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Completion of Compact Separator Laboratory

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MASTER THESIS

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The Compact Separator Laboratory
Finalizing of Phase 1

Oil and gas fields produce a substantial amount of water as an unwanted by-product. Traditionally, the water has been removed from the oil and gas topside. However, as fields age and the water cut (water percentage in the fluid stream) increases, existing topside facilities may be unable to handle the increased water production. A potential solution is to build water treatment facilities subsea. In green (new) fields, this would allow for smaller or if combined with other novel solutions potentially no topside facilities.

There are technical and scientific challenges associated with developing water treatment systems suitable for subsea use; one constraint is that they have to be significantly smaller than topside equivalents. To study these compact separator systems, the Department of Mechanical and Industrial Engineering has been constructing a small-scale laboratory.

The initial design of the laboratory was done in the spring semester of 2016. Construction started in the fall semester of 2017. Design and construction of pump and reservoir system necessary to power the laboratory is scheduled for the fall semester of 2017.

In this project, the students will finalize Phase 1 of the laboratory, to wit:

1. Finish remaining construction
2. Design and implement the electrical system
3. Design and implement the human/machine interface in LabView
4. Finalize the analog-to-digital and digital-to-analog connections necessary for the PC to communicate with sensors and actuators
5. Perform tests (including leak tests) to ensure that the lab is ready for use
6. Fix any errors or design flaws that come to light

At the end of the project, Phase 1 of the laboratory should be fully operational and ready for use, pending completion of the pump and reservoir system.

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Summary

As the petroleum business explore deeper waters and more remote locations in the quest for new hydrocarbon reservoirs, challenges that were not that relevant in earlier years now become more common. To face these challenges, the Subsea Production and Processing (SUBPRO) center for research-based innovation, a cooperation between several oil and gas companies and the Norwegian University of Science and Technology (NTNU), have launched several subprojects. One of these sub-projects is on control of subsea processes. Control algorithms will be developed and then validated in a small scale laboratory that will include hydrocyclones, a Compact Flotation Unit (CFU) , a bulk separator, a coalescing pump and low shear control valves in addition to standard processing equipment. This Master thesis is a part of this sub-project, focusing on the construction of Phase 1 of the Compact Separator Laboratory (CSL).

The primary objective of this Master thesis is installing the instrumentation and electrical system of the CSL, designing and configuring a control system and Human Machine Interface (HMI), in addition to leak testing the CSL. Much of the engineering of the CSL have already been done during the specialization project [11]. Work done in this Master thesis is the basis for further development of the CSL.

The CSL is to be built in four Phases, and this Master thesis focuses on Phase 1. Facilitation for Phases 2-4 during the construction of Phase 1 is a necessity in order to avoid unnecessary extra work later on. For this reason, getting familiar with all Phases both technically and design-wise is an essential part of the thesis. Since Phase 1 is completed throughout this Master thesis, the uncertainty lies in acquiring or constructing a pump and reservoir system. Options like buying or leasing a pump temporarily prior to the construction of the pump and reservoir system in Phase 3 have been considered, but the best option seems to be to wait for a permanent system. This will make the CSL able to separate oil and water, not just testing the CSL with water.

Preface

This Master's thesis is the continuation of a construction project that started with the specialization project [11] in September 2016, within the Department of Mechanical and Industrial Engineering at the Norwegian University of Science and Technology.

This project came as a result of the SUBPRO research organization, which aims to develop new and innovative subsea solutions for increased oil recovery of existing fields. A problem description was formulated by Associate Professor Christian Holden to complete the construction of a small-scale subsea process control laboratory for hydrocylones.

The prerequisites for understanding the contents of this Master thesis is basic knowledge about; oil and gas, mechanical construction, instrumentation, automation, and electrical installations in hazardous areas. However, the Master thesis explains most of the fundamental concepts in order for the reader to get the complete understanding of the construction of the CSL.

During the project, a lot of equipment has been purchased, and some of the tenders are considered to be confidential by the suppliers, and therefore, the details in tenders will not be presented in this Master thesis.

Acknowledgment

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Contents

Summary i
Preface iii
List of Figures vii
List of Tables x
Abbreviations xii
Nomenclature xiv

1 Introduction **1**
1.1 Background 1
1.2 Objectives 2
1.3 Approach 3
1.4 Limitations 3
1.5 Structure of the Report 3

2 Front End Engineering Design **5**
2.1 Structure 5
2.1.1 Spill Tray 5
2.2 Process 6
2.2.1 Temporary Water Pump System 6
2.2.2 Modified P&ID 7
2.3 Instrumentation 9
2.3.1 Flow Meter 9
2.3.2 Absolute Pressure Transmitters 12
2.3.3 Cable Tray Routing 13
2.3.4 Testing of Cables 14
2.4 Automation 14
2.4.1 Hardware 14
2.4.2 Software 15
2.5 Commissioning 24
2.5.1 Flushing 24
2.5.2 Leak Test 24
2.5.3 Testing of Instrumentation and Automation System 26

3 Construction Phase **29**
3.1 Structure . . . 29
3.1.1 Painting of Structure Frames . . . 29
3.1.2 Structure Frame for Marshalling Cabinet . . . 29
3.2 Instrumentation . . . 31
3.2.1 Valves . . . 31
3.2.2 Flow Meters . . . 32
3.2.3 Differential Pressure Transmitters . . . 33
3.2.4 Absolute Pressure Transmitters and Manometer . . . 34
3.2.5 Temperature Transmitters . . . 35
3.2.6 Pressure Switch . . . 35
3.2.7 Sampling Points . . . 36
3.2.8 Cable Trays . . . 37
3.2.9 Junction Boxes and Cabling . . . 38
3.2.10 Pneumatic Supply System . . . 40
3.2.11 Tagging of Equipment . . . 42
3.3 Automation . . . 42
3.3.1 Hardware . . . 42
3.3.2 Software . . . 44

