HEAT EXCHANGER PROCESS UTILIZING FEEDFORWARD AND CASCADE CONTROL WITH FEEDBACK TRIM IN A DELTAV DCS

PREPARED FOR: VICTOR MENDEZ

BY: KORBEN JOHNSON, TYLER DRIESEN, EMILY LOUGHEED, JADE MOORE-JACKSON, CARSON WEST, AND ZARON GIBSON

DATE: APRIL 10, 2019

ACKNOWLEDGEMENT

In preparation for this project, we had to acquire aid from multiple advisors, the manufacturer and multiple instructors regarding system values, resources, design specifications and other requirements. Throughout this project, these individuals taught us how to overcome difficult challenges, provide information that weren't accessible by the group members themselves and provide feedback for certain objectives after completion.

On behalf of the team members for this project, we would like to thank the following individuals for their advice and continued effort in aiding all of us throughout the semester in completing this project:

Victor Mendez, M.Sc., P.Eng.

Craig West, M.Sc., P.Eng.

Clifford Long, C.E.T, RSE.

Charles Ying, M.Sc.

Saleh Hosseini, M.Sc., P.Eng.

Brad House, C.E.T, Spartan Controls

Neal Tetreault, Spartan Controls

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LIST OF ACRONYMS

Acronym	Definition
ASET	Association of Science and Engineering Technology
CO	Controller Output
CV	Controlled Variable
DCS	Distributed Control System
DST	Device Signal Tag
EET	Electrical Engineering Technologies
FB	Function Block
HMI	Human-machine interface
I/O	Input - Output
IET	Instrumentation Engineering Technologies
ILD	Instrument Loop Diagram
ISA	International Society of Automation
MV	Manipulated Variable
P&ID	Process and Instrument Diagram
PID	Proportional - Integral - Derivative
PV	Process Variable
RDC	Red Deer College
SP	Setpoint

Table 1 - List of Acronyms

ABSTRACT

This final report marks the completion of 2019 Capstone project entitled “Heat Exchanger Process Utilizing Feedforward and Cascade Control with Feedback Trim in a DeltaV DCS”. The main objective of this report was to give a detailed account of our project from start to finish. Inside you will find a comprehensive scope, list of deliverables, background study, feasibility assessment, roles and responsibilities, critical analysis, work breakdown structure, time management plan, communication management, change management, risk management strategy and team charter.

All content contained within this report follows the format defined by the Association of Science and Engineering Technology (ASET) professionals of Alberta, in their published “Prior Learning Assessment and Recognition: Technical Report Guidelines” manual. All engineering schematics designed by the project team follow the applicable standards published by the International Society of Automation (ISA).

1 INTRODUCTION

In the fall of 2017, Red Deer College (RDC) expanded their Engineering Technologies department with the introduction of the Instrumentation Engineering Technologies (IET) discipline. With instrumentation being the art and science of measuring, controlling, and automating common variables like pressure, temperature, and flow in various industrial systems, it was quickly identified that RDC was missing the equipment to support one of the most common industrial processes, heat exchangers.

In the year to follow, all the necessary equipment and infrastructure required to commission a fully operational heat exchanger was gathered and would become a headlining Capstone project for RDC’s first graduating instrumentation class. Together with the support of electrical engineering technology students we were tasked with bringing the equipment online and developing the automated control strategy by use of DeltaV DCS software.

1.1 MOTIVATION

Being a team composed of 4 instrumentation engineering technologists, and 2 electrical engineering technologists, with 1 having already acquired a diploma in mechanical engineering technologies, we were all looking for a Capstone project that would be uniquely challenging and present an opportunity to expose us to the industrial equipment that we are likely to work with once we graduated.

This heat exchanger project is the culmination of the teachings in the instrumentation discipline and will provide us the chance to prove our capabilities as adaptive technologists working together on a multifaceted team to achieve success beyond our established knowledge base. It will require a deep understanding of DeltaV DCS implementation, process control strategies, and instrument expertise.

Having a distinct team of six individuals on this project will allow for its members to continue building their critical thinking and problem-solving aptitude, project management abilities, as well as refine their communication and teamwork skills.

2 PROJECT SCOPE

The project scope details the objectives of the project and what goals must be met to achieve success. Defining the scope outlines the parameters or limitations of the project and spells out exactly what is to be included and what is to be excluded from the project.

2.1 STATEMENT

We will be bringing the newly acquired heat exchanger equipment into service and assuring all components are tested and operating as designed. This system will function by automatically combining a cold and hot water stream to create an inlet fluid at an adjustable and controlled temperature before entering the heat exchanger and being subjected to the thermodynamic energy carried by the supplied steam line. Exiting the heat exchanger our outlet fluid temperature will be increased to another adjustable and controlled temperature (initial range of 20°- 50°C will be sought) and sustained from any upstream disturbances.

In evaluation of what will need to be accomplished to successfully commission the heat exchanger we identified 3 main areas of focus; they are as follows:

2.1.1 DELTAV CONFIGURATION AND PROGRAMMING

Our heat exchanger process will be fully automated and controlled with a distributed control system (DCS) by use of Emerson’s software known as DeltaV. As is the modern standard for many large manufacturing plants, a DCS allows for the centralization of process monitoring and control, thus enabling an operator to comfortably remain at their workstation while still having real time updates about the equipment and process they are responsible for.

To achieve this, we will be collecting all the data from our field devices with DeltaV's state of the art electronic marshalling input/output architecture known as CHARM. This data will then be fed into a controller that automatically performs the sophisticated control strategies we develop in order to achieve full automation. Representing this process will be a user-friendly graphical interface enabling us to witness what is always happening and take quick action, should the process need manual intervention. For future use, this human-machine interface (HMI) will allow the complex process to be easily understood by RDC students new to the equipment and manipulated for demonstration purposes.

2.1.2 CALIBRATION AND TUNING

To have control of our process, we must first verify the collected data sent to the DCS is an accurate characterization of the process variables the field devices are measuring. This will ensure no error is introduced which impacts our process control performance. To accomplish this, we will be performing a zero calibration on the various pressure, flow, and temperature transmitters as well as setting the instrument spans to the desired upper-range values in order to create a calibration range that is suitable for our process. We will then be testing several points within this operating range to verify the measured value is within an acceptable tolerance to the process variable (PV) that will be determined by the calibration and tuning team.

Once the DCS has been configured, it will be essential to tune the controllers to attain optimization during both servo and regulatory responses. This procedure involves adjusting the Proportional gain, Integral time, and Derivative values used by the controller’s PID algorithm to meet our process response requirements. These requirements are unique to each control loop and outline how the process variable should respond to any load disturbance or setpoint (SP) changes. Based on the safety requisite or control strategy specification we will fine-tune the 3 PID values to control the speed of response and how much overshoot is taken by the PV when returning to the SP. Incorrect tuning parameters can result in the process becoming unstable or too sluggish to attain adequate control and therefore is one of the most critical aspects of our project.

2.1.3 PROCESS ENGINEERING

For the DeltaV system to be programmed and configured, the control strategies we plan to utilize must first be defined. This will require research into the methodology of cascade control, feedforward control, ratio control, feedback control, and feedback trim. Block diagrams will then be created for each loop and with collaboration of the programming team, the approach on how to implement these control strategies into our system will be outlined. This includes exploring the 3 common structures (interactive, non-interactive or parallel) of the PID algorithm and deciding which variation should be applied to our control system.

To understand and describe the dynamic behaviour of our system, we will be developing a process model in the form of transfer functions. To obtain the data necessary to create this model, we will first need to attain the characteristics of our process. This will be accomplished through a procedure known as a step test and will reveal the relationship between each control loop's PV and its associated controller output (CO). Through analysis of the captured test data we can create the required transfer functions and, with the tuning team, determine the appropriate PID parameters for initial use.

2.2 MANAGEMENT

The scope will adhere to the boundaries defined unless a scope change is proposed and a change management request form is submitted. If this form is submitted, it will be reviewed by the team and a decision will be made whether to implement the scope change will occur. This process will be logged as well as the decision the team has come to.

2.3 VERIFICATION

The project will be considered successful upon its completed commissioning, enabling the plant to have automated control of its process fluid inlet temperature, flow, and the process outlet fluid temperature. The degree of its rated success will be indicative of the temperature range the system is able to control and how well the plant can handle upstream load disturbances.

2.4 EXCLUSIONS

2.4.1 BOILER

The boiler and its accompanying piping used to supply our process with steam will be provided for us on behalf of RDC. The project team’s interaction with the boiler is limited to only activating/deactivating the equipment, therefore any engineering and construction regarding its operation is deemed out of scope and will not be included in this report.

2.4.2 ENGINEERING AND CONSTRUCTION

Mechanical Analysis: The project arrived already constructed with completed calculations regarding mechanical stress, pressure, and flow for the mechanical limits of the system. Therefore, the required responsibility to complete stress-strain analysis and mechanical deformation analysis of the system is deemed out of scope and will not be included in this report.

Electrical Analysis and Electrical Wiring: The project arrived with the DeltaV hardware already connected, the required wiring for all instruments completed and system power delivery setup. The electrical failure analysis required for this project is predicted to be done by manufacturer.

2.4.3 PROCUREMENT AND BUDGET

Due to the plant being constructed before the project began, it will not be necessary for the project team to be sourcing or purchasing any parts. Therefore, no budgeting is required, and it will not be included in our scope.

2.5 ASSUMPTIONS

2.5.1 DESIGN

Spartan Controls performed all the initial calculations and design work; therefore, we are assuming that all the instrumentation chosen for our system is sized to spec and will function properly. This encompasses the sizing and compatibility done for the piping, orifice plate, vortex meter, control valves and actuators, heat exchanger, steam trap, SIS components, DeltaV DCS components.

2.5.2 ASSEMBLY AND CONSTRUCTION

Assuming the heat exchanger plant was properly built and tested by the manufacturer, Spartan Controls, this includes the construction and installation of the following: piping, transmitters, sensors, meters, valves, heat exchanger, pneumatic tubing, DeltaV hardware, and electronic control wiring.

2.6 CONSTRAINTS

2.6.1 KNOWLEDGE

Restricted capabilities for the project due to each member missing educational classes/courses required to complete certain tasks (e.g. Carson and Zaron are restricted from full DeltaV capabilities).

2.6.2 TIME

There are constraints on the amount of time each team member will be able to dedicate to the project. Reasons for this include the need to work around the assignments, labs, and exams for the other courses the team members are taking. There are also personal time constraints due to work and other obligations.

2.6.3 STEAM SUPPLY

The steam supply system, responsible for creating and carrying the steam to our process has yet to be constructed as of 02/04/19. All work relating to this system will be completed by a third-party contractor and managed by RDC. We are unable to operate our process until this work is finished.

2.6.4 WATER SUPPLY

Requiring water supply to the system for use (this has been completed). Note that there is an issue with having no location to transport the water output for storage or for use again.

3 DELIVERABLES

Deliverables are the outputs that result from the project process. They are the result of the project's life-cycle and are delivered based on the promised milestones and schedules.

3.1 ENGINEERING DRAWINGS AND SPECIFICATIONS

- Process and Instrument Diagrams (P&ID)
- Electrical Drawing
- Instrument Loop Diagrams (ILD)

3.2 CALIBRATED INSTRUMENTS

- Measurable ranges for instruments determined
- Zero & Span calibration
- Calibration verification

3.3 PROCESS MODELS

- Bump tests performed on each loop
- Analysis of bump test data
- Transfer functions created

3.4 CONTROL STRATEGIES

- Block diagrams created
- Implementation strategy outlined
- PID algorithm variation chosen (Interacting, Non-Interactive, Parallel)

3.5 DELTAV CONTROL

- Control Loops Programmed
- HMI Created

3.6 PROCESS TUNING

- Tuning parameters for control strategy created by process group
- Determining tuning strategy that works with instruments
- Determine tuning strategy that works for heat exchanger process
- Recording and documenting all test and results

4 BACKGROUND STUDY

The background study is a study of the information and material that is available at the start of the project. This information is necessary in helping to determine the steps necessary for completion of the project.

4.1 PIPING AND INSTRUMENT DIAGRAM

The piping and instrument diagram (P&ID) illustrates the entire process in detail showing process flow, vessels, valves, and other control devices used. The following figure shows the P&ID for this project. For the complete P&ID, refer to APPENDIX A: PIPING AND INSTRUMENT DIAGRAM.

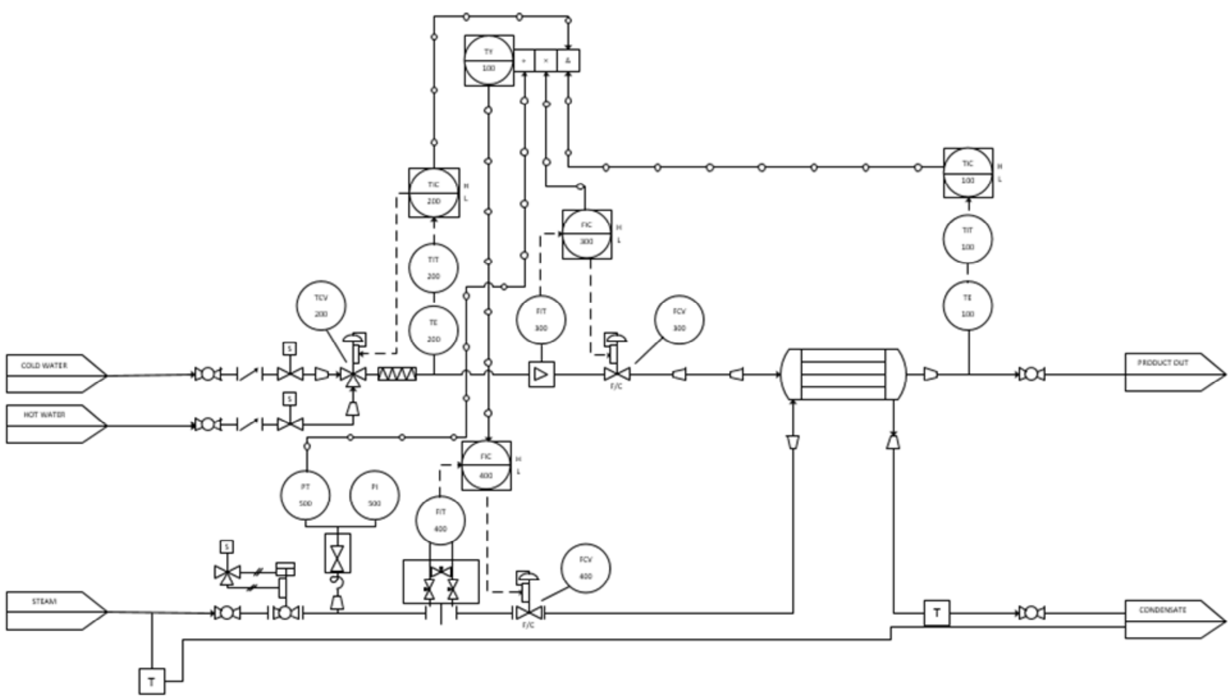


Figure 1 - P&ID Version 3 (PARTIAL)

4.2 INSTRUMENT LOOP DIAGRAM (ILD)

The instrument loop diagram illustrates the individual loops within a process. Wiring, labels, tags, and physical media are all shown with the control devices used in the diagram loop. Below is the ILD of the loop FIC-400, and for all the completed ILDs, refer to APPENDIX B: INSTRUMENT LOOP DIAGRAMS.

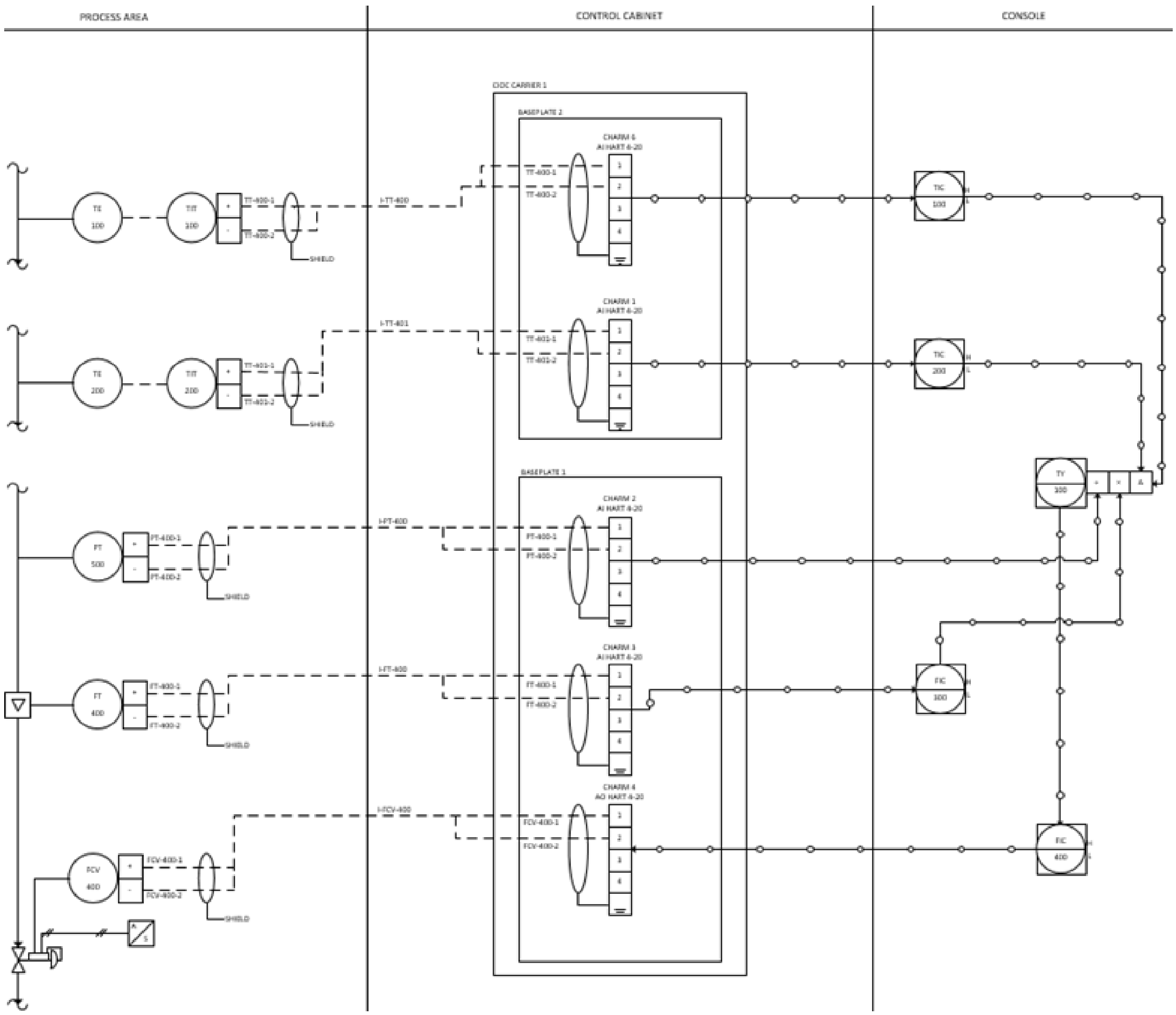


Figure 2 - ILD FIC-400 Version 3 (PARTIAL)

4.3 EXTERNAL DIAGRAMS, SKETCHES, AND SCHEMATICS

Spartan Controls, the company that engineered the heat exchanger process, provided electrical and instrumentation schematics that we have used as references in creating and understanding the project process. All schematics can be found in ANNEX A: SPARTAN SCHEMATICS AND DIAGRAMS. While creating the instrument loop diagrams found in this document, team members utilized a loop diagram template created by an instructor, to view this template refer to ANNEX B: INSTRUMENT LOOP DIAGRAM TEMPLATE.

5 FEASIBILITY ASSESSMENT

This feasibility assessment will serve to prove the viability of the proposed project.

This project was created with the specific intention of providing future RDC students the opportunity to learn about an industrial process not currently afforded. Heat exchangers are a common system found in the instrumentation field and after the completion of this project, students will be able to become familiar with how they operate as well as see functioning process control strategies.

The team members working on this project can apply the knowledge learned throughout their studies to commission the heat exchanger with DeltaV DCS control. Members of the team are knowledgeable, have access to internal consultation and can seek out any additional resources required for aid in the project.

6 ROLES AND RESPONSIBILITIES

This section is a summary of the project teams' organizational structure. It provides an overview of member accountability during each stage of the project, the roles they serve and task responsibility.

6.1 ORGANIZATIONAL CHART

This diagram is a graphical representation of the project teams' relation and helps illustrate how the project work is being managed.

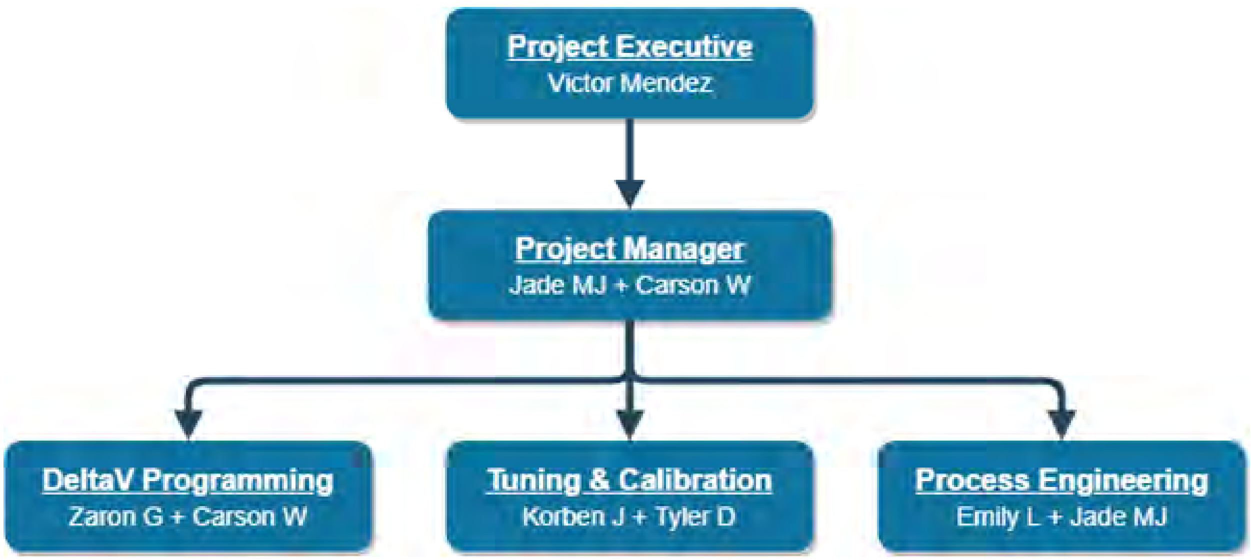


Figure 3 - Organizational Chart

6.1.1 PROJECT EXECUTIVE

VICTOR MENDEZ

Victor will have the main responsibility of overseeing the completion of the project and ensuring it meets the standards of Red Deer College. During the process, regular meetings will take place with the project managers, as well as their team, where project progress will be shared and documented. At these meetings it is the project executive's responsibility to ensure the project is on track and the quality workmanship is up to the owner's standard.

6.1.2 PROJECT MANAGERS

JADE MOORE-JACKSON & CARSON WEST

As co-project managers they share the overall responsibility for the successful initiation, planning, execution, monitoring, controlling and closure of the project. In conjunction they will perform the day-to-day management of the project and have specific accountability for managing the project within the approved constraints of scope, quality workmanship, and project requirements.

6.1.3 DELTAV PROGRAMMING LEADERS

CARSON WEST & ZARON GIBSON

The programming team will oversee the configuration of the DeltaV software, the development of the HMI screen, and the implementation of the control strategies established by the process engineering team. This will involve setting up the DeltaV system, communication modules, I/O CHARMs, and the Safety Instrumented System (SIS). The control strategies devised by the process engineering team will then be implemented in the software and the Human Machine Interface (HMI) will be designed to relay information to the user.

6.1.4 PROCESS ENGINEERING LEADERS

JADE MOORE-JACKSON & EMILY LOUGHEED

The process engineers will be responsible for the determination of the best control strategies and process models to successfully reach the processes' operational needs. This will include the development of process block diagrams as well as the implementation of the control strategy they have determined functions as designed. A PID algorithm variation must also be selected. This will conclude their work regarding control strategies. The process models can later be determined by conducting bump tests on the system. The information gathered from the bump tests will be used to create the process transfer functions. These functions will be taken to the DeltaV programming team. The two teams, process engineering and DeltaV programming, will work together to implement control strategies into the process.

6.1.5 CALIBRATION AND TUNING LEADERS

KORBEN JOHNSON & TYLER DRIESEN

The calibration and tuning team will oversee the validation of all sensors and transmitters during initial project execution. The proper calibration of these instruments will take place when the system is fully functional, allowing the proper zero and spanning of instruments to take place. They will then be responsible for choosing a suitable tuning method and applying it to each control loop.

6.2 RESPONSIBILITY MATRIX

The table below shows the responsibility breakdown of individual members.

Deliverables	Carson West	Emily Lougheed	Jade Moore-Jackson	Korben Johnson	Tyler Driesen	Zaron Gibson	Victor Mendez
Calibrated instruments	I	I	I	RA	RA	I	I
Process Models	I	RA	RA	I	I	I	C
Control Strategies	I	RA	RA	I	I	I	C
DeltaV Configured	RA	I	I	I	I	RA	I
DeltaV HMI	RA	I	I	I	I	RA	I
Process Tuned	C	C	C	RA	RA	C	I
A: Accountable	**R: Responsible**		**C: Consulted**		**I: Informed**		

Table 2 - Responsibility Matrix

Accountable (A): The individuals in charge of making sure that the task is completed.

Responsible (R): The individuals in charge of physically completing the task.

Consulted (C): The individuals who are collaborated with throughout task completion.

Informed (I): The individuals who are notified of task status and completion.

7 CRITICAL ANALYSIS

7.1 PROCESS ENGINEERING

7.1.1 FEEDBACK CONTROL

Feedback control loops are composed of four components: the main system process (sometimes referred to as the “plant”), the measurement and transmitter, the controller, and the final control element (commonly valves). These four components together form the loop as seen in the following block diagram.

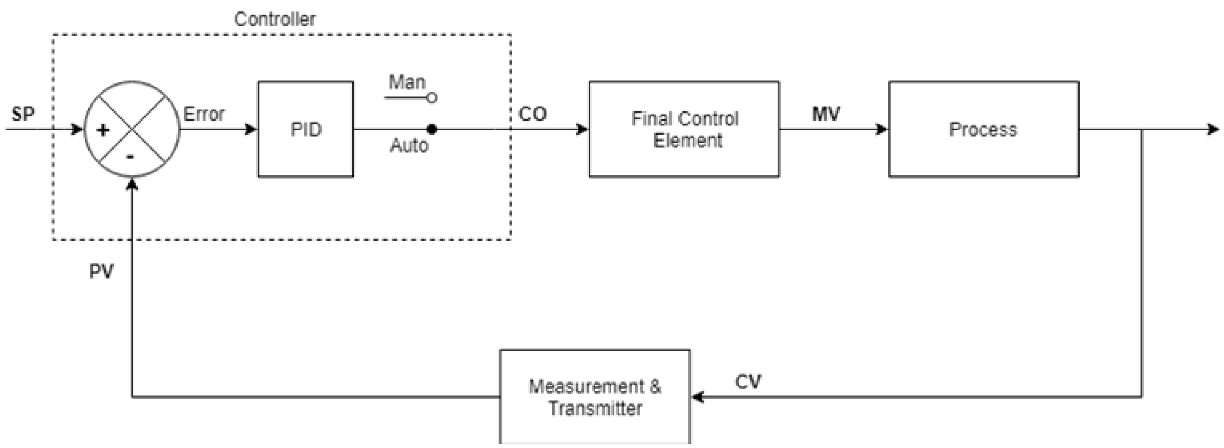


Figure 4: Feedback Control Loop

The process is the variable (flow, temperature, pressure, etc…) that the control loop is trying to regulate to a pre-set specification. It tries to accomplish this by measuring the current process conditions (CV) and transmitting this value to the controller (PV). The controller then compares the PV to the desired value for the process (SP) and determines how much error exists. This error is used by the PID algorithm to calculate how the controller should manipulate the final control element in order to eliminate said error. The generated correction signal (represented as CO) is sent to the final control element which acts to manipulate a variable (MV) that affects the process conditions to the degree needed in order to restore it back to the set point.

Our plant will utilize the feedback control strategy in the following loops:

- Loop 200: Product fluid inlet temperature
- Loop 300: Product fluid inlet flow
- Loop 400: Steam inlet flow
- Loop 100: Product outlet temperature

Loops 100 and 400 will be discussed about in 11.1.4, as they are part of the feedforward control strategy.

7.1.2 LOOP 200: PRODUCT FLUID INLET TEMPERATURE

This negative feedback loop is attempting to control the product fluids inlet temperature by manipulating the flow rates at which the hot and cold-water streams mix.

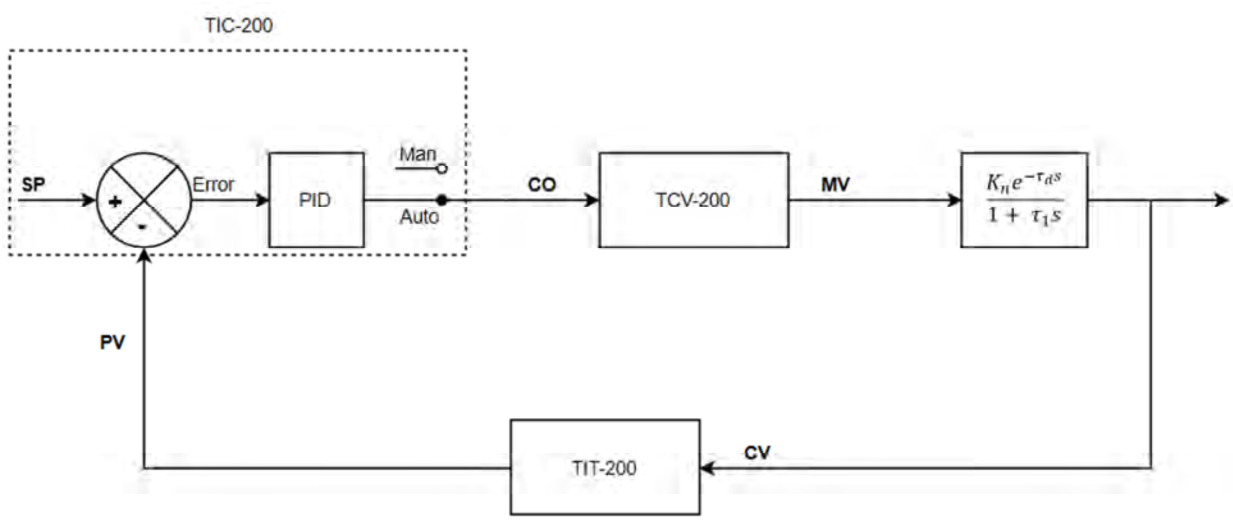


Figure 5: Loop 200 Block Diagram

7.1.3 LOOP 300: PRODUCT FLUID INLET FLOWRATE

This negative feedback loop is attempting to control the product fluids inlet flowrate by directly manipulating the ratio of the combined water streams with a control valve.

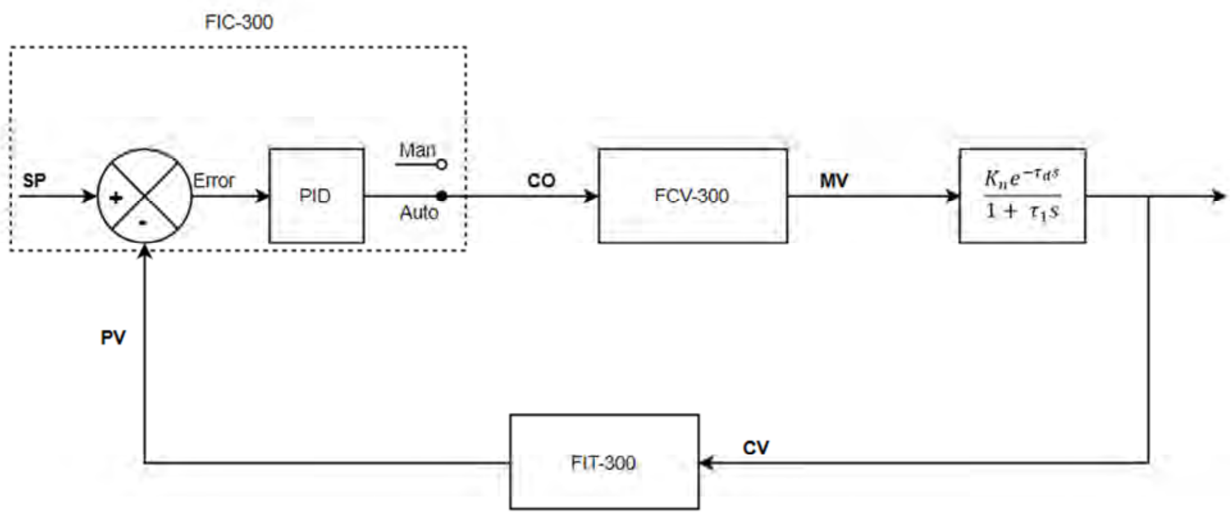


Figure 6: Loop 300 Block Diagram

7.1.4 FEEDFORWARD CONTROL

The main control loop for our plant will be a static model predictive feedforward control strategy with feedback trim and a cascaded inner negative feedback control loop.

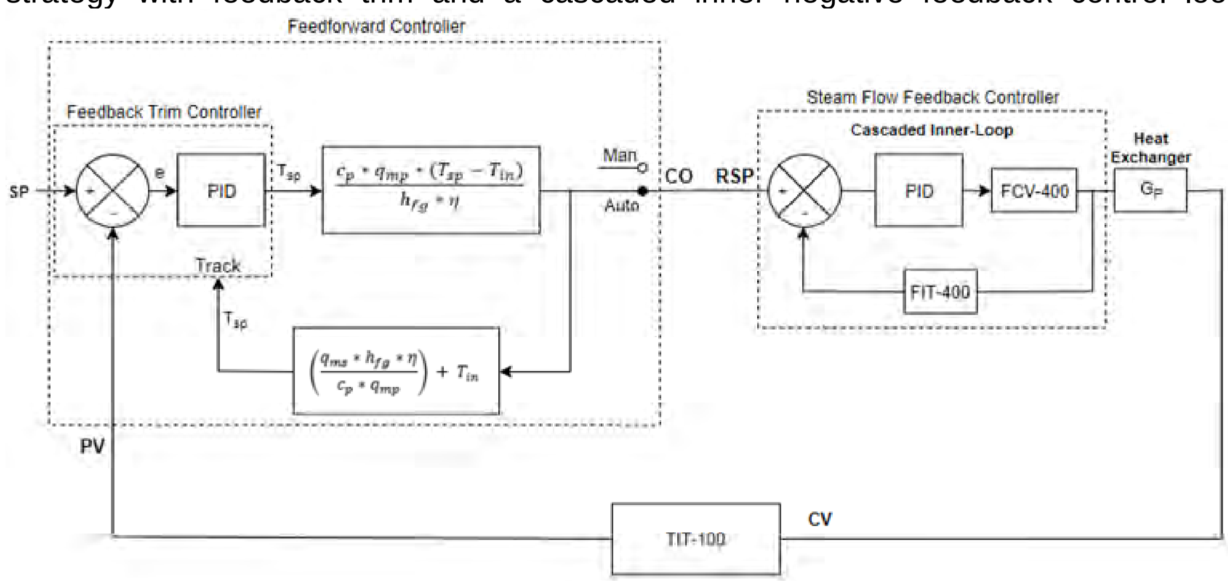


Figure 7: Loop 100 & 400 Block Diagram

Model predictive control uses a mathematical model developed from an energy balance equation to design the control strategy. This allows us to calculate the steam flow required to reach any desired product outlet temperature and accounts for process disturbances such as the product flowrate, product inlet temperature, steam enthalpy, and the specific heat of our product fluid. This control strategy does not require the process to be linear.

The product outlet temperature is the main SP for our plant and is used by TIC-100 to calculate the error from the actual product outlet temperature PV (as reported by TIT-100). This error is used by the PID algorithm to generate the required temperature set-point for the feedforward model. Also used in the model's calculation is the product fluid inlet temperature (as reported by TIT-200) and the product fluid inlet flowrate (as reported by FIC-300). Measuring and implementing these two variables into the model, allows for the control strategy to react to the disturbances they may create before they impact our process.

Energy Loss by Steam

$E = q_{ms} * h_{fg} * \eta$

q_{ms} = Steam mass flow

h_{fg} = Specific Enthalpy of Steam

η = Efficiency

Energy gained by Product

$E = c_p * q_{mp} * (T_{sp} - T_{in})$

c_p = Specific heat

q_{mp} = Product mass flow

T_{sp} = Product Outlet Temperature

T_{in} = Product Inlet Temperature

Using the two energy equations we can substitute and solve for q_{ms}, the required steam flowrate.

$$Energy\ loss\ by\ steam = Energy\ gained\ by\ product$$

$$q_{ms} * h_{fg} * \eta \;=\; c_p * q_{mp} * \left(T_{sp} - T_{in}\right)$$

$$q_{ms} \;=\; \frac{c_p * q_{mp} * (T_{sp} - T_{in})}{h_{fg} * \eta}$$

In order to satisfy the back-calculation tracking requirements DeltaV uses for bump-less transfer and preventing reset windup, we need to solve for T_{sp}.

$$Energy\ loss\ by\ steam = Energy\ gained\ by\ product$$

$$q_{ms} * h_{fg} * \eta \;=\; c_p * q_{mp} * (T_{sp} - T_{in})$$

$$T_{sp} = \left(\frac{q_{ms} * h_{fg} * \eta}{c_p * q_{mp}}\right) + \; T_{in}$$

7.1.5 PID ALGORITHM

The PID algorithm is what the controller uses to calculate the correction signal sent to the final control element. This algorithm can take multiple forms but is based off the following logic.

$$CO = MO + Proportional + Integral + Derivative$$

Where:

$$MO = Manual\ offset\ (or\ initial\ PV = SP)$$

$$Proportional = K_c(e)$$

$$Integral = \; K_c K_i \int (e)\, dt$$

$$Derivative = \; K_c K_d \frac{de}{dt}$$

The equation becomes as follows and represents the standard PID algorithm.

$$CO = MO + K_c(e) + K_c K_i \int (e)\,dt + K_c K_d \frac{de}{dt}$$

$$CO = MO + K_c\left((e) + K_i \int (e)\,dt + K_d \frac{de}{dt}\right)$$

Where:

$$e = error = PV - SP\ (for\ direct\ acting)\ or\ SP - PV\ (\ for\ reverse\ acting)$$

$$K_c = Proportional\ gain\ constant$$

$$K_i = Integral\ gain\ constant\ in\ repeats/minute$$

$$K_d = Derivative\ gain\ constant\ in\ minutes$$

Below is the PID algorithm as contained within the PID function blocks used by DeltaV in the control modules.

The standard form is a discrete implementation of:

$$OUT(s) = \pm GAIN_a \bullet \left(KNL \bullet \left(\frac{P(s) \bullet T_r s}{(T_r s + 1)} + \frac{E(s)}{(T_r s + 1)} \right) + \frac{D(s) \bullet T_r s \bullet T_d s}{(T_r s + 1)(\alpha T_d s + 1)} \right) + \frac{L(s) - F(s)}{(T_r s + 1)} + F(s)$$

For L = OUT (which is the same as OUT being unconstrained) and P = D = E the equations reduce to:

A conventional Standard PID with feedforward,

$$OUT(s) = GAIN_a \bullet \left(1 + \frac{1}{T_r s} + \frac{T_d s}{(\alpha T_d s + 1)} \right) \bullet E(s) + F(s)$$

Where:

E(s) is error (SP-PV)

± is + for reverse acting and – for direct acting (Direct_Acting in CONTROL_OPTS)

KNL is nonlinear gain applied to P + I terms but not to D term. Nonlinear action is activated in FRSIPID_OPTS by selecting Use_Nonlinear_Gain_Modification.

P(s) is the variable to which proportional action is applied. P(s) is determined by parameters STRUCTURE and BETA (which sets the weighting factor for proportional action applied to SP change).

D(s) is the variable to which derivative action is applied. D(s) is determined by parameters STRUCTURE and GAMMA (which sets the weighting factor derivative action on SP change).

L(s) is the external reset input which is either from BKCAL_IN or OUT.

T_r is reset time (parameter RESET) in seconds.

T_d is derivative time (parameter RATE) in seconds

$GAIN_a$ is normalized gain after scaling the parameter GAIN from PV to OUT (DeltaV works in engineering units so it is necessary that the parameter GAIN be scaled to maintain the meaning of the normalized entry).

F(s) is the feedforward contribution.

Figure 8: PID Algorithm

7.1.6 PRELIMINARY FUNCTION BLOCK DIAGRAMS

The DeltaV system utilizes IEC-61131 languages (e.g. Function Block Diagrams, Sequential Function Charts and Structured Text) for developing the control strategies. Our control modules were programmed using Function Block Diagrams (FBD's) and contain a limited amount of structured text within certain blocks. A function block is the basic component of a control module and can be thought of as the building blocks of the control module. Each function block contains grouped coding to achieve standard process control applications (such as applying the PID algorithm, Analog In/Out signal transducing, Discrete In/Out signal transducing). When "wired" together in a logical sequence, multiple function blocks connect and form a control module. Following a contingency plan created in response to the programming sub-team having delayed access to DeltaV, preliminary FBD control modules were created to aid in expediting the programming task. Below you will find the preliminary function block modules for each of our control loops.

Loop 200: Product inlet temperature, feedback control, composed of:

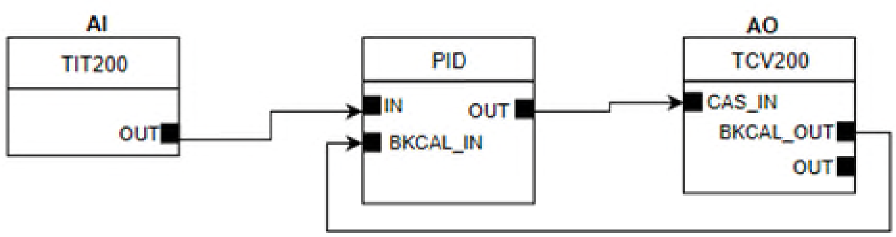


Figure 9: Loop 200 Preliminary Function Block

- Analog Input FB
- PID Algorithm FB
- Analog Output FB

Loop 300: Product inlet flow, feedback control, composed of:

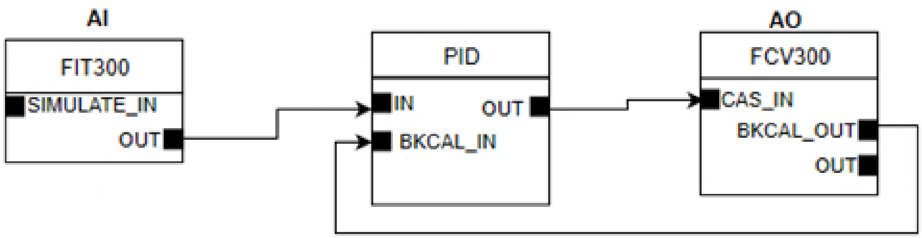


Figure 11: Loop 300 Preliminary Function Block

- Analog Input FB
- PID Algorithm FB
- Analog Output FB

Loop 100: Product outlet temperature, feedback trim, cascade master
Loop 400: Steam flow in, feedforward/feedback control, cascade slave

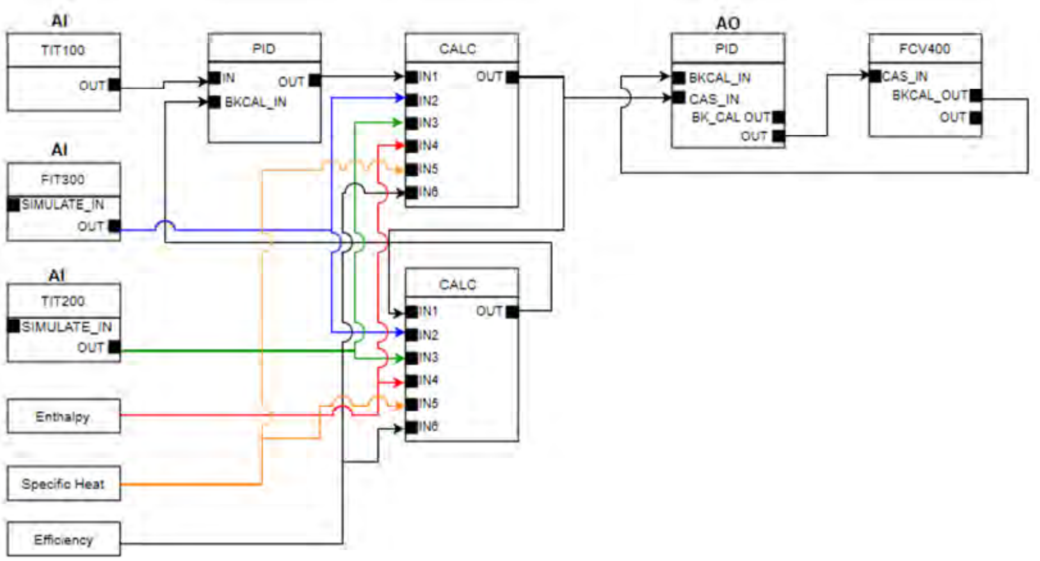


Figure 12: Loops 100 & 400 Preliminary Function Block

The product outlet's temperature control strategy will be more complex. This control strategy requires data from loops 100, 200, 300, and 400. The CV's from each loop are inputted into our feedforward algorithm (contained within the CALC FB), which determines the required position of Loop 400's flow control valve. By manipulating how much steam is entering the heat exchanger we are able to control the product outlets temperature.

