shock Testing	5 days
14		PLC Programming	20 days
15		Rate of Cooling Control	8 days
16		Data Handling	9 days
17		Data Display	2 days
18		Integration	15 days
19		Initial Assy	4 days
20		Hardware/softwar integration	4 days
21		Troubleshoot	3 days
22		Functional Testing	3 days
23		Test Requirements	15 days
24		Cools Steel Sampl	5 days
25		Displays Thermal	5 days
26		Displays System Power Usage	5 days
27		Project Report	20 days
28		Outline	1 day
29		Top Level Project Summary	4 days
30		Draft	4 days
31		Meet report requirements	3 days
32		Edit Draft	3 days
33		Grammer/Formatt check	1 day
34		Change discrepancies	1 day
35		Final	2 days
36		Presentation	18 days
37		Outline	1 day
38		Draft	4 days
39		Meet Presentation	3 days
40		Edit Draft	2 days
41		Grammer/Formatt Check	2 days
42		Rehearse	1 day
43		Meet timing requirements	1 day
44		Final	2 days

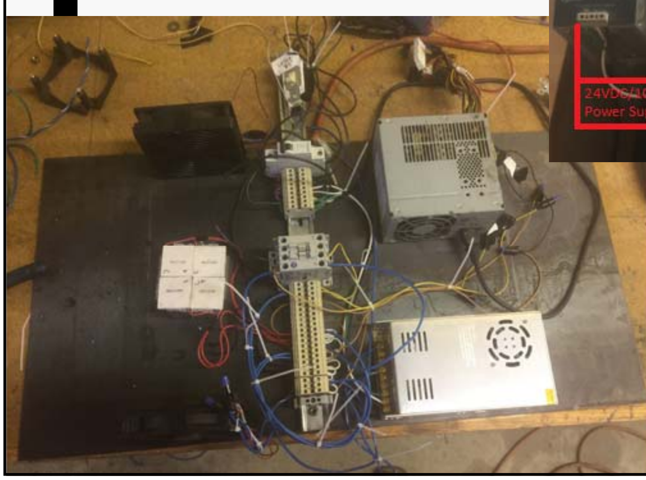


Proof of Concept

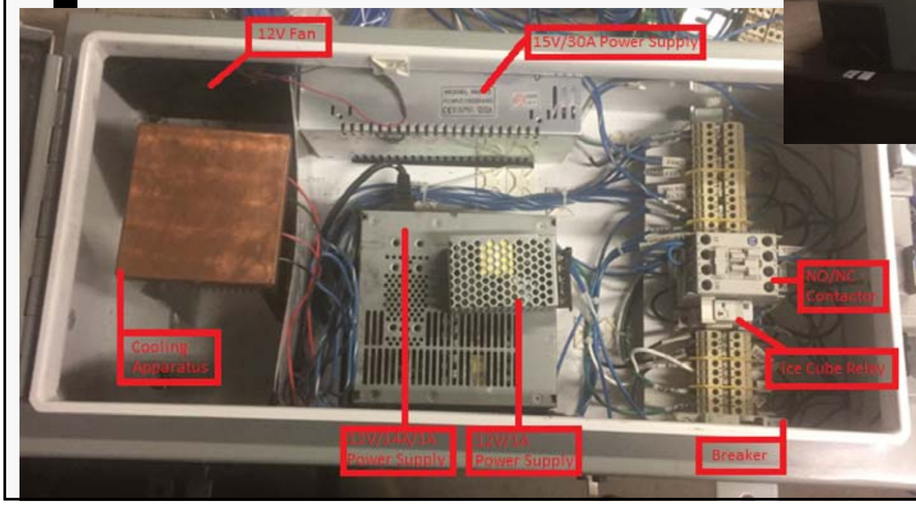


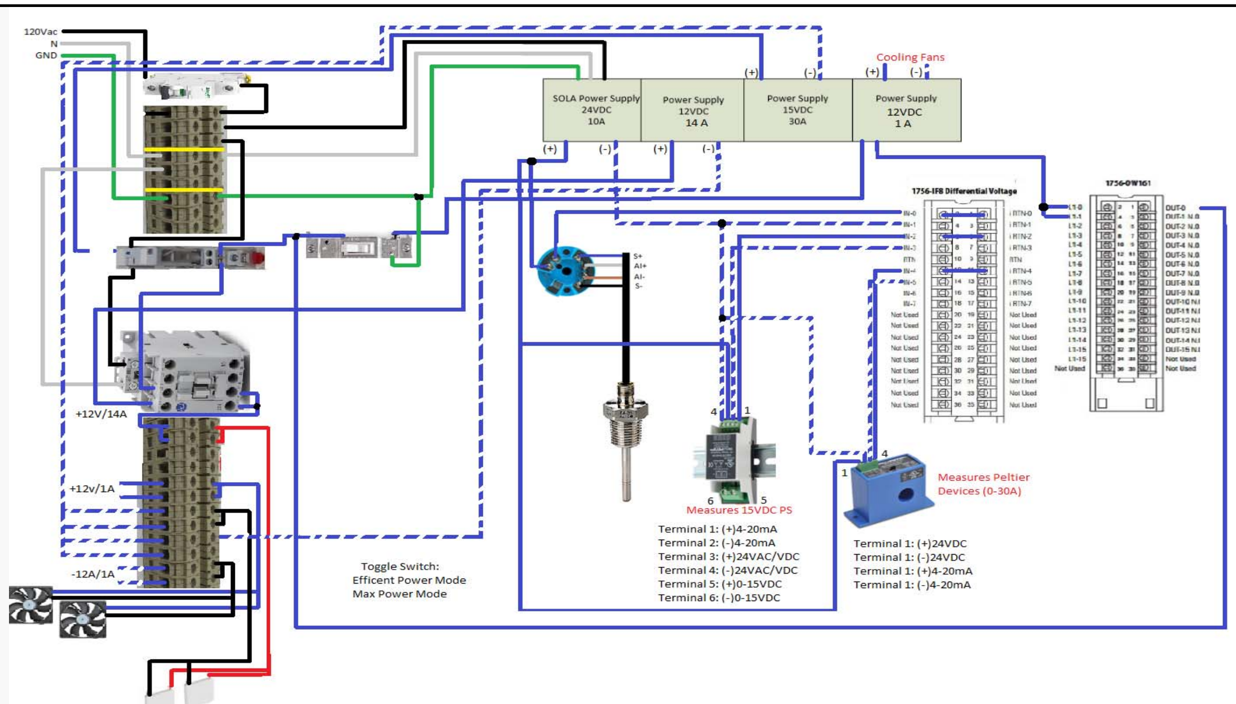
Testing Stage





Finalized System





Risk Register

ID	Entry Date	Type		Risk Description: 'IF statement'		Consequence of Risk: 'THEN statement'	Status	Likelihood (1-5)	Severity (1-5)	Score	Rank*	Response	Description of Response
1	27-Mar-16	Technical	IF	Program will not communicate with the SDI network	THEN	Testing data cannot be transferred from the test station.	Open	2	5	10	Medium	Mitigate	Verify that the communication is setup before system implementation.