4 Operation Procedures **55**
4.1 Procedure to Operate Sampling Points . . . 55
4.2 Start-up Checklists . . . 56
4.2.1 Mechanical . . . 56
4.2.2 Automation . . . 57

5 Commissioning Phase **59**
5.1 Flushing . . . 59
5.2 Leak Test . . . 60
5.2.1 Leak Test of the CSL . . . 60
5.2.2 Leak Test of Pneumatic Supply System . . . 61
5.3 Testing of Instrumentation and Automation System . . . 61
5.3.1 Factory Acceptance Test . . . 61
5.3.2 Site Acceptance Test . . . 61

6 Project Cost **63**

7 Conclusion **65**
7.1 Discussion . . . 65
7.2 Conclusion . . . 66
7.3 Recommendations for Further Work . . . 67
7.3.1 Tuning PI Controller . . . 67
7.3.2 Maintenance of the Vessel Housing . . . 67

7.3.3 Further Development of the Software 67
7.3.4 Pump and Reservoir System 68
7.3.5 Position Verification of the Safety Valve 68
7.3.6 Air Drainage Valves 68
7.3.7 Calibration of Flow Control Valves 69
7.3.8 Oil in Water Sensor 70
7.3.9 Updating Documentation for Future Phases 70

Bibliography **71**

A IS Calculation **73**

B Gas Volume Calculations **75**

C FAT/SAT Procedure **79**

D Engineering Numbering System **95**

E Marshalling Cabinet Equipment **99**

F Signal Range Configuration **101**

G Modified Loop Diagrams **103**

H Modified Signal List **127**

I 24 V Power Distribution **129**

J Marshalling Cabinet Layout **131**

K Electronic Appendices **133**

List of Figures

2.1 Suggested spill tray for the CSL. 5
2.2 Modified P&ID. 9
2.3 Pipe grounding of Electromagnetic Flow Meter 10
2.4 Emerson Coriolis mass flow meter 10
2.5 Emerson Coriolis mass flow meter channel wiring 11
2.6 Hawke compound gland 12
2.7 Suggested routing of cable trays Skid 1. 13
2.8 Suggested routing of cable trays Skid 2. 14
2.9 Wiring of continuity test with multimeter 15
2.10 Main software components on HMI screen 1 and 2. 16
2.11 An example of the use of tabs in LabVIEW. 17
2.12 HC illustration with description and variable names 17
2.13 C&E diagram for Phase 1 of the CSL. 21
2.14 Shutdown logic diagram for Phase 1 of the CSL. 22
2.15 Example of Formula node in LabVIEW block diagram. 23
2.16 FAT setup. 26
2.17 SAT setup. 28
3.1 Structure frames after painting. 30
3.2 Steel frame for marshalling cabinet. 31
3.3 Example of dismounted dummy valve. 32
3.4 Example of installed control valve. 32
3.5 Example low drainage point in the CSL. 32
3.6 Electromagnetic flow meter 33
3.7 Installation of fittings in vice. 34
3.8 Example of installed PDT on the third vessel housing. 34
3.9 Example of installed PT and PI on the inlet process pipe. 35
3.10 Example of installed temperature transmitter in the CSL. 35
3.11 Installed pressure switch in the CSL. 36
3.12 Example of installed sampling point after HC2. 36
3.13 Example of cable trays for Skid 2. 37
3.14 Protective lists on cable trays between Skid 1 and Skid 2. 37
3.15 Installed field cable topology for the CSL 38

3.16 Cabling and installed IS junction box on Skid 1. 39
3.17 Mounted IS multicore in junction box 40
3.18 P32E air pressure regulator. 41
3.19 Mounting bracket for air pressure regulator. 41
3.20 Pneumatic routing skid 1. 41
3.21 Pneumatic routing skid 2. 42
3.22 12 mm Pneumatic T-fitting. 42
3.23 Steel plate for marshalling cabinet 43
3.24 Marshalling cabinet with installed content. 44
3.25 Find network devices in NI MAX. 45
3.26 Devices has appeared under Network Devices in NI MAX. 45
3.27 Set IP address to Static. 46
3.28 Project Explorer for SAS. 47
3.29 PID gains pop-up window. 48
3.30 HMI Screen 1. 50
3.31 HMI Screen 2. 52
3.32 Structure of the block diagram in LabVIEW. 54
4.1 Sampling point at water outlet HC2. 56
5.1 Workshop water feeding system connected to the CSL. 59
5.2 Flushed and clean vessel housing with one liner installed. 60
5.3 Leak test of the CSL. 61
7.1 Safety valve presumably in closed position. 69
7.2 Safety valve with solenoid valve. 69

List of Tables

2.1 Suggested spill tray for the CSL. 6
2.2 Key components in the P&ID. 9
2.3 Control system upgrade equipment for frequency signal. 11
2.4 *Ex d* compound gland. 12
2.5 IS circuit requirements. 13
2.6 Cable tray equipment. 14
2.7 Alarm and priority level. 19
2.8 Process alarm list for the CSL Phase 1. 20
2.9 Example of an H pressure alarm. 20
2.10 Variable and data descriptions for (2.6). 25
3.1 Rack description of the marshalling cabinet. 43
6.1 Project cost for Phase 1. 64
6.2 Remaining budget for Phase 1. 64
C.1 FAT/SAT procedure abbreviations. 79
E.1 Marshalling cabinet equipment 100
F.1 Signal Range Conversion 101

Abbreviations

AI	Analog Input.
AO	Analog Output.
BSP	British Standard Pipe.
cDAQ	Compact Data Acquisition
C&E	Cause and Effect.
CFU	Compact Flotation Unit.
CH	Choke Valve.
CPU	Central Processing Unit.
CSL	Compact Separator Laboratory.
DCS	Distributed Control System.
DI	Digital Input.
DO	Digital Output.
ENS	Engineering Numbering System.
ESD	Emergency Shutdown.
Ex d	Explosion Protected Enclosure.
Ex ia	Intrinsically Safe Application.
FAT	Factory Acceptance Test.
FEED	Front End Engineering Design.
FT	Flow Transmitter.
FV	Flow Control Valve.
H	High.
HC	Hydrocyclone.
HH	High High.
HMI	Human Machine Interface.
I/O	Input/Output.
IE	Instrument Earth.
IP	Internet Protocol.
IS	Intrinsically Safe.
ISE	Intrinsically Safe Earth.
L	Low.

LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench.
LL	Low Low.
mA	Milliampere.
MAX	Measurement and Automation Explore
MV	Manuel Valve.
NI	National Instruments.
NTNU	Norwegian University of Science and Technology.
OIW	Oil in Water.
OS	Operator Station.
P&ID	Piping and Instrument Diagram.
PC	Personal Computer.
PCS	Process Control System.
PDR	Pressure Differential Ratio.
PDT	Pressure Differential Transmitter.
PE	Protective Earth.
PI	Pressure Indicator.
PI	Proportional-Integral.
PS	Pressure Switch.
PT	Absolute Pressure Transmitter.
PTFE	Polytetrafluoroethylene.
SAS	Safety and Automation System.
SDL	Shutdown Logic.
Skid	Metal Frame.
SP	Sampling Point.
SUBPRO	Subsea Production and Processing.
SV	Safety Valve.
TT	Temperature Transmitter.
VAT	Value-Added Tax.
VI	Virtual Instruments.
IT	Information Technology.

Nomenclature

α_o	Mass fraction of the oil in water.
C_c	Cable capacitance.
C_i	Internal capacitance field equipment.
C_o	Maximum capacitance galvanic isolator.
e	Error.
I_i	Maximum current field equipment.
I_o	Maximum current galvanic isolator.
K_p	Gain.
L_c	Cable inductance.
L_i	nternal inductance field equipment.
L_o	Maximum inductance galvanic isolator.
P_m	Measured pressure.
P_{CSL}	Leak pressure of the CSL.
P_h	Highest pressure range value.
P_i	Maximum power field equipment.
P_l	Lowest pressure range value.
P_B	Pressure in nitrogen bottle.
P_o	Maximum electrical power galvanic isolator.
P_1	Pressure at vessel inlet.
P_2	Pressure at oil reject.
P_3	Pressure at water outlet.
Φ_{PDR}	Pressure Differential Ratio.
r	Setpoint.
T_{CSL}	Room temperature of the CSL.
T_B	Temperature in nitrogen bottle.
T_i	Integral time.
u	Control variable.
U_i	Maximum voltages field equipment.
U_o	Maximun output voltage galvanic isolator.
V_c	Converted voltage value.
V_{CSL}	Volume of the CSL.

V_h	Highest voltages range value.
V_l	Lowest voltages range value.
V_B	Volume in nitrogen bottle.
y	Process value.
Z_{CSL}	Compressibility factor for the CSL.
Z_B	Compressibility factor for the nitrogen bottle.

Chapter 1

Introduction

1.1 Background

During its lifetime, an oil and/or gas well will change its production parameters, such as gas volume fraction, water cut, and reservoir pressure. In late phases of a fields lifetime, reservoir pressure decreases and water cut often increases [12]. Less upstream pressure means an increased energy demand for transporting the produced water to the topside processing platform. This leads to high operational cost that increases along with increased water cuts in the well stream. The method of liquid-liquid separation with hydrocyclones (HCs) has during the last 20 year emerged as the preferred solution for produced water treatment [12].

The conventional gravity separator is often bulky and space-inefficient. In the interest of implementing more space-efficient subsea solutions the oil and gas community is driven towards HCs. These are mainly used for separating the remaining oil droplets from the already separated water. A pure HC separation strategy on subsea production fields is feasible in cases where the amount of produced water could be up to 90 % [12]. The main weakness of HCs is the sensitivity towards variations in volumetric flow rate and variations in flow patterns in produced water stream from a well. Unlike large gravity separators, that are able to cope with the variations in a large vessel size and long retention time, HCs require stability in flow to function as intended by the designers. This brings us to the focus of the project which this Master thesis is a part of, namely control of the flow through HCs using instrumentation and control valves. When the compact separator laboratory (CSL) is operational the aim is to develop control algorithms that will enable the system to cope with irregular flow patterns generated by a feeding system.

The authors carried out a specialization project [11] during the fall of 2016. In this project, the primary objectives were to construct two skids for the CSL, and then install process piping, vessel housings, dummy valves and flow meters. The secondary objectives were to conduct a detailed engineering study on the electrical,

instrumentation, and automation system. This Master thesis is a continuation of the construction- and engineering work carried out in the specialization project [11], and will only cover subjects which are necessary to complete the construction of Phase 1.

The CSL is planned to be built in the following Phases:

- ***Phase 1:*** Construct two skids for HCs, piping, valves, and instrumentation. Design and implement a safety and automation system (SAS) for the CSL.
- ***Phase 2:*** Construct a gas reservoir, a compressor, a Compact Flotation Unit (CFU) and a skid for these components, then implement this with Phase 1.
- ***Phase 3:*** Construct and implement a new pump system, a reservoir system, a bulk separator, a de-liquidizer, a phase-splitter and a low shear Typhoon valve.
- ***Phase 4:*** Implementation of experimental equipment; A Typhonix coalescing pump and a low shear Typhoon valve.

1.2 Objectives

The main objectives of this Master thesis are:

1. ***Complete the construction of the CSL.***
   (a) Follow-up on deliveries ordered in the specialization project [11].
   (b) Painting of the steel frames.
   (c) Installation of instrumentation.
   (d) Installation of the electrical and automation system.
2. ***Construction of a safety and automation system for the CSL.***
   (a) Develop and configure a software program in National Instruments (NI) Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW).
3. ***Commissioning of the CSL.***
   (a) Flushing.
   (b) Leak testing.
   (c) Instrument loop testing.
   (d) Testing of the safety and automation system.