7.1.7 BUMP TESTS AND TRANSFER FUNCTIONS

In the beginning of the project, it was determined that it would be required to perform bump tests on each control loop in order to create transfer functions. These transfer functions would then be used to understand and control the process. Due to time constraints and the direction that was taken by the process engineering team, it was no longer necessary to acquire the transfer functions for the project to be successful. For this reason, the bump tests, bump test analysis and the creation of transfer functions were not performed.

7.2 DELTAV CONFIGURATION AND PROGRAMMING

In conjunction to the delay of other tasks caused by the preparations and set-up of the project, the DeltaV programming deliverable and its associated tasks started later than what was predicted. We did expect the deliverables to be completed by March 22. However, we then had another delay after the mini-presentation date where we still could not access the IO cards for our system. This was due to issues with a bad cable, both cables going into the redundant switch, and the switches not having the port configured to allow traffic. Our programming was completed April 3rd.

Through initial set-up of programming and configuration of the DeltaV system, the DeltaV team had to start off with programming the function blocks alongside the CHARMs and the associated tags set for the components of the project.

7.2.1 CONTROL MODULE PROGRAMMING

Using a plant area named "HEAT_EXCHANGER", we created the required control modules in order to automate control of the plant and implement the necessary safety shutdowns. The control modules contain function blocks which perform calculations based on the input variables that then are sent to outputs. The control modules get their process input data from the CHARMS (I/O modules) by reading the values in the device signal tags (DSTs), then use these values in function blocks which perform calculations and ultimately output control values to valves, using DSTs again. Below is a list of all the control modules for our plant.

Contents of 'HEAT_EXCHANGER'

Name	Type	Description	W...	Node Assignment	Scan Rate	Primary Control	Detail	Faceplate
FIC-300	Control Module	PID control loop	No	CTRL2	1 sec	RDC_H_E_MAIN	LOOP_DT	LOOP_FP
FIC-400	Control Module	Slave PID control loop	No	CTRL2	500 ms	RDC_H_E_MAIN	LOOP_DT	LOOP_FP
PI-500	Control Module	STEAM PRESSURE	No	CTRL2	1 sec	RDC_H_E_MAIN	AI_dt	AI_fp
SAFETY_SOLENOID	Control Module	Control Module	No	<unassigned>	1 sec	RDC_H_E_MAIN		MOD_FP
SIS-530	Control Module	Control Module	No	CTRL2	500 ms	RDC_H_E_MAIN	RDC_DL_...	RDC_DL_fp
SV_401	Control Module	Inlet Hot SV	No	CTRL2	1 sec	RDC_H_E_MAIN	RDC_DL_...	RDC_DL_IL_fp
SV_402	Control Module	Inlet Cold SV	No	CTRL2	1 sec	RDC_H_E_MAIN	RDC_DL_...	RDC_DL_IL_fp
TIC-100	Control Module	Master PID control loop	No	CTRL2	2 sec	RDC_H_E_MAIN	LOOP_DT	LOOP_FP
TIC-200	Control Module	PID control loop	No	CTRL2	1 sec	RDC_H_E_MAIN	LOOP_DT	LOOP_FP
TY-100	Control Module	Control Module	No	CTRL2	1 sec	RDC_H_E_MAIN		RDC_calc_fp
XV_530	Control Module	Steam SIS AIR Pressure	No	CTRL2	1 sec	RDC_H_E_MAIN	RDC_DL_...	RDC_DL_IL_fp
XV_531	Control Module	Plant Air Inlet	No	CTRL2	1 sec	RDC_H_E_MAIN	RDC_DL_...	RDC_DL_IL_fp

Figure 13: Heat Exchanger Control Modules

7.2.2 TAGS AND CHARMS

For the DeltaV function block programming, we had to configure and assign device signal tags to the CHARMs contained within the marshalling cabinet. This was required for the DeltaV to control and monitor certain components of the project at any time. The CHARM I/O Controllers (CIOC's) have a 50ms scan time for fast and reliable control. The hardware for the CHARMs is very easy to use, physically snapping into the carrier module with secure DIN-rail latches and interlocking carrier connectors. Below is a list of the active CHARMS in our system. Listed by their physical module and slot number, you can view the assigned type of CHARM it is, a description of what that signal is, the device signal tag assigned, and what the functionality of the charm is.

Contents of 'CHARMs'

Name	Type	Description	Needs D...	Device T...	CHARM Functionality	Node Assignment
CHM1-01	DO 24 VDC Isolated CHARM	Air Supply to Steam SIS Valve	No	XV-530	Discrete Output CHARM	CTRL2
CHM1-02	AI 4-20 mA HART CHARM	Steam Pressure	No	PT-500	HART Analog Input CHARM	CTRL2
CHM1-03	AI 4-20 mA HART CHARM	Steam Flow	No	FIT-400	HART Analog Input CHARM	CTRL2
CHM1-04	AO 4-20 mA HART CHARM	Steam Valve	No	FCV-400	Analog Output 4-20 mA CH...	CTRL2
CHM1-05	AO 4-20 mA HART CHARM	Steam Pressure	No	SV-530	HART Analog Output CHARM	CTRL2
CHM1-07	DO 24 VDC Isolated CHARM	Inlet Hot	No	SV-401	Discrete Output CHARM	CTRL2
CHM1-08	DO 24 VDC Isolated CHARM	Inlet Cold	No	SV-402	Discrete Output CHARM	CTRL2
CHM1-09	AO 4-20 mA HART CHARM	3-Way Valve	No	TCV-200	HART Analog Output CHARM	CTRL2
CHM2-01	AI 4-20 mA HART CHARM	Inlet Temperature	No	TIT-200	HART Analog Input CHARM	CTRL2
CHM2-02	AI 4-20 mA HART CHARM	Inlet Flow	No	FIT-300	HART Analog Input CHARM	CTRL2
CHM2-03	AO 4-20 mA HART CHARM	Inlet Valve	No	FCV-300	HART Analog Output CHARM	CTRL2
CHM2-06	AI 4-20 mA HART CHARM	Outlet Temperature	No	TIT-100	HART Analog Input CHARM	CTRL2
CHM2-09	DO 24 VDC Isolated CHARM	Air Pressure	No	XV-531	Discrete Output CHARM	CTRL2

Figure 14: Heat Exchanger CHARM's

See APPENDIX M: CIOCs AND CHARMs for a picture of the CIOC and CHARM hardware used in our plant.

7.2.3 TIC-100

Loop 100: Product Outlet Temperature, Cascade master

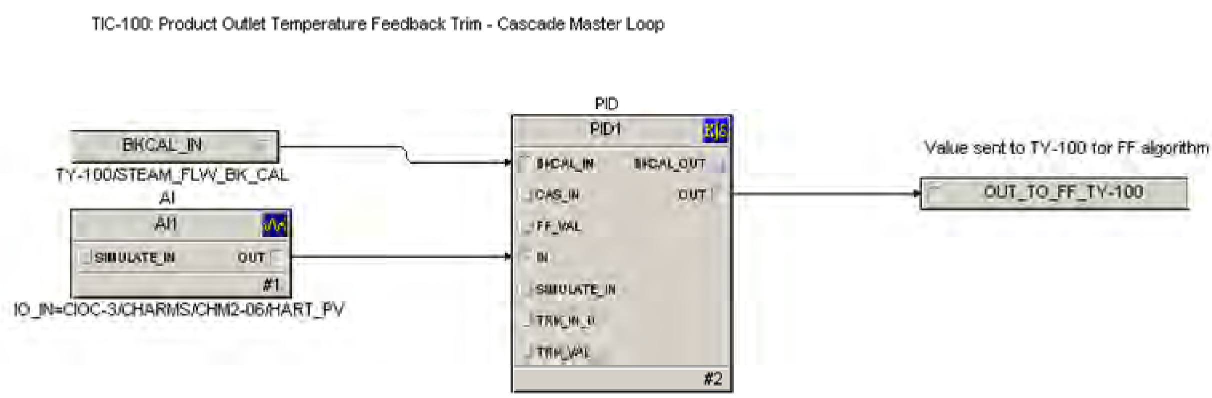


Figure 15:TIC-100 Control Module

This control module, TIC-100, is used to control the temperature of the product as it leaves the plant. As the master in the cascade loop, the output signal from the PID function block does not go to a valve, but instead is sent to the TY-100 control module where the value is used in the feedforward algorithm. This provides the feedback trim to our plant and will account for any steady state offset of the PV from SP that would result from using a feedforward model that is theoretically derived. Composed of an analog input FB assigned to DST TIT-100, a PID algorithm FB, and an external parameter which supplies the signal to the other control module.

7.2.4 TY-100

Feedforward Temperature Relay, see APPENDIX K: TY-100 CONTROL MODULE for an expanded figure.

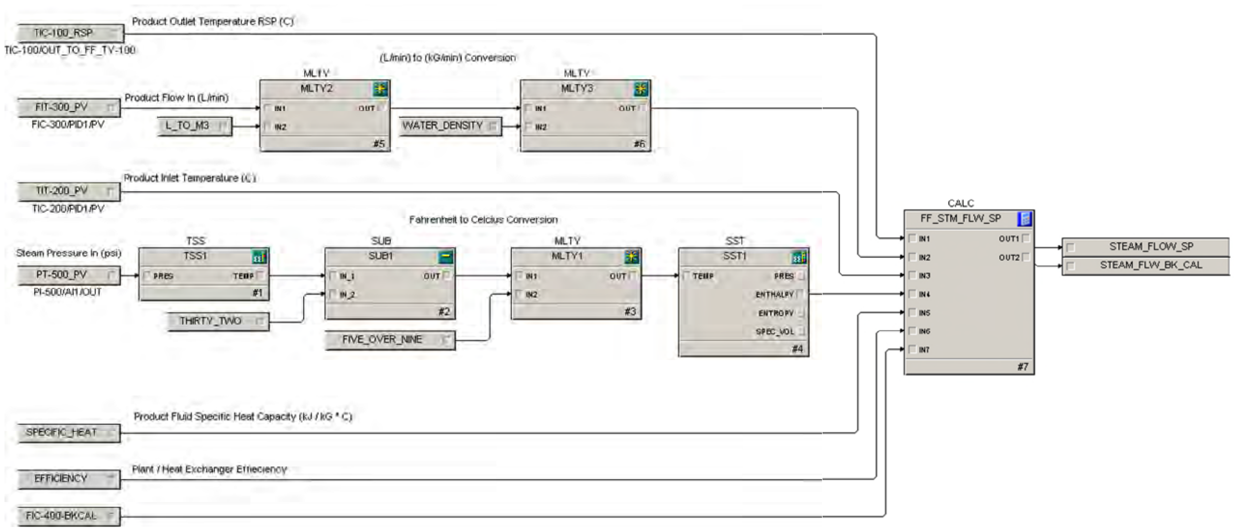


Figure 16: TY-100 Control Module

This control module, TY-100, is what represents the feedforward control aspect of our plant. There are two outputs, the back-calculation value sent to TIC-100 and the RSP sent to FIC-400. The RSP is calculated by the feedforward model CALC block, which has the following six inputs:

- Product Outlet Temperature RSP: sent from the TIC-100 control module in °C to the CALC block.
- Product Flow In: the PV of loop 300, sent in LPM then converted to kg/min by using two multiply blocks. The first (MLTY2) is multiplying by 1000 to convert L to m^3, the second (MLTY3) is multiplying by the product fluid density (997 kg/m^3 for water). The resulting mass flow rate is then to the CALC block.
- Product Inlet Temperature: the PV of loop 200, sent in °C to the CALC block.
- Steam Pressure In: measured by PT-500 in psi units, this signal is sent to the Saturated Temperature (TSS) block which calculates the steam temperature at saturation at the measured steam pressure. The TSS block is set to US units and its temperature output is in Fahrenheit, however we need °C for the SST block. Therefore, we used the combination of a subtraction and a multiplication block to perform the conversion to Celsius $°C = (°F - 32) * \frac{5}{9}$. The temperature is then sent to the Saturated Steam Properties - Given Temperature (SST) block which calculates the steam enthalpy at the reported temperature. Finally, this enthalpy is sent to the CALC block. The SST block is set to metric or SI units.
- Product Fluid Specific Heat Capacity: this is a constant value used within the CALC block, set to 4.18 $\frac{kJ}{kg(°C)}$.
- Plant (Heat Exchanger) Efficiency: this is another constant value used in the CALC block to compensate for the real-life efficiency reductions of the plant versus the theoretical maximum, which is what the model is based on. Set to 93% efficient (values used are in decimal form: .93)

All 6 inputs of the TY-100 feed into the FF_STM-FLW-SP CALC block. This function block is where the model for our feedforward control resides. Using structured text, we are able to program in the mathematical equation, as seen below in the CALC expression figure. Line 8 is calculating the required steam flowrate to satisfy the TIC-100 SP while taking into account the major disturbances of the plant before they affect the product outlet temperature. Line 11 and 12 are for status handling through the CALC block, required for the downstream PID block, without this code the FIC-400 controller will not leave Iman mode.

Expression:

```
1  Outlet_Temp:=IN1;
2  Inlet_Flow:=IN2;
3  Inlet_Temp:=IN3;
4  Steam_Enthalpy:=IN4;
5  Specific_Heat:=IN5;
6  Efficiency:=IN6;
7  Steam_Flow:=OUT1;
8  OUT1:=(Specific_Heat * Inlet_Flow  * (Outlet_Temp - Inlet_Temp)) / (Steam_Enthalpy * Efficiency);
9  OUT2:=((Steam_Flow * Steam_Enthalpy * Efficiency) / (Specific_Heat * Inlet_Flow)) + Inlet_Temp;
10 'OUT2.ST'  := 'IN7.ST';
11 IF  ('IN1.ST'<128)OR('IN2.ST'<128)OR('IN3.ST'<128)OR('IN4.ST'<128)THEN
12 'OUT1.ST':=BAD;
13 ENDIF;
```

Figure 17: CALC Expression

7.2.5 FIC-400

Steam Flowrate In, Cascade slave.

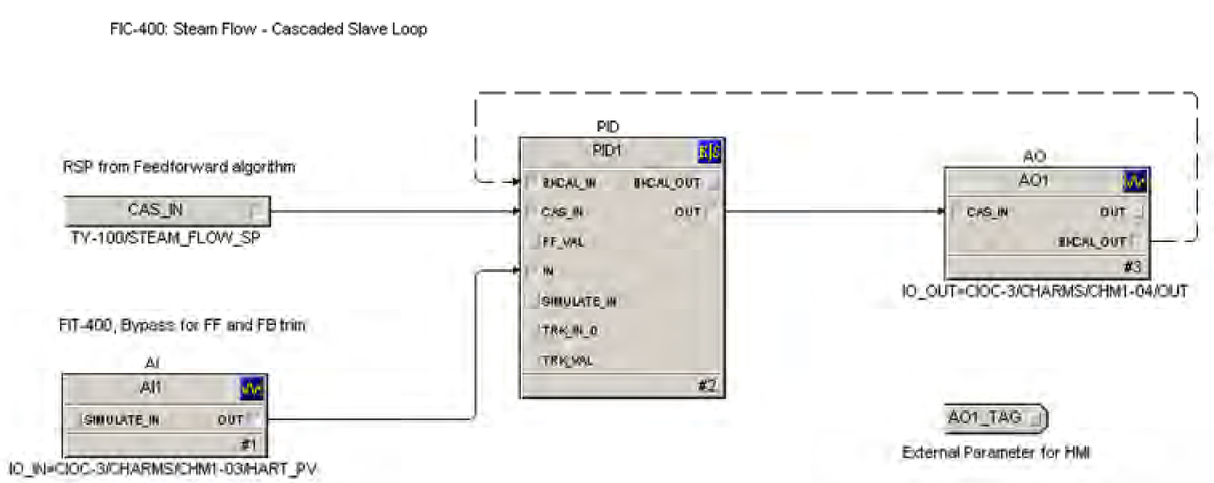


Figure 18: FIC-400 Control Module

This control module, FIC-400, controls the flow rate of the steam entering the plant. Being the cascaded slave loop for TIC-100, instead of receiving a set-point from an operator, the required steam flow set-point is collected from the TY-100 feedforward algorithm output. Composed of an analog input FB assigned to DST FIT-400 (to allow a bypass from feedforward control to feedback only), a PID algorithm FB, and an analog output FB assigned to DST FCV-400.

7.2.6 TIC-200

Product Inlet Temperature, Cascade master

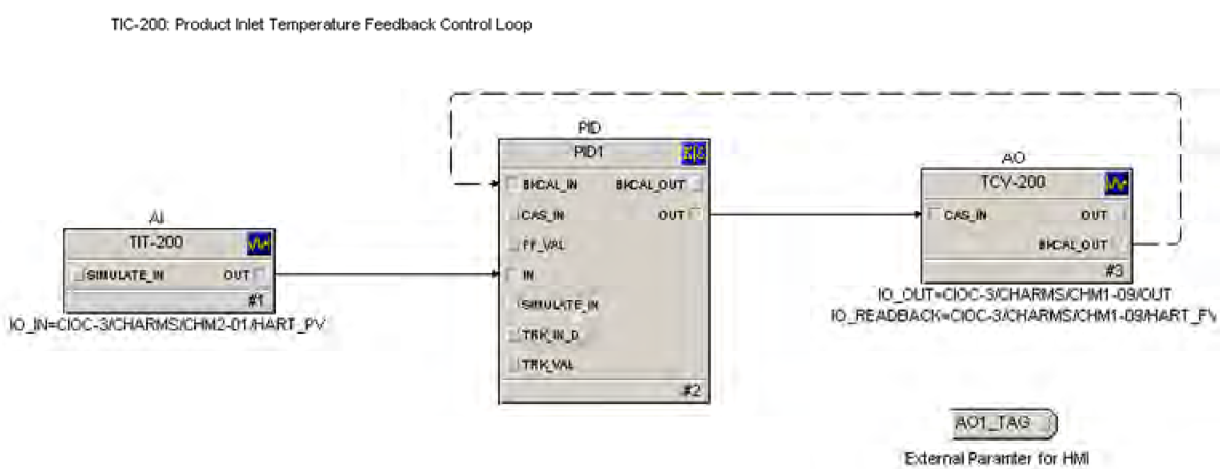


Figure 19: TIC-200

This control module, TIC-200, controls the temperature of the product inlet fluid. Composed of an analog input FB assigned to DST TIT-200, a PID algorithm FB, and an analog output FB assigned to DST TCV-200.

7.2.7 PT-500

Steam Pressure In

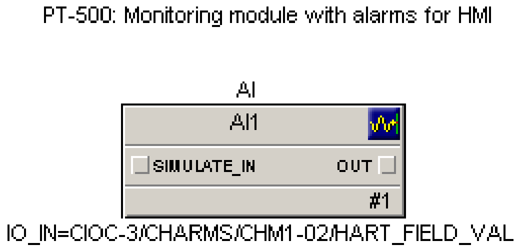


Figure 20: PT-500

This control module was created to only collect the measurement from the pressure transmitter 500. This measurement is used in the TY-100 control module to dynamically calculate the steams enthalpy and is displayed on the HMI.

7.2.8 FIC-300

Product Inlet Flow

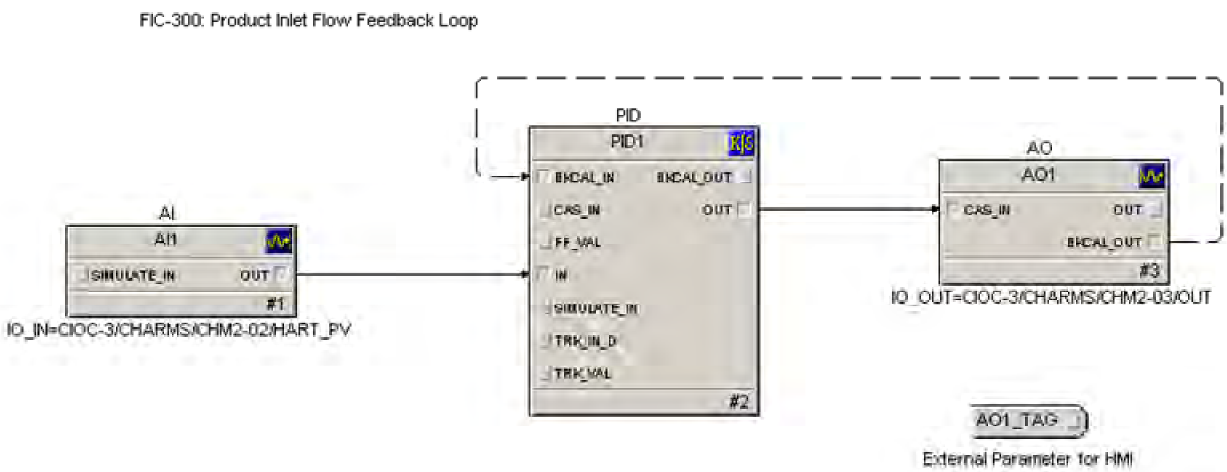


Figure 21: FIC-300 Control Module

This control module, FIC-300, controls the product inlet flow to the heat exchanger. Composed of an analog input FB assigned to DST FIT-300, a PID algorithm FB, and an analog output FB assigned to DST FCV-300.

7.2.1 SIS-530

Process safety implementation for the SIS valve on the plant steam supply line.

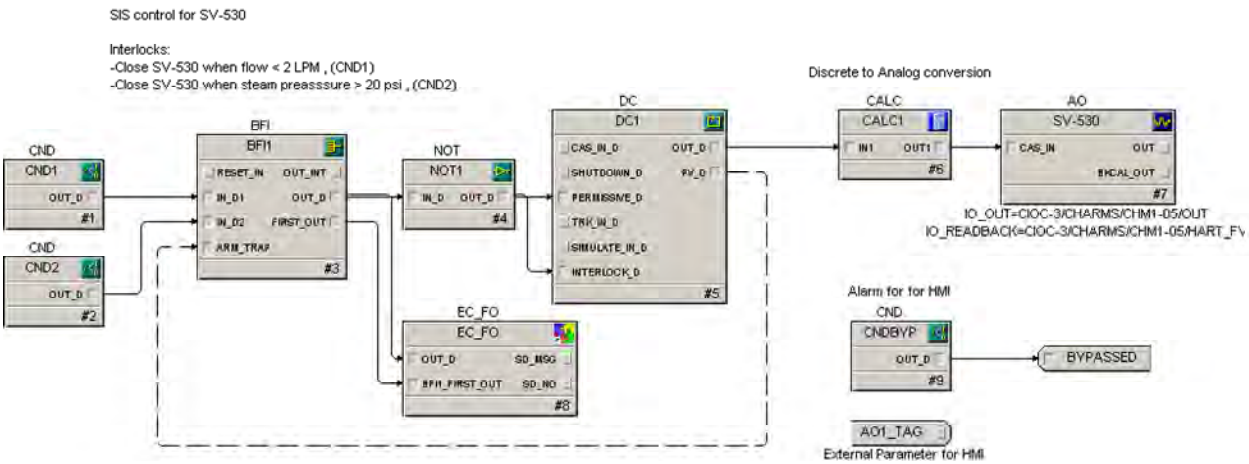


Figure 22: FIC-300 Control Module

This control modules, SIS-530, is the implementation of our safety conditions for the SIS valve which can block in the plant steam supply line. Normally open, the valve only shuts when one of the specified two safety limits are reached. The two currently programmed safety conditions are:

- No product flow: when the flow rate of the product inlet line falls under 2 LPM as measured by FIT-300, the SIS valve will close. This is to prevent the steam from thermal cracking dry tubes within the heat exchanger.
- High steam pressure: when the pressure of the steam supply line rises above 20 psi as measured by PT-500, the SIS valve will close. This is to prevent off-spec and potentially dangerous pressures of steam to enter the heat exchanger.

Each condition block is programmed to have an expression that goes true when its associated safety condition is met. This causes the SIS valve to interlock, close, and send an alarm. This control module can be expanded to have up to 8 separate conditions and is composed of multiple condition blocks, a Boolean fan input block, NOT logic block, device control block, external parameters, and a custom block. Due to the DVC on the SIS valve requiring a 4-20mA signal an analog output block must be used, however the output signal from the DC block is a Boolean. To enable the DC to still control the valve we introduced a CALC block that multiples the input value by 100, then sends its signal to the AO block. This gives us analog On/Off control of the SIS valve from the discrete signal.

7.2.2 SV-401 AND SV-402

Solenoid Safety Valves: Product inlet hot (SV-401) and product inlet cold (SV-402).

This control module is not in current use however it would allow interlocks to be implemented on the SV-401 valve (process inlet. hot)

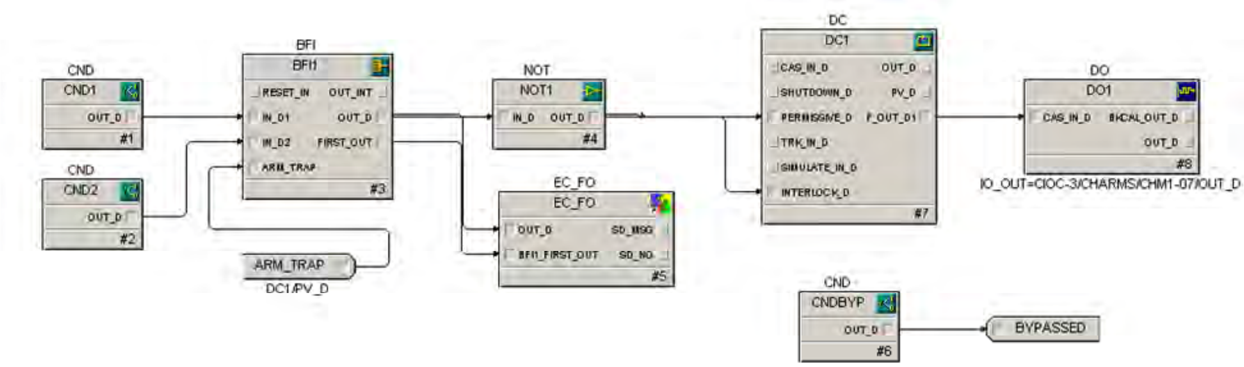


Figure 24: SV-401 Control Module

This control module is not in current use however it would allow interlocks to be implemented on the SV-402 valve (process inlet cold)

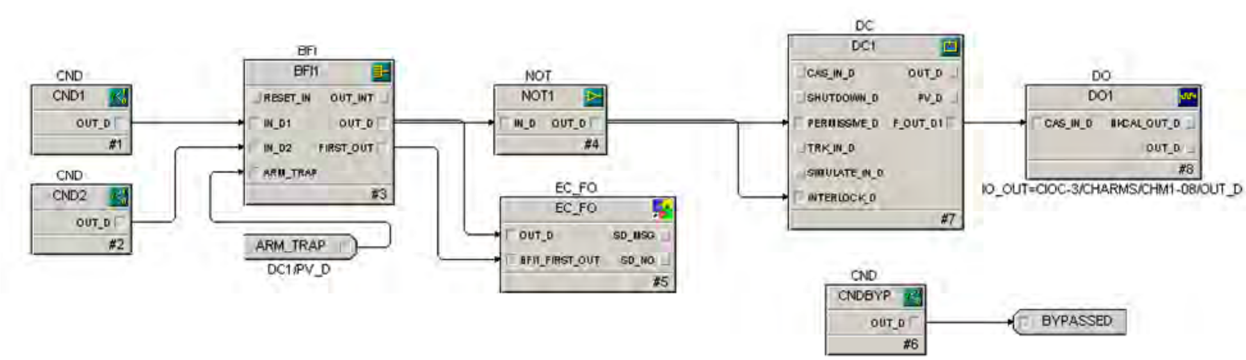


Figure 23: SV-402 Control Module

These two control modules, SV-401 and SV-402, allow for the implementation of safety conditions on the solenoid valves located on the product inlet line for both hot and cold streams. Currently not being used, each condition block can be programmed to have an expression that when true, would cause the associated valve to interlock, close, and send an alarm. This control module can be expanded to have up to eight separate conditions.

Composed of multiple condition blocks, a Boolean fan input block, NOT logic block, device control block, discrete output block, external parameters, and a custom block.

7.2.3 XV-530 AND XV-531

Solenoid Safety Valves: Plant air supply (XV-531) and air supply to the steam SIS valve (XV-532).

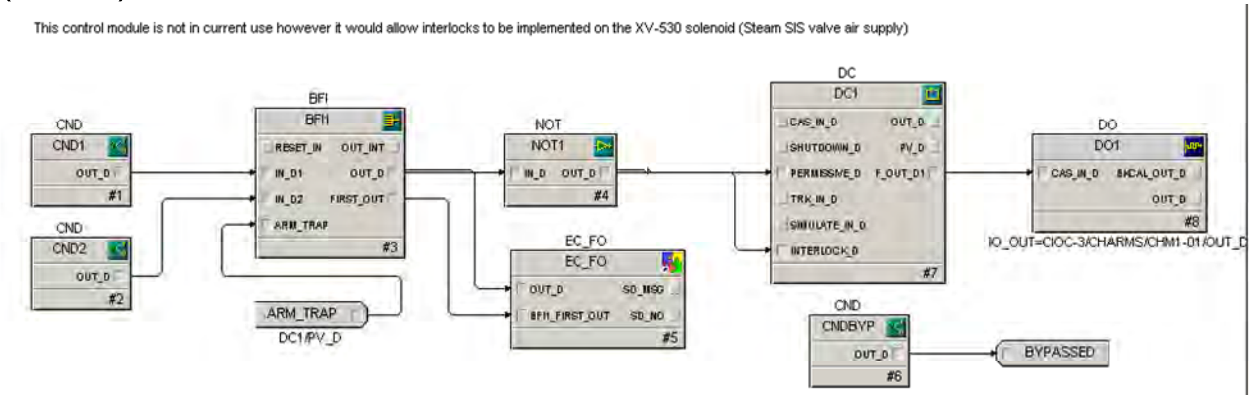


Figure 26: XV-530 Control Module

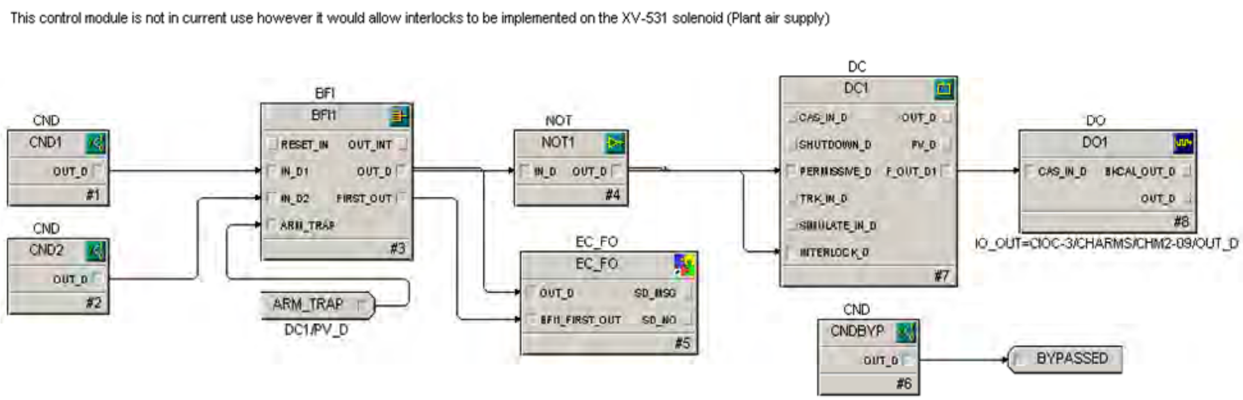


Figure 25: XV-531 Control Module

These two control modules, XV-530 and XV-531, allow for the implementation of safety conditions on the solenoid valves located on the plant air supply line, and on the air supply line to the steam SIS valve. Currently not being used, each condition block can be programmed to have an expression that when true, would cause the associated valve to interlock, close, and send an alarm. This control module can be expanded to have up to eight separate conditions.

Composed of multiple condition blocks, a Boolean fan input block, NOT logic block, device control block, discrete output block, external parameters, and a custom block.

7.2.4 HUMAN MACHINE INTERFACE

The Human Machine Interface (HMI) was designed based off the P&ID of the plant but was stripped of any information that was not necessary for the operation of the plant. The HMI main screen displays the system containing all the controllers, transmitters, control and safety valves. The individual controllers can be expanded to display their faceplate, showing vital operational information such as the PV, the current SP and the CO. Using the faceplate, a user can put the loop into cascade/automatic/manual, change the SP or CO, access trends and detailed PID information, view and acknowledge alarms, and open the associated control module. The HMI and the faceplates allow the Tuning and Calibration team to set alarms, view trends, and change PID parameters with the plant on-line to quickly tune the process. It also allows users to easily introduce and control disturbances, to demonstrate different process control methodologies.

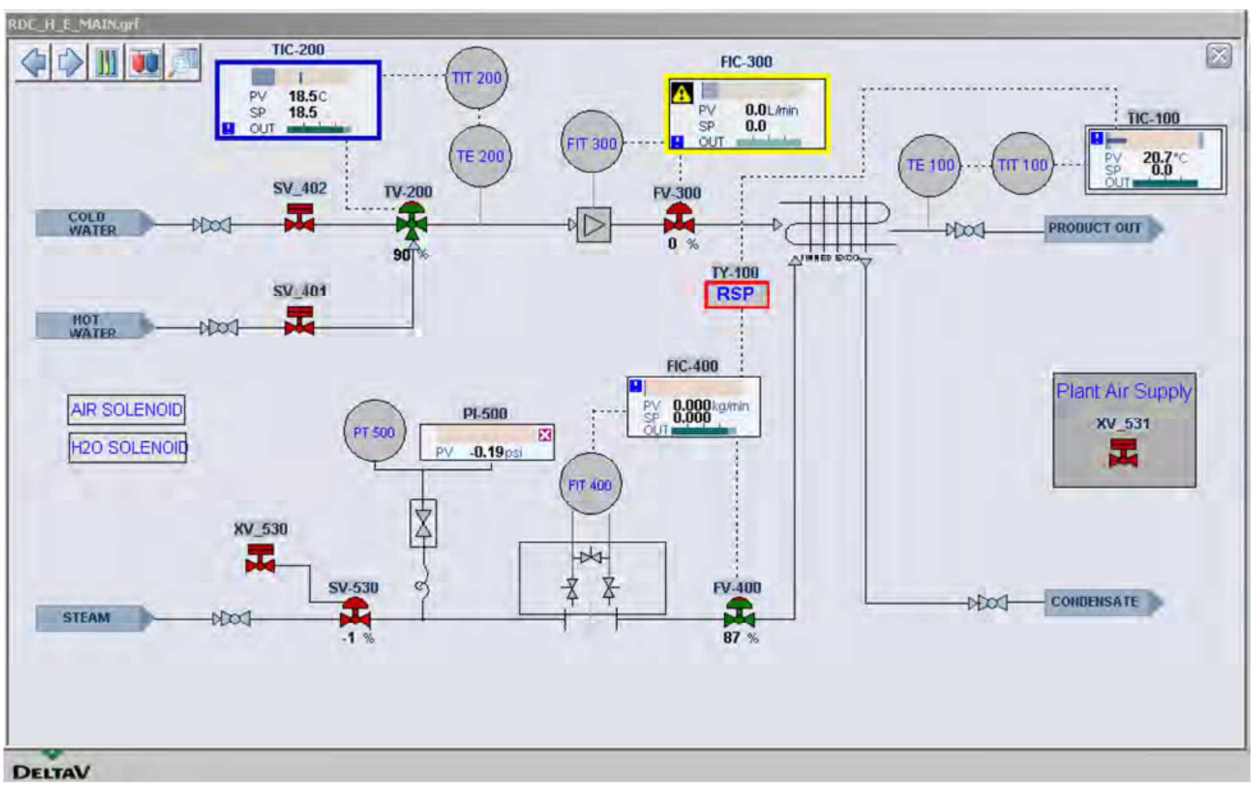


Figure 27 – HMI System Screen

The heat exchanger HMI is a picture called RDC_H_E_Main. This was built from a template using Dynamos from RDC_Dynamos and other sources. The main HMI screen contains figures that can be controlled such as valves while excluding others such as the pipe expanders and reducers and the backflow value because they do not have an ability to control them. Since we have a three-way mixing valve, a custom 3-way valve was created for the project.

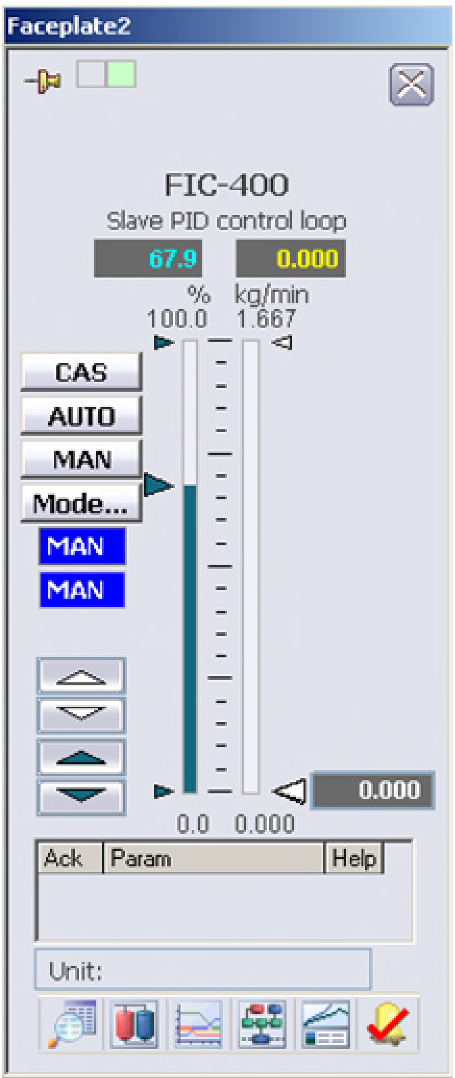


Figure 29: FIC-400 Faceplate

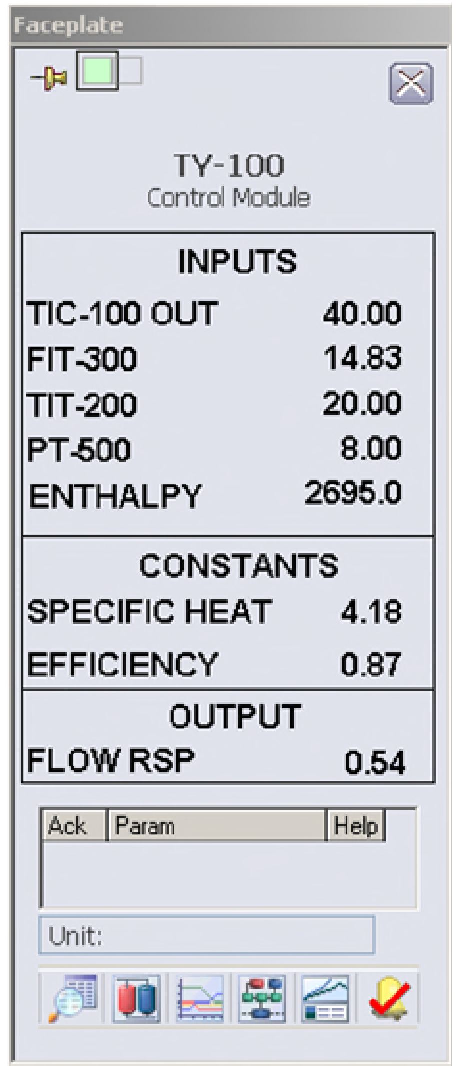


Figure 28: TY-100 Faceplate

Here is an example of a faceplate for FIC-400 and the custom-built faceplate for the TY-100 feedforward relay, which displays the values going into the algorithm and allows you to easily change the constants. See APPENDIX J: CONTROLLER PID FACEPLATES for an example of the detailed information you can gain access to by using the faceplate.

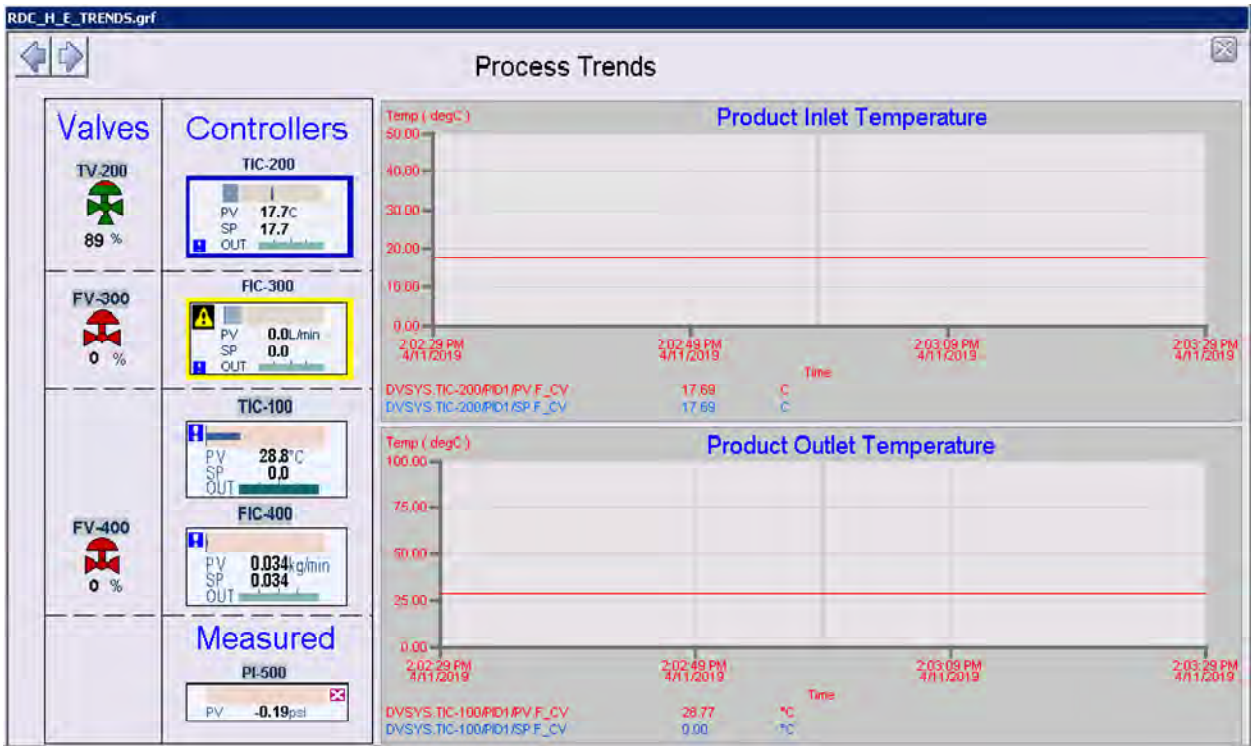


Figure 30 – HMI Trends Graphs

The other HMI screen that has been created displays the trends of the product temperature into and out of the heat plant. The values shown in the y-axis are the temperatures represented as degrees Celsius and as time on the x-axis. The HMI trend will continuously update and scroll until the system is taken out of run mode. The left-hand columns contain the valves and the loops so that the operator can click on them to bring up the faceplates and change the values while monitoring changes in the trend charts.

7.3 DRAWINGS, CALIBRATION, MAINTENANCE AND TUNING

7.3.1 DRAWINGS

For the creation of the piping and instrument diagram (P&ID) individual loops were identified and tags were applied following the individual loops. All symbols used in the creation of the P&ID of the plant follow ISA-5.1-2009 standards.