2	27-Mar-16	Technical	IF	Logix 5000 software is unavailable	THEN	the PLC program portion of the lab cannot be completed.	Open	2	5	10	Medium	Mitigate	Try to get a different programming platform, Siemens s7-1200 PLC and Oracle software.
3	27-Mar-16	Schedule	IF	Time is mismanaged	THEN	project will not be completed by the end of the semester	Open	2	5	10	Medium	Mitigate	Include buffer times in the schedule to account for missed deadlines.
4	27-Mar-16	Schedule	IF	PLC programming takes longer than expected	THEN	Project processes will be delayed and becoming behind schedule.	Open	1	4	4	Low	Avoid	Stay on top of project scheduling and make sure lessons are reached in a timely manner during programming.
5	27-Mar-16	Schedule	IF	parts do not arrive on time	THEN	assembly and testing of the prototype will be delayed.	open	1	4	4	Low	Mitigate	Look at different suppliers and plan to have parts ordered early enough so delays can be handled.
6	27-Mar-16	Technical	IF	wrong peltier devices are chosen that can't handle the desired temperature range	THEN	the cooling application will not work.	Open	2	5	10	Medium	Mitigate	choose peltier devices that can handle the desired minimum operating temperature.
7	27-Mar-16	Cost	IF	Destroy parts in testing	THEN	have broken parts and a nonfunctional system	Open	2	5	10	Medium	Mitigate	order new parts and change system design.
8	24-Apr-16	Cost	IF	SDI decides to not fund the project	THEN	the project will be halted until funds are reestablished	Open	2	1	2	Low	Avoid	the project will need to be funded by myself.