1.3 Approach

The Master thesis is a combination of engineering, construction and commissioning, and therefore, the following approach has been used:

1. ***Follow-up:***
    (a) Follow-up on deliveries ordered in the specialization project [11].
    (b) Follow up on welding of the CSL process piping.
2. ***Engineering***:
    (a) Look at possibilities to either buy or lease a temporary feeding system.
    (b) Design guidelines for the safety and automation system.
3. ***Installation:***
    (a) Construct a steel frame for marshalling cabinet, and brackets for fastening instrumentation and sampling points.
    (b) Installation of instrumentation, electrical system and automation system.
4. ***Commissioning:***
    (a) Flushing and leak test of the CSL.
    (b) Testing of the automation system.

1.4 Limitations

Completion of the CSL is limited to:

1. An economical boundary of NOK 3,000.000 set by SUBPRO.
2. The overall design of Phase 1 in the Master thesis [1] and the design and construction in the specialization project [11].

1.5 Structure of the Report

The Master thesis focuses on three main objectives; engineering, construction, and commissioning of the CSL. As a result, the report is organized in the following chapters:

- *Chapter 1* gives the reader an introduction to the thesis.
- *Chapter 2* presents the detailed engineering of uncovered subjects within each discipline.

- *Chapter 3* describes how the remaining installation of the CSL is conducted within each discipline.
- *Chapter 4* presents the operational procedures of the CSL.
- *Chapter 5* presents how the CSL was commissioned.
- *Chapter 6* presents the project cost for Phase 1.
- *Chapter 7* summarizes the work with a discussion, conclusion and recommendations for further work.

Chapter 2

Front End Engineering Design

The Front End Engineering Design (FEED) study will be a continuation of the FEED study conducted during the specialization project [11], and will only cover subjects that need detailed engineering prior to completing the construction of Phase 1.

2.1 Structure

2.1.1 Spill Tray

After some operational time, the CSL may start to leak from weak points, like connections and fittings. The CSL is inconveniently placed directly above a trench, which leads spill water to a cleaning and recycle water reservoir system at Valgrinda. For that reason, potential spillage from the CSL containing oil must not enter the reservoir system. To prevent this from happening, a system that captures the initial spillage before the operator can stop the pump system and prevent any major leakage, is recommended.

Figure 2.1: Suggested spill tray for the CSL.

Leakages will most likely occur as dripping from connections, i.e flanges, valves, and fittings. For that reason, the authors recommend using spill trays, as shown in Figure 2.1, under neat the most exposed connections of the CSL. That way, the operator have time to shut down the pump system, before the leak floods the spill tray. Table 2.1 shows the suggested spill tray for the CSL.

Table 2.1: Suggested spill tray for the CSL.

Supplier	Type	Description
Grainger	Polypropylene spill tray	Length: 44", Width: 23-1/2", Height: 2-3/4"

2.2 Process

2.2.1 Temporary Water Pump System

To execute a flow test of the CSL, a temporary water pump system were desired, prior to the construction of the permanent pump and reservoir system in Phase 3. The following options have been considered throughout both the specialization project [11] and the Master thesis period:

- ***Borrowing or buying an existing pump system from SINTEF:*** This was discarded, since SINTEF would not sell the system, or allow SUBPRO to borrow the system witch would mean disassembling and relocating the system to the CSL.
- ***Using the workshop water supply system:*** The workshop supply system operates at 5.5 bar according to the responsible NTNU service engineer [4], which is not enough pressure to operate the CSL.
- ***Leasing a pump:*** The authors have not been able to find a supplier that leases a water pump, which meets the requirements of the CSL.
- ***Borrowing a pump from the Department of Geoscience and Petroleum at NTNU:*** The pump that the Department of Geoscience and Petroleum could lend did not meet the requirements of the CSL regarding pressure and flow rate.
- ***Buying a brand new pump:*** Since none of the above options proved viable, the best option for testing Phase 1 of the CSL, is buying a new water pump. A potential new pump needs to meet the CSLs requirements regarding operational pressure and flow. As a result, the authors recommends to preform a FEED study on a brand new pump and reservoir system, which is customized for all the Phases of the CSL. Then, the water pump can be purchased, and Phase 1 can be flow tested.