Instrument loop diagrams (ILD) help to define how the instruments are interacting in each control loop of the plant. These loops also help to illustrate what inputs and outputs an individual controller is in control of. The diagram shows what the controller's output is controlling or sending a signal or data to.

A spreadsheet was created identifying the wiring conventions used and were the wires connected, which helped to ease the identification of the instruments and the configuration of the DeltaV charms.

7.3.2 CALIBRATION AND MAINTENANCE

Before calibration could begin the ranges of each element needed to be determined. The inlet into the plant is two streams of water; we had to determine what the temperature of each stream was coming in and the flow rate was when the streams combined to enter the heat exchanger. For the hot water inlet a maximum temperature of 43°C was determined and for the cold water inlet a minimum of 5°C was determined. With both inlets fully open a maximum flow rate of 30 litres per minute (L/min) was found. After determining these values ranges for the plant were determined.

In the steam inlet loop the instrument FIT-400 was displaying an error and not displaying a flow rate, which after further investigation into the error codes the cause was determined to be no temperature probe was connected to the transmitter. After troubleshooting a possible solution was found to fix the temperature at a specific value of the steam. To confirm this solution or to find a better solution Spartan Control was contacted, which confirmed that the model of the FIT-400 can be installed without a temperature element and the solution was to fix the temperature. To find the temperature an infrared detector and steam tables were used, which both found the temperature of the steam to be approximately 105°C.

There was a part of the plant that we could not find looking at the plant its self, the static mixer, but with the help of Clifford Long we were able to remove a section of pipe. In this section of pipe, we found the static mixer and documented it. Refer to **Error! Reference source not found.** to view an image taken after disassembly.

When calibrating the temperature transmitter, we noticed that we were not getting a correct milliamp reading for the corresponding temperature. To trouble shoot this problem we took off the back plates of each transmitter and noticed they contained a three-wire RTD. Further investigation into the problem involved going into the basic setup of the temperature transmitter was set, the result was the selected wiring was a 4-wire RTD. After correcting this setup issue with the Trex communicators the correct readings were transmitting from the transmitters.

When we started up the process, we noticed the three-way valve was not functioning properly, this was identified by a loud screeching notice when attempting to fully open the valve. Upon further investigation we noticed that the valve body was on backwards. After correcting the position of the valve body testing confirmed the valve was functioning correctly.

7.3.3 TUNING

Once the DeltaV programming and the Human Machine Interface (HMI) configuration was complete the tuning of the plant could commence. The methods for tuning the plant were the Zeigler Nichols Open and Closed loop tuning methods and the DeltaV Insight tuning software. Both provided approximate parameters that were complemented with additional fine adjustments if required. With the feedback and feedforward control strategies implemented tuning needed to be completed in a specific order to allow for the feedforward cascade loops to interact with each other correctly. The project required the control to be static only so the tuning parameters that were used were proportional and integral actions, or PI control. Proportional is the amount of change in the control variable required to get the loop output to zero to a hundred percent. Integral parameter refers to the continuing effect of increasing or decreasing the output range as long as no offset or drop off exists. The four controllers needed to be tuned in a certain order to allow for the feedforward cascade control loops to act correctly and fast enough to allow for required compensation if a disturbance was introduced. The feedback loops were tuned first to provide fast and accurate data to the TY-100 block for the steam flow calculation. Then the FIC-400 was tuned as the inner loop in the feedforward cascade control, meaning the FIC-400 controller needed to be five times faster than the TIC-100 controller to provide effective feedforward control, and once complete, the TIC-100 loop could be tuned.

7.3.4 FIC-300 LOOP TUNING

To tune the FIC-300 loop, the Ziegler-Nichols' Closed Loop tuning method was applied. To use this method, we needed to manipulate the loop parameters to reach a sustained oscillation state, meaning the output of the process will fluctuate up and down without increasing or decreasing in amplitude. To achieve this the controller parameters are set as follows: the proportional action is adjusted to reach the state, the integral action is set to the maximum possible to effectively negate the effect, and the derivative action is set to zero. After the parameters have been set, the controller is placed into automatic (AUTO) mode at a steady state, then a step change in setpoint is applied. Depending on how the process responds the proportional action may need to be increased or decreased, in our case the response amplitude decreased and reached a steady state. After increasing the proportional action, the response reached the sustained oscillation required, refer to Figure 31 - FIC-300 Sustained Oscillationsto view the FIC-300 loop in sustained oscillation. With the process in the sustained oscillation state the proportional action and the period of the response are recorded to determine the proportional and integral action parameters values using the Ziegler-Nichols' Closed Loop table, refer to Table 3 – Ziegler-Nichols' Closed Loop Table for the table used. The recorded value of the proportional action was 1.00 and the period of oscillation was 7 seconds, then using the table the following calculations were completed providing the proportional and integral action parameter value used.

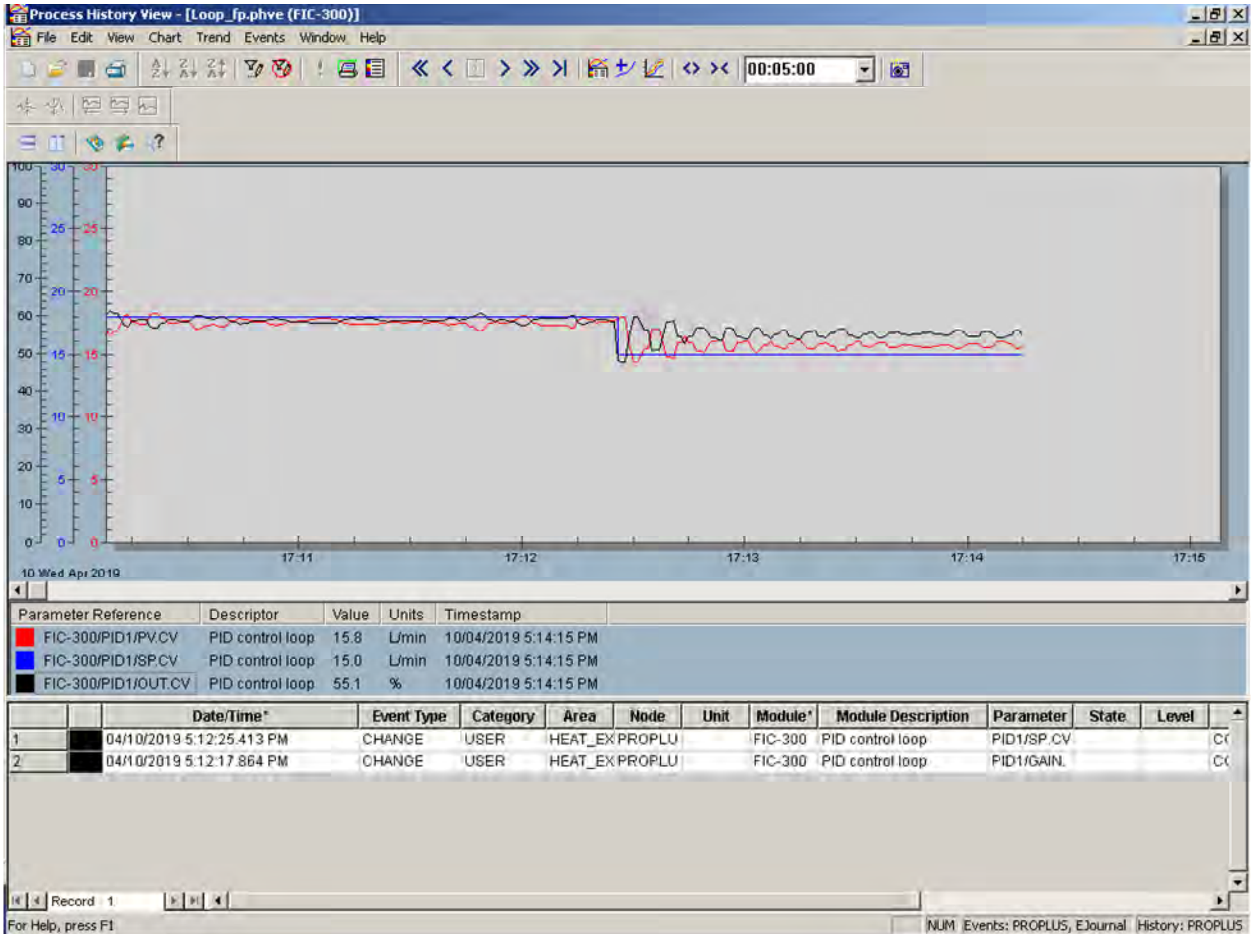


Figure 31 - FIC-300 Sustained Oscillations

	K_p	T_i	T_d
P controller	$0.5K_{p_u}$	∞	0
PI controller	$0.45K_{p_u}$	$\frac{P_u}{1.2}$	0
PID controller	$0.6K_{p_u}$	$\frac{P_u}{2}$	$\frac{P_u}{8} = \frac{T_i}{4}$

Table 3 – Ziegler-Nichols' Closed Loop Table

$$Proportional\ Action = K_P = 1.00 \rightarrow P_{controller} = 0.45(K_P) = 0.45(1.00) = 0.45$$

$$Integral\ Action = P_u = 7 \rightarrow I_{controller} = \frac{P_u}{1.2} = \frac{7}{1.2} = 5.8\ sec/rpt$$

After applying the parameters calculated above, a 10% step change in the setpoint was applied to and the process response reached the setpoint in an acceptable time, but additional fine tuning was applied. The fine-tuning changes made included changing the proportional and integral actions, but after further testing the best response required a decrease in the integral action from 5.8 seconds per repeat to 4.0 seconds per repeat. Figure 32 - FIC-300 DeltaV Operate (Run) and HMI Tuning Windowsillustrates the DeltaV Operate (Run) interface with the created HMI windows and Figure 33 - FIC-300 Tuned Responsedemonstrates the process response in a step setpoint change of 10% in the positive and negative directions.

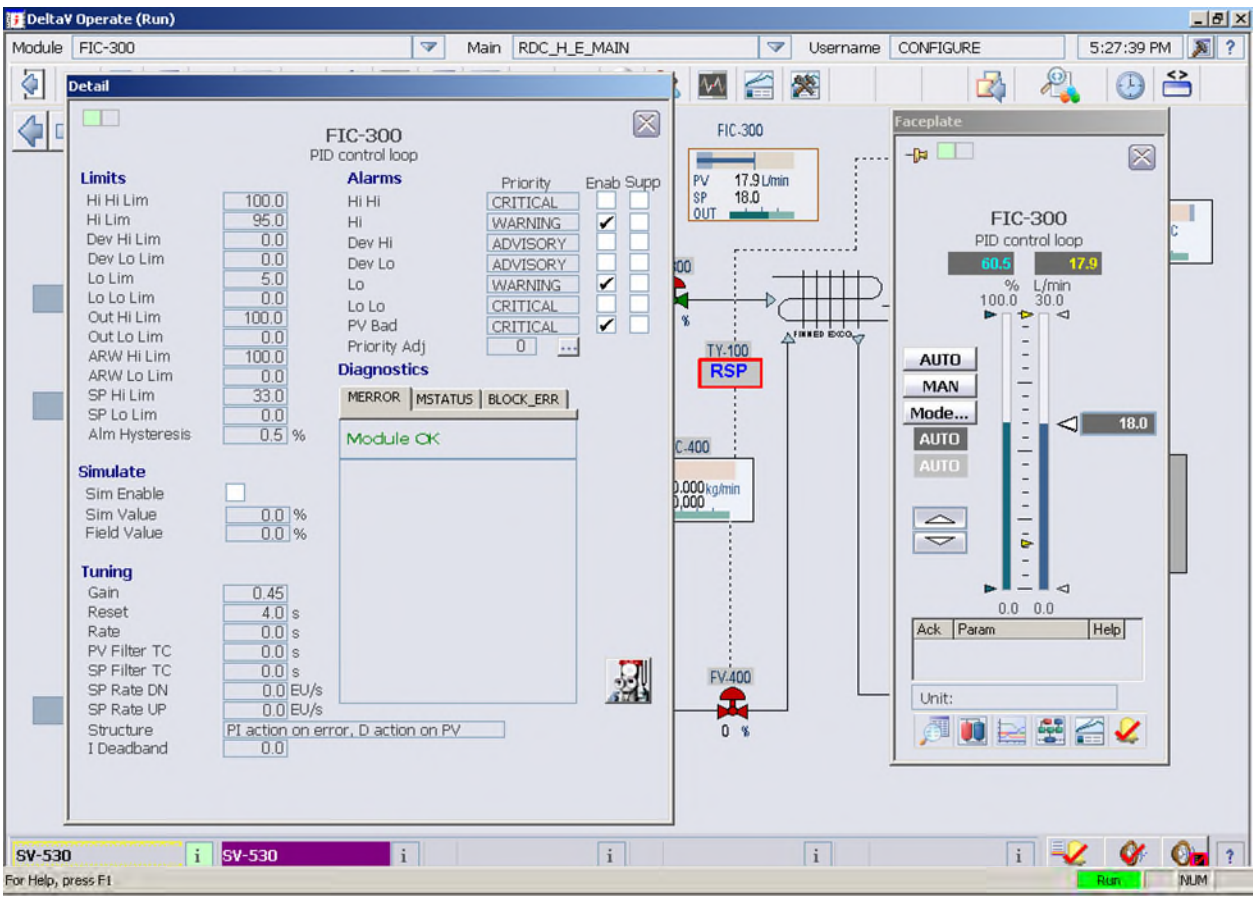


Figure 32 - FIC-300 DeltaV Operate (Run) and HMI Tuning Windows

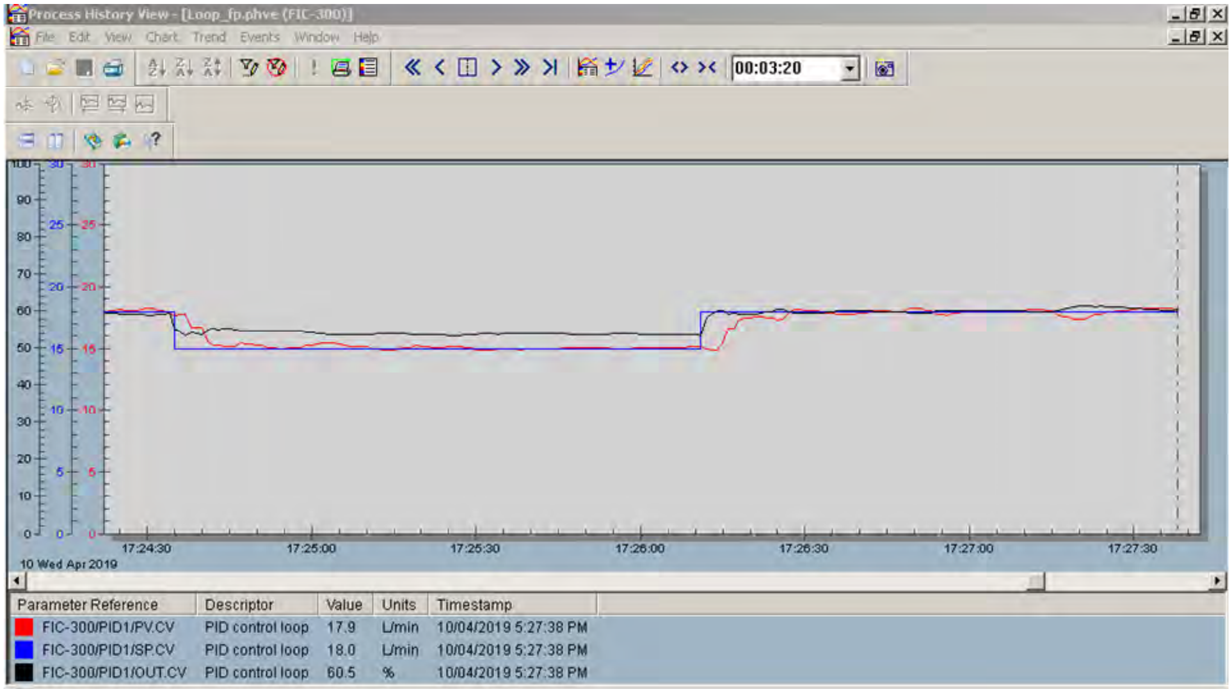


Figure 33 - FIC-300 Tuned Response

7.3.5 TIC-200 LOOP TUNING

When tuning the temperature inlet to the heat exchanger we used the Ziegler-Nichols' Open Loop tuning method. For this strategy we placed the TIC-200 controller in manual (MAN) mode with a step change in the controller output of the inlet temperature and recorded the response. Using the trendline response shown in Figure 34 - TIC-200 Open Loop Responsewe determined the process gain, the first-order time constant, and the dead time constant. The first variable found was the process gain, represented by K_p. The change of the process variable was calculated by the difference in temperature before and after the step change and converted to percent of range. The initial temperature was 10°C, then after the step change reached 40°C, which is a change of 30°C. The range of the temperature transmitter is 0-50°C, which was converted to a range of 0-100% using cross multiplication.

$$PV_1 = 10°C, PV_2 = 40°C \rightarrow \Delta PV = PV_2 - PV_1 = 40°C - 10°C = 30°C$$

$$\frac{\Delta PV_{\circ C}}{\Delta Range_{\circ C}} = \frac{\Delta PV_{\%}}{\Delta Range_{\%}} = \frac{30°C}{50°C} = \frac{\Delta PV_{\%}}{100\%} \rightarrow \Delta PV_{\%} = \frac{(30°C)(100\%)}{(50°C)} = 60\%$$

The step change in the output used was 100%, which was used to allow for a response curve the previous calculations could determine. Previous tests were performed to ensure the plant would not fall out of our control and cause damage. Using the 100% change in controller output and the calculated process variable change the gain of this process could be calculated. The variable K_P is found by taking the change in the process variable and dividing it by the change in controller output.

$$K_p = \frac{\Delta PV}{\Delta CO} = \frac{60\%}{100\%} = 0.6$$

The first order time constant (τ_1) is the difference in time between when the process variable reaches 63.2% of its total change and the time the process response starts to change after the dead time has ended. To find the first-order time constant the change in the process variable is calculated and multiplied by 0.632, which is done since the response of the process is a first order plus deadtime response. The initial process variable before the step change is added to determine the point where the process reached 63.2% of the change. With the percent where the process variable has reached 63.2% of the total change found, the time of this point is determined. Once found the difference in time between where the process variable reached 63.2% of change and the point where the deadtime ended is calculated.

$$G(s) = \Delta PV * 0.632 + PV_{initial}$$

$$G(s) = (60\%) * 0.632 + (20\%)$$

$$G(s) = (37.9\%) + (20\%) = 57.9\%$$

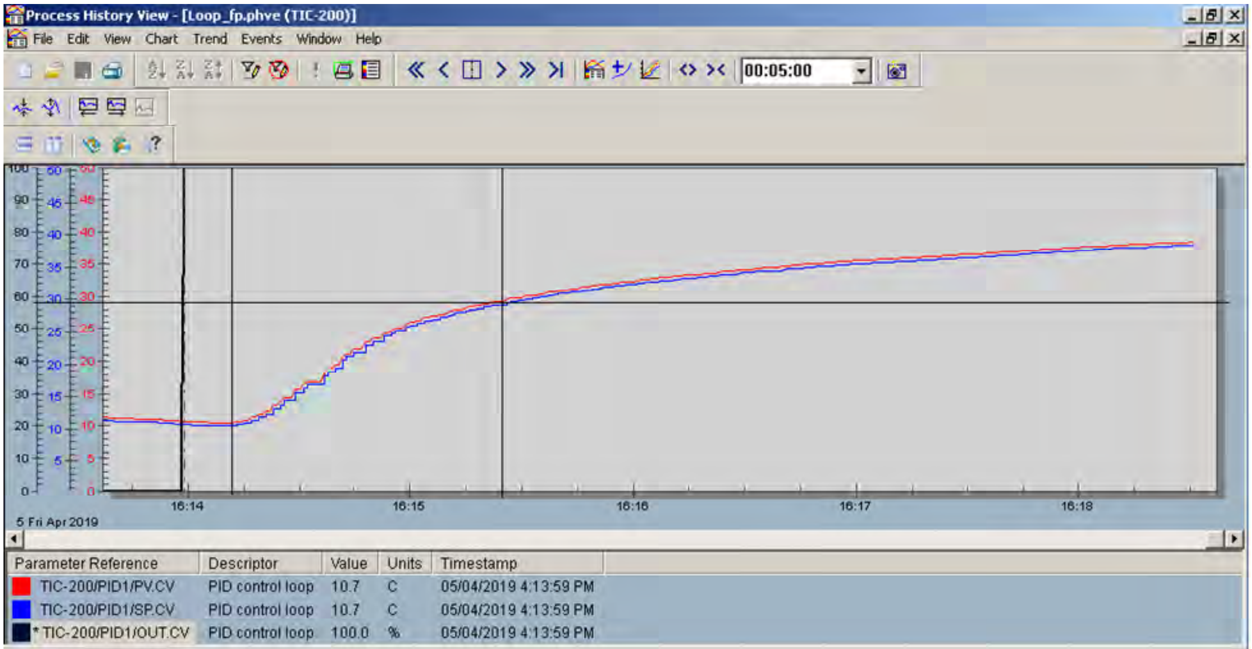


Figure 34 - TIC-200 Open Loop Response

On Figure 34 - TIC-200 Open Loop Responselines have been drawn to illustrate where the step change was introduced, where the dead time ends, and where the process variable reaches 63.2%. The difference in time between the two vertical lines to the right is our first time constant, which is 73 seconds.

To find the dead time (τ_d), the difference in time from when the step change was introduced to when the process variable begins to respond to the change is determined, which was equal to 18 seconds. Now to find the proportional and integral action values, the equations in Table 4 - Ziegler-Nichols' Open Loop Table are applied.

Ziegler-Nichols' Open	Proportional	Integral	Derivative
P-only	$K_c = \frac{\tau_1}{K_p * \tau_d}$		
PI	$K_c = 0.9\frac{\tau_1}{K_p * \tau_d}$	$\tau_i = 3.33 * \tau_d$	
PID	$K_c = 1.2\frac{\tau_1}{K_p * \tau_d}$	$\tau_i = 2 * \tau_d$	$\tau_D = 0.5 * \tau_d$

Table 4 - Ziegler-Nichols' Open Loop Table

The calculations shown below are for the proportional action.

$$K_c = 0.9\frac{\tau_1}{K_p * \tau_d} = 0.9\frac{73}{0.6 * 18} = 6.08$$

$$K_c = \frac{6.08}{2} = 3.04$$

The calculations shown below are for the integral action.

$$\tau_i = 3.33 * \tau_d$$

$$\tau_i = 3.33 * 18\ sec$$

$$\tau_i = 59.94\ s/rpts$$

A proportional action parameter value of 6.08 was calculated, but using a common rule with the Ziegler-Nichols' Open Loop tuning method the value was divided by two to create a slower but controlled process response. Fine tuning was applied but the best response required a decrease in the proportional action from 3.08 to 3.35. The integral action parameter values of 59.94 seconds per repeat was calculated. Additional fine tuning was applied and the value of 50 seconds per repeat with the proportional action of 3.35

provided the best response. Figure 35 shows the response of the tuned loop with a step change on 10%, which is slower due temperature taking additional time to change.

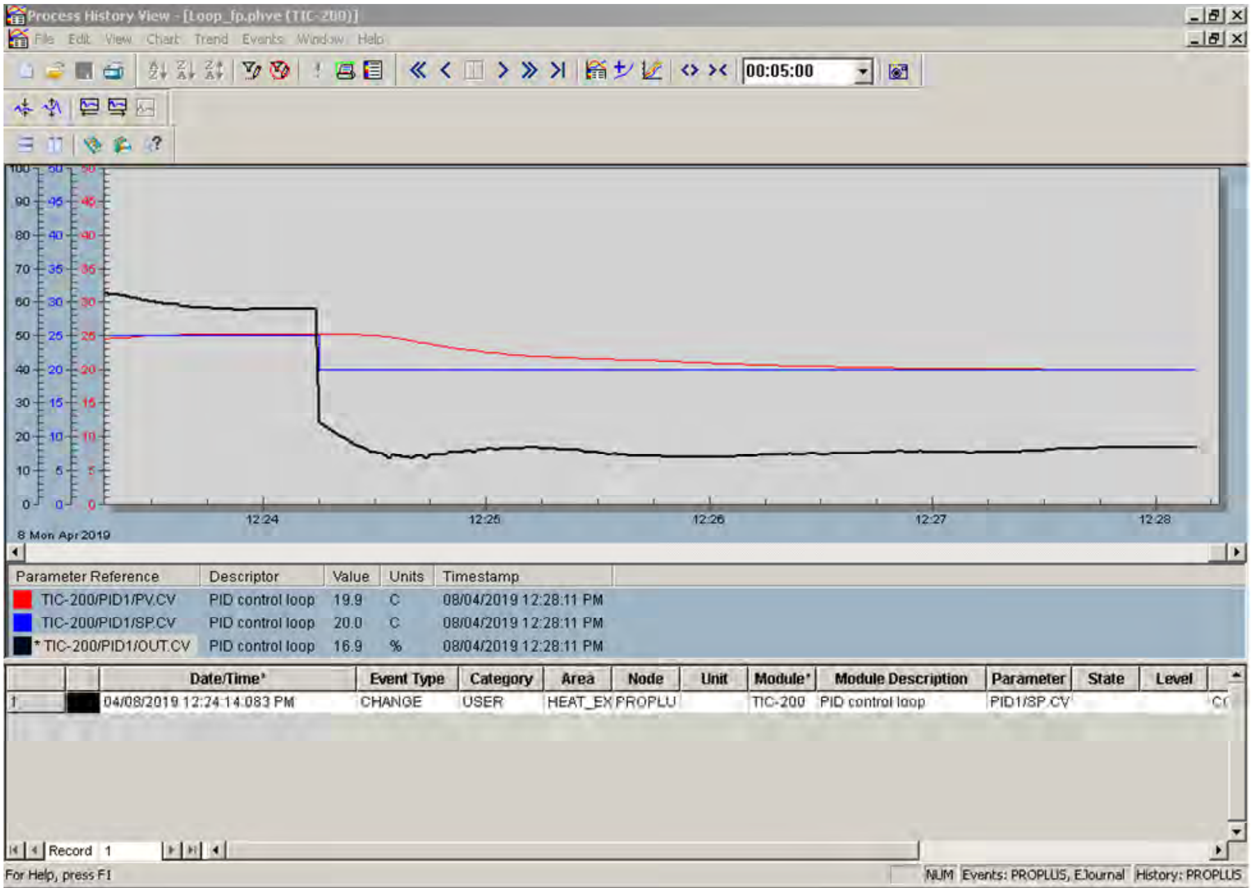


Figure 35 - TIC-200 Tuned Response

7.3.6 FIT-400 LOOP TUNING

Tuning the FIT-400 loop proved to more difficult than the previously tuned FIT-300 loop due to a few factors with the steam loop. As mentioned previously FIT-400 does not contain a temperature element to supply real-time steam temperature to the mass flow rate calculation the transmitter completes, but instead uses the approximated 105°C. Due to mass flow rate fluctuating without a real-time temperature the Ziegler-Nichols' Closed Loop method did not provide parameters for the proportional and integral actions that were sufficient even after attempts with fine tuning. The DeltaV Insight software was applied to the FIC-400 loop to achieve parameters that supplied a reasonable control that with fine tuning would be acceptable. Figure 36 and Figure 37 show the DeltaV Insight software applying step changes to the response in quick succession and the trendline of the response.

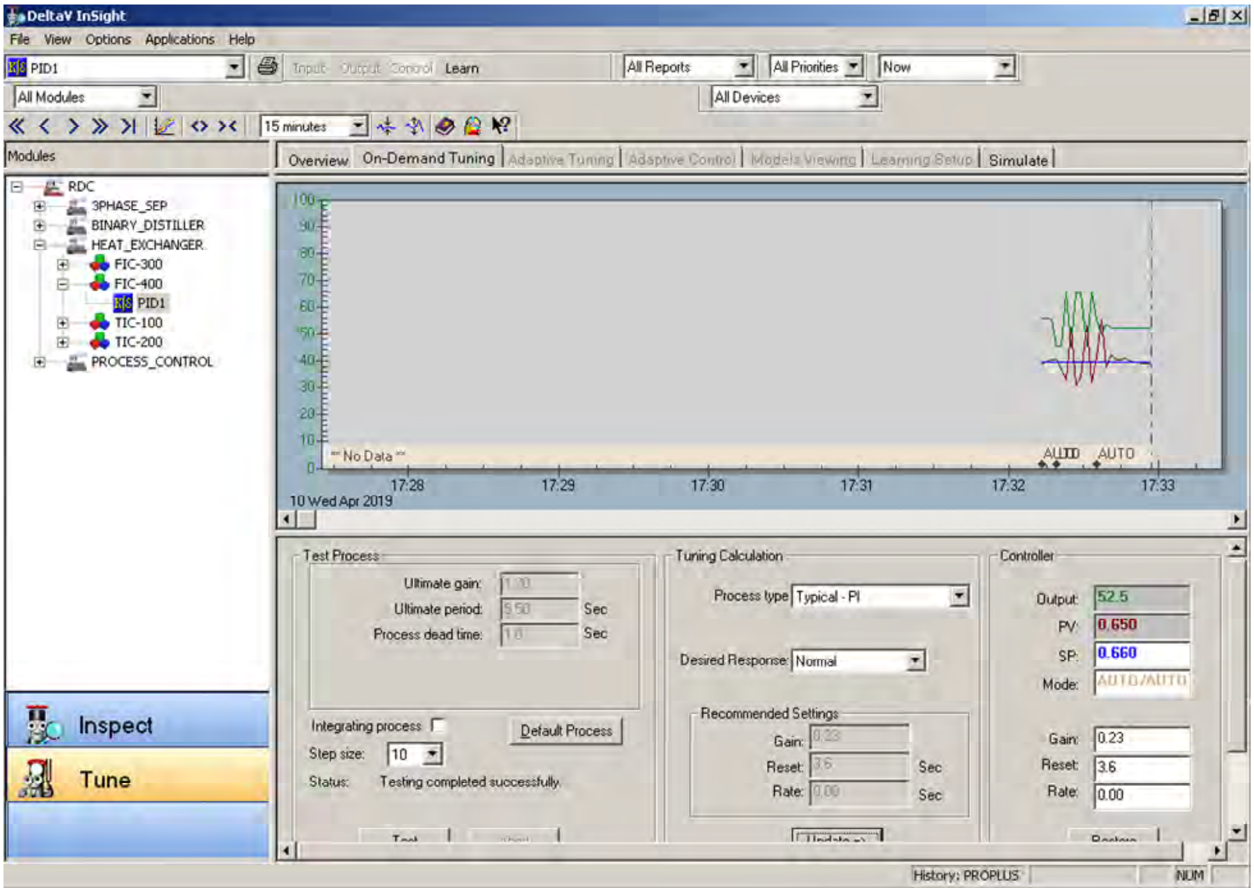


Figure 36 - FIC-400 DeltaV Insight Window

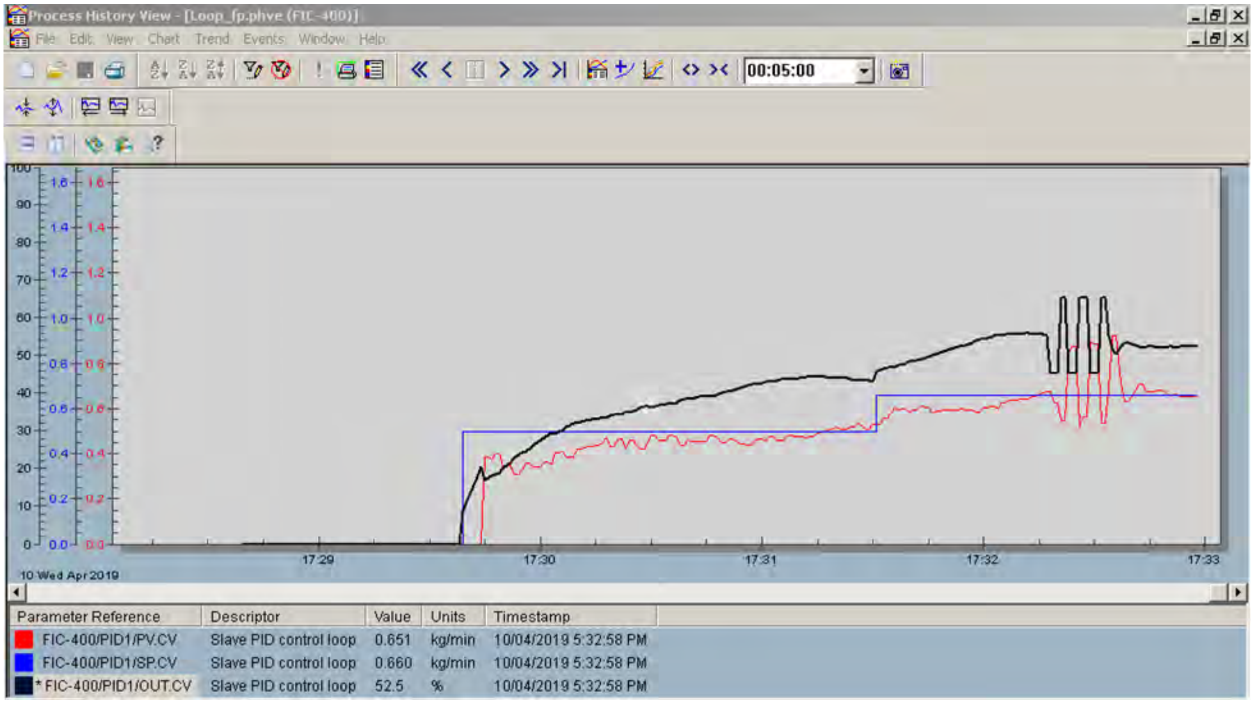


Figure 37 - DeltaV Insight Response

After applying the DeltaV Insight software the parameters for static control are calculated to the best ability of the software. With the proportional action of 0.23 and an integral action of 3.6 seconds per repeat a 10% step change in the setpoint was applied. Fine tuning was applied as well with an increase to the proportional action from 0.23 to 0.40, which provided the best response shown in Figure 38 with step changes applied.

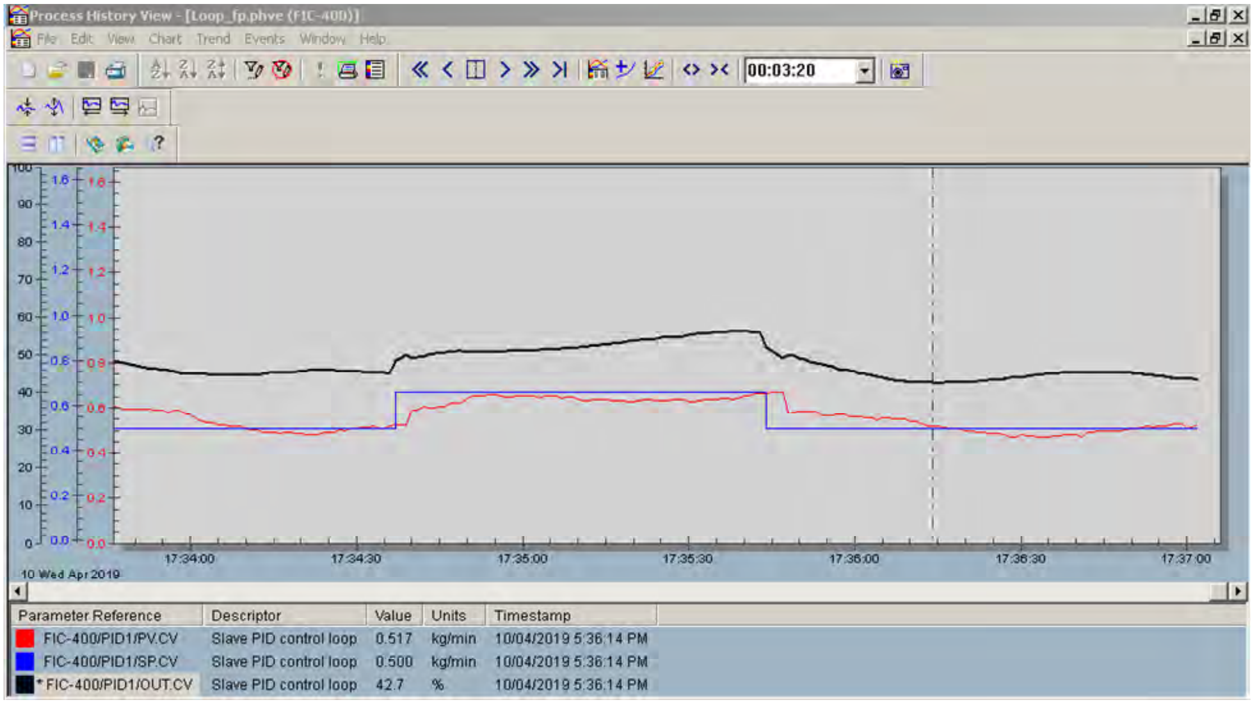


Figure 38 – FIC-400 Tuned Response

7.3.7 TIC-100 LOOP TUNING

For TIC-100 the tuning strategy used was the Ziegler-Nichols' Open loop method, which was applied in TIC-200. After completing the steps used in TIC-200, the values determined for the process gain, first-order time constant and dead time respectively were 0.89, 185 seconds, and 45 seconds. This loop was very slow and that is why the time constants are so high. For this loop we used the PI-controller again, so using Table 4 - Ziegler-Nichols' Open Loop Table the proportional integral action parameter values are calculated.

The calculation shown below are for the proportional action.

$$K_c = 0.9 \frac{\tau_1}{K_p * \tau_d}$$

$$K_c = 0.9 \frac{185}{0.89 * 45}$$

$$K_c = 4.62$$

The calculations shown below are for the integral action.

$$\tau_i = 3.33 * \tau_d$$

$$\tau_i = 3.33 * 45\ sec$$

$$\tau_i = 150\ s/rpts$$

No fine tuning was applied for this loop because the response was quite good already and additional fine tuning would take a large amount of time. Refer to Figure 39 for a response of TIC-100 with a step change of 10% applied after tuning has been complete.

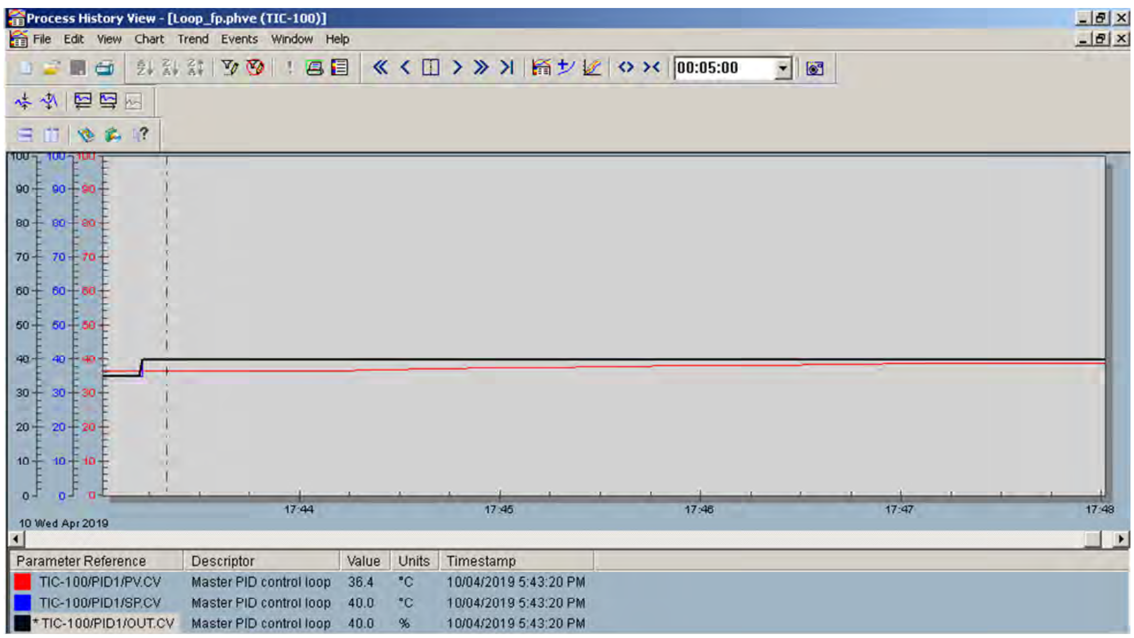


Figure 39 - TIC-100 Tuned Response

7.3.8 DISTURBANCES

After the tuning was completed for the four controllers of the plant, disturbances were applied to record how the plant responds. First a disturbance in the temperature was applied by decreasing the inlet temperature of water from 20°C to 15°C. The inlet temperature response acted in response and reach the setpoint in a time of XX seconds, but over shot due to the quarter amplitude decay the Ziegler-Nichols' methods supply. The temperature eventually reached a steady state as the temperature of the outlet reached state of minimal change. In response to the temperature change, the outlet temperature decreased by 2°C and then began climbing back to the setpoint of 40°C. Figure 40 - TIC-100 Temperature Disturbanceshows the step change in the temperature and the initial effects to the process outlet.