Risk Matrix

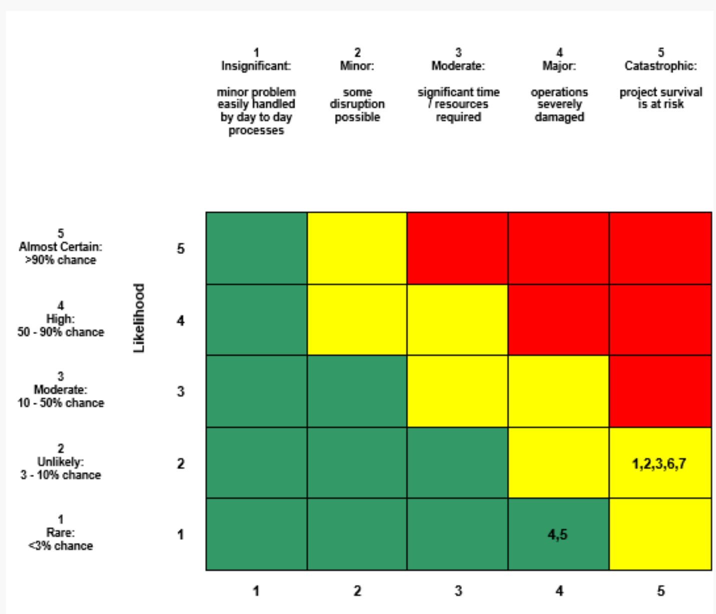
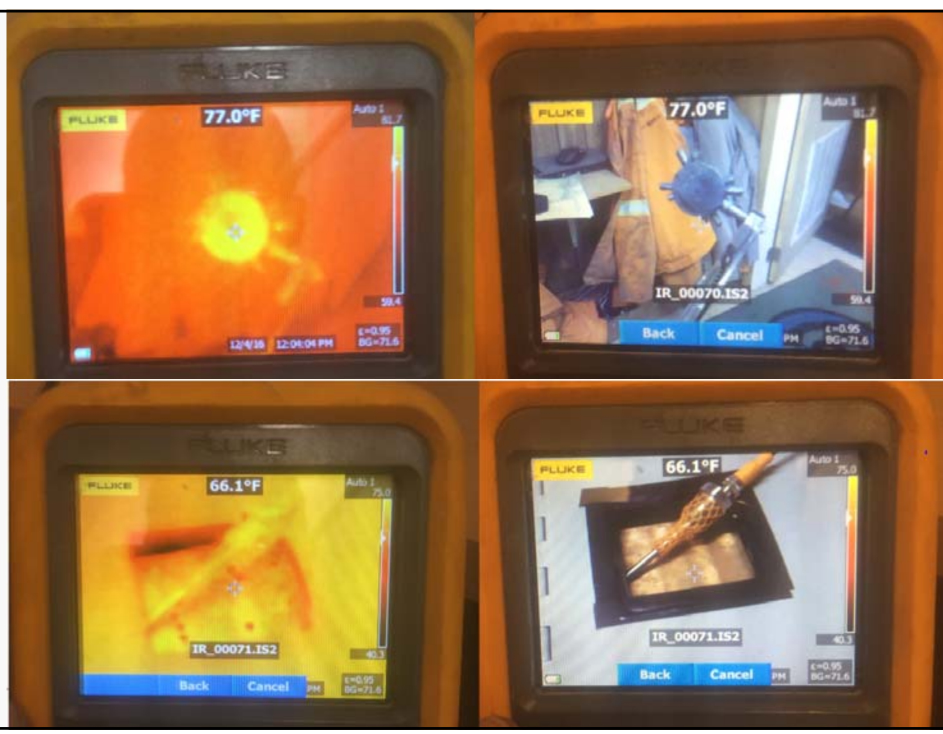


Figure 11 Risk Matrix

Lessons Learned

- 1: Test Rack
- 2: Heat Sink issue
- 3: Power Supply Calibration
- 4: Wire Clean up
- 5: HMI
- 6: Contactor Jumper issue



Demo