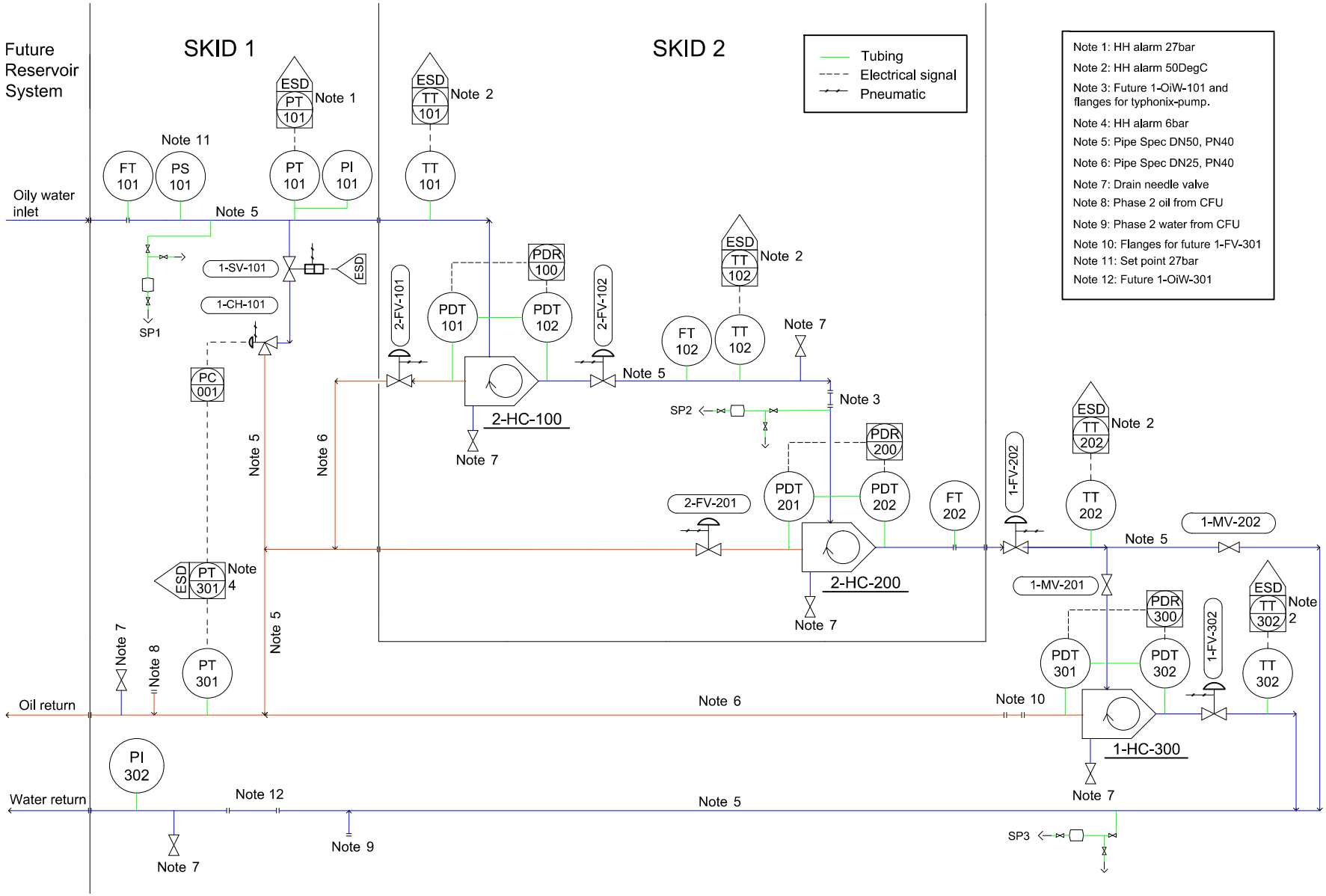
2.2.2 Modified P&ID

The Piping and Instrument Diagram (P&ID) created in the specialization project [11] has been updated with the following features:

- 1-PT-101 and 2-TT-101 have switched location due to lack of installation space for the pressure transmitter in the original location.
- The color of the oil have been changed to orange, which is common for oil indication, in opposition to light green/blue.
- Air supply lines have been implemented on all pneumatic valves, to indicate air driven actuators.
- Control loop for the emergency line (EL) was implemented based on the design in Section 2.4.2.5.
- Distributed control system (DCS) symbols have been implemented with high high (HH) alarm limits to indicate a function in the control system.
- Emergency shutdown (ESD) triangle symbols have been implemented for causes and effects, and connected to the DCS symbol.

The P&ID is presented in Figure 2.2, where Table 2.2 presents the key components in the P&ID.

High (H) alarms are normally not indicated on the P&ID, because they are not linked to a shutdown level. HH alarms are indicated on the P&ID, because they are linked to a shutdown level. The CSL only has one shutdown level, called ESD, and the ESD level is indicated with a triangle symbol. The pointing direction of the ESD triangle symbol will indicate cause or effect. The causes are indicated with an ESD triangle pointed away from the cause, and the effects are indicated with an ESD triangle pointed towards the effect.


Future Reservoir System
SKID 1
SKID 2
Tubing
Electrical signal
Pneumatic
Note 1: HH alarm 27bar
Note 2: HH alarm 50DegC
Note 3: Future 1-OiW-101 and flanges for typhonix-pump.
Note 4: HH alarm 6bar
Note 5: Pipe Spec DN50, PN40
Note 6: Pipe Spec DN25, PN40
Note 7: Drain needle valve
Note 8: Phase 2 oil from CFU
Note 9: Phase 2 water from CFU
Note 10: Flanges for future 1-FV-301
Note 11: Set point 27bar
Note 12: Future 1-OiW-301
Oily water inlet
Oil return
Water return
ESD PT 101
Note 1
Note 11
FT 101
PS 101
PT 101
PI 101
ESD TT 101
Note 2
TT 101
Note 5
1-SV-101
ESD
1-CH-101
SP1
PC 001
Note 5
Note 6
2-FV-101
PDT 101
PDR 100
PDT 102
2-FV-102
2-HC-100
Note 7
ESD TT 102
Note 2
FT 102
TT 102
Note 7
Note 5
Note 3
SP2
PDR 200
2-FV-201
PDT 201
PDT 202
FT 202
2-HC-200
Note 7
1-FV-202
ESD TT 202
Note 2
TT 202
1-MV-202
Note 5
ESD PT 301
Note 4
Note 7
Note 8
PT 301
Note 5
1-MV-201
PDR 300
PDT 301
PDT 302
1-FV-302
ESD TT 302
Note 2
TT 302
Note 6
Note 10
1-HC-300
Note 7
PI 302
Note 12
Note 5
Note 7
Note 9
SP3

See Figure 2.2 on page 8.

Figure 2.2: Modified P&ID.

Table 2.2: Key components in the P&ID.