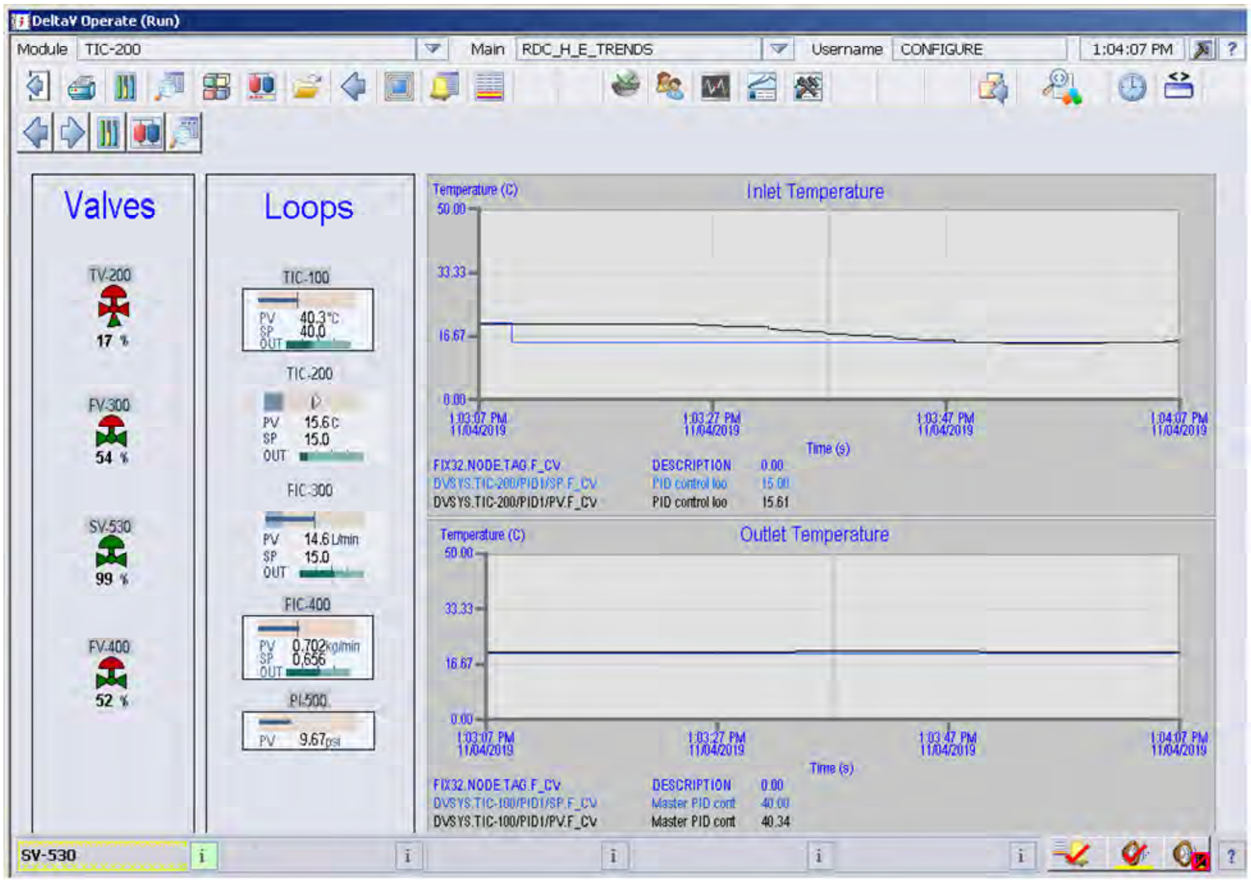


Figure 40 - TIC-100 Temperature Disturbance

Once the response was complete, the setpoint of the inlet temperature was increased from 15°C to 20°C. After the process reach a steady state after returning to the standard setpoints a disturbance in the inlet flow was introduced by increasing the flow from 15

L/min to 18 L/min. The response in the process outlet was minimal at best with a change of 0.2°C

8 WORK BREAKDOWN STRUCTURE (WBS)

The Work Breakdown Structure (WBS) is a view into the project which shows what work the project encompasses. It is a tool which helps to easily communicate the work and processes involved to execute the project. The Project Manager and project team use the WBS to develop the project schedule, resource requirements and costs. For a clearer WBS, refer to APPENDIX E: WORK BREAKDOWN STRUCTURE

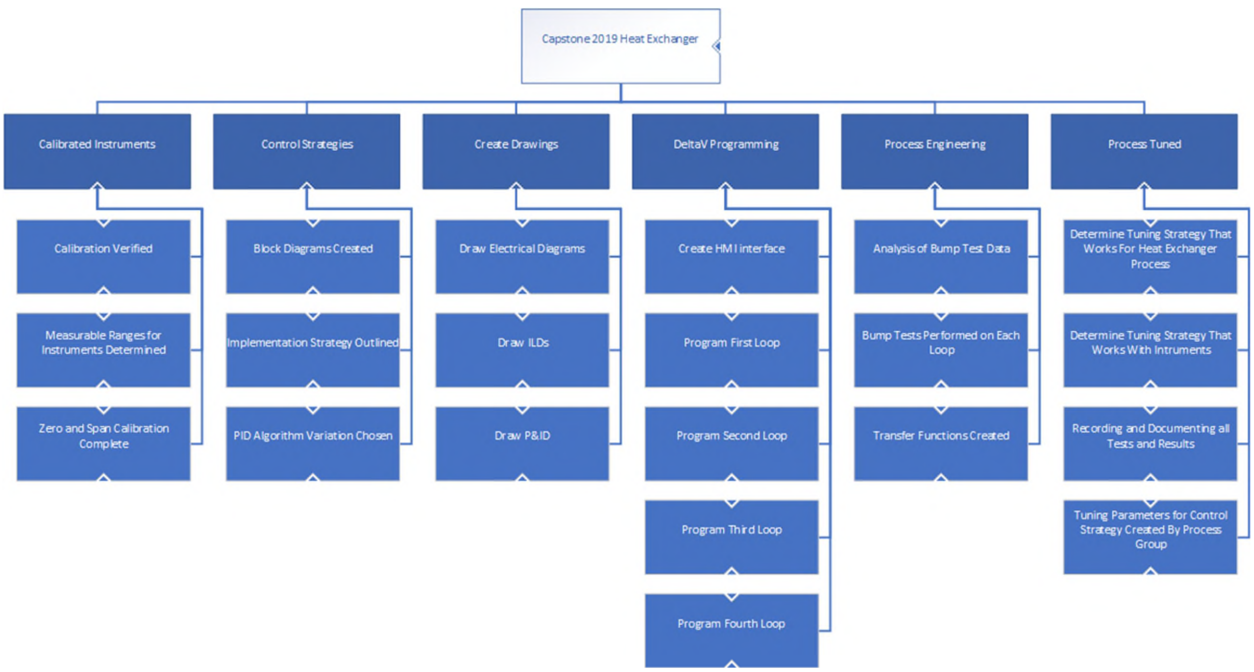


Figure 41 - Work Breakdown Structure

8.1 WBS DICTIONARY

The following table will describe the components contained within the WBS.

WBS Level	WBS Name	Description
1	Heat Exchanger	The entire project
2	Calibrated Instruments	The instruments for the heat exchanger all require steps to be properly calibrated
2	Control Strategies	Steps that need to be taken in order to come up with a strategy to control the heat exchanger system
2	Create Drawings	The drawings that will be created as part of the project
2	DeltaV Programming	The programming tasks that need to be undertaken to control the heat exchanger
2	Process Engineering	The tasks that need to be completed in order to develop the transfer functions that will be programmed in to control the heat exchanger
2	Process Tuned	The tasks to be performed to tune the control strategy within the DeltaV for optimum performance of the system
3	Measurable Ranges for Instruments Determined	The instruments all have a range that they will measure. These need to be determined
3	Proper Calibration Complete	The calibration of the instruments to make their output proportional to the measured values
3	Block Diagrams Created	Determine major components within control loops and how they interact to reach desired output
3	Implementation Strategy Outlined	Work with programming team to provide framework for DCS loop control
3	PID Algorithm Variation Chosen	Identifying operational needs and determining which PID algorithm best reaches those needs
3	Draw ILDs	Diagrams that illustrate each control loop and their physical connections from DCS to process instruments

3	Draw Electrical Diagrams	Draw diagrams to relate the process with the electrical connections
3	Draw PID	Draw the process components to view the relation between them
3	Create HMI Interface	Creation of the interface that displays important information to the user and allows the user to control the process
3	Program First Loop	Program the control of the first loop of the process
3	Program Second Loop	Program the control of the second loop of the process
3	Program Third Loop	Program the control of the third loop of the process
3	Program Fourth Loop	Program the control of the third loop of the process
3	Bump Tests Performed on Each Loop	Bump tests performed and documented
3	Analysis of Bump Test Data	Determine response characteristics from bump test data.
3	Transfer Functions Created	Creation of the transfer functions that will be programmed into the DeltaV to control the process
3	Determine Tuning Strategy That Works with Heat Exchanger	Research and determine tuning strategies that can be successfully used to tune a heat exchanger process.
3	Determine Tuning Strategy That Works with Instruments	Research and determine tuning strategies that can be successfully used to tune all instruments
3	Tuning Parameters for Control Strategy Created by Process Group	Calculate, test, and document tuning parameters for the determined control strategy
3	Recording and Documenting All Tests and Results	Recording and documenting all tests, calculations, meetings, and discussions throughout the entire project

Table 5 - WBS Dictionary

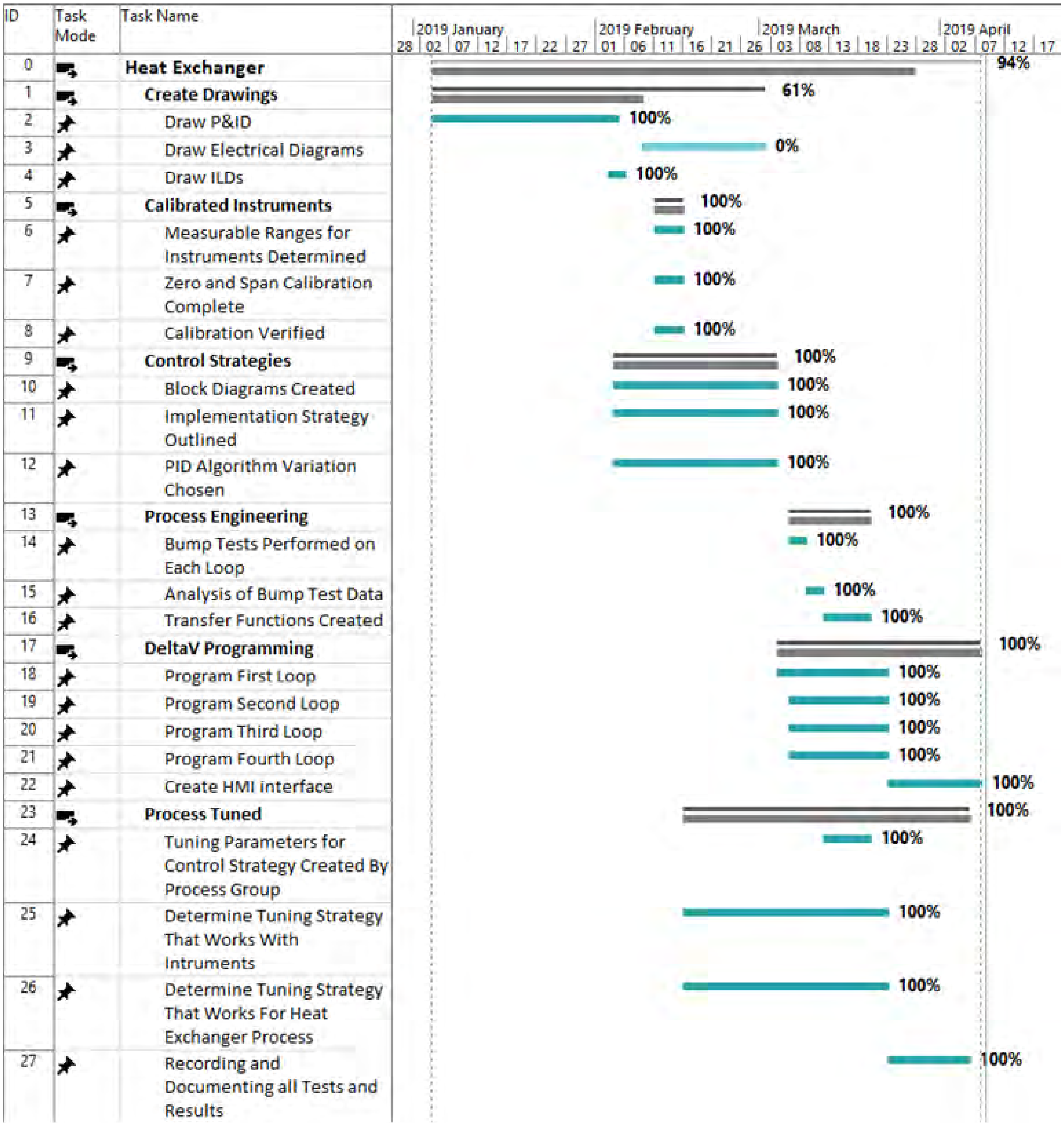
9 TIME MANAGEMENT

Time management involves taking the project charter objectives, breaking them down into manageable sections and attaching deadlines to the tasks. The tasks are prioritized and given the amounts of time needed to complete the objectives with some extra time added for troubleshooting. The objectives are then put together and assigned to each team member. The completion of the tasks will be tracked as they progress and if a task runs too long, additional resources and time might be needed to be allocated to the task. This might further delay following tasks so proper time management and planning is critical throughout the project. Times allocated to tasks are negotiated within the team and the final deadline is negotiated with all stakeholders.

9.1 GANTT CHART

A Gantt chart can is defined as a timeline of the tasks to be completed for a project to be closed. The use of a Gantt chart allows for ease of planning, coordinating, and tracking of tasks throughout the project. The following figure illustrates the Gantt chart for this project, for the complete Gantt chart, refer to

.



ID	Task Mode	Task Name
0		**Heat Exchanger**
1		**Create Drawings**
2		Draw P&ID
3		Draw Electrical Diagrams
4		Draw ILDs
5		**Calibrated Instruments**
6		Measurable Ranges for Instruments Determined
7		Zero and Span Calibration Complete
8		Calibration Verified
9		**Control Strategies**
10		Block Diagrams Created
11		Implementation Strategy Outlined
12		PID Algorithm Variation Chosen
13		**Process Engineering**
14		Bump Tests Performed on Each Loop
15		Analysis of Bump Test Data
16		Transfer Functions Created
17		**DeltaV Programming**
18		Program First Loop
19		Program Second Loop
20		Program Third Loop
21		Program Fourth Loop
22		Create HMI interface
23		**Process Tuned**
24		Tuning Parameters for Control Strategy Created By Process Group
25		Determine Tuning Strategy That Works With Intruments
26		Determine Tuning Strategy That Works For Heat Exchanger Process
27		Recording and Documenting all Tests and Results

Figure 42 - Gantt Chart

9.2 TASK AND STATUS RECORDS

Task Mode	Task Name	Duration	Start	Finish	Rev. Fin.	Resource Names	Status
Auto Scheduled	**Heat Exchanger**	**66 days**	**Fri 19-01-04**	**Sun 19-04-07**	-		94%
Auto Scheduled	**Create Drawings**	**41 days**	**Fri 19-01-04**	**Fri 19-03-01**	**Sun 19-04-07**		61%
Manually Scheduled	Draw P&ID	22 days	Fri 19-01-04	Mon 19-02-04	-	Tyler Driesen,Korben Johnson	100%
Manually Scheduled	Draw Electrical Diagrams	16 days	Sat 19-02-09	Fri 19-03-01	Sun 19-04-07	Carson West,Zaron Gibson	0%
Manually Scheduled	Draw ILDs	3 days	Sun 19-02-03	Tue 19-02-05	-	Korben Johnson, Tyler Driesen	100%
Auto Scheduled	**Calibrated Instruments**	**5 days**	**Mon 19-02-11**	**Fri 19-02-15**	**Wed 19-03-22**	**Korben Johnson, Tyler Driesen**	100%
Manually Scheduled	Measurable Ranges for Instruments Determined	5 days	Mon 19-02-11	Fri 19-02-15	Wed 19-03-22	Korben Johnson, Tyler Driesen	100%
Manually Scheduled	Zero and Span Calibration Complete	5 days	Mon 19-02-11	Fri 19-02-15	Wed 19-03-22	Korben Johnson, Tyler Driesen	100%
Manually Scheduled	Calibration Verified	5 days	Mon 19-02-11	Fri 19-02-15	Wed 19-03-22	Korben Johnson, Tyler Driesen	100%
Auto Scheduled	**Control Strategies**	**20 days**	**Mon 19-02-04**	**Sun 19-03-03**	**-**	**Emily Lougheed,Jade Moore**	100%
Manually Scheduled	Block Diagrams Created	21 days	Mon 19-02-04	Sun 19-03-03	-	Emily Lougheed ,Jade Moore	100%

Manually Scheduled	Implementation Strategy Outlined	21 days	Mon 19-02-04	Sun 19-03-03	-	Emily Lougheed ,Jade Moore	100%
Manually Scheduled	PID Algorithm Variation Chosen	21 days	Mon 19-02-04	Sun 19-03-03	-	Emily Lougheed ,Jade Moore	100%
Auto Scheduled	**Process Engineering**	**10 days**	**Wed 19-03-06**	**Tue 19-03-19**	**Fri 19-03-29**	**Emily Lougheed,Jade Moore**	100%
Manually Scheduled	Bump Tests Performed on Each Loop	3 days	Wed 19-03-06	Fri 19-03-08	Fri 19-03-29	Emily Lougheed ,Jade Moore	100%
Manually Scheduled	Analysis of Bump Test Data	2 days	Sat 19-03-09	Mon 19-03-11	Fri 19-03-29	Emily Lougheed ,Jade Moore	100%
Manually Scheduled	Transfer Functions Created	6 days	Tue 19-03-12	Tue 19-03-19	Fri 19-03-29	Emily Lougheed ,Jade Moore	100%
Auto Scheduled	**DeltaV Programming**	**25 days**	**Mon 19-03-04**	**Sun 19-04-07**	**-**	**Carson West,Zaron Gibson**	100%
Manually Scheduled	Program Loop 100	15 days	Mon 19-03-04	Fri 19-03-22	-	Carson West,Zaron Gibson	100%
Manually Scheduled	Program Loop 200	13 days	Wed 19-03-06	Fri 19-03-22	-	Carson West,Zaron Gibson	100%
Manually Scheduled	Program Loop 300	13 days	Wed 19-03-06	Fri 19-03-22	-	Carson West,Zaron Gibson	100%
Manually Scheduled	Program Loop 400	13 days	Wed 19-03-06	Fri 19-03-22	-	Carson West,Zaron Gibson	100%
Manually Scheduled	Create HMI Interface	12 days	Sat 19-03-23	Sun 19-04-07	-	Carson West,Zaron Gibson	100%

Auto Scheduled	**Process Tuned**	**35 days**	**Sat 19-02-16**	**Fri 19-04-05**	**-**	**Korben Johnson, Tyler Driesen**	100%
Manually Scheduled	Tuning Parameters for Control Strategy Created By Process Group	6 days	Tue 19-03-12	Tue 19-03-19	Fri 19-03-22	Korben Johnson, Tyler Driesen	100%
Manually Scheduled	Determine Tuning Strategy That Works With Instruments	26 days	Sat 19-02-16	Fri 19-03-22	-	Korben Johnson, Tyler Driesen	100%
Manually Scheduled	Determine Tuning Strategy That Works For Heat Exchanger Process	26 days	Sat 19-02-16	Fri 19-03-22	-	Korben Johnson, Tyler Driesen	100%
Manually Scheduled	Recording and Documentin g all Tests and Results	11 days	Sat 19-03-23	Fri 19-04-05	-	Korben Johnson, Tyler Driesen	100%

Table 6 - Task and Status Records

9.3 MILESTONES

Milestone	Original completion date	Revised completion date	Actual completion date
Planning Phase Complete	Feb 6, 2019	N/A	Feb 6, 2019
Calibration Complete	Feb 15, 2019	March 20, 2019	March 20, 2019
Initial DCS Configuration Complete	March 8, 2019	March 22, 2019	March 25, 2019
Implementation of Control Strategies Complete	March 19, 2019	March 29, 2019	April 3, 2019
HMI Screen Complete	April 7, 2019	N/A	April 3, 2019
Tuning Complete	April 7, 2019	N/A	April 8, 2019

Table 7 - Milestone Register

10 COMMUNICATION MANAGEMENT

10.1 STAKEHOLDER REGISTER

Name	Position	Internal / External	Project Role	Contact Information
Red Deer College	Organization	Internal	Project Owner	N/A
Dale Gust	Associate Dean	Internal	Project Owner Liaison	Dale.gust@rdc.ab.ca
Victor Mendez	RDC Instructor	Internal	Project Executive Sponsor	Victor.mendez@rdc.ab.ca
Jade Moore-Jackson	Student	Internal	Project Manager & Process Engineer	Jade.moore-jackson@rdc.ab.ca 403-505-7955
Emily Lougheed	Student	Internal	Process Engineer	Emily.lougheed@rdc.ab.ca 587-877-1149
Korben Johnson	Student	Internal	Tuning & Calibration	Korben.johnson@rdc.ab.ca 403-550-9964
Tyler Driesen	Student	Internal	Tuning & Calibration	Tyler.driesen@rdc.ab.ca 403-505-7974
Carson West	Student	Internal	Project Manager & DeltaV Programming	Carson.west@rdc.ab.ca
Zaron Gibson	Student	Internal	DeltaV Programming	Zaron.gibson@rdc.ab.ca
Clifford Long	RDC Instructor	Internal	Support for DeltaV	Clifford.long@rdc.ab.ca
Charles Ying	RDC Instructor	Internal	Support for process engineering & DeltaV	Charles.ying@rdc.ab.ca

Brad House	Spartan Controls	External	Support for DeltaV	House.brad@spartancontrols.com
Neal Tetreault	Spartan Controls	External	Support for calibration & tuning	Tetreault.neal@spartancontrols.com

Table 8 - Stakeholder Register

10.2 MEETING MINUTES

10.2.1 TEAM MEETING MINUTES

For complete team meeting minutes documents refer to

.

Date (MM/DD/YY)	Summary	Time and Location	Members Absent	Duration	Completion
1/7/19	Overview of Project and first Meeting Objectives	Start: 12:00pm Location: Library	None	1 hour	100% Complete
1/14/19	Discussing Tasks, scope and other duties	Start: 12:00pm Location: Library	All	Predicted 1-2 hours	0% Complete (Canceled)
1/18/19	Milestones, Separate Individual work defined	Start: 1:00pm Location: Library	None	1 hour	100% Complete
1/25/19	DeltaV availability, Feasibility, and Open discussion	Start: 1:30pm Location: Lab	None	2 hours	100% Complete
1/28/19	Completing Tasks and Keeping document up to date	Start: 12:00pm Location: Library	All	Predicted 1 hour	0% Complete (Canceled)
1/30/19	Discussion of document contents and further plans	Start: 4:00pm Location: Library	None	2 hours	100% Complete

2/1/19	Discussion of project contents, format and meetings, etc	Start: 12:05pm Location: Library	None	27 minutes	100% Complete
2/4/19	Finalization of tasks and document before submission to advisor	Start: 3:00pm Location: Library	None	2.5 hours	100% Complete
2/6/19	Final checkup for report 1 before submission	Start: 4:00pm Location: Library	None	2 hours	100% Complete
3/6/19	Catch up with group after two-week break	Start: 5:00pm Location: Library	None	1 hour	100% Complete
3/11/19	Work on Report two and discuss the contents	Start: 3:00pm Location: Library	None	1.5 hours	100% Complete
4/3/19	Review report three mark, start planning for project completion	Start: 4:00pm Location: Library	None	2 hours	100% Complete
4/8/19	Work on report three and discuss presentation	Start: 3:30pm Location: Library	None	2 hours	100% Complete
4/9/19	Review and submit report 3 and work on presentation	Start: 5:00pm Location: Library	None	2 hours	100% Complete

Table 9 – Team Meeting Minutes

10.2.2 ADVISOR MEETING MINUTES

Date (MM/DD /YY)	Summary	Time and Location	Members Present	Duration	Completion
1/11/19	Planning of Project with Advisor	Start: 1:00pm Location: Lab	All	2 hours	100% Complete
1/18/19	Timetable and Tuning documents, introduction to DeltaV	Start: 12:00pm Location: Lab	All	50 minutes	100% Complete
1/25/19	Brief checkup with advisor regarding progression through project	Start: 1:00pm Location: Lab	All	30 minutes	100% Complete
2/1/19	Meeting with advisor discussing questions	Start: 12:00pm Location: Library	All	30 minutes	100% Complete
2/8/19	Conflict discussion and final report revisions	Start: 1:00pm Location: Conference Room	All	1.5 hours	100% Complete
3/8/19	Review mark for report one. Catch up on what has been changed to the heat exchanger	Start: 12:00 pm Location: Library	All but Jade Moore-Jackson	1 hour	100% Complete
3/22/19	Work in lab along side instructor and Spartan Controls Rep	Start: 12:00pm Location: Lab	All	4 hours	100% Complete

Table 10 - Advisor Meeting Minutes

10.3 CONTENT REVISION AND EVALUATION

The table below describes the indicators used when reviewing the content in our documents as well as a description for each indicator.

Revision Color Indicator	Meaning and Representation
Red	Content is incorrect
Blue	Content is repeated multiple times, content is missing or is incorrectly placed
Green	Content is correct but is recommended to be in more detail
Purple	Content should be removed completely

Table 11 - Revision Colour Indicator Table

11 CHANGE MANAGEMENT

Change management documents and tracks the necessary information required to effectively manage project change from project inception to delivery. Its intended audience is the project manager, project team, project sponsor and any senior leaders whose support is needed to carry out the plan. The change management process establishes an orderly and effective procedure for tracking the submission, coordination, review, evaluation, categorization, and approval for release of all changes to the project's baselines.

11.1 CHANGE REQUEST PROCESS FLOW

The following table outlines the steps taken whenever a change to the project

Step		Description
1	Generate CR	A submitter completes a CR form and sends the completed form to the Project manager
2	Log CR Status	The Change Manager enters the CR into the CR Log. The CR's status is updated throughout the CR process as needed
3	Evaluate CR	Project personnel review the CR and provide an estimated level of effort to process, and develop a proposed solution for the suggested change
4	Authorize	Approval to move forward with incorporating the suggested change into the project/product
5	Implement	If approved, make the necessary adjustments to carry out the requested change and communicate CR status to the submitter and other stakeholders

Table 12 - Change Request Process Table

11.2 CHANGE REQUEST FORM AND CHANGE MANAGEMENT LOG

Change Request		
Project:		Date:
Change Requestor:		Change No:
Change Category (Check all that apply): ☐ Schedule ☐ Cost ☐ Scope ☐ Requirements/Deliverables ☐ Testing/Quality ☐ Resources		
Does this Change Affect (Check all that apply): ☐ Corrective Action ☐ Preventative Action ☐ Defect Repair ☐ Updates ☐ Other		
Describe the Change Being Requested:		
Describe the Reason for the Change:		
Describe all Alternatives Considered:		
Describe any Technical Changes Required to Implement this Change:		
Describe Risks to be Considered for this Change:		
Estimate Resources and Costs Needed to Implement this Change:		
Describe the Implications to Quality:		
Disposition: ☐ Approve ☐ Reject ☐ Defer		
Justification of Approval, Rejection, or Deferral:		
Change Board Approval:		
Name	Signature	Date

Table 13 - Change Request Form

12 RISK MANAGEMENT

A risk is an event or condition that, if it occurs, could have a positive or negative effect on a project’s objectives. This Risk Management Plan defines how risks associated with our project will be identified, analysed, and managed. It outlines how risk management activities will be performed, recorded, and monitored throughout the lifecycle of the project and provides templates and practices for recording and prioritizing risks.

The project managers working with the project team and project executive will ensure that risks are actively identified, analysed, and managed throughout the life of the project. Risks will be identified as early as possible in the project to minimize their impact. The steps for accomplishing this are outlined in the following sections.

12.1 IDENTIFICATION

Risk identification will involve the project team, and appropriate stakeholders. It will be an evaluation of any factors that could hinder the project’s success. Careful attention will be given to the project deliverables, tasks, assumptions, constraints, and schedule.

12.2 ANALYSIS

The project managers working with the project team and project executive will ensure that risks are actively identified, analysed, and managed throughout the life of the project. Risks will be identified as early as possible in the project to minimize their impact. The steps for accomplishing this are outlined in the following sections.

12.2.1 QUALITATIVE RANKING

The likelihood and impact of occurrence for each identified risk will be assessed by the project manager’s with input from the project team. The matrix found below will be used to apply a numerical rating based on the parameters above then documented in the risk register. For more information on risk severity and likelihood definitions, refer to

Severity							
	5	Critical	5	10	15	20	25
	4	Major	4	8	12	16	20
	3	Moderate	3	6	9	12	15
	2	Minor	2	4	6	8	10
	1	Insignificant	1	2	3	4	5
Risk Matrix			Rare	Unlikely	Possible	Likely	Expected
			1	2	3	4	5
			Likelihood				

Table 14 - Risk Matrix

12.3 REGISTER

As part of our risk management plan the following table will contain all identified risks, date of recognition and their potential impact to our project's success. For more information with risks with an impact greater than four, refer to APPENDIX C

ID #	Date Raised	Risk Description	Likelihood	Severity	Impact	Mitigating Action
Operational Risks						
O1	01/18/19	Thermal shock cracking tubes within heat exchanger from supplying steam before process fluid	1	5	5	Make sure to turn on water when using the equipment. Make sure programming reflects that there is process fluid flowing in HE before allowing steam flow
O2	01/18/19	Burns from hot steam	3	3	9	Wear gloves and face shield around active equipment
O3	01/18/19	Leaks from construction	3	1	3	Operate as is, fix leak if found

O4	01/25/19	Inadequately sized steam trap. The installed Armstrong 2011 steam trap is rated for a max pressure of 400 psig @ 800°F (28 bar @ 427°C) this is extremely oversized for our operating pressure and has the potential to cause unforeseen issues	1	2	2	Operate as is, noting potential for unforeseen complications
O5	01/18/19	Pressure changes caused by miscalculations	1	4	4	Verify calculations before activating equipment
O6	01/18/19	Performance changes with the system due to miscalibration of the instrumentation equipment	2	2	4	Ensure proper calibration of equipment by two-man verification
O7	01/18/19	Having the system to draw more power than it would be rated caused by a higher mechanical demand in the system	1	2	2	None
Long-Term Operational Risks						
L1	01/18/19	Harmonics within heat exchanger from steam causing baffles to cut tubes	1	3	3	Maintain steam and process fluid flows as according to specs
L2	01/18/19	Water scaling reducing thermodynamic efficiency and control	5	1	5	Periodic maintenance performed to de-scale equipment
L3	01/18/19	Mechanical stress overload	1	4	4	None
Resource Risk						
R1	01/18/19	Team member incapacitated	1	3	3	Work is divided in ways that provide redundancy (co-leaders)
R2	01/18/19	Restricted access to DeltaV	4	2	8	Plan to enter the lab based on restrictions in place. Secondary DCS simulation access set up

Table 15 - Risk Register

12.3.1 HAZARD ASSESSMENT

For our project, a hazard is an event or condition that, if it occurs, could have a negative effect on personal safety. Separate from the risk register, but following the same management strategy, this hazard assessment will ensure that all hazards are actively identified, analysed, and managed throughout the life of the project.

The heat exchanger process relies on various instruments and machinery for its operation. The system will contain hot and cold fluids as well as high electrical power to be supplied for the system to run which will be hazardous if the system were to experience a failure or if the system were to have a leak. The individuals who will be working with the system must be wearing the appropriate PPE before entering the environment where it'll operate, such as:

- Safety glasses
- Protective gloves (moderate heat and impact resistant)
- In a specific scenario, coveralls or lab coat

Hazard #	Type of Hazard	Description of Hazard	Effects of Hazard Occurring
1	Heavy Equipment	Handling heavy equipment in the work area	Toes being crushed or injured
2	Pressurized components	Compressed components in the system that are exposed to the surroundings	Sight could be damaged, or eyes can be injured
3	High temperature components and contents	Heat from certain components which can be exposed to the members in contact or proximity of the source	Injuries resulting from the hot temperatures of the contents or various components of the system
4	Heat	Hot system components resulting from the high energy steam	Burns

5	Electrical Shock	Power supplies and open wiring	Burns, neurological damage, muscle contractions, heart failure

Table 16 – Table of Hazards

13 TEAM CHARTER

13.1 COMMUNICATION

- Team members main communication platform will be Facebook Messenger. There, members are expected to be checking for member updates daily.
- Team members are expected to update team on task completion status.
- Team members encouraged to bring their problems to other team members for collaboration to help with problem solving.

13.2 COLLABORATION

- Team members are expected to complete their tasks in the agreed upon format and timeline, in order to not interfere with the task completion of other team members.
- Team members are expected to attend all scheduled meetings, this includes faculty advisor meetings as well as team only meetings.
- Team members are required and responsible for the detailed documentation of tasks they've completed as well as the submission of those documents to project managers.

13.3 CONFLICT RESOLUTION

- Team will gather to discuss and solve any problems that result from members not fulfilling expectations as outlined above, meetings will be documented with meeting minutes.
- If team fails to resolve problem, then the faculty advisor will be consulted.

13.4 SIGNATURES

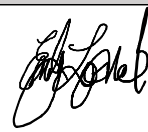
Member Names	Signatures
Emily Lougheed	
Jade Moore-Jackson	
Carson West	
Zaron Gibson	
Tyler Driesen	
Korben Johnson	

Table 17 - Table of Signatures

REFERENCE LIST

Smuts, J. (2010). OptiControls Inc. Retrieved from http://blog.opticontrols.com/site-map

PID Tuning: Step Behavior - Overshoot Criteria. (2001). Retrieved from http://support.motioneng.com/downloads-notes/tuning/pid_overshoot.htm

Wade, H. (2005, May 1). Trial and error: An organized procedure. Retrieved from https://www.isa.org/standards-and-publications/isa-publications/intech-magazine/2005/may/control-and-tuning-trial-and-error-an-organized-procedure

CDC UP | Templates. (n.d.). Retrieved from https://www2a.cdc.gov/cdcup/library/templates/

Works Cited

[1] J. Smuts, “Dead Time versus Time Constant,” 21 June 2011. [Online]. Available: http://blog.opticontrols.com/.

APPENDICES

APPENDIX A: PIPING AND INSTRUMENT DIAGRAMS

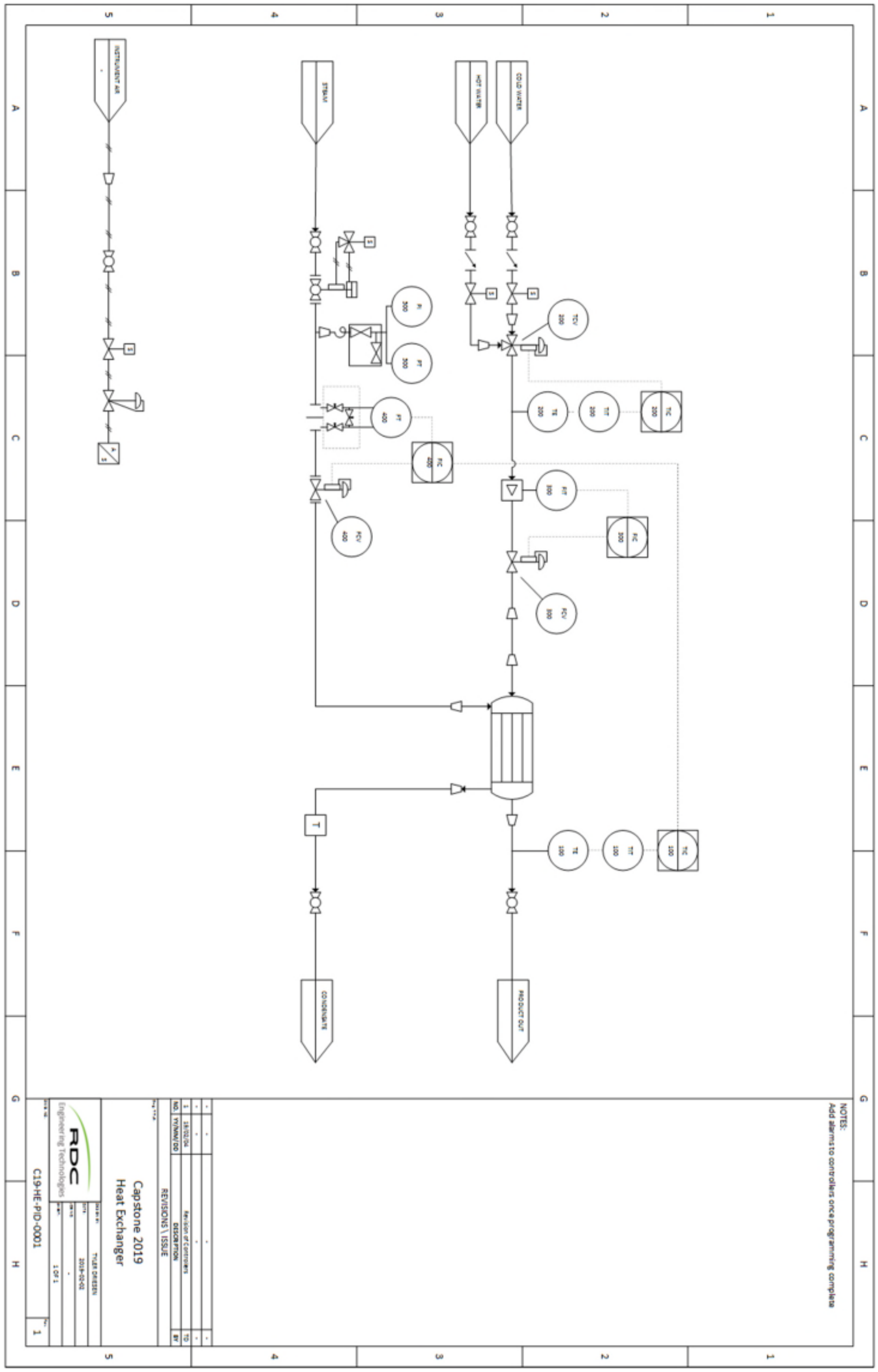


Figure 43 - P&ID Version 1 (OUTDATED)

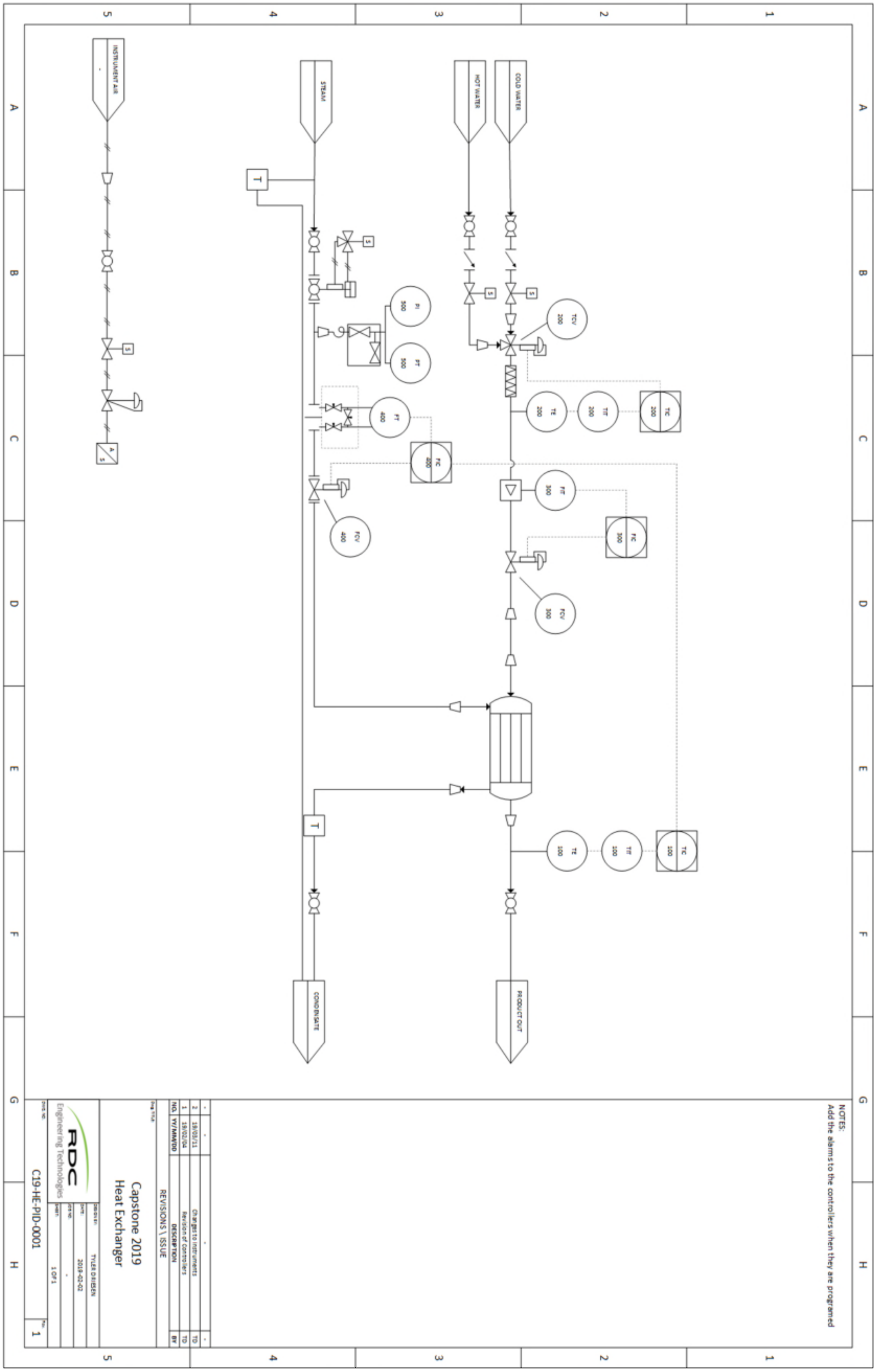


Figure 44 - P&ID Version 2 (OUTDATED)

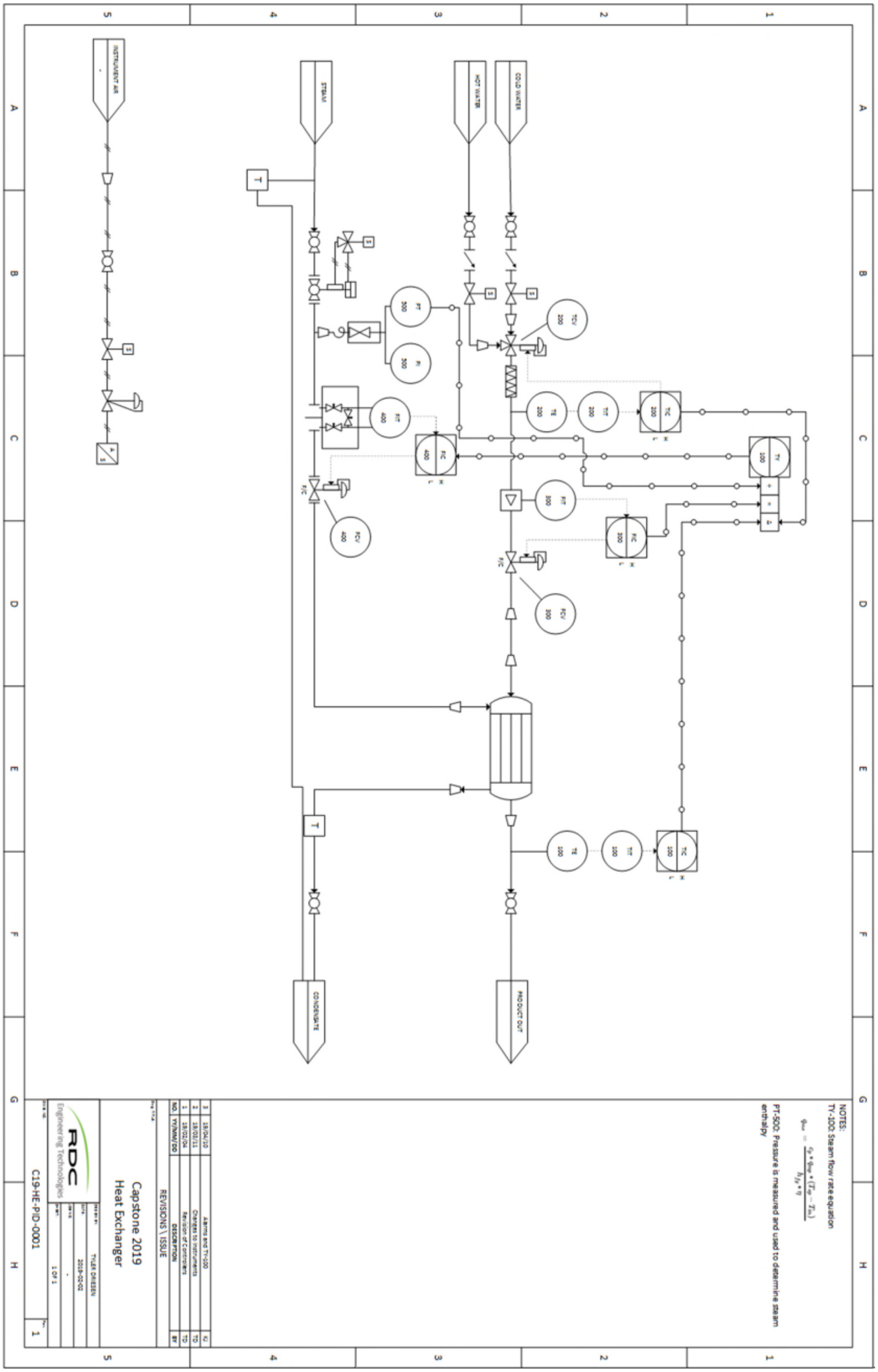


Figure 45 - P&ID Version 3

APPENDIX B: INSTRUMENT LOOP DIAGRAMS

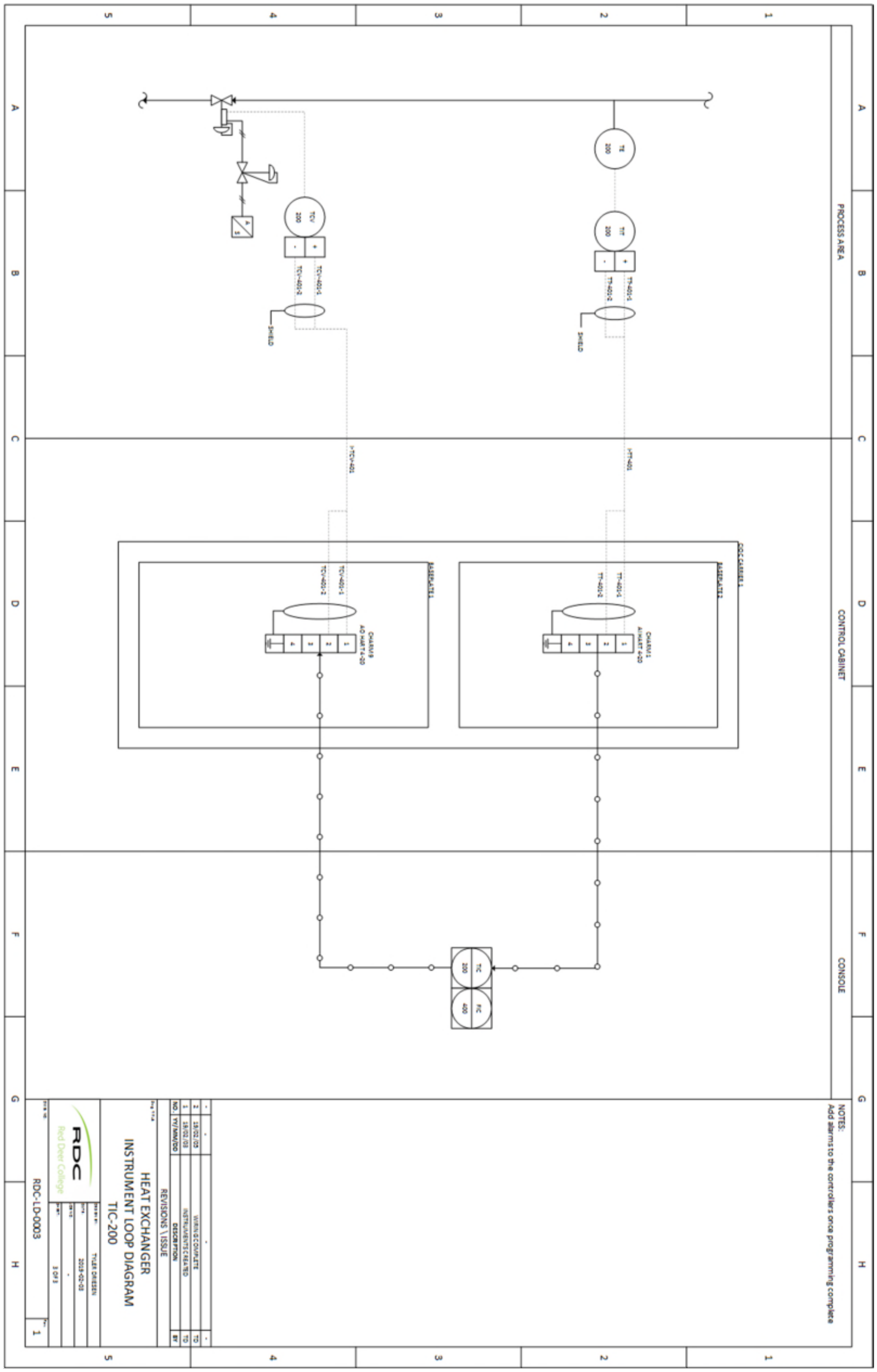


Figure 46 - ILD TIC-200 Version 1 (OUTDATED)

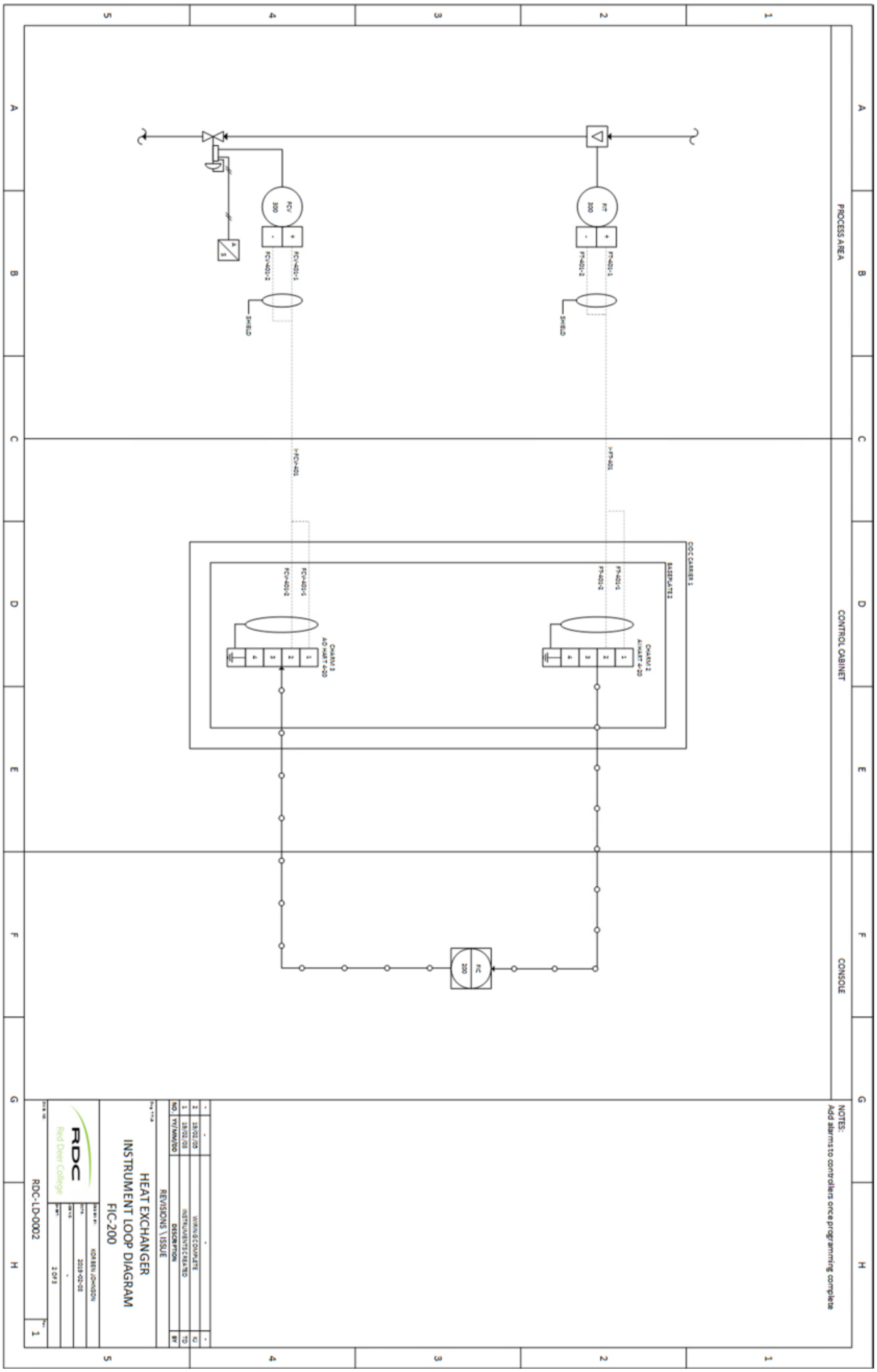


Figure 47 - ILD FIC-200 Version 1 (OUTDATED)

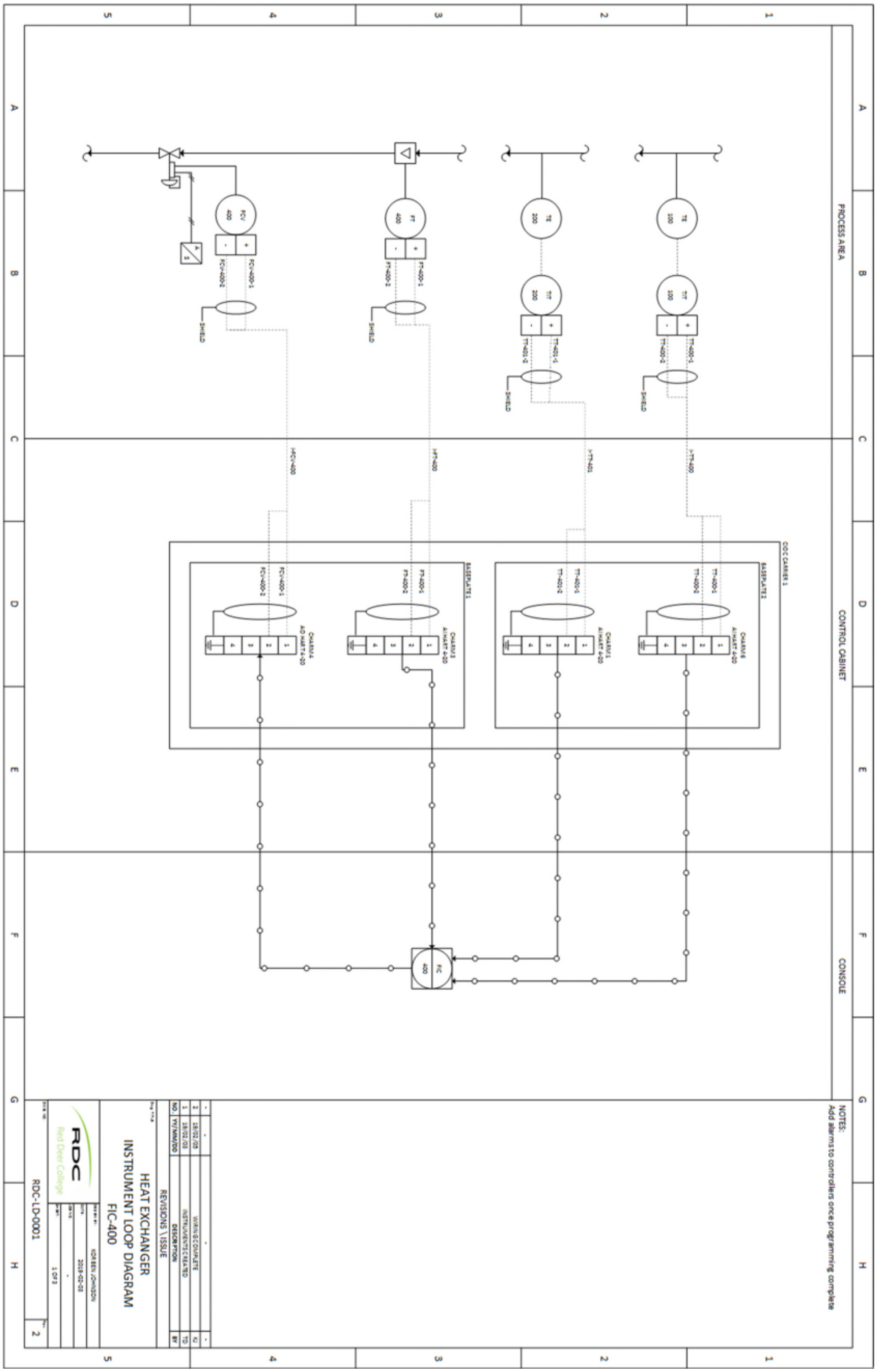


Figure 48 - ILD FIC-400 Version 1 (OUTDATED)

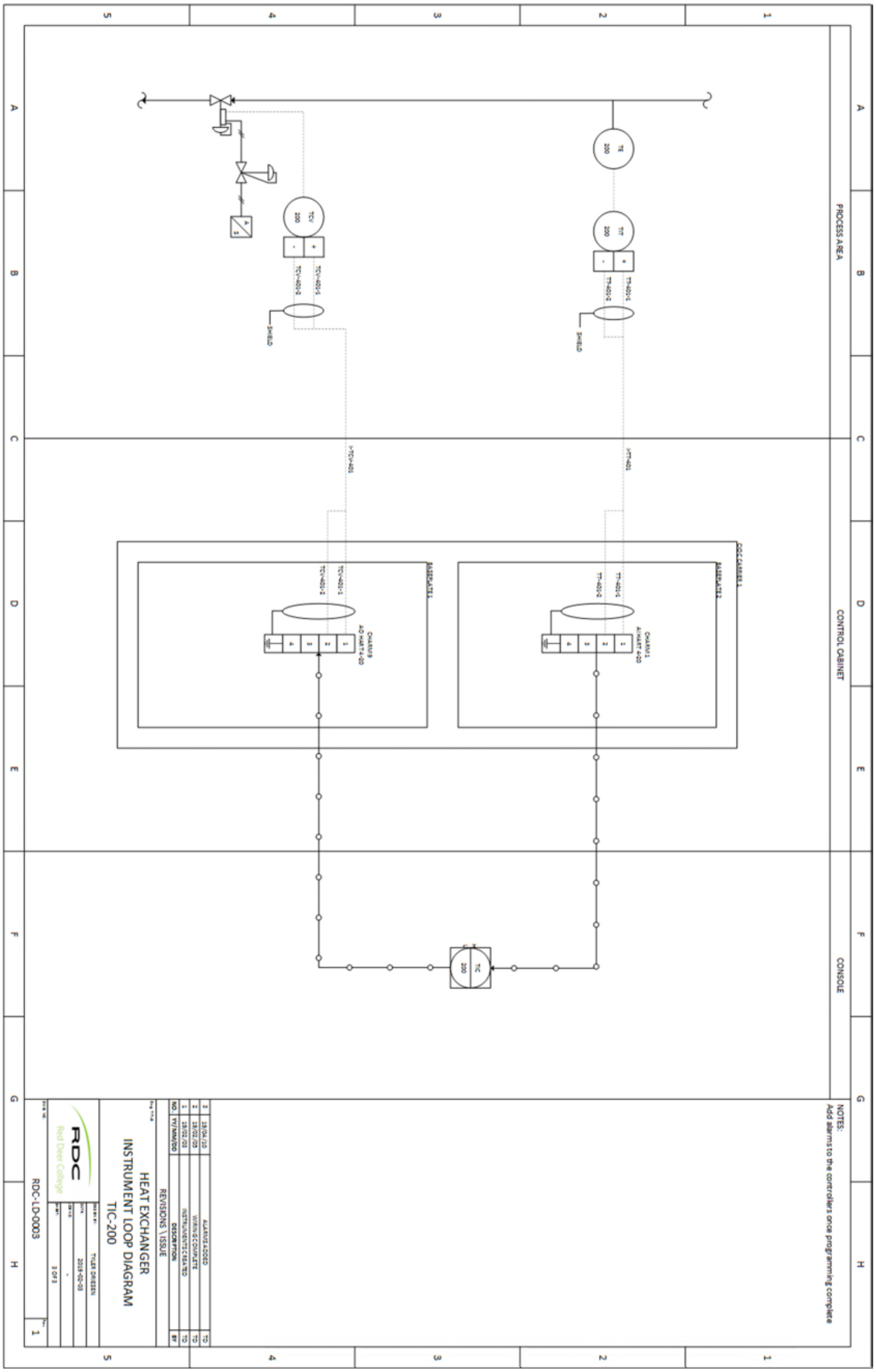


Figure 49 - TIC-200 Version 3

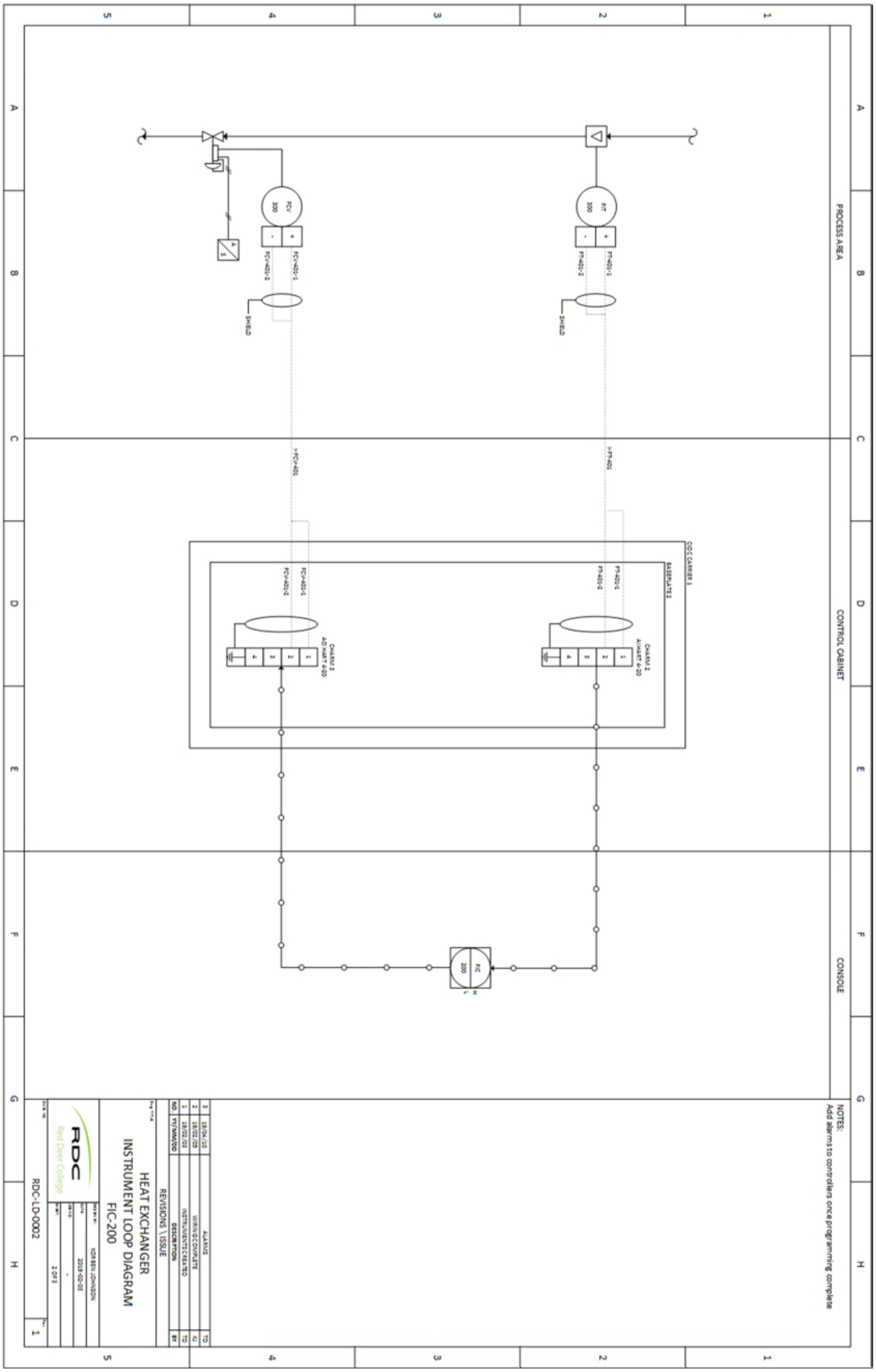


Figure 50 - FIC-300 Version 3

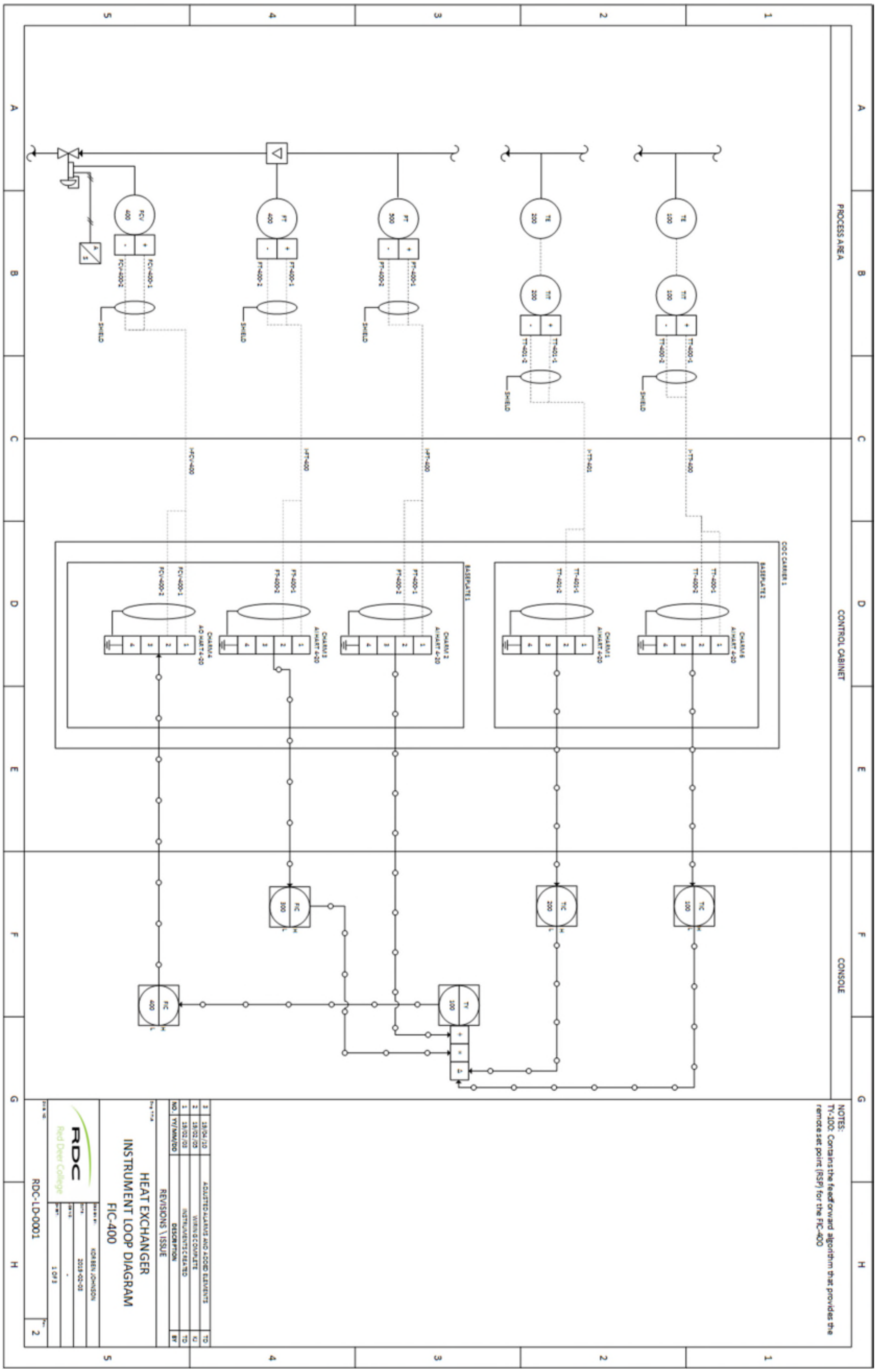


Figure 51 - FIC-400 Version 3 (COMPLETE)

APPENDIX C: RISK EXPLANATIONS

RISK O1 – THERMAL SHOCK CRACKING TUBES

Risk O1 describes the system experiencing thermal shock cracking tubes within heat exchanger from supplying steam before process fluid. The heat exchanger while being exposed to the steam going through the system may experience thermal induced stress cycling which could cause the metal in the heat exchanger to be fatigued and mechanically fail. This risk could potentially be hazardous for individuals around the heat exchanger as well as the overall performance of the system itself as the heat exchanger is a major component of the system.

RISK O2 – BURNS FROM HOT STEAM

Risk O2 describes a risk that can result in hot steam leaving the system and burning any individual nearby. The outlet steam of the system as well as any component carrying steam which fails causing the steam to be released could cause 3rd degree burns immediately on contact to an individual if they are too close. This risk can be very dangerous and more likely to occur than other risks described in this document.

RISK O5 – MECHANICAL LINE FAILURE

Risk O5 describes that the pressure in the system (specifically through the lines) can be altered due to any miscalculation. The pressures in the lines could also be altered due to other errors such as miscalibrations but if the pressures are altered, the system won't complete its original function and desired output temperature of 20-50 degrees. This is a risk to the performance and success of this project as one of the main objectives is for the group to acquire 20-50 degrees temperature coming out of the system.

A solution to minimize this risk is for multiple group members to check each other's calculations when completed. It is common in large calculations that one person can make an error however having multiple people check the same calculations can minimize this, note that this won't completely negate the risk as there is still a possibility that despite the 3 people checking a calculation, all 3 people can miss an error which can still result in a system failure, etc.

RISK O6 – EQUIPMENT FAILURE

Similar to the description of risk O5, risk O6 describes that the system or multiple parts of the system can be altered, damaged, etc. due to miscalibration or the instrumentation equipment. The instrumentation students associated to this project will be doing most of the calibrations for the equipment, making sure they are well prepared for the parameters that is needed to acquire 20-50 degrees outputting the system. Just like a miscalculation error, this risk threatens the safety of individuals around the work area as well as the performance of the system.

A solution to minimize this risk is to have multiple group members check a calibration on each of the equipment required for the task to be performed. This is very similar to the solution to that in risk 9 where the risk can be minimized but not entirely negated. Note that this would be a higher concern as a risk amongst the list due to the system having a lot of instrumentation equipment to calibrate.

RISK O7 –ELECTRICAL POWER CONSUMPTION

This risk describes an issue regarding power consumption for the system or more specifically the power being drawn directly from the wall outlet into the DeltaV system. In the components of this project, the DeltaV system had a source wall plug-in that was rated for 120 volts and 15 amps. The DeltaV system however, required 20 amps to be drawn through this plug-in which causes a risk of the main power source to be cut off due to long time exposure to high current. This restricts the system from operating for long periods of time if the demand for it is necessary.

A solution to this problem would be to replace the existing wall plug-in into one that is rated for 20 amps or more so that the system can be able to run for longer periods of time.

RISK R1 – PROJECT DELAY

Risk R1 describes that the project can be altered if a group member happens to be absent from his/her role for a period of time. The severity or how much damage the risk can do depends on multiple factors:

The tasks that is left unattended upon the member's departure where more time would have to be spent for a group member if the task is difficult or very large

The member who is going to accommodate for the absence may take more time on the tasks if he/she is not in that field of study. For example, if this group contained one member experienced in mechanical field and he/she is absent, the other members would have a more difficult time trying to accommodate for the absence as they are not familiar with that specific field of study.

The risk level for this risk depends on the workload for the members in this semester. Since not every member will have the same workload, there will be a lower risk for members who have less courses or less difficult courses in conjunction to the capstone course. This also depends on the strengths of the member for those courses as well as the content, instructor, etc.

The task that is unattended also affects the risk level at which it affects the system. There is a higher risk if the task that is unattended happens to be more crucial to the objective of the project than one that is a minor task to be completed.

Note that all the above factors will not cause life threatening risks for the group members or any other individual near the equipment. However, if a member is to complete tasks that are unattended from an absent member, there can be a risk of miscalculations, miscalibrations, etc. if the task is not in the same field of study for the member who is compensating for the absence. Otherwise, all the above factors will cause the tasks to be delayed by a vast amount. Since one of our objectives is for us to make the system work and since all of the roles are major roles, having a member absent from the project presents a danger to the success of the project. There is a specific time limit at which this project needs to be done and delaying tasks will cause the project to potentially be incomplete or rushed to completion.

To provide a solution to this as a risk is for a member to cover the role of a member who is absent. This is difficult as the compensating member must make free time to work on the unattended tasks. This would result in the project to stay on course or schedule but for the compensating member to do more work for the time being.

RISK L3 – MECHANICAL STRESS OVERLOAD

This risk describes the actions of fluids, forces and movement through the system and how these actions can cause deformation, unequal supports and other issues regarding stress in the mechanical parts of the system. Forces caused by the pressurized steam through the pipes and from the other fluids through the system can cause damage over time internally through extension and compressive forces. These forces can change the support values for the bearings on the end of values and fittings such that the system could experience uneven support sections creating a higher potential for risks if the system were to run for a long period of time. The thermal capabilities of the system can cause or lead to this happening if the temperature became too high in certain parts of the system (high temperature in the small diameter sections, etc.).

APPENDIX D: QUALITATIVE RISK RANKINGS

Likelihood of Occurrence

- Rare: Very unlikely to occur to impossible
- Unlikely: Unlikely to occur
- Possible: Could occur at some point
- Likely: Likely to occur eventually
- Expected: Likely to occur soon to immediately

Severity of Consequence

- Insignificant: Near miss
- Minor: Injury only requiring first aid
- Moderate: Non-serious injury, illness or damage, etc.
- Major: Severe injury, serious illness, property and equipment damage, etc.
- Critical: Causing deaths, occupational illness, loss of facilities, environmental impact, etc.

Risk Response Zones

Dependant on which zone the risk falls into will justify the type of response taken. For any risk resulting in a score of yellow, red, or dark red, that risk shall receive a breakdown within the appendix.

- Green (0-4) – Risk accepted
- Yellow (5-9) – Risk discussed for action.
- Red (10-19) – Active mitigation/contingency required
- Dark Red (20-25) – Immediate attention required before continuing

APPENDIX E: WORK BREAKDOWN STRUCTURE

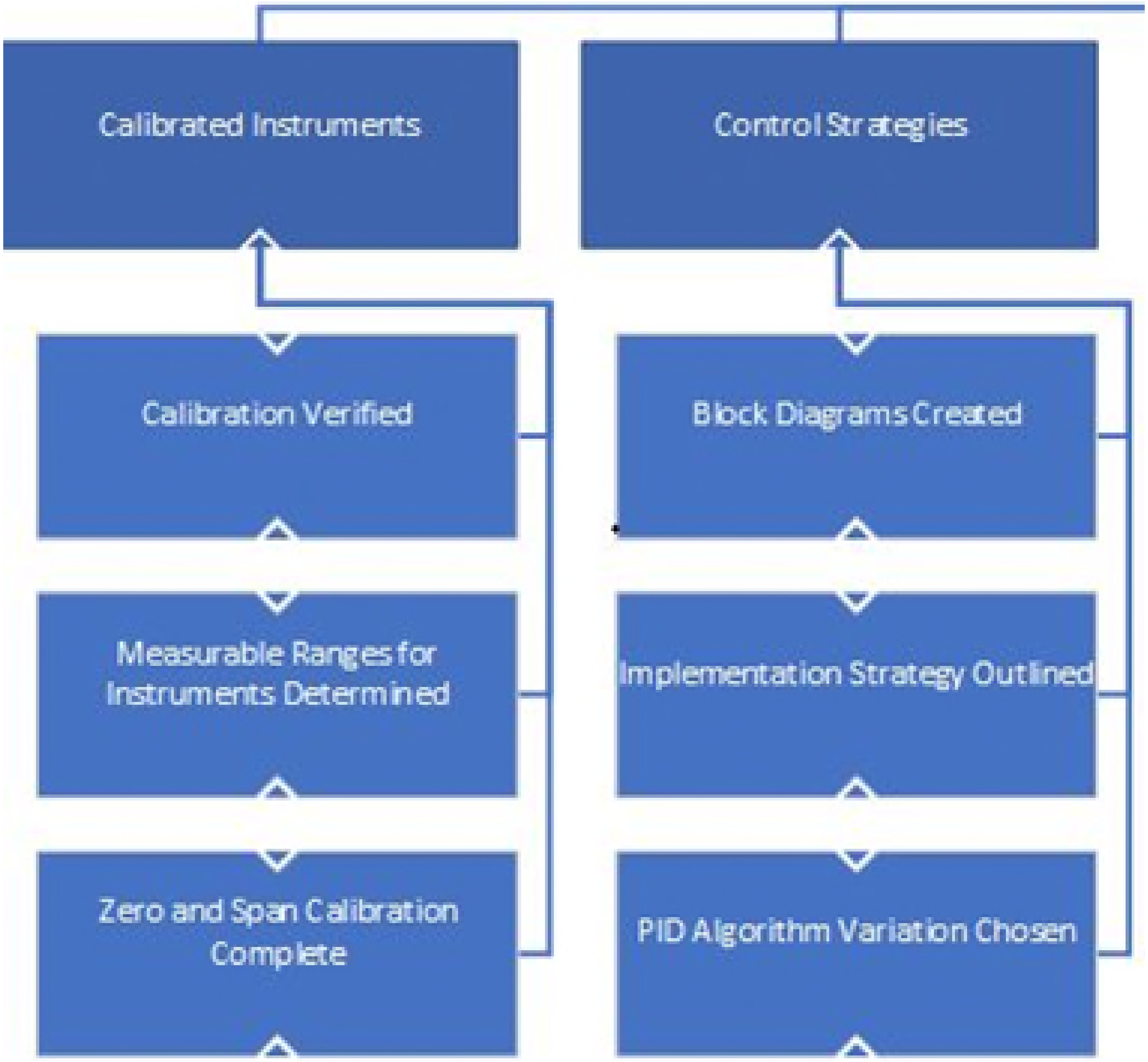


Figure 52 - WBS Calibrated Instruments and Control Strategies

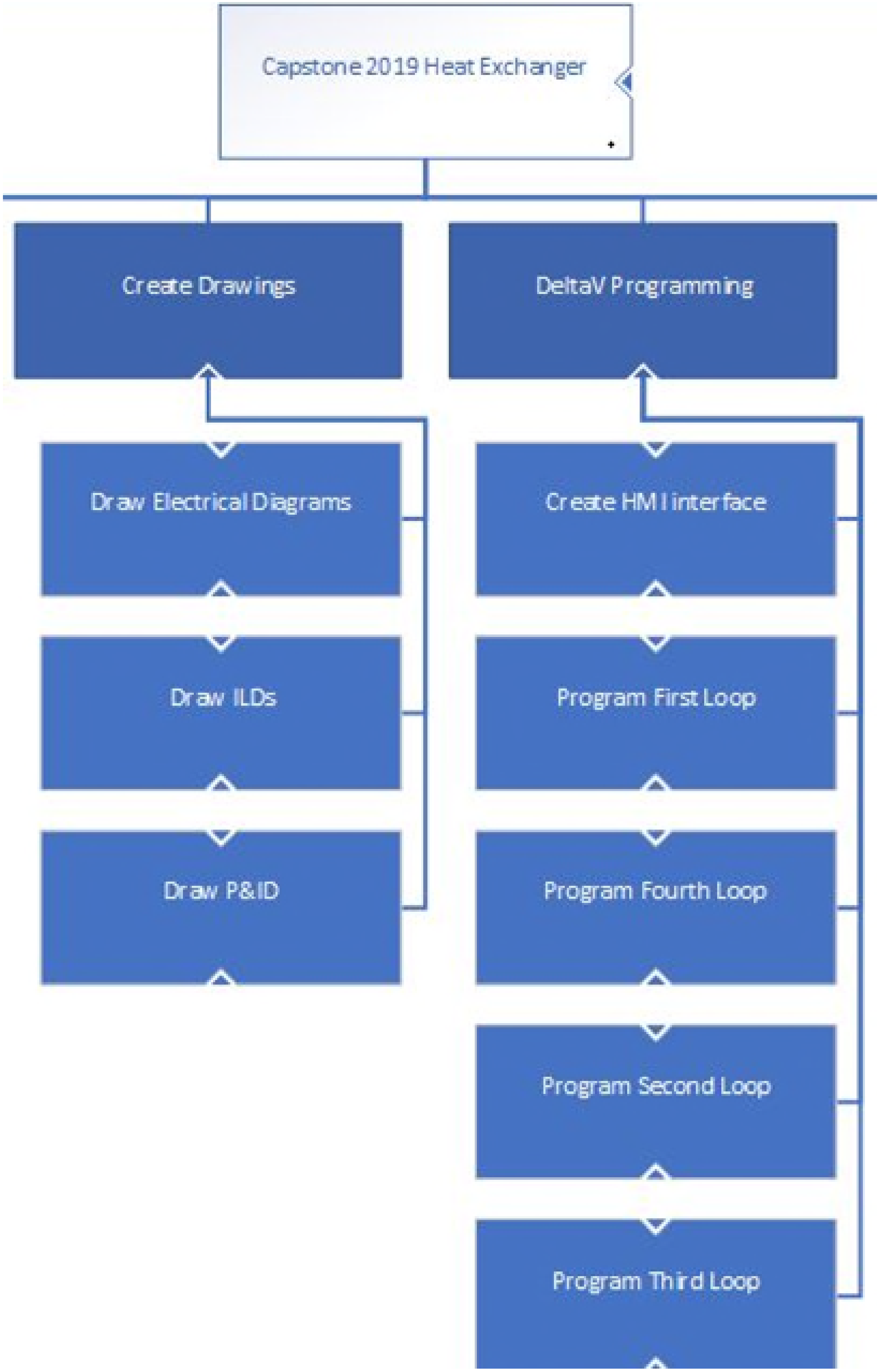


Figure 53 - WBS Create Drawings and DeltaV Programming

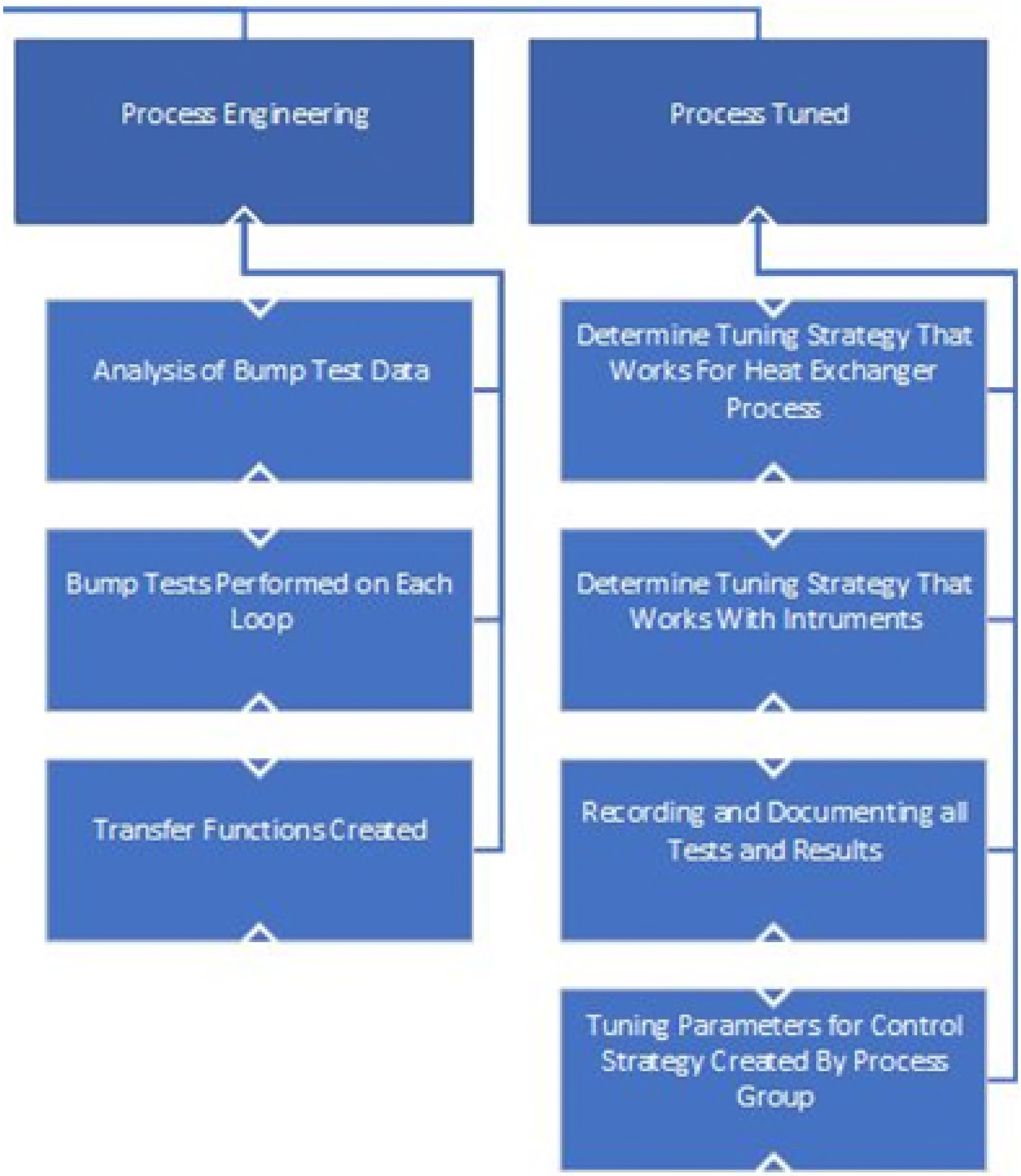


Figure 54 - WBS Process Engineering and Process Tuned

APPENDIX F: GANTT CHART

February 8, 2019

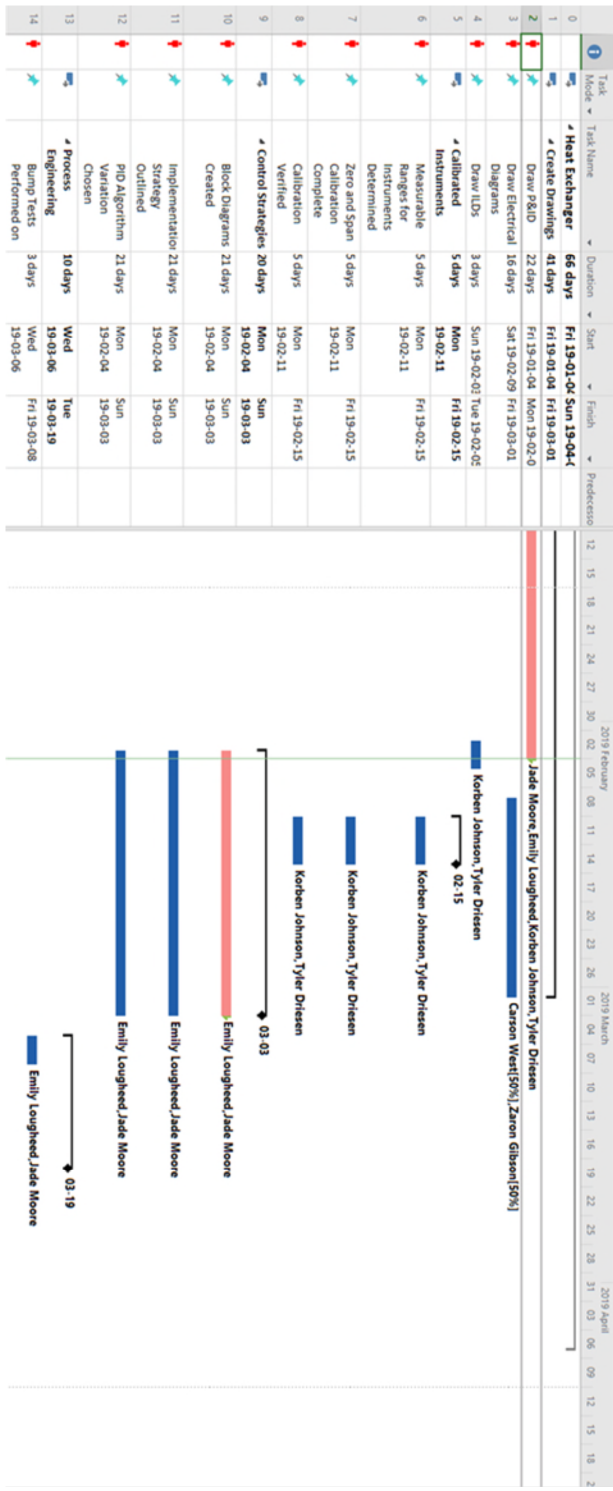


Figure 55 - Gantt Chart Start to Process Engineering (OUTDATED)

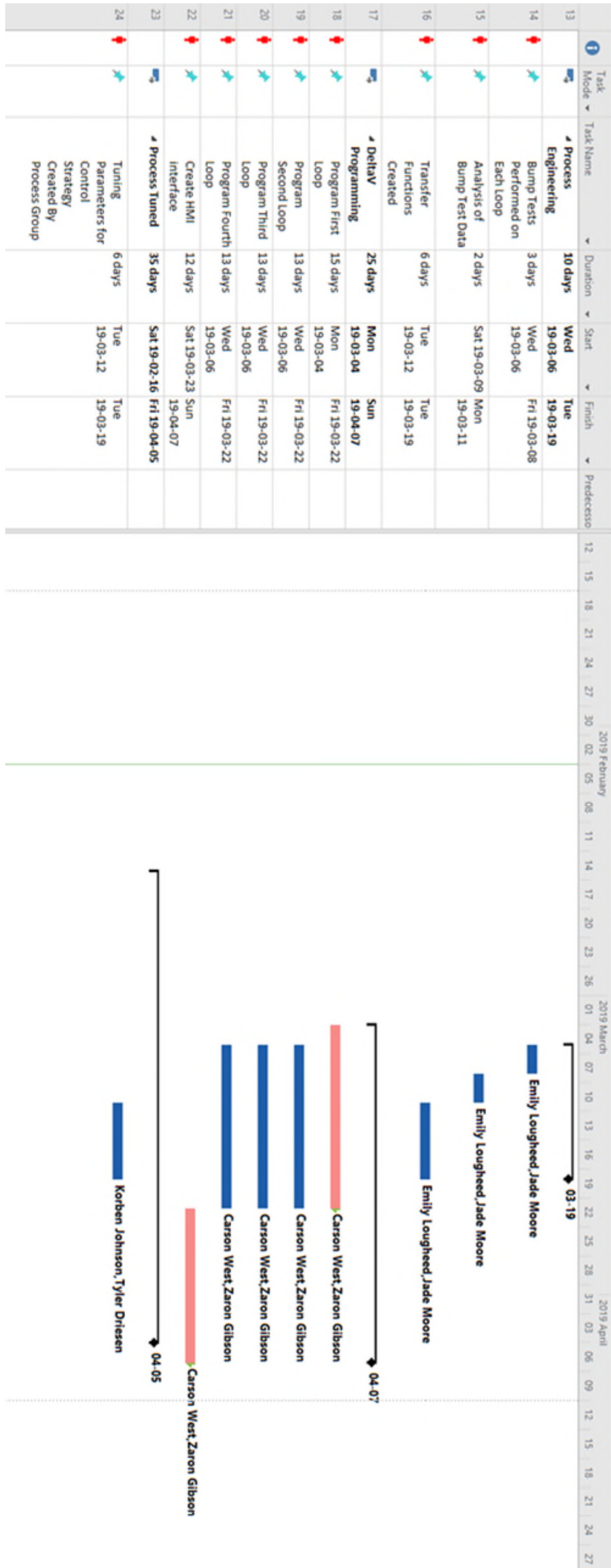


Figure 56 - Gantt Chart Process Engineering to Process Tuned (OUTDATED)