Tag type	Description
CH	Choke valve
FT	Flow transmitter
FV	Flow control valve
MV	Manuel valve
PDT	Pressure differential transmitter
PI	Pressure indicator
PS	Pressure switch
PT	Absolute pressure transmitter
SP	Sampling point
SV	Safety valve
TT	Temperature transmitter

2.3 Instrumentation

2.3.1 Flow Meter

2.3.1.1 Electromagnetic Flow Meter

It is important to ground the electromagnetic flow meter, in order to ensure that the signal from the transmitter is as stable as possible. There are several grounding options, but grounding the electromagnetic flow meter to the process piping creates the lowest noise environment for the transmitter. The electromagnetic flow meter has an external grounding screw, where grounding cables can be connected and terminated to the process flanges, as shown in Figure 2.3. [8]

2.3.1.2 Coriolis Mass Flow Meter

The Master thesis [1] specifies that the Coriolis mass flow meter shall be able to measure the density of the process fluid so that the software can make a mathematical approximation of the oil concentration. The selected Coriolis mass flow meter in the Master thesis [1], specifies only the flow sensor and not the flow transmitter, where Figure 2.4 shows the sensor and the transmitter. This caused the 2016 summer students to purchased a flow transmitter without density as an option for the milliampere

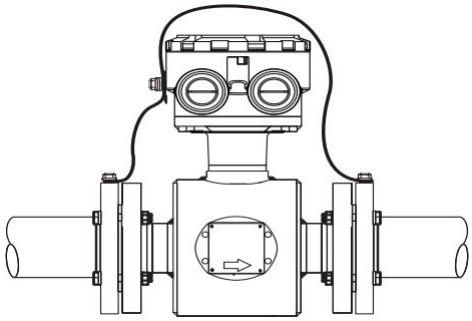


Figure 2.3: Pipe grounding of Electromagnetic Flow Meter [8].

(mA) output channel. The authors contacted Emerson Norge, the supplier, who were willing to run a software update free of charge. As a result, density can be selected as the output signal with a range of 700-1200 kg/m^3.

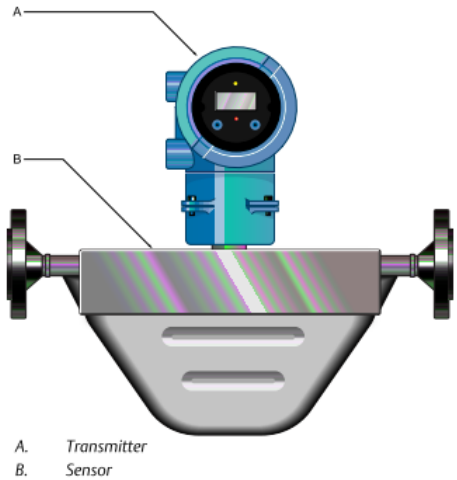


Figure 2.4: Emerson Coriolis mass flow meter [16].

The flow transmitter is also equipped with a second output channel, which is a frequency output, where flow is the only process variable. After consulting with supervisor Christian Holden, it was decided to specify the necessary equipment to upgrade the control system for future use of frequency channels. The frequency channel is calibrated to 0-5 m^3/h, which corresponds to 0-10000 Hz. There are two options to get the frequency signals integrated into the control system, a digital input module or a frequency to current converter. However, since a digital input (DI) module is necessary for future emergency stop switches, the DI module is the best choice.

When selecting the DI module for NI with such a high update rate, the selection is small. The NI9423 has an update rate of 1 μs, which corresponds to an update frequency of 1000000 Hz. The update rate is larger than the frequency output of the flow transmitter, which implies that the NI-9423 has no problem detecting the

frequency signal from the flow transmitter, and is, therefore the selected DI module.

The original one-pair cable must be replaced with a two-pair cable. This is because there is only one gland available for signaling on the flow transmitter. The cable type must be of the same as specified in the specialization project [11], RFOU(I), and it is taken into account that the two-pair cable shall fit the selected gland in Section 2.3.1.3. Table 2.3 shows the selected DI module and the selected two-pair cable.

Table 2.3: Control system upgrade equipment for frequency signal.

Supplier	Type	Description
NI	NI-9423	24 V, 8 Channel, 1 μs, C Series DI Module
Solar	RFOU(i) S1/S5	2x2x0,75 mm^2 Instrument Cable

Figure 2.5 shows the channel wiring of the flow transmitter, where the original loop diagram in Appendix G, must be updated accordingly, if the frequency output shall be used.

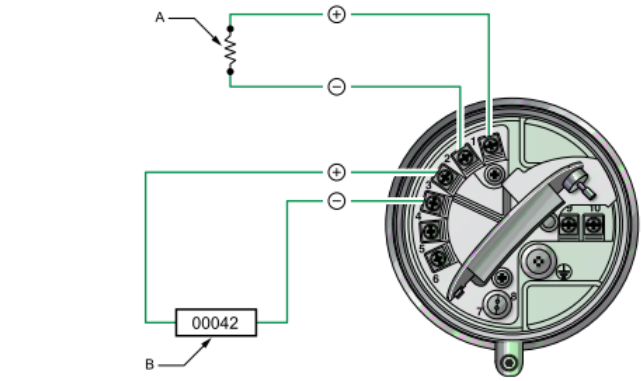


Figure 2.5: Emerson Coriolis mass flow meter channel wiring [16].

2.3.1.3 *Ex d* Gland

The flow meters in the CSL uses *Ex d* protection, which means the enclosure must withstand an inner explosion and prevent the explosion from spreading to the surroundings [11]. An explosion inside the enclosure will create an overpressure, which will try to escape through the glands. As a result, the *Ex d* gland must satisfy the same requirements as the *Ex d* enclosure [7]. There are many types of *Ex d* glands available, but when considering that the selected the RFOU(I) cable is armored [11], the selection of glands is narrowed down to compression- and compound glands. The difference between compound- and compression glands is the inner gas seal, where

the compression gland uses a rubber seal, while the compound gland uses a rubber sleeve filled with two-component sealing mass. Furthermore, the compound gland seals better than the compression gland for cables with several pairs, because of the two-component mass, which fills between the wires. From the previous Section 2.3.1.2, the Coriolis mass flow meter needs a two-pair cable, to be able to run both density and flow measurements at the same time, hence the compound gland is selected. Table 2.4 and Figure 2.6 presents the selected *Ex d* gland.