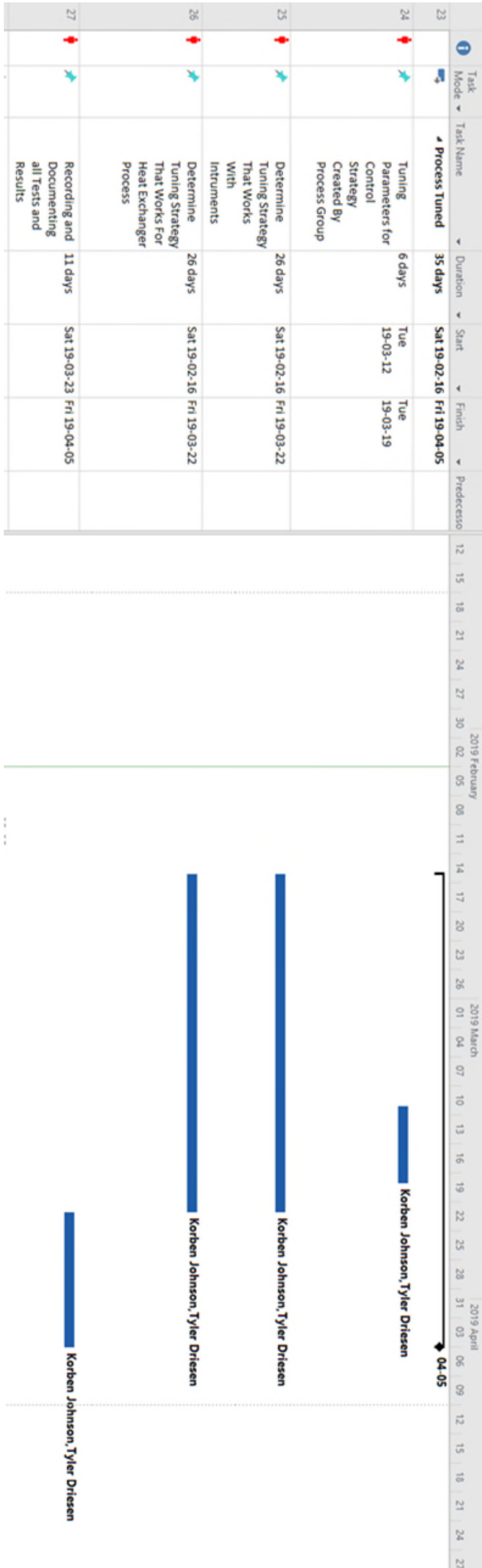
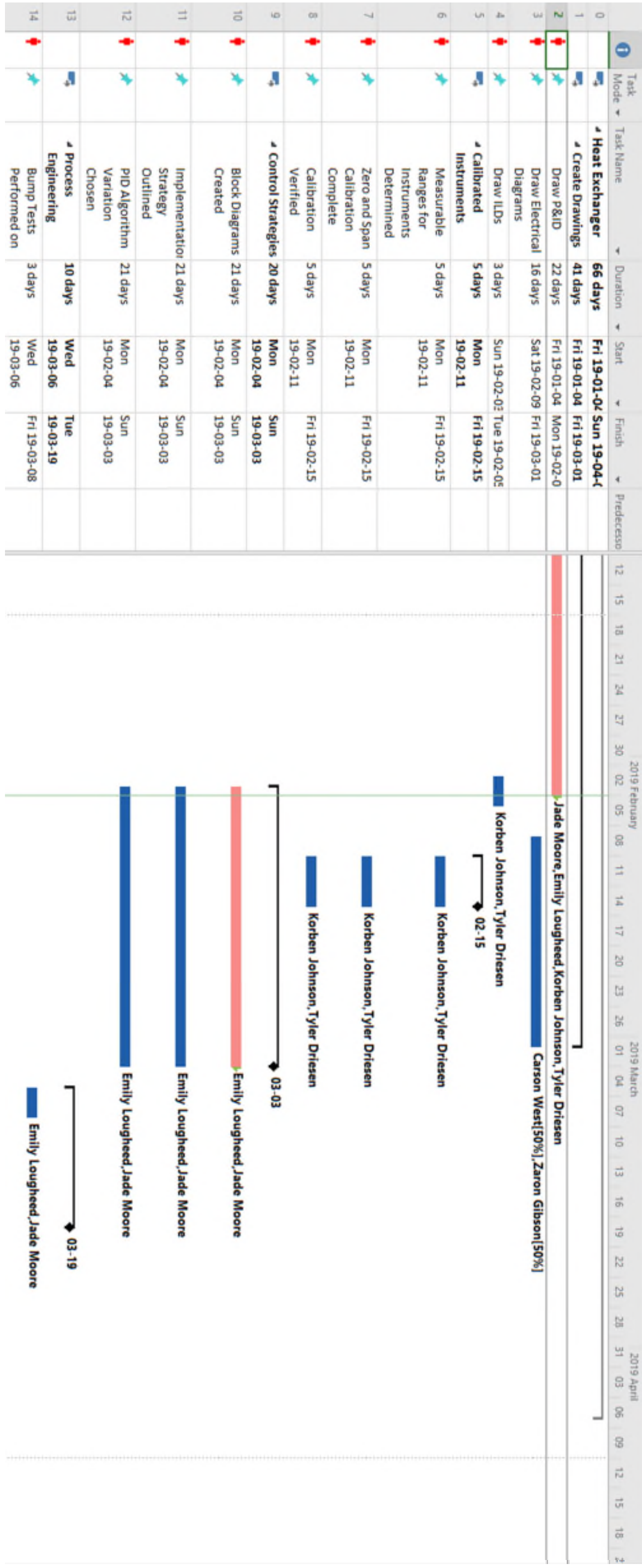


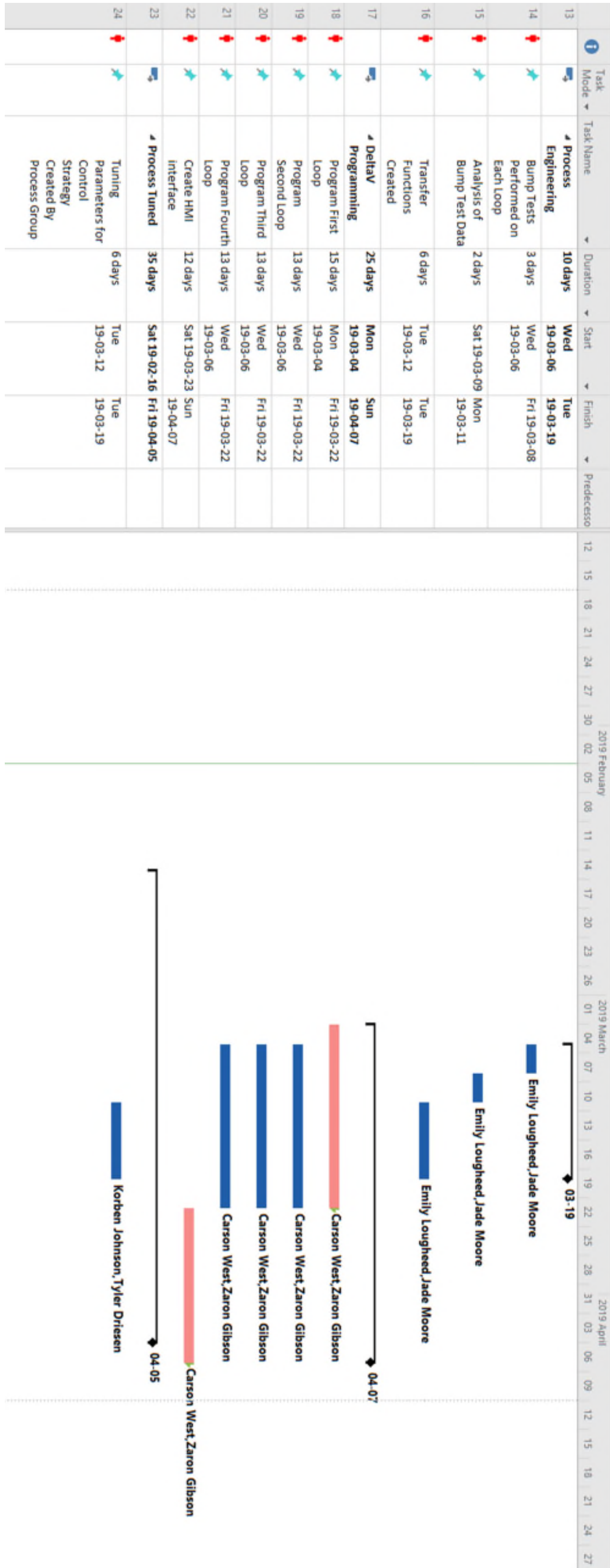
Figure 57 - Gantt Chart of Process Tuned to Completion (OUTDATED)

March 12, 2019



	Task Name	Duration	Start	Finish	Predecessors
0	Heat Exchanger	66 days	Fri 19-01-04	Sun 19-04-(	
1	Create Drawings	41 days	Fri 19-01-04	Fri 19-03-01	
2	Draw P&ID	22 days	Fri 19-01-04	Mon 19-02-0	
3	Draw Electrical Diagrams	16 days	Sat 19-02-09	Fri 19-03-01	
4	Draw ILDs	3 days	Sun 19-02-03	Tue 19-02-05	
5	Calibrated Instruments	5 days	Mon 19-02-11	Fri 19-02-15	
6	Measurable Ranges for Instruments Determined	5 days	Mon 19-02-11	Fri 19-02-15	
7	Zero and Span Calibration Complete	5 days	Mon 19-02-11	Fri 19-02-15	
8	Calibration Verified	5 days	Mon 19-02-11	Fri 19-02-15	
9	Control Strategies	20 days	Mon 19-02-04	Sun 19-03-03	
10	Block Diagrams Created	21 days	Mon 19-02-04	Sun 19-03-03	
11	Implementation Strategy Outlined	21 days	Mon 19-02-04	Sun 19-03-03	
12	PID Algorithm Variation Chosen	21 days	Mon 19-02-04	Sun 19-03-03	
13	Process Engineering	10 days	Wed 19-03-06	Tue 19-03-19	
14	Bump Tests Performed on	3 days	Wed 19-03-06	Fri 19-03-08	

Table 18 - Gantt Chart Start to Process Engineering (OUTDATED)



	Task Name	Duration	Start	Finish	Predecessors
13	**Process Engineering**	**10 days**	**Wed 19-03-06**	**Tue 19-03-19**	
14	Bump Tests Performed on Each Loop	3 days	Wed 19-03-06	Fri 19-03-08	
15	Analysis of Bump Test Data	2 days	Sat 19-03-09	Mon 19-03-11	
16	Transfer Functions Created	6 days	Tue 19-03-12	Tue 19-03-19	
17	**DeltaV Programming**	**25 days**	**Mon 19-03-04**	**Sun 19-04-07**	
18	Program First Loop	15 days	Mon 19-03-04	Fri 19-03-22	
19	Program Second Loop	13 days	Wed 19-03-06	Fri 19-03-22	
20	Program Third Loop	13 days	Wed 19-03-06	Fri 19-03-22	
21	Program Fourth Loop	13 days	Wed 19-03-06	Fri 19-03-22	
22	Create HMI Interface	12 days	Sat 19-03-23	Sun 19-04-07	
23	**Process Tuned**	**35 days**	**Sat 19-02-16**	**Fri 19-04-05**	
24	Tuning Parameters for Control Strategy Created By Process Group	6 days	Tue 19-03-12	Tue 19-03-19	

Table 19 - Gantt Chart Process Engineering to Process Tuned (OUTDATED)

Table 20 - Gantt Chart of Process Tuned to Completion (OUTDATED)

April 10, 2019

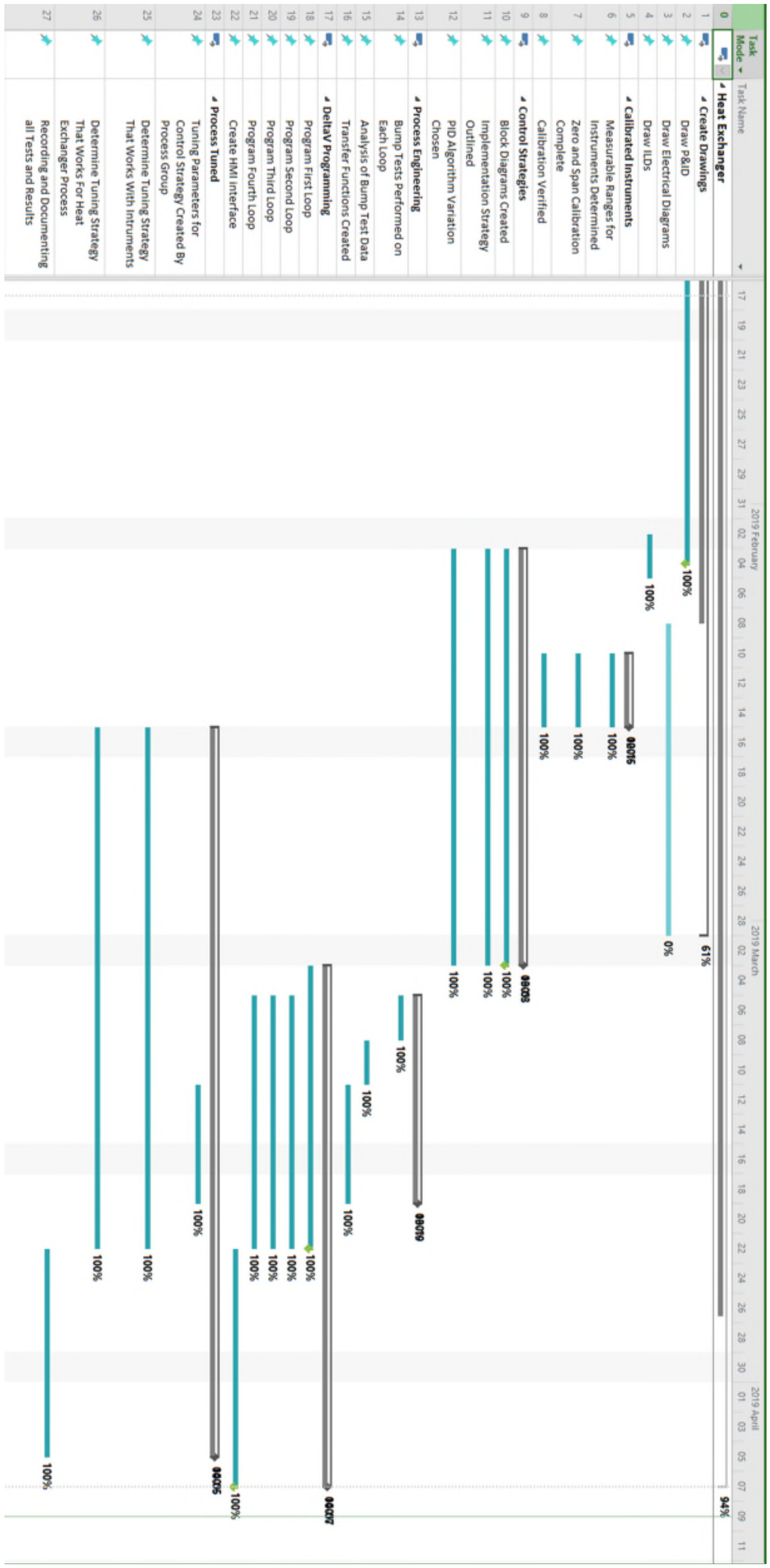


Figure 58 - Gantt Chart Complete

APPENDIX I: STATIC MIXER

The mixing valve controlling the flow of the two water sources has been tested with the cold-water flow to understand the function and characteristics of the valve.

Figure 59 - Static Mixer within Pipe

APPENDIX J: CALIBRATION, MAINTENANCE, AND TUNING

PREVIOUS NOTES

Due to the plant not being initialized until March 8, 2019, and the main functions still not operational, the deliverables associated with the calibration have not been complete. With the minimal functions available, the plant was turned on and the instruments have been checked for power, but not calibrated to determined ranges. All instruments have been labelled to the convention defined in the P&ID we created.

APPENDIX K: CONTROLLER PID FACEPLATES

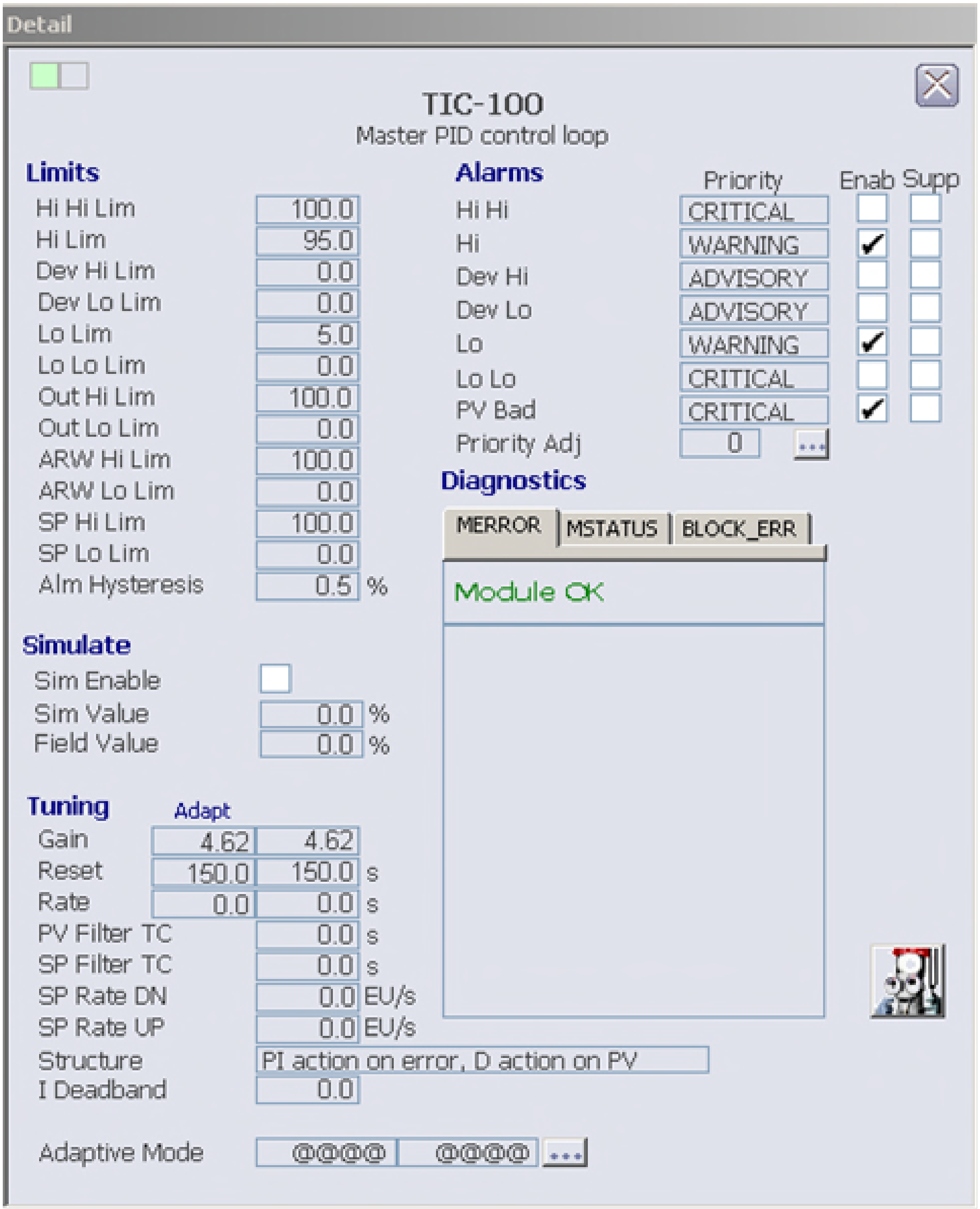


Figure 60: TIC-100 PID Panel

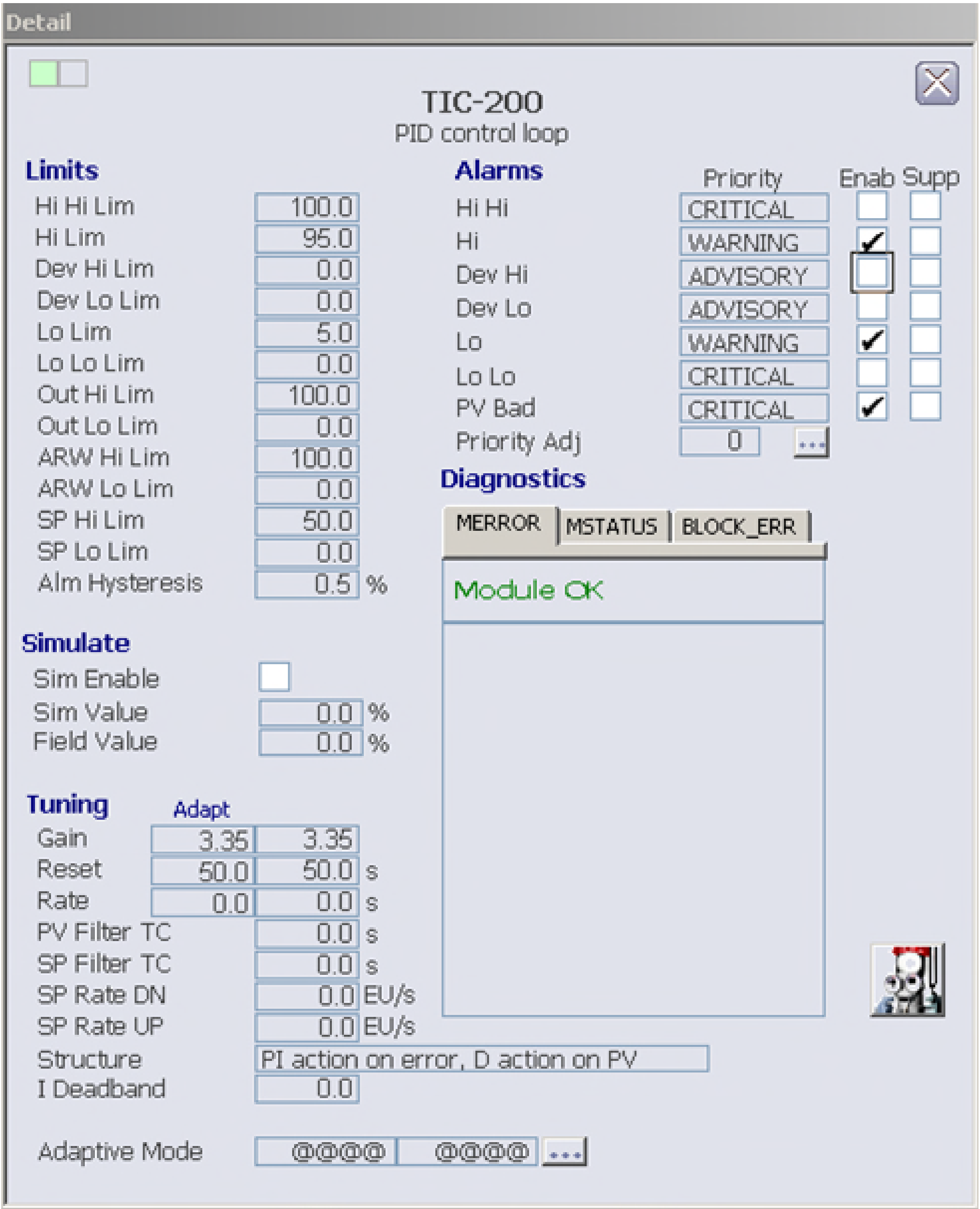


Figure 61: TIC-200 PID Panel

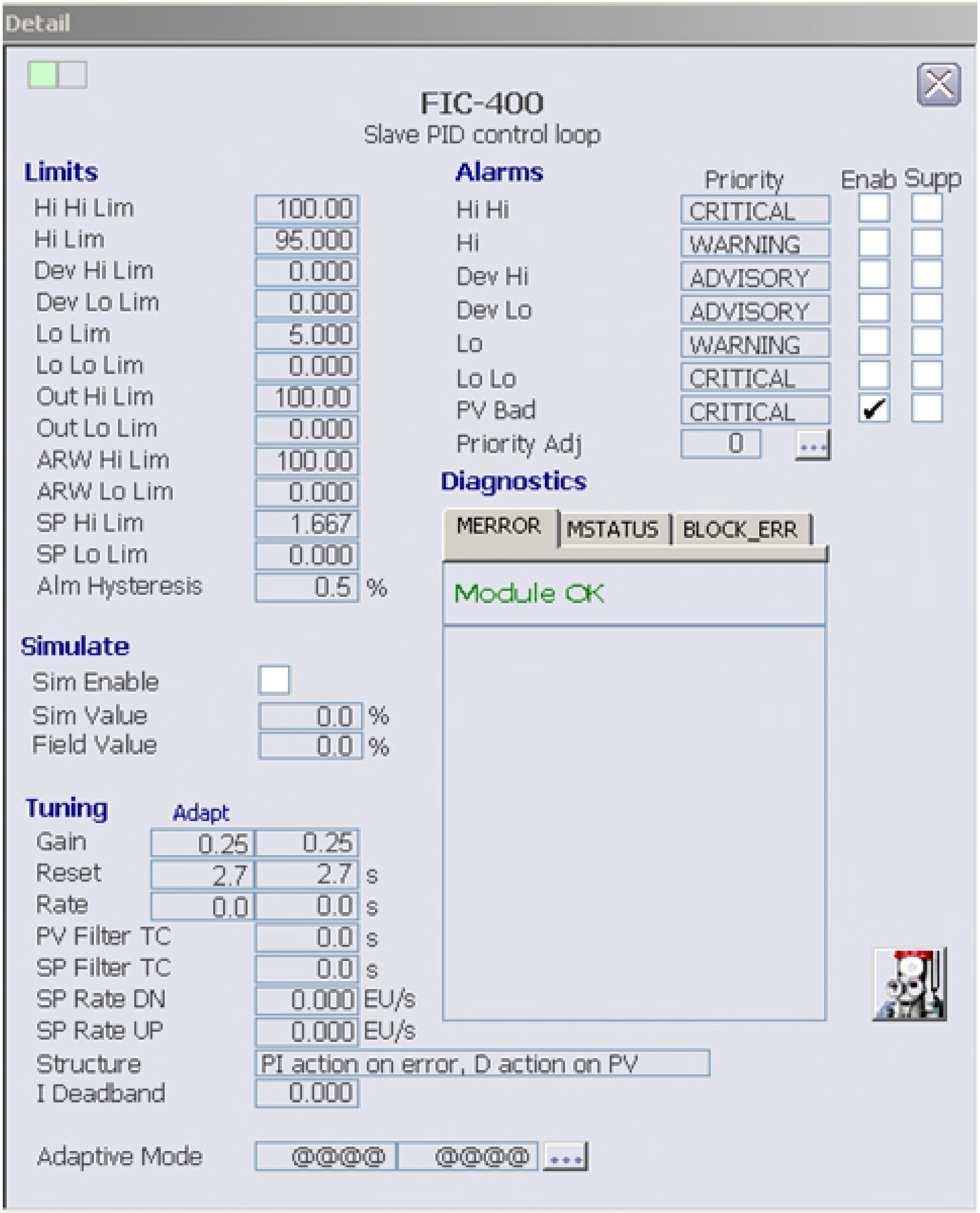


Figure 62: FIC-400 PID Panel

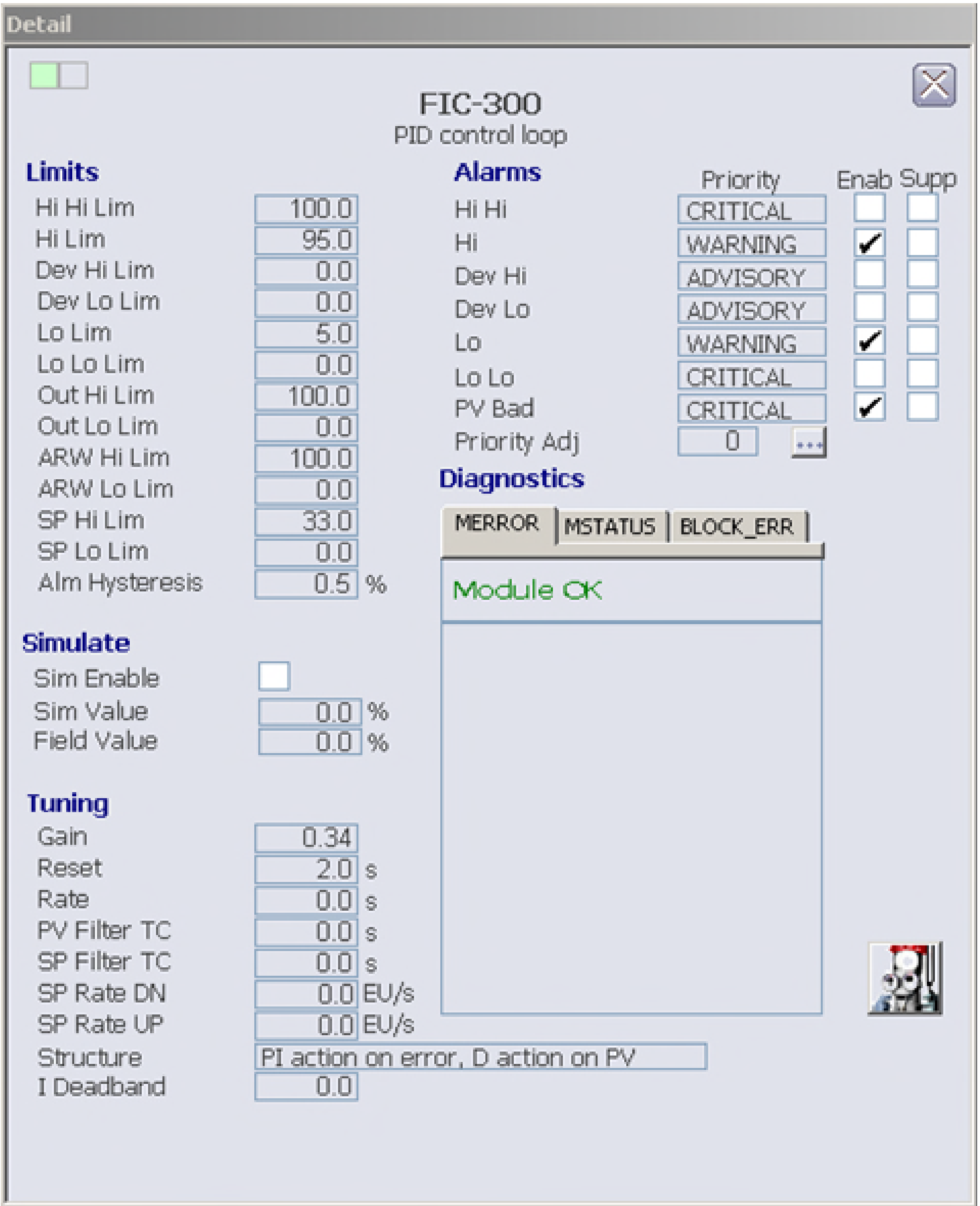


Figure 63: FIC-300 PID Panel

APPENDIX L: TY-100 CONTROL MODULE

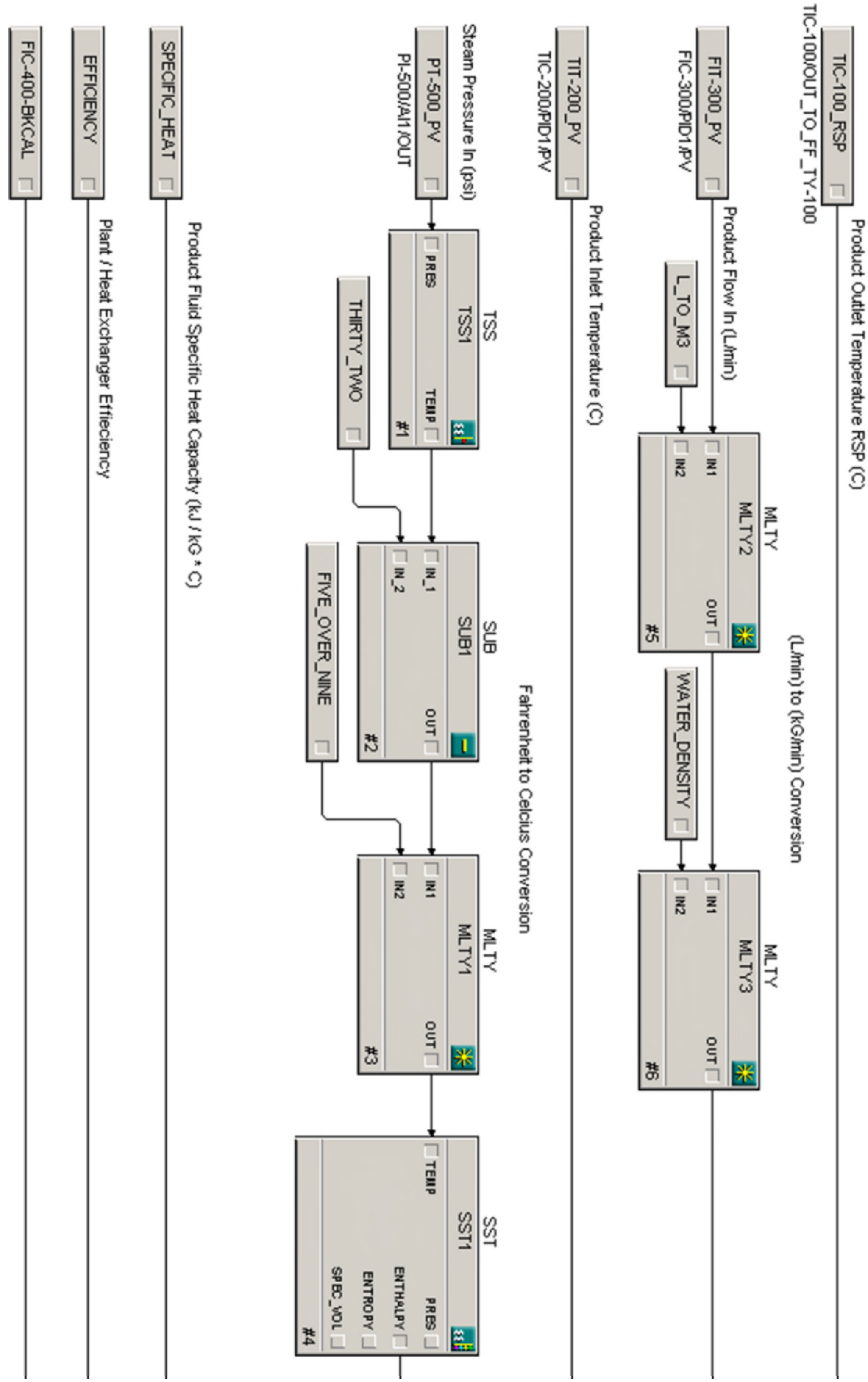


Figure 64: TY-100 Expanded

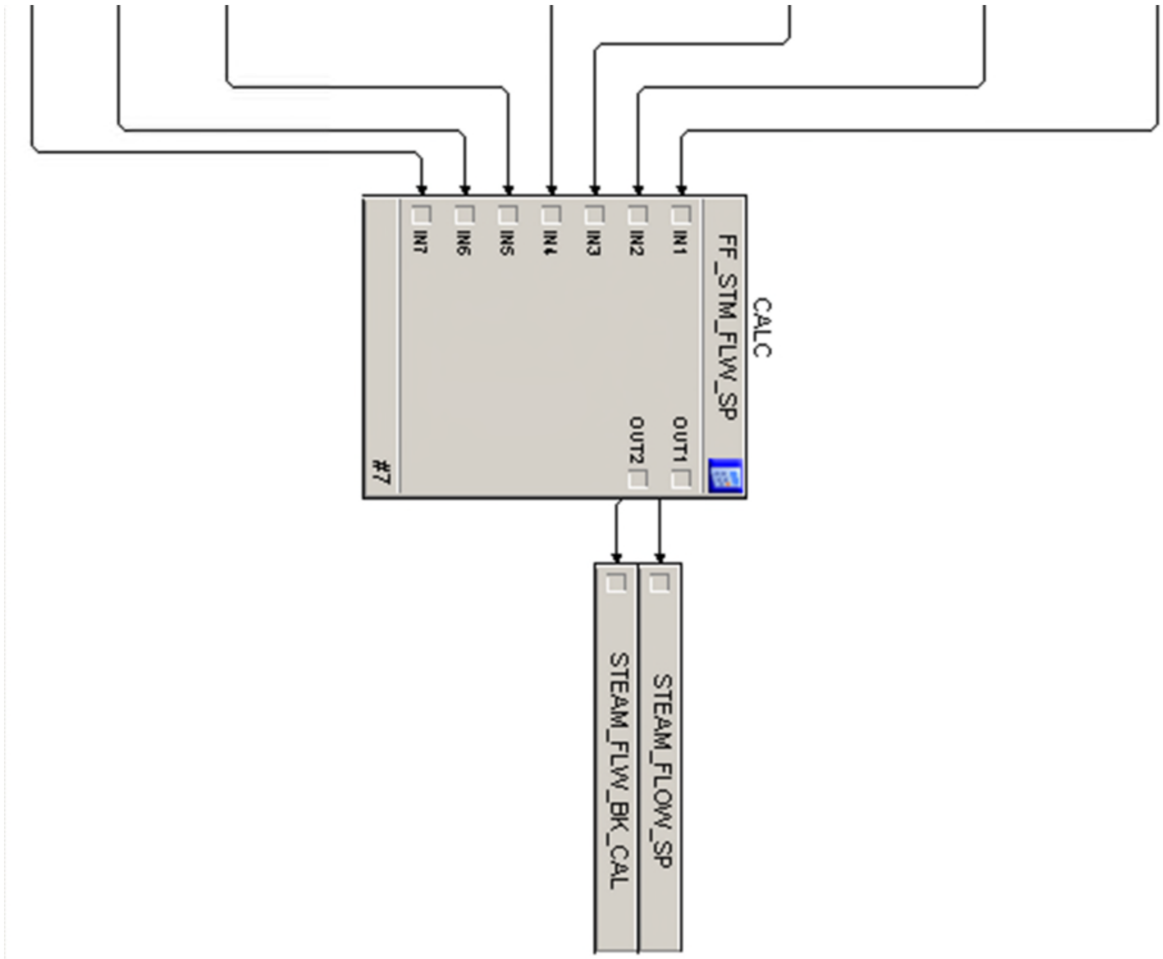


Figure 65: TY-100 Expanded 2d

APPENDIX M: CIOCs AND CHARMs

Figure 66: CIOC and CHARM hardware

APPENDIX N: PLANT PICTURES

FULL SKID

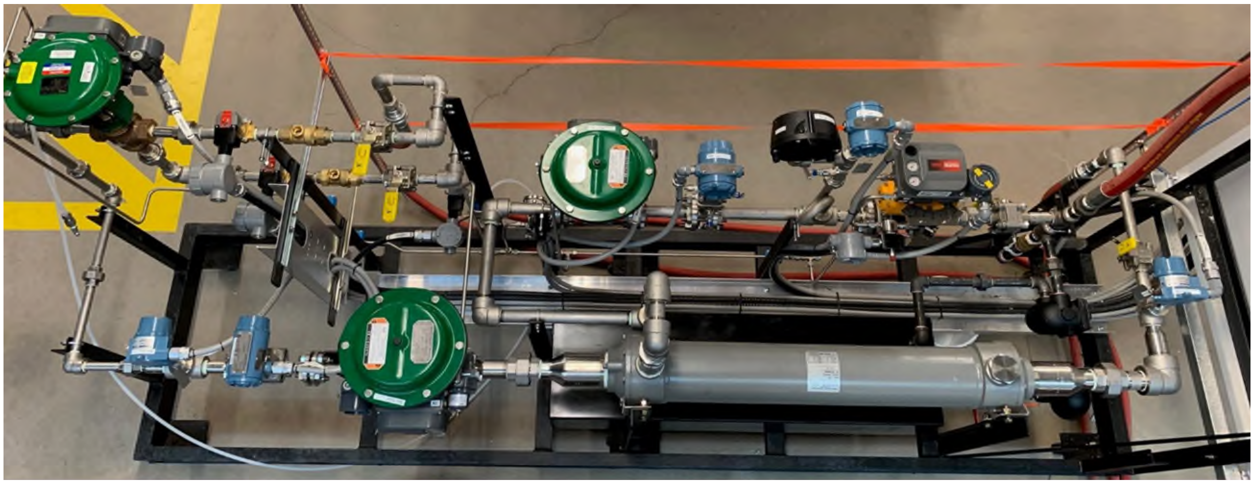


Figure 67: Full plant top-down

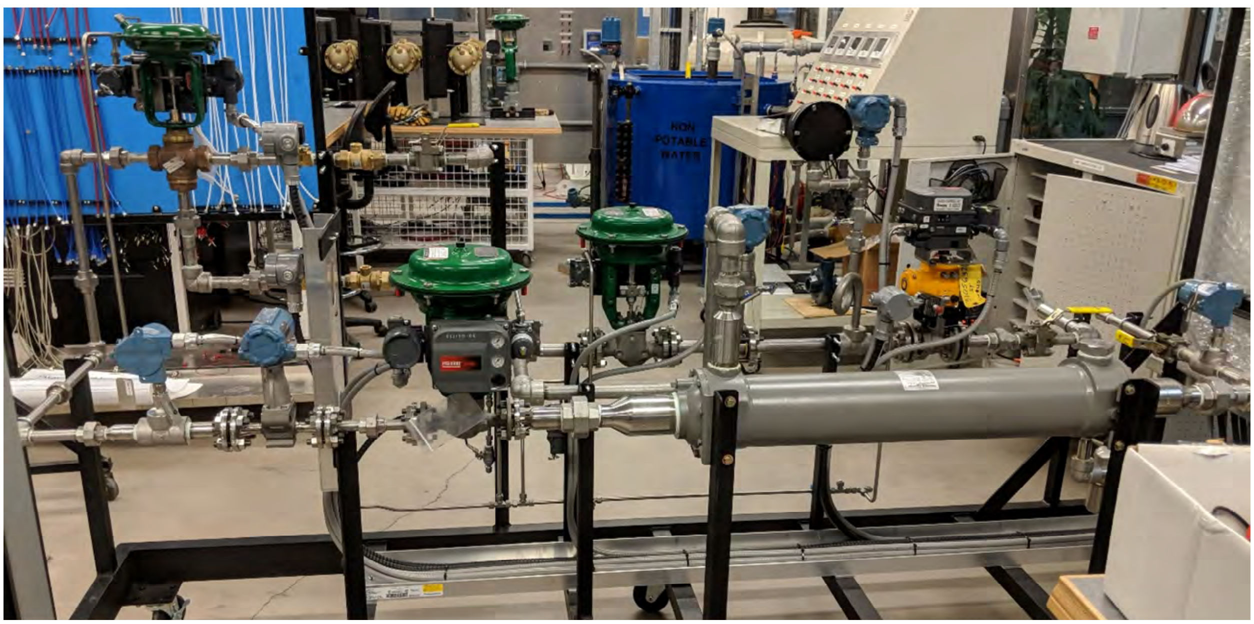


Figure 68: Full plant, Heat Exchanger side

Figure 69: Full plant, inlet and outlet side

PROCESS INLET LINES

Seen in the picture is FIT-300, FCV-300, TIT-200, TCV-200, SV-401, SV-402.

Figure 70: Plant Process Inlet Lines

STEAM LINE INSTRUMENTS

Seen in the picture is SIS valve 530, XV-530, PT-500, PI-500, FIT-400 and FCV-400.

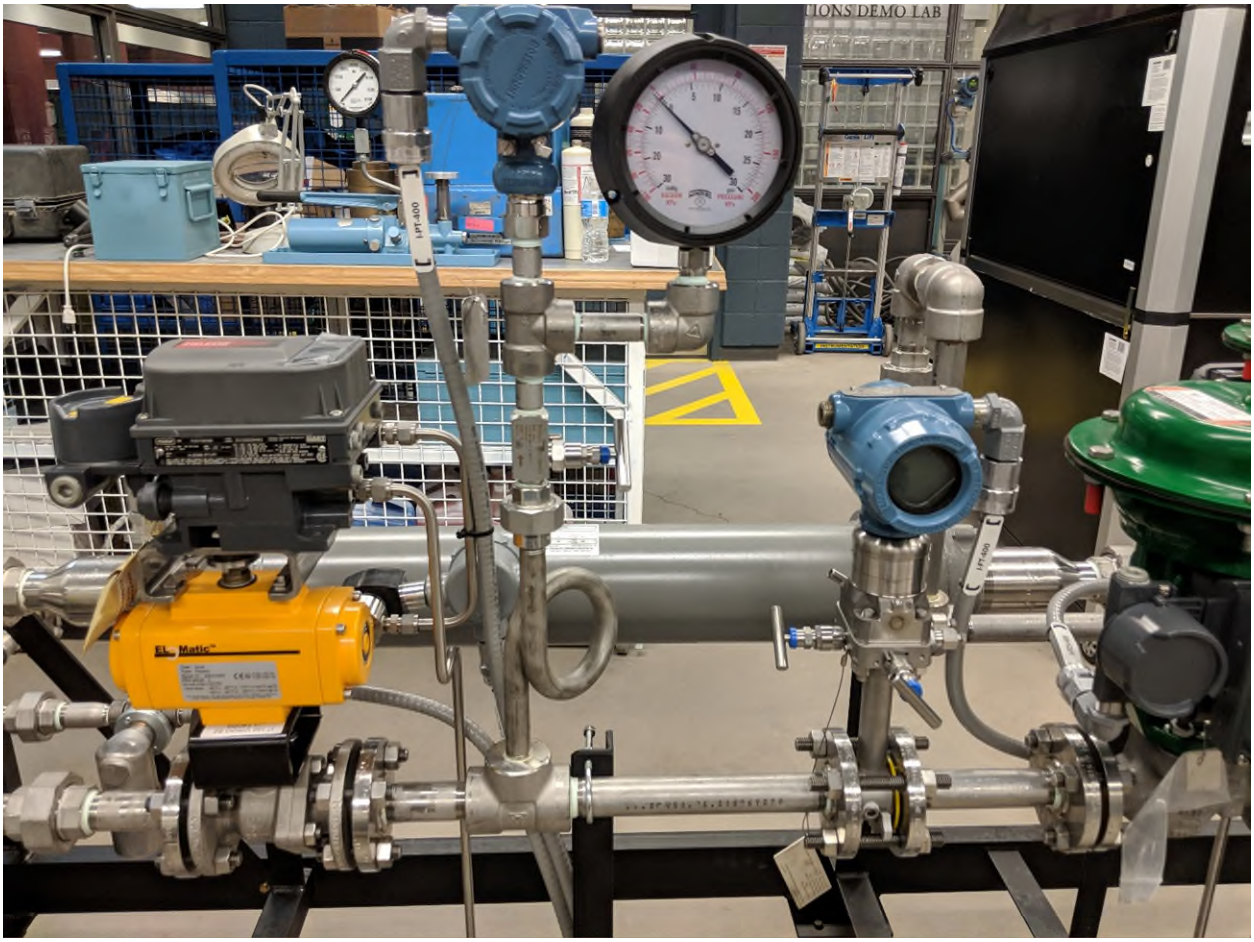


Figure 71: Plant steam line instrumentation

MODIFIED CONDENSATE TRAPS

Below is a picture of the plant condensate traps that were added to the system.