Table 2.4: *Ex d* compound gland.

Supplier	Type	Description
Solar	ICG653/UNIV/O	Hawke gland M20 (9,5-16) Mess. EECDE

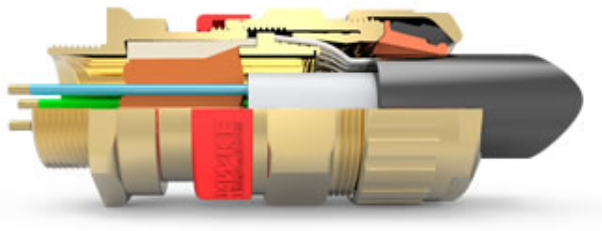


Figure 2.6: Hawke compound gland to be used for all *Ex d* enclosures in the CSL [15].

2.3.2 Absolute Pressure Transmitters

Statoil has kindly provided the project with two absolute pressure transmitter, which uses the same *Ex* protection as the already delivered pressure and temperature transmitters in the CSL, namely *Ex ia*. The *Ex ia* classification means that the equipment is intrinsically safe and uses a safety barrier located in a safe area, to energy restrict the circuit out to the hazardous area [11]. The safety barrier is located in the marshalling cabinet and shall prevent the circuit from producing sparks or heat, such that explosive gases or vapors will not ignite under operation [11]. New IS calculations must be conducted for the new pressure transmitters to verify that the requirements in Table 2.5 is valid. Appendix A presents the IS calculations, and it shows that the same type of galvanic isolator as the existing pressure and temperature transmitter, STAHL 9160/23-11-10, can be used. IS calculations for the rest of the instruments were conducted in the specialization project [11], and is not shown in this report.

Table 2.5: IS circuit requirements.

Field Equipment		Galvanic Isolator
U_i	$\geq$	U_o
I_i	$\geq$	I_o
P_i	$\geq$	P_o
C_i+C_c	$\leq$	C_o
L_i+L_c	$\leq$	L_o

U_i Maximum voltages field equipment.
I_i Maximum current field equipment.
P_i Maximum power field equipment.
C_i Internal capacitance field equipment.
C_c Cable capacitance.
L_i Internal inductance field equipment.
L_c Cable inductance.
U_o Maximun output voltage galvanic isolator.
I_o Maximum current galvanic isolator.
P_o Maximum electrical power galvanic isolator.
C_o Maximum capacitance galvanic isolator.
L_o Maximum inductance galvanic isolator.
[11]

2.3.3 Cable Tray Routing

Figure 2.7 and Figure 2.8 shows the suggested routing of the cable trays inside the structure frame. The routing is planned so that there is a minimal amount of cabling outside the trays. To get a smooth transition for both horizontal and vertical bends, tee-pieces, flat elbows and flexi risers are used. Table 2.6 presents the needed cable trays and equipment for this routing.

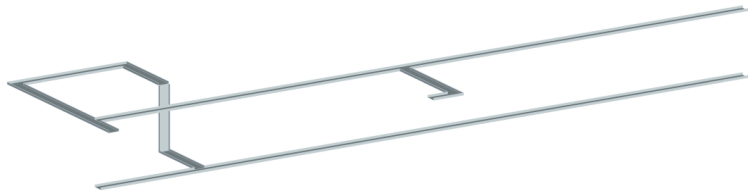


Figure 2.7: Suggested routing of cable trays Skid 1.

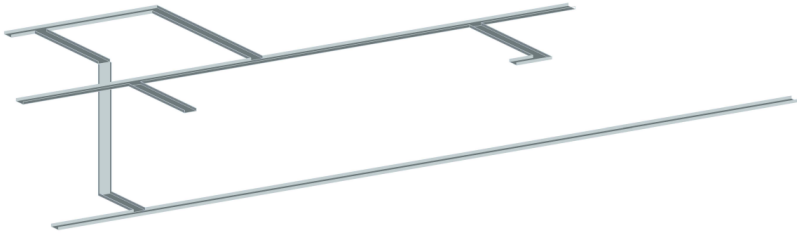


Figure 2.8: Suggested routing of cable trays Skid 2.

Table 2.6: Cable tray equipment.

Supplier	Type	Description
Solar	SPBE-40-150 SS	Light cable tray for tubing and cable installations.
Solar	SPB-RF40 TE-150 SS	Tee-piece with integrated splice connectors.
Solar	SPB-RF40 FR-150 SS	Flexible inside and outside riser from 0-90°.
Solar	SPB-RF-40-90-150 SS	90° Flat elbow with integrated splice connectors.

2.3.4 Testing of Cables

The cables are usually bent and pulled through cable trays when installed. The cable might get damaged, or if may be faulty from production. To avoid any unnecessary troubleshooting and faults during commissioning, a continuity test needs to be conducted, in order to test the field cables and the cross wiring within the marshalling cabinet. A continuity test is a test which checks the presence of a complete path of a current [5]. The continuity test principle is illustrated in Figure 2.9. The multimeter gives an audible response when it detects an enclosed current circuit [5].

2.4 Automation

2.4.1 Hardware

2.4.1.1 Modified Loop Diagrams

The loop diagrams created in the specialization project [11] have been updated with some minor input/output (I/O) numbering correction, because of the location change of the temperature transmitter and the pressure transmitter described in Section 2.2.2. The updated loop diagrams are found in Appendix G.