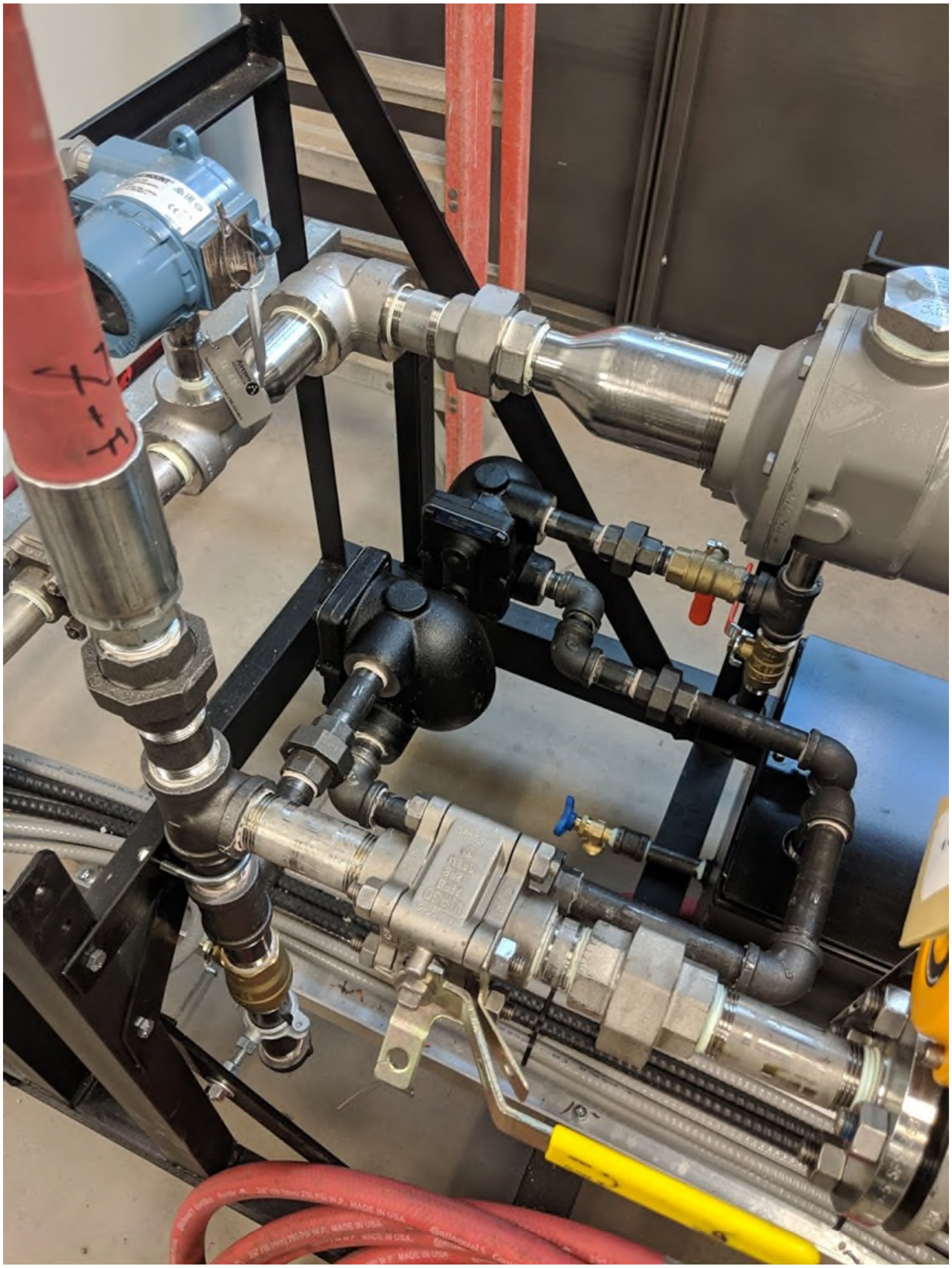


Figure 72: Plant condensate traps

ANNEXES

ANNEX A: SPARTAN SCHEMATICS AND DIAGRAMS

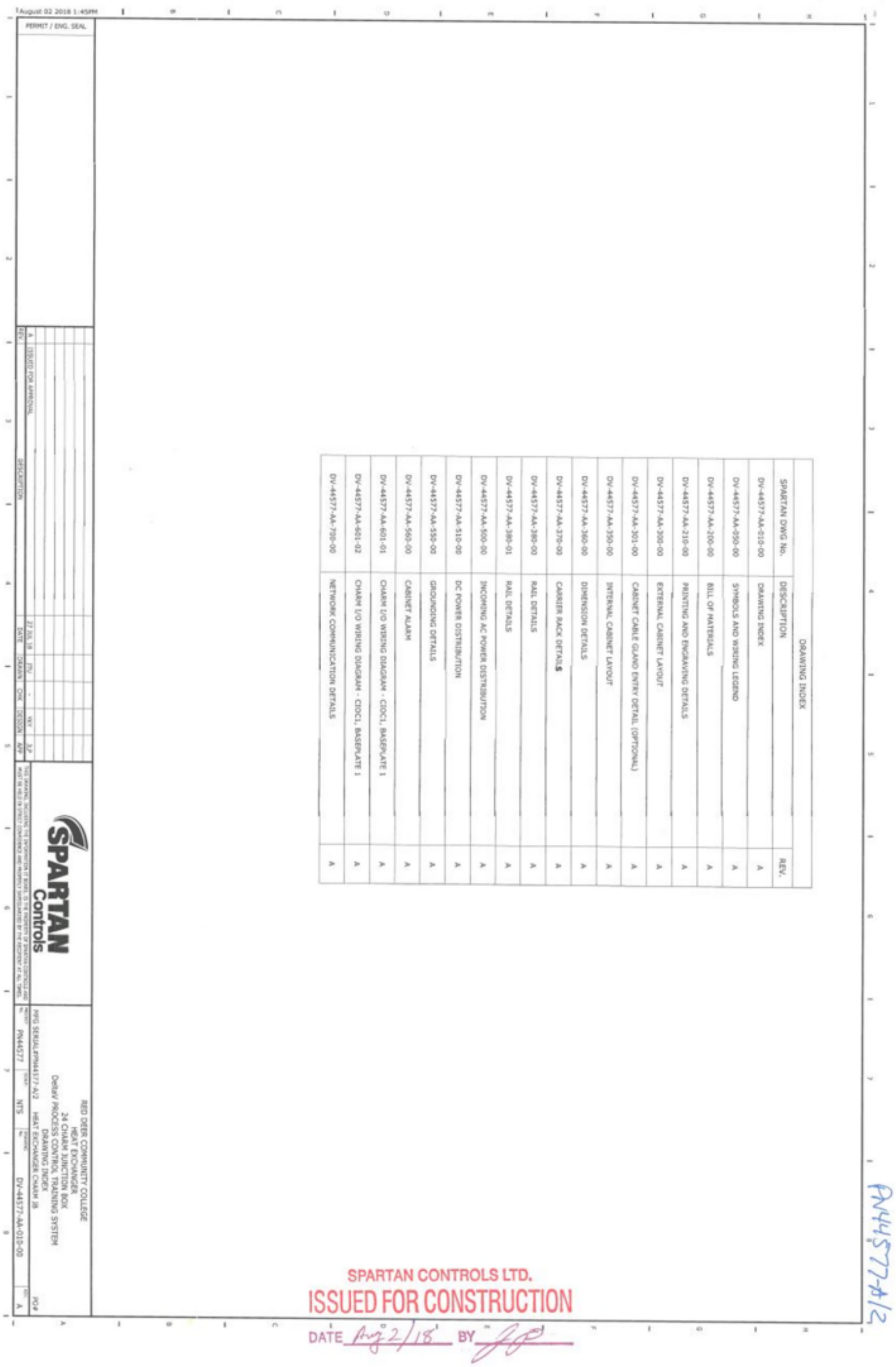


Figure 73 - Charm Junction Box

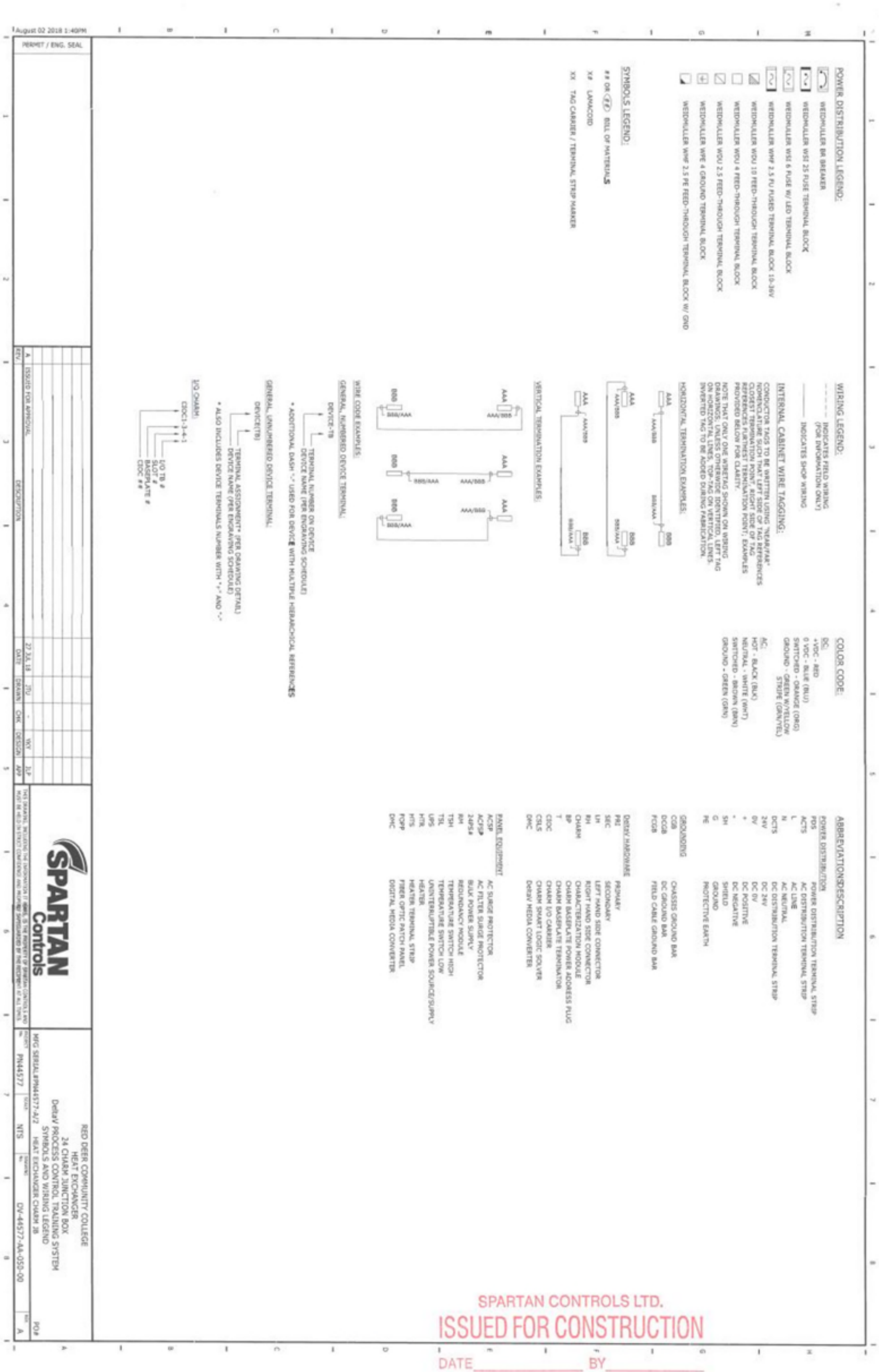


Figure 74 - Symbols and Wiring Legend

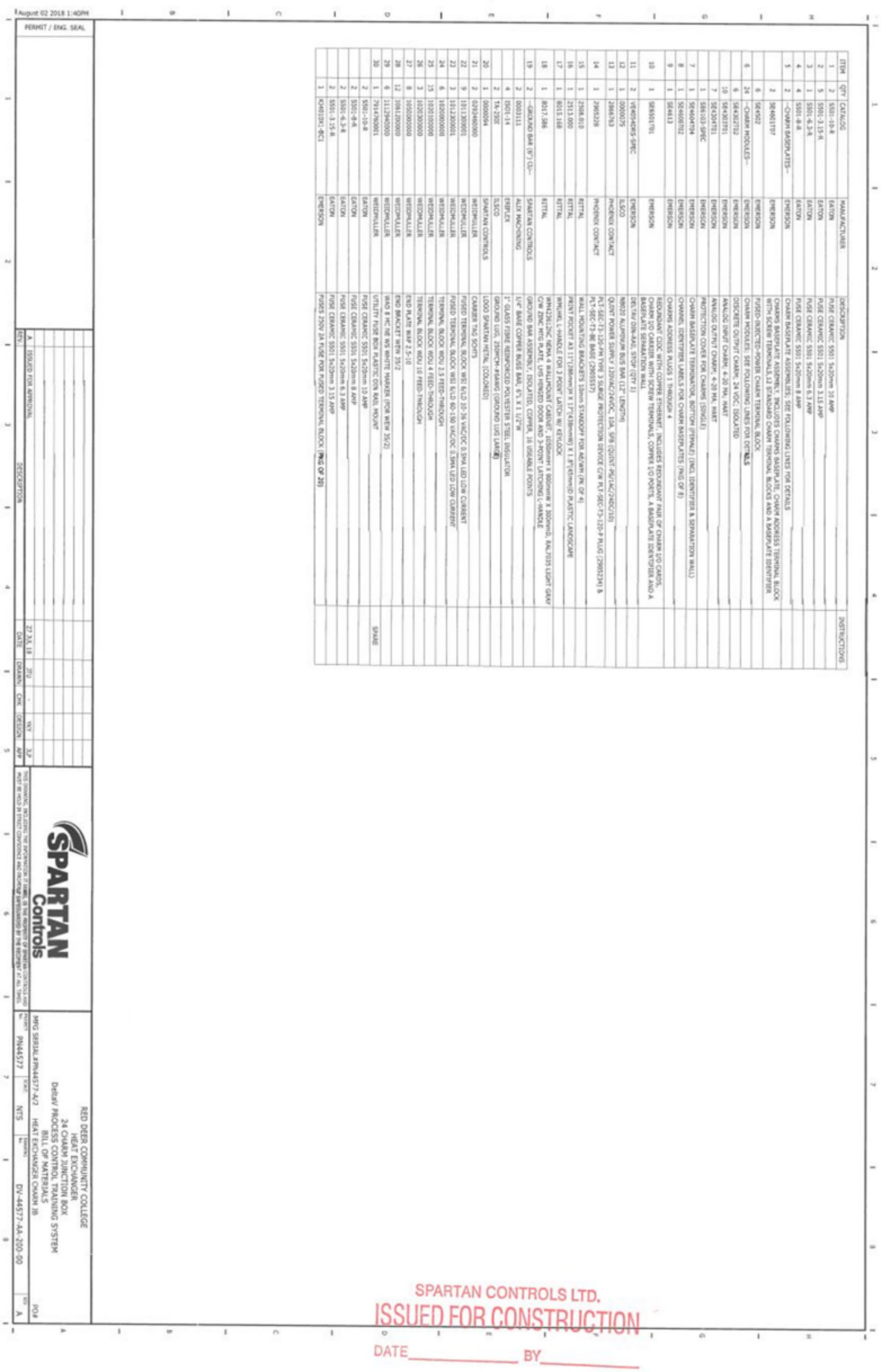


Figure 75 - Bill of Materials

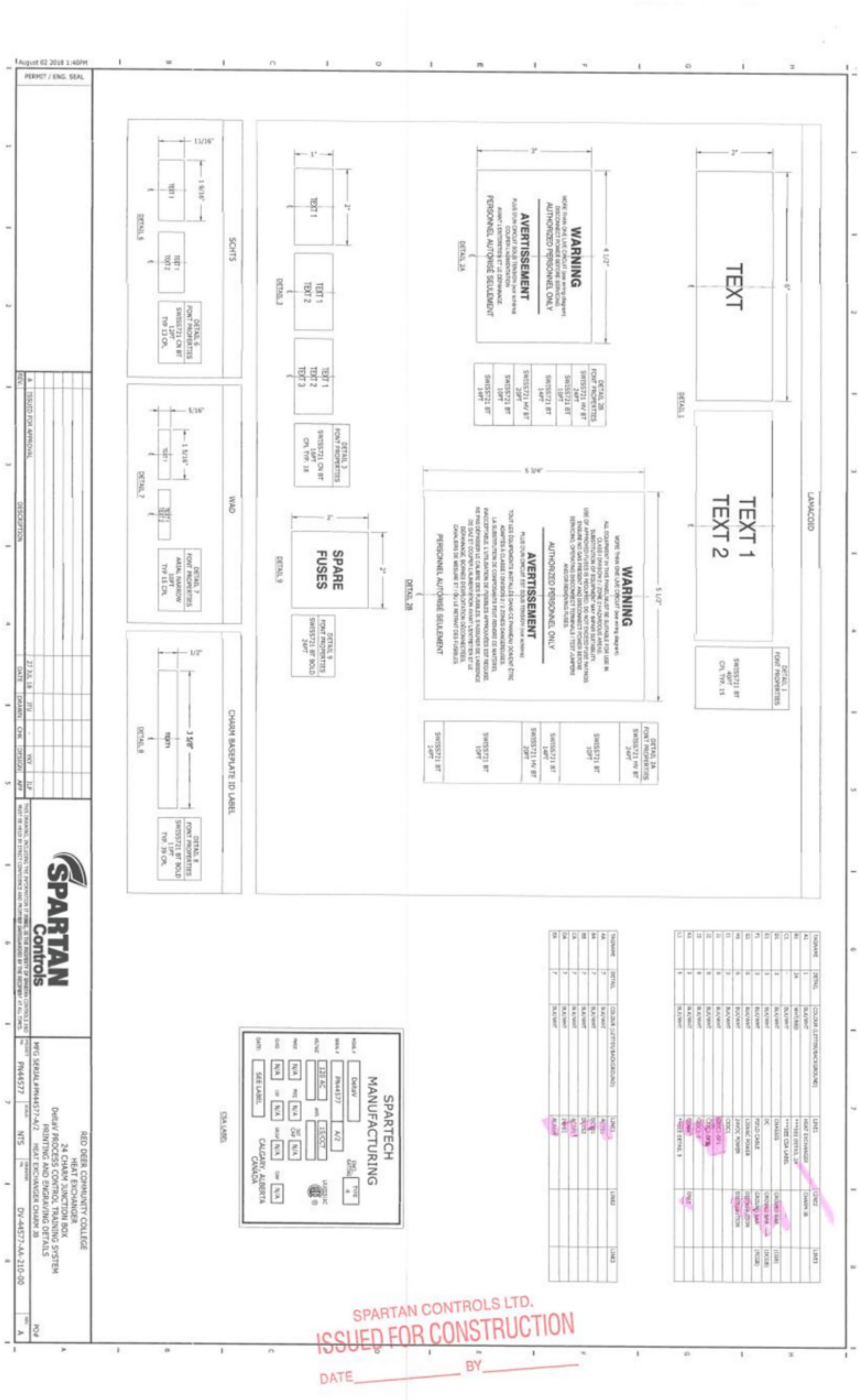


Figure 76 - Printing and Engraving Details

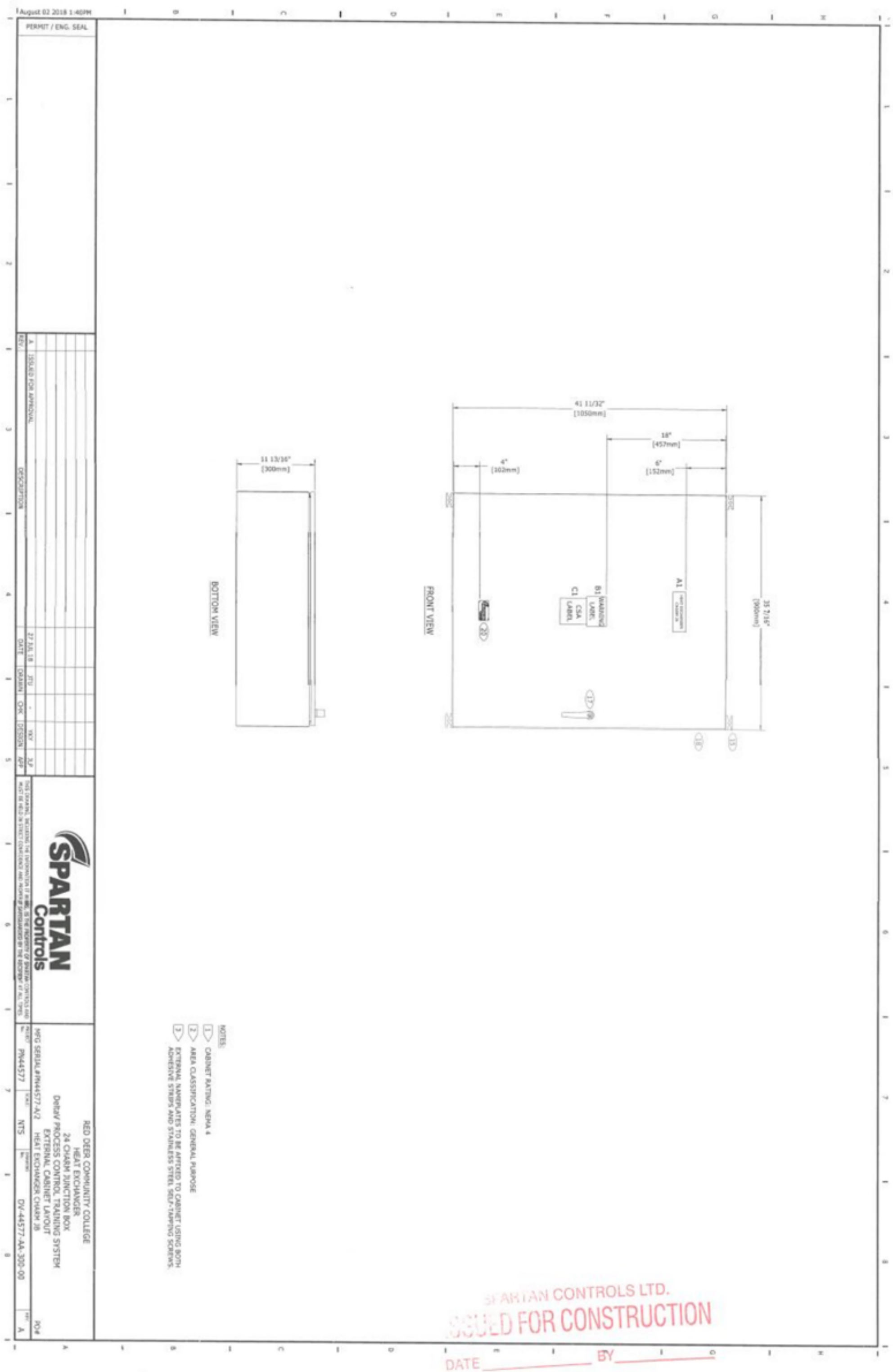


Figure 77 - External Cabinet Layout

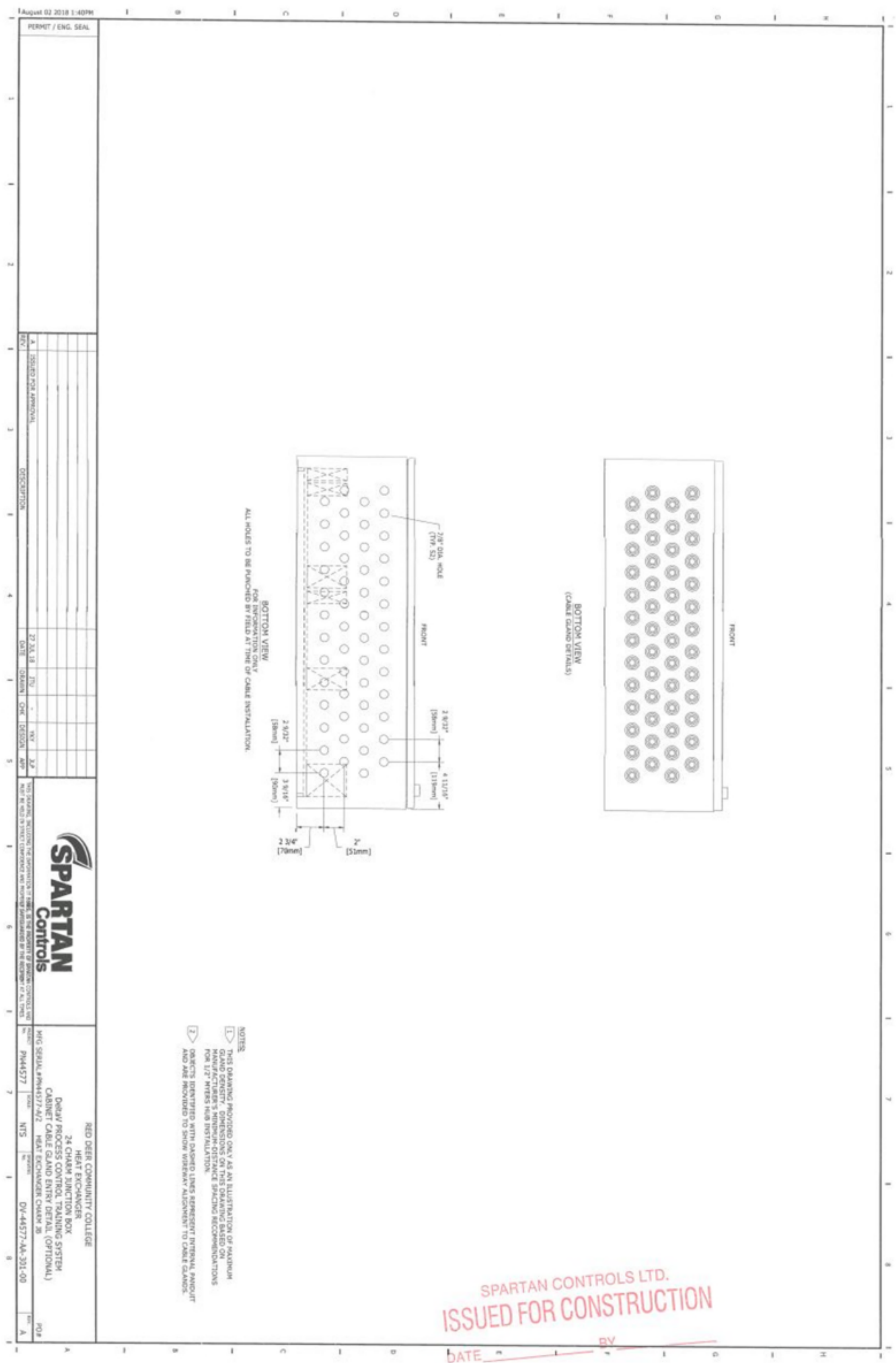


Figure 78 - Cabinet Cable Gland Entry Details

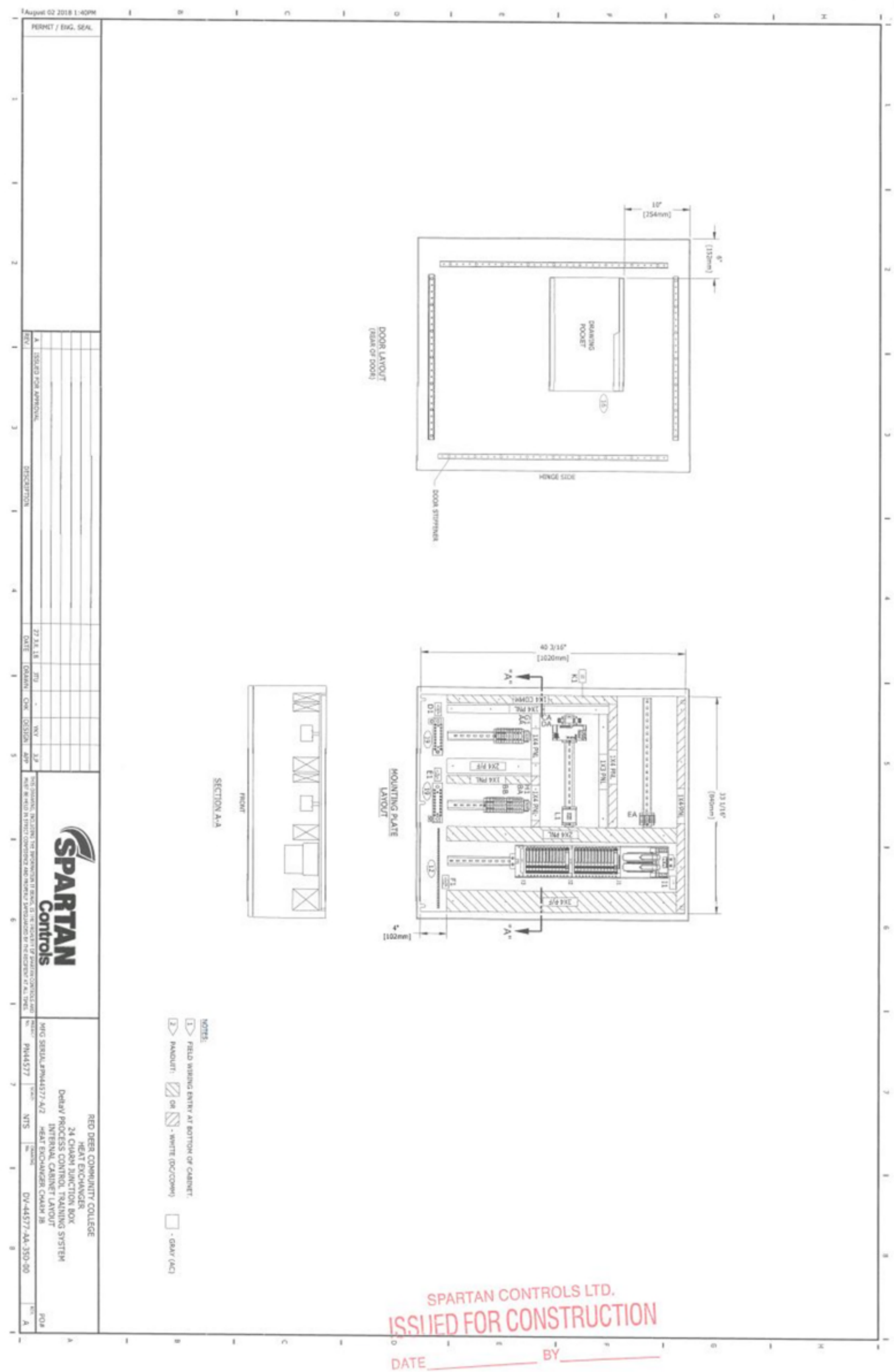


Figure 79 - Internal Cabinet Layout

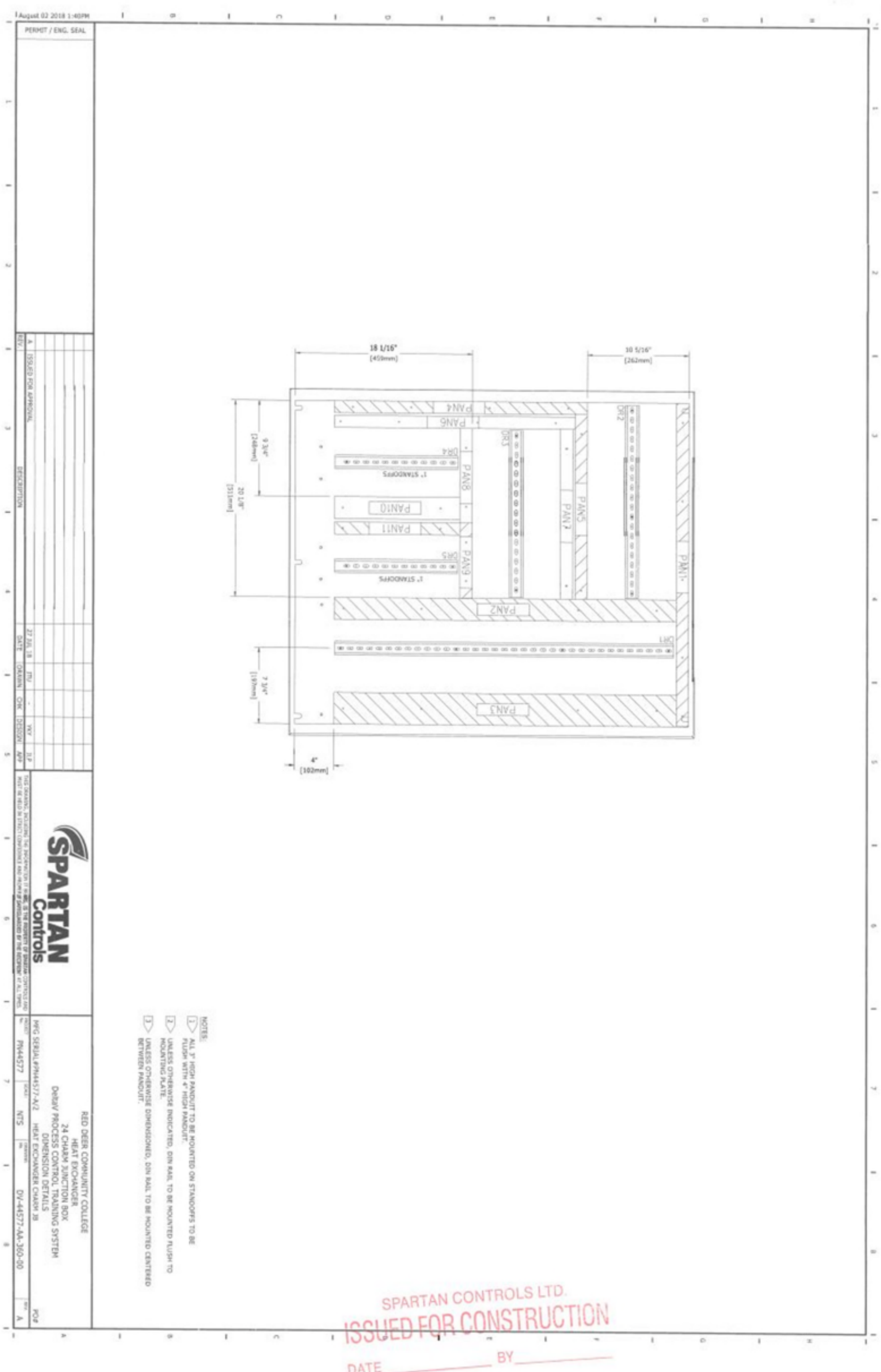


Figure 80 – Dimension Details

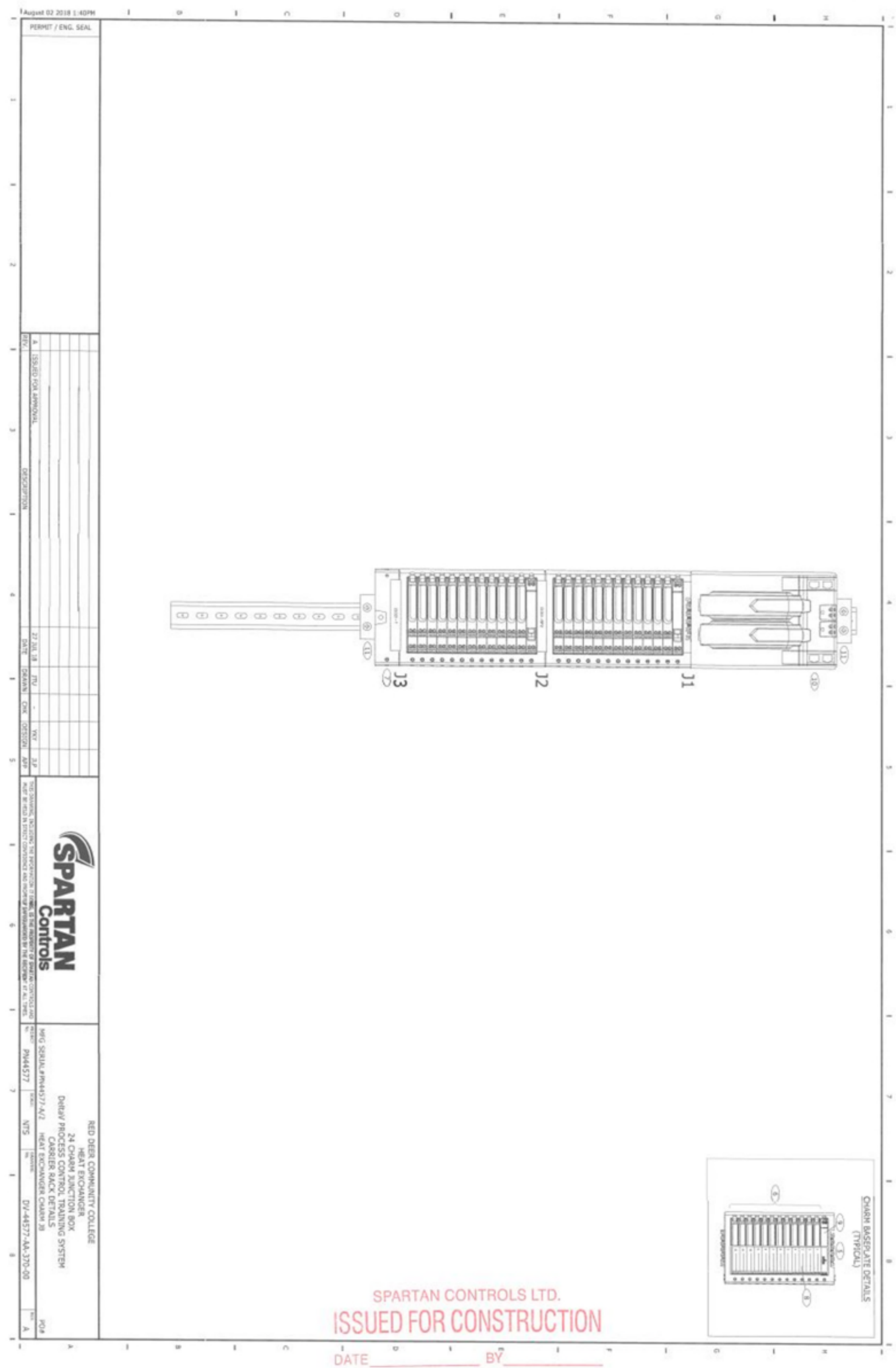


Figure 81 - Carrier Rack Details

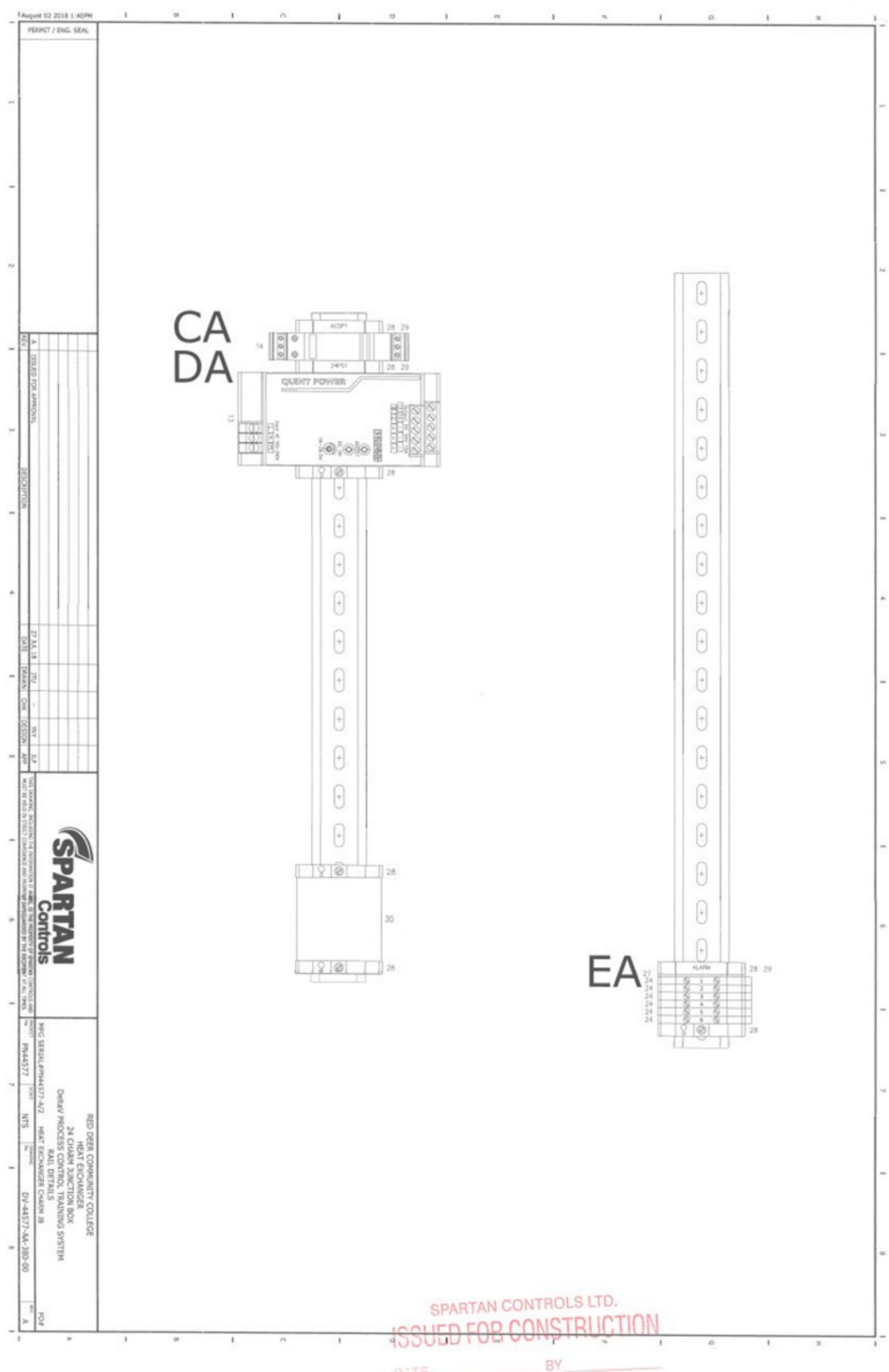


Figure 82 - Rail Details-1

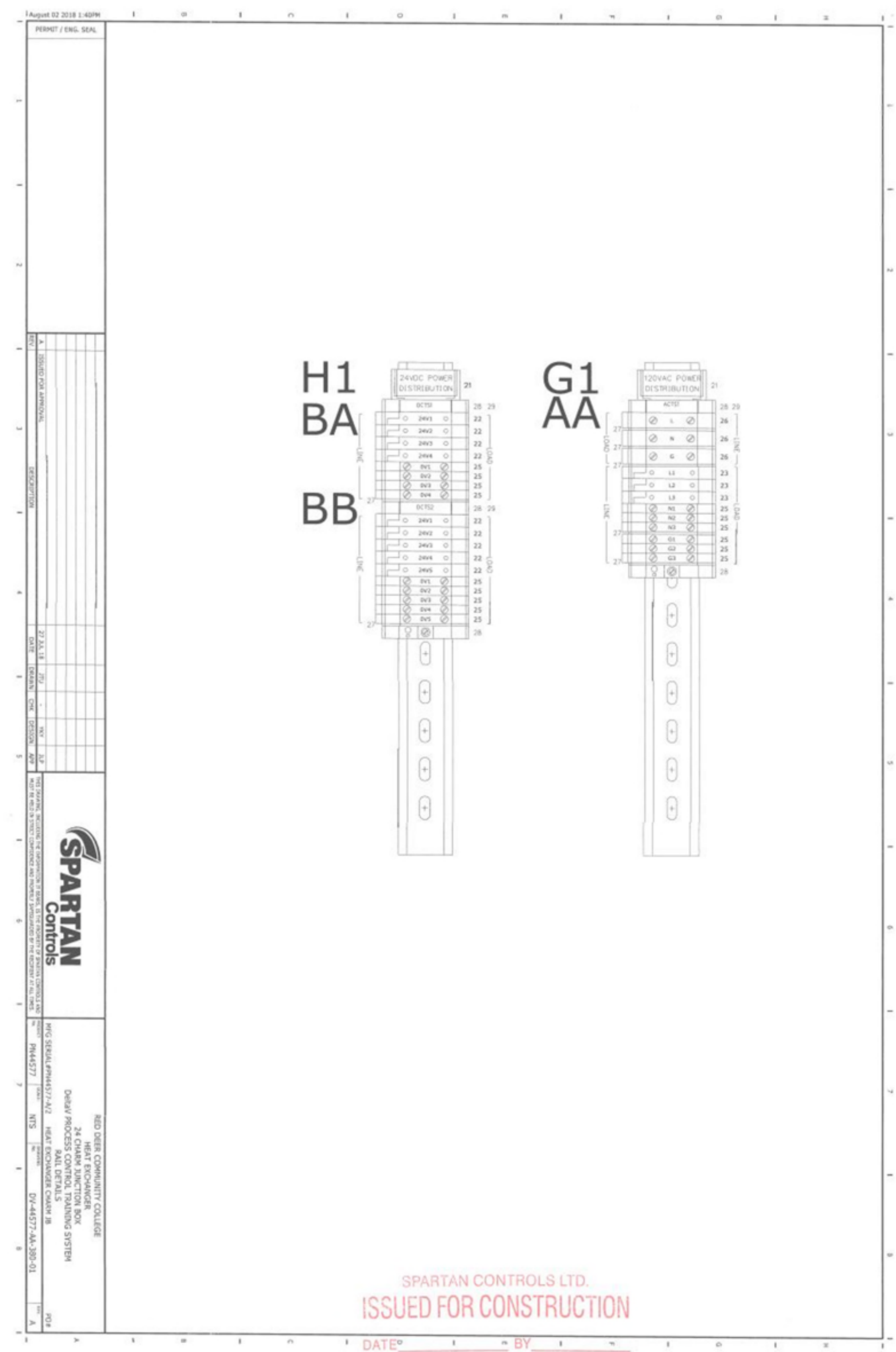


Figure 83 - Rail Details-2

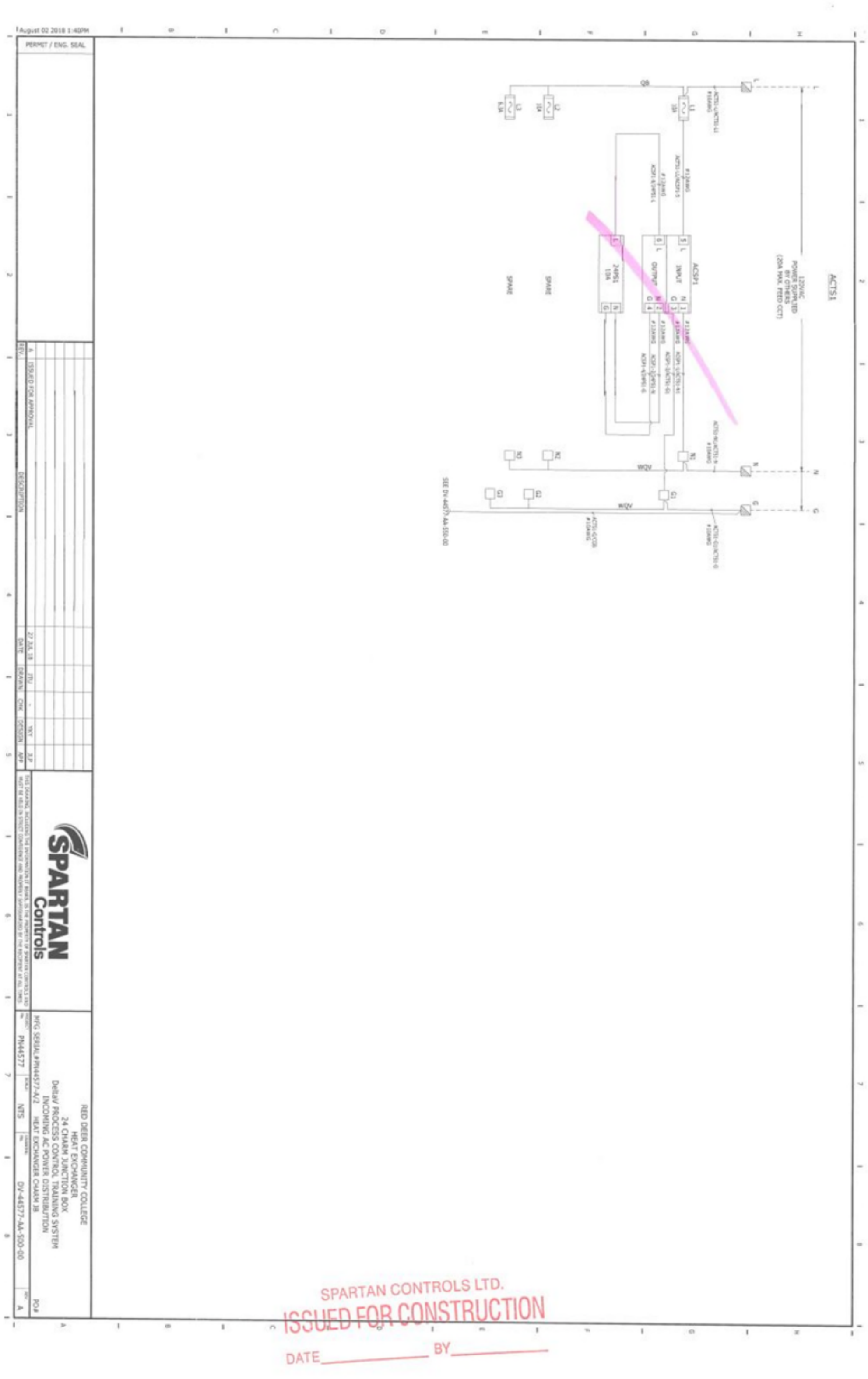


Figure 84 - Incoming AC Power Distribution

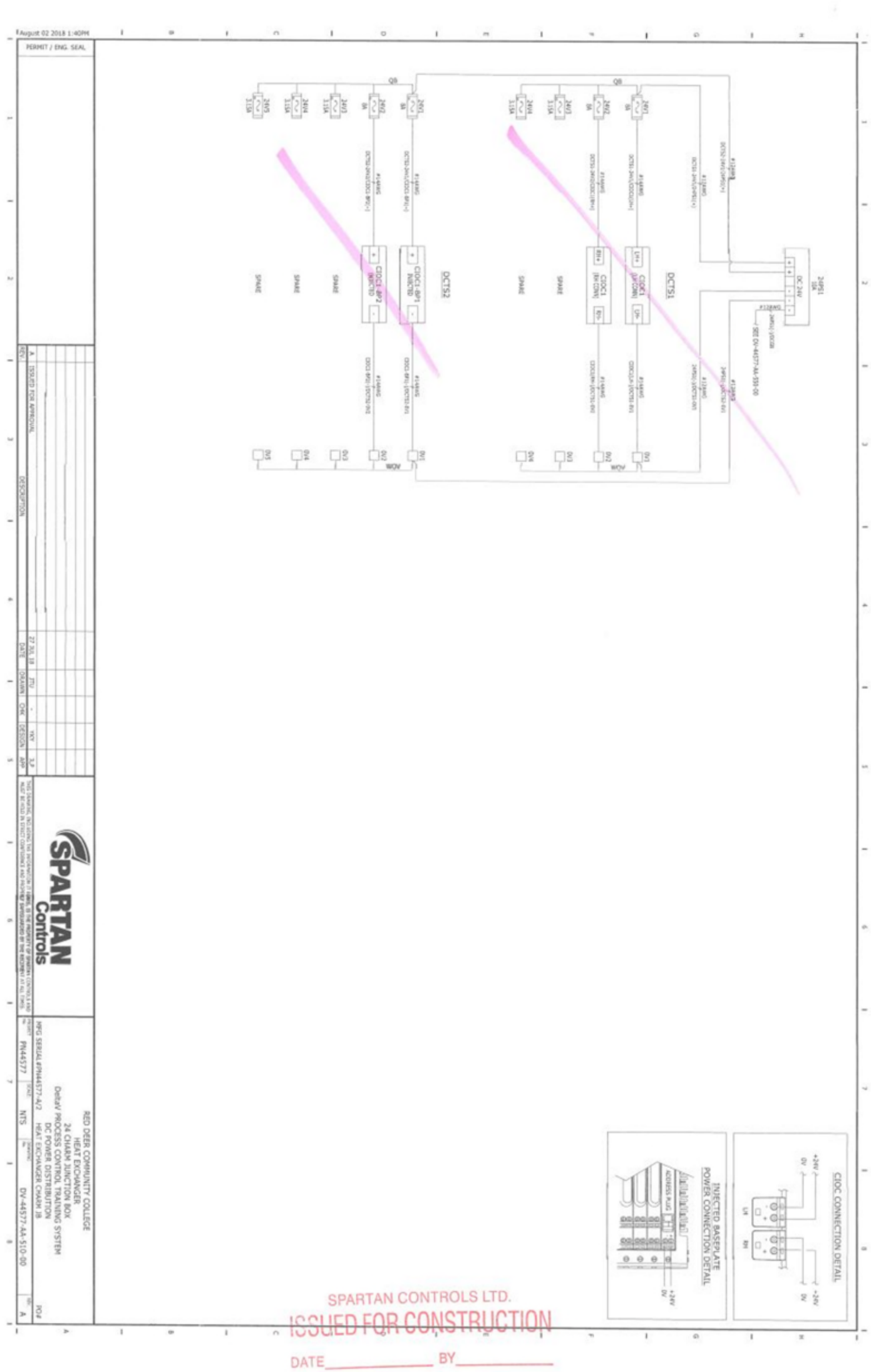


Figure 85 - DC Power Distribution

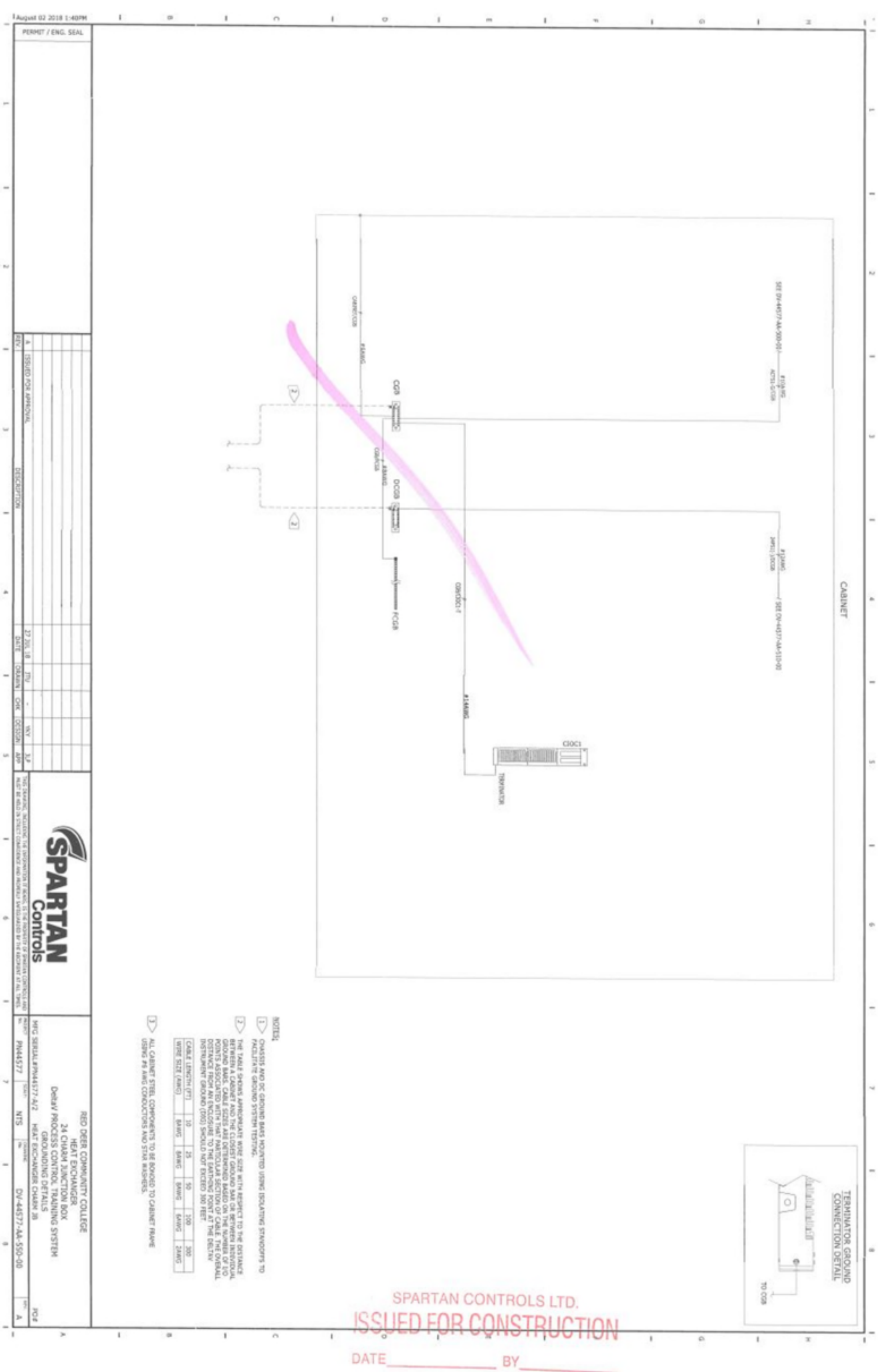


Figure 86 - Grounding Details

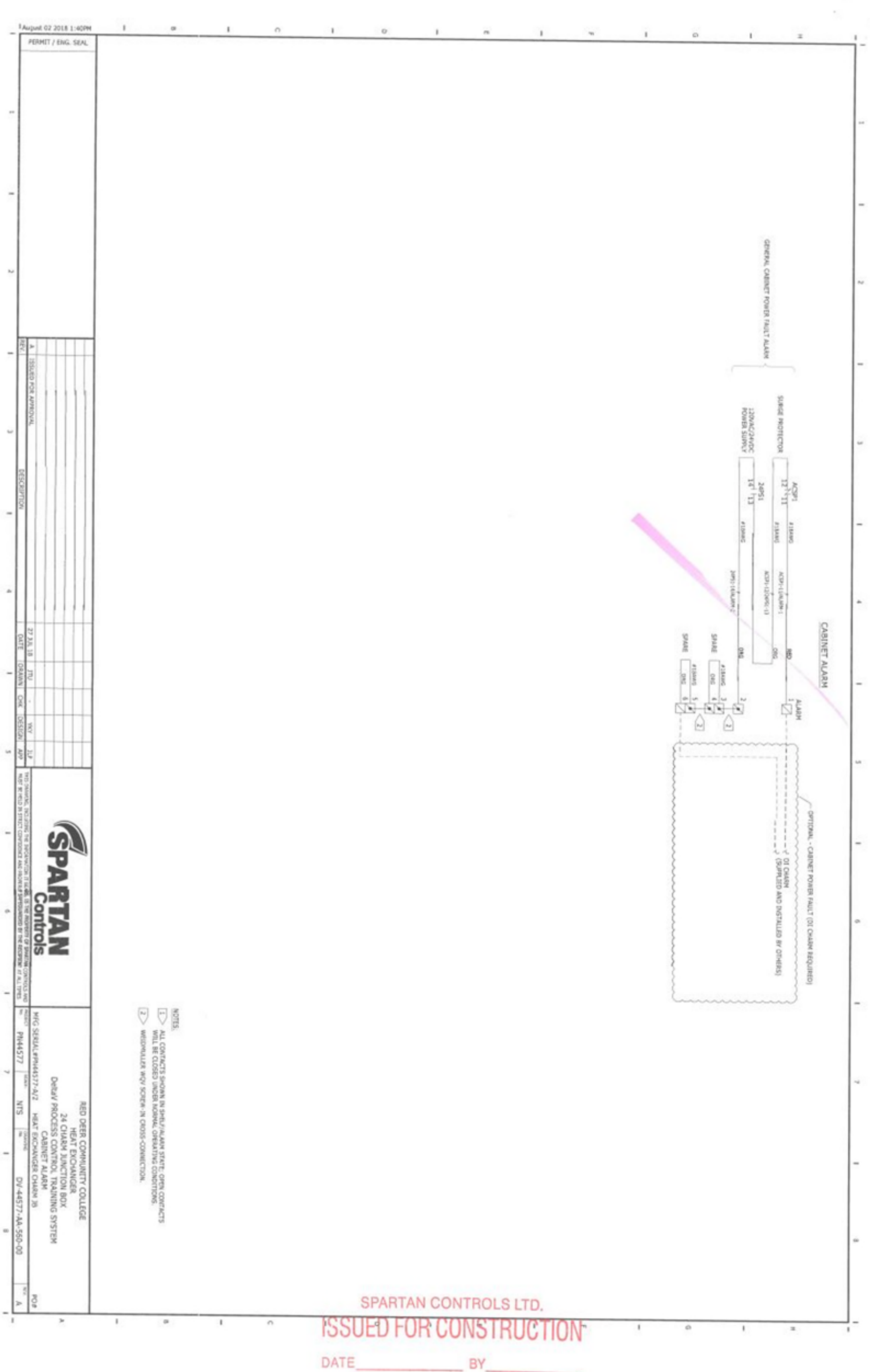


Figure 87 - Cabinet Alarm

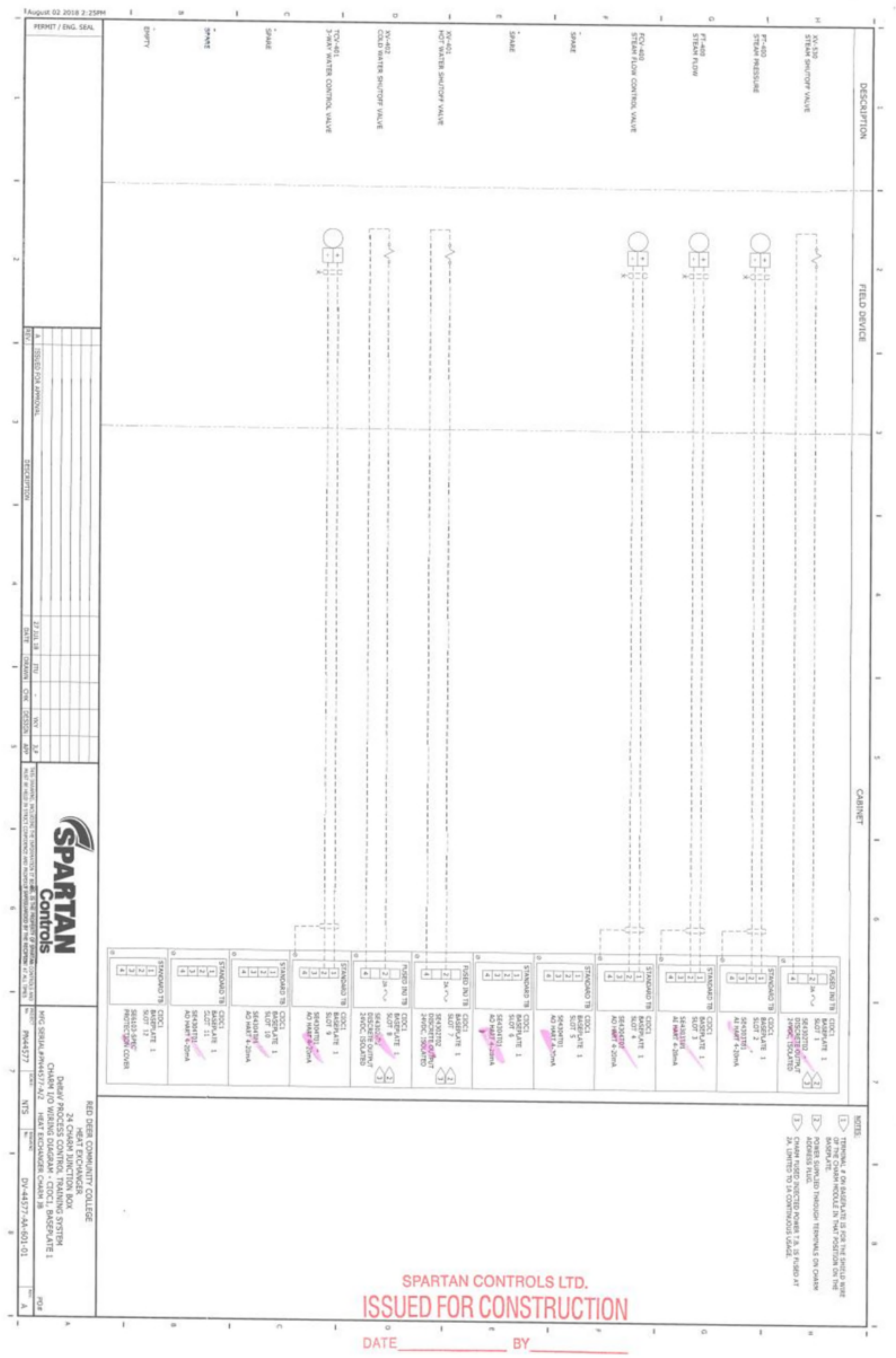


Figure 88 - Charm I/O Wiring Diagram CIOC1 Baseplate 1

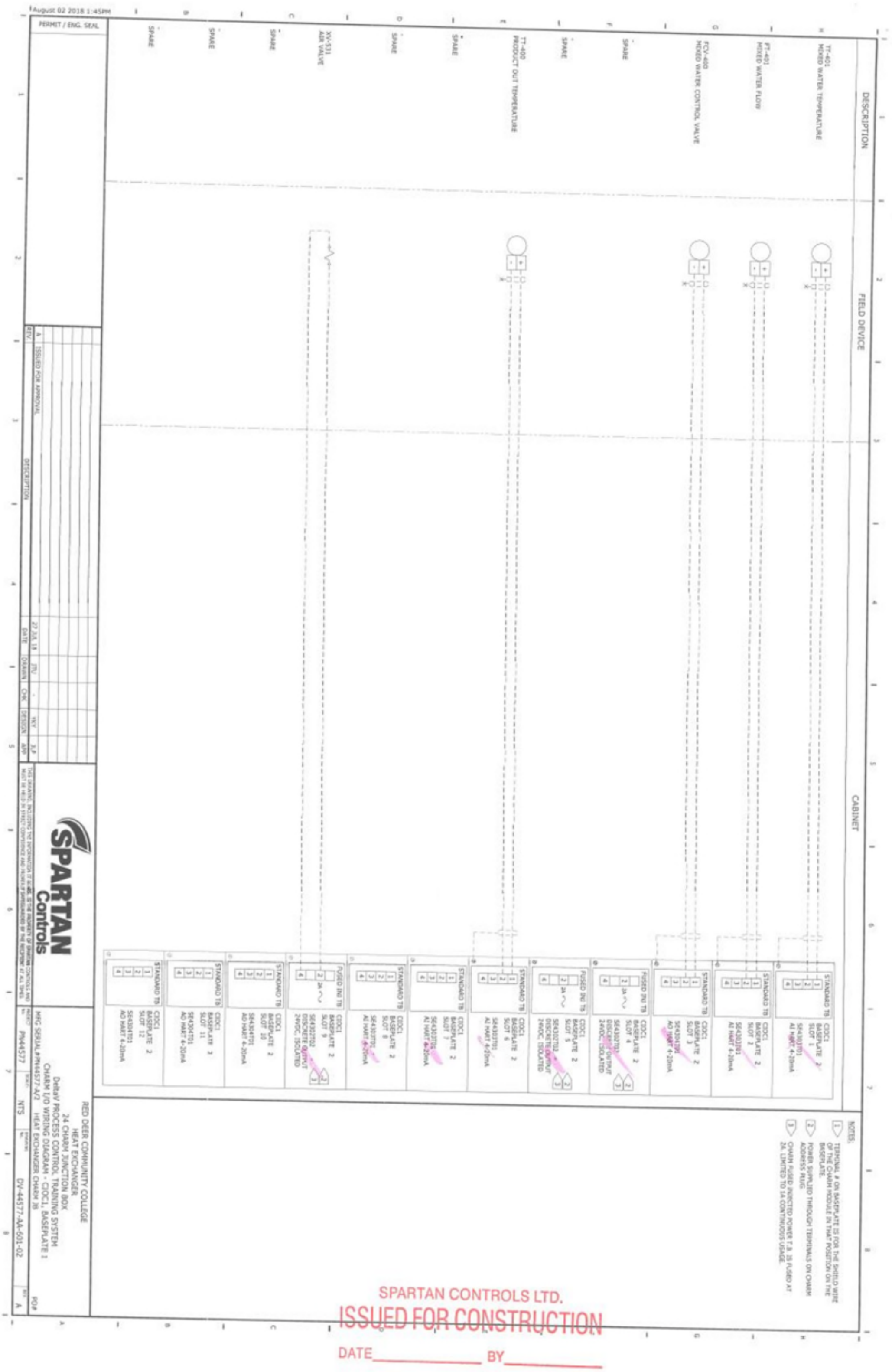


Figure 89 - Charm I/O Wiring Diagram CIOC1 Baseplate 2

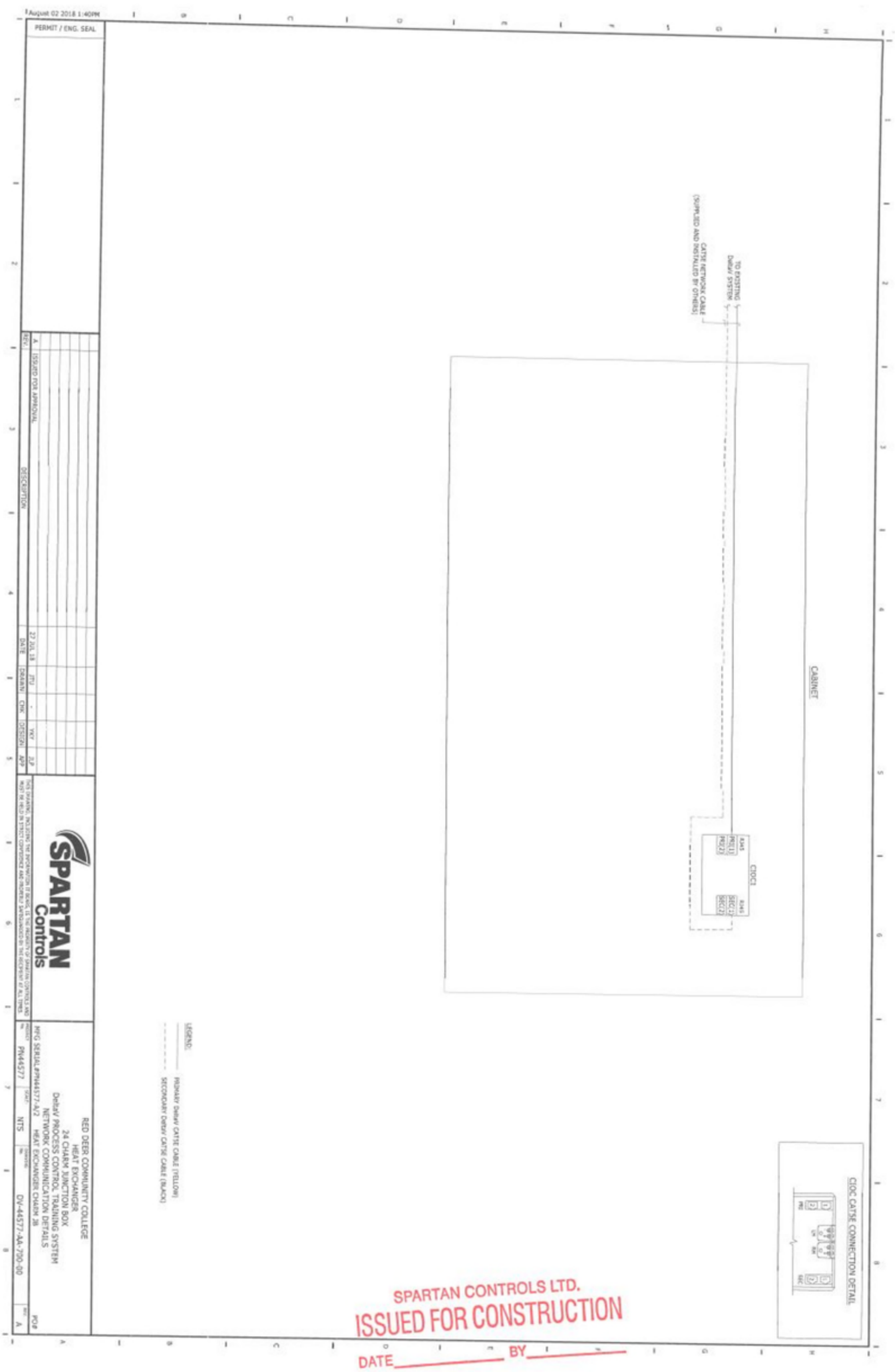


Figure 90 - Network Communication Details

ANNEX B: INSTRUMENT LOOP DIAGRAM TEMPLATE

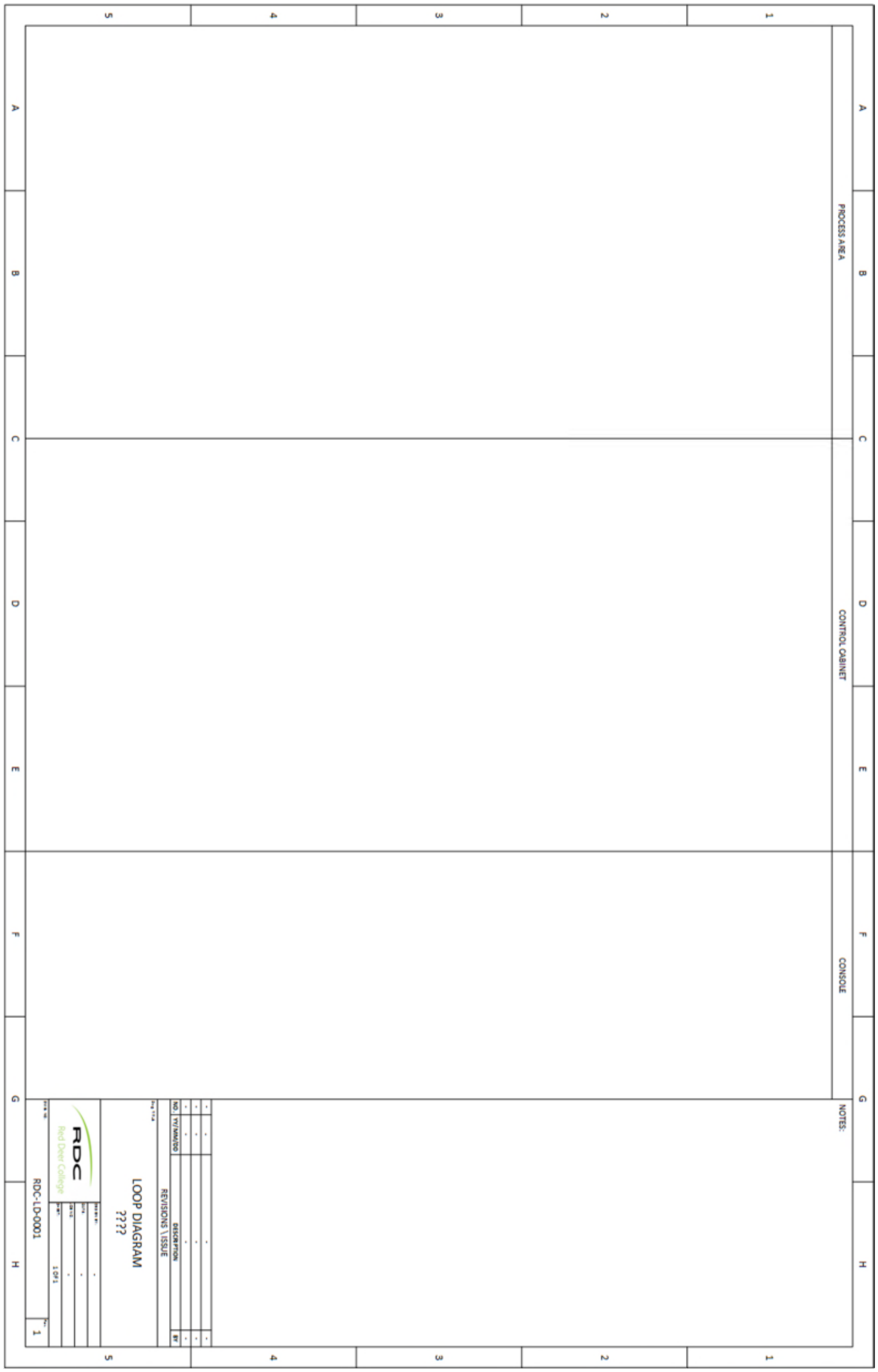


Figure 91 - ILD Template

HEAT EXCHANGER PROCESS UTILIZING FEEDFORWARD AND CASCADE CONTROL WITH FEEDBACK TRIM IN A DELTAV DCS

PROJECT CLOSURE

PREPARED FOR: VICTOR MENDEZ

BY: KORBEN JOHNSON, TYLER DRIESEN, EMILY LOUGHEED,

JADE MOORE-JACKSON, CARSON WEST, AND ZARON GIBSON

DATE: April 10, 2019

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1 Project Closure Report Purpose

The Project Closure Report is the final document produced for the project and is used to review and validate the milestones and success of the project, confirm outstanding issues, risks, and recommendations, outline tasks and activities required to close the project, identify project highlights and best practices for future projects, and formally sign off the project.

2 Project Closure Report Summary

2.1 Project Background Overview

We have brought the newly acquired heat exchanger equipment into service and assured all components are tested and operating as designed. This system functions by automatically combining a cold and hot water stream to create an inlet fluid at an adjustable and controlled temperature before entering the heat exchanger and being subjected to the thermodynamic energy carried by the supplied steam line. Exiting the heat exchanger our outlet fluid temperature is increased to another adjustable and controlled temperature (initial range of 20°- 50°C will be sought) and sustained from any upstream disturbances.

2.2 Project Timeline

Milestone	Planned completion date	Revised completion date	Actual completion date
Planning Phase Complete	Feb 6, 2019	N/A	Feb 6, 2019
Calibration Complete	Feb 15, 2019	March 20, 2019	April 8, 2019
Initial DCS Configuration Complete	March 8, 2019	March 22, 2019	March 25, 2019
Implementation of Control Strategies Complete	March 19, 2019	March 29, 2019	April 3, 2019
HMI Screen Complete	April 7, 2019	N/A	April 3, 2019
Tuning Complete	April 7, 2019	N/A	April 8, 2019

Table 1: Milestone Timeline

2.3 Project Closure Synopsis

The project is being closed due to the project being complete and reaching its deadline.

Most of the deliverables have been met but the electrical wiring diagram is not complete.

All the required deliverables have been completed.

3 Project Performance

3.1 Goals and Objectives Performance

The main objective of this project was to commission the heat exchanger plant. We programmed DeltaV DCS to automate the control of the process and respond to disturbances, so they have minimal impact on the product outlet temperature. The following are our controlled variables and their associated goal:

- Product outlet temperature: control over a range of 20-50 °C
- Steam inlet flow: control over the supplied range of 0-1.67 kg/min
- Product inlet temperature: control to 20 °C
- Product inlet flowrate: control over the supplied range, 0-30 LPM

3.2 Success Criteria Performance

The criteria of success for our project was in achieving the goal of automated control on each controlled variable. The level of success was defined as to how well the process was controlled over the entire specified range, and how robust the process was against disturbances.

All criteria for our project was achieved and we believe the project achieved a high level of success with all defined criteria. As is evidenced in the final report, we have attained automated control of each variable, over the required ranges, and are happy with the characteristics of process responses to introduced disturbances.

3.3 Milestone and Deliverables Performance

All milestones were met, and all deliverables were completed except for those deemed not required for project completion. As the project progressed the process engineering sub-team deemed all the Process Model deliverables as nonessential for the success of the project and will not be completed. Due to the time constraint we faced, the Programming sub-team was unable to complete the electrical diagrams for the project, however, this deliverable was also deemed nonessential as all the electrical wiring had been completed prior to receiving the project.

3.4 Schedule Performance

After our project left the project management phase and started to progress past the design into working with the equipment, we begun having delays that would propagate until the project completion. These delays were largely to do with RDC and the tasks they were required to do in order for us to operate the plant. These delays included:

- Data communication cable from CIOC’s to DeltaV Controller misconfigured
- Boiler installation was delayed
- Construction of the steam supply line was delayed
- Construction of the insulation around the steam supply line was delayed (and partially unfinished as of 11/04/19)
- Construction of the water supply lines were delayed and had staggered completion dates
- Design and construction of a place for the heated product outlet line to go was delayed
- New components were added to the plant without any explanation
- Issues with getting account privileges to access and edit the DeltaV software
- Outdated DeltaV DCS software was missing the DD files required to communicate with our HART enabled instruments

- The static mixer was unlabelled and unidentifiable to if it was installed in our system
- Temperature transmitters were misconfigured
- Delays with determining the principle of operation for the 3-way mixing valve
- 3-way mixing valve was delivered to us installed backwards

These factors resulted in tasks to be delayed from the date that was scheduled to be completed.

3.5 Contingency Plans

In order to deal with the setbacks in our work we arranged for more lab time with instructors and the lab technicians, so we could get more time with the heat exchanger process as well as the DeltaV computer. We also were told the login information for remote access to the DeltaV system, so we could program it while sitting just outside the lab for those times we could not get access to the lab.

3.5.1 Delayed Tasks

The project has completed and has no outstanding delayed tasks; however, delays were faced as the progress progressed and were discussed about in section 3.4 Schedule Performance.

3.5.2 R1 Changes and Modifications

Some parts of the R1 report were changed to adjust to the delay in certain tasks and to the unforeseen developments including the Gantt chart, P&ID and block diagrams being modified, meeting minutes being updated, WBS and WBS dictionary being updated, and some small minor revisions for the entire document.

3.5.3 R2 Changes and Modifications

The R2 report was modified to account for further delays in certain tasks and to the unforeseen developments including the Gantt chart, another P&ID revision, meeting minutes being updated, and revisions to individual sections for the individual teams.

4 Project Closure Tasks

4.1 Knowledge Transfer

The P&ID is in the door of the DeltaV cabinet. All other documents pertaining to the project are being stored in a Microsoft OneDrive cloud storage account owned by Jade Moore-Jackson and is available upon request.

4.2 Issue Management

No issues that have been identified with our project remain open.

4.3 Risk Management

The steam line is still not insulated. When we asked about the expected date, we were told it should be completed around April 12th. This poses a risk of serious burns if the boiler is turned on.

5 Project Reflection

We had several factors that contributed to the success of the project. These include a good collaborative determination to finish the project. We collaborated well during the push in the final few weeks when we had a fully operational system. This compressed the expected time to complete each task. We also had a lot of help from the RDC faculty in getting more time in the lab as well as troubleshooting equipment and advice on how to complete the project as well as expectations of the deliverables. Finally, we received a lot of help from Spartan Controls. Brad House came to assist us in our networking issues as well as DeltaV and was instrumental to the success of the project.

What worked well was that everybody within the group was willing and eager to help each-other in accomplishing tasks. What did not work well was that we did not always have good communication. This led to people not knowing what others were doing and in turn not having the opportunity to collaborate. This was resolved through the progression of the project.

If we were to restart this project, we would have more consistent team meetings that are not in the lab. Ones we could just use to discuss what everybody is doing and use to aid in collaboration of tasks. This would assist us in having clearer communication. In conjunction to this, the DeltaV team would want to have more knowledge of the DeltaV programming prior to working through this project. Starting the project tasks earlier would also have been helpful. During the progress of working through this project, the group experienced some delays which postponed some tasks from their original completion date. Having to learn DeltaV during the DeltaV stages of the project created a difficult challenge to overcome for the students. If we learned DeltaV programming ahead of time it would have provided more efficiency for accomplishing the tasks, so they can be completed earlier, which would allow the group to tune the system without having time constraints towards the final due date of the project.

The faculty advisors could have applied more pressure to make sure that RDC and its subcontractors complete the construction of the heat exchanger. The boiler, the plumbing, the networking, and the insulation needed to be completed before we could begin working on the unit. The delays we acquired from this not having been completed in a timely manner greatly set back our timeline for completion. Also, having more open access to the lab for students to complete their projects would help all future students. Also, the training units had licensing issues which did not allow us to practice all necessary aspects of the DeltaV before working on the heat exchanger itself.

5.1 Recommendations

The following are some ideas or things to be considered going forward:

- The plant attempted to implement some SIS philosophy, however the only true SIS component is the SV-530 valve and its associated DVC-6200. The way the valve was wired into the system and controlled by DeltaV is not following proper SIS standards
- The control modules could easily be edited to allow for the plant to be controlled by feedback only, feedforward only and then compared to what we programmed, feedforward with feedback trim. This would allow for easy demonstrations of control methodologies and how the process is able to respond to disturbances
- The licensing RDC has for DeltaV DST’s is reaching its limit

- Currently no safety interlocks are programmed for the solenoid valves, this could be something RDC wants to implement in the future

6 Project Closure Approvals

These signatures formally close the project, ceasing all involvement of the project team and turning it over to the project champion on behalf of Red Deer College.

Role	Name	Signature of Approval
Project Champion	Victor Mendez	
Project Manager	Jade Moore-Jackson	
Project Manager	Carson West	
Project Team	Emily Lougheed	
Project Team	Zaron Gibson	
Project Team	Korben Johnson	
Project Team	Tyler Driesen	

Table 2: Project Team Sign-off