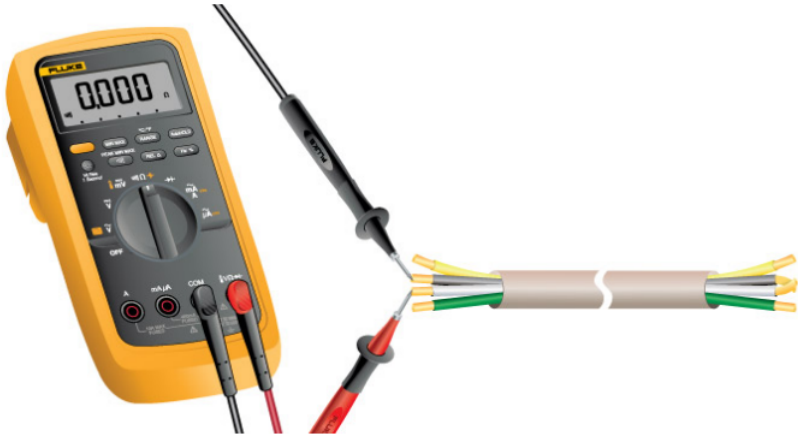


Figure 2.9: Wiring of continuity test with multimeter [5].

2.4.2 Software

Two software programs for control and monitoring of the CSL were considered, MATLAB and LabVIEW. Both programs has their pros and cons, but LabVIEW was chosen as the software solution based on its compatibility with the NI hardware. [11]

Programs developed in LabVIEW are called virtual instruments (VIs). The VIs consist of two main components, front panel, and block diagram. The front panel is used to configure the Human Machine Interface (HMI), while the block diagram is used to configure the logic. Components chosen in the front panel will automatically appear in the block diagram. The block diagram uses a graphical programming language as the main language. Different function nodes can be connected by drawing connection lines. [9]

Before starting the software programming, it is important to plan the HMI layout, decide color guidelines, define alarms, and design the control algorithms, such that the programming can be carried out as efficient as possible.

2.4.2.1 HMI Design

There are several correct ways to design an HMI layout, but the main principle is to not overwhelm the operator with unnecessary information. Specifically, keep the HMI layout clean and simple, be consistent, consider the operator tasks, and what information is needed to understand the state of the process. [3]

The operator station (OS) for the CSL has two screens, hence it is natural to distribute the HMI layout over two screens. HMI Screen 1 shall contain a process control system (PCS), while HMI Screen 2 shall contain the alarm and monitoring system, the ESD system, graph data display, and the logging system. Figure 2.10 illustrates on which screen the main software components are located.

There are no written standards on HMI coloring, but there are some best practices

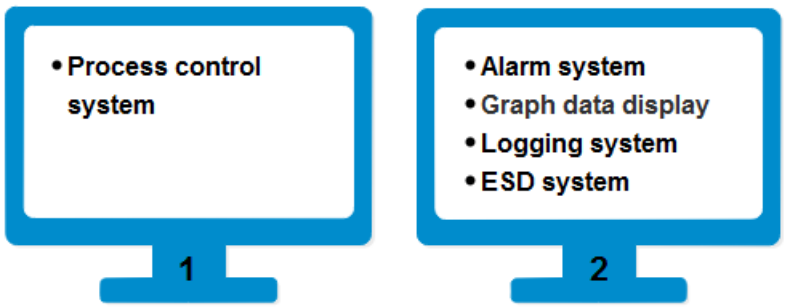


Figure 2.10: Main software components on HMI screen 1 and 2.

on how to choose colors for software components [2]. The following list contains guidelines for the coloring of the HMI layout for the CSL.

- ***Background:*** Grey, a natural color, which is gentle to the eyes.
- ***Led:*** Green for active and grey for inactive.
- ***Alarm led:*** Grey for inactive alarm, purple, yellow, or red for active alarm. Note that these colors shall only be used to indicate alarms in the HMI.
- ***Valve:*** Green for open and grey for closed.
- ***Pipes:*** Blue for water, orange for oil, and yellow for gas.
- ***Buttons:*** Grey. Choose buttons which clearly states the position of the button, and use explanatory text.
- ***Animations:*** Shall only be used for alarms to draw attention to where the alarm is located, and the colors shall be the same as the alarm colors.

2.4.2.2 Process Control System

The PCS layout is expected to be quite large, especially when all Phases of the CSL is implemented. This implies that the layout may be developed over several tabs on HMI Screen 1. An example of the tabs in LabVIEW is presented in Figure 2.11.

The process layout and the PCS will be created based on the P&ID in Figure 2.2. The process pipes will be displayed with line arrows to indicate flow direction. Numeric indicators will be placed alongside the flow lines to display the measured values, while numeric controls will be used to enable the operator to set values to the SAS. All numeric indicators will have a corresponding LED to indicate alarms and measurement point. Controls or information which are not frequently used will be available in pop-up windows. Valves shall be represented by a simple graphical symbol, while the color of the valve shall change depending on whether the valve is open or closed.

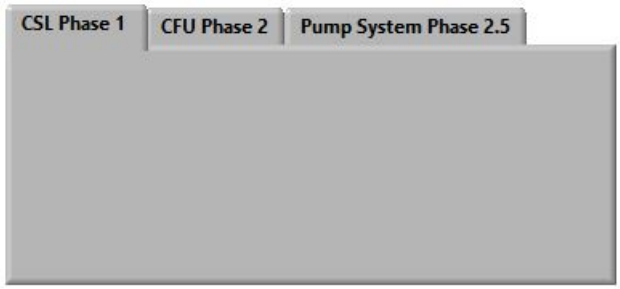


Figure 2.11: An example of the use of tabs in LabVIEW.

2.4.2.3 Pressure Differential Ratio

Pressure differential ratio (PDR) is a measurement of the flow split in the HC, which correlates to the HC separation efficiency [23]. The goal for optimal HC separation efficiency is to keep the PDR constant during variable flow rates, which means that the flow split is kept constant. In order to monitor the separator efficiency and prepare the SAS for implementation of future control algorithms, the PDR calculation shall be implemented in the SAS. The PDR is defined as

$$\Phi_{PDR} = \frac{P_1 - P_2}{P_1 - P_3} \tag{2.1}$$

where Φ_{PDR} is the PDR, P_1 is the oily water inlet, P_2 is the oil outlet, and P_3 is the treated water outlet of the HC, which is presented in Figure 2.12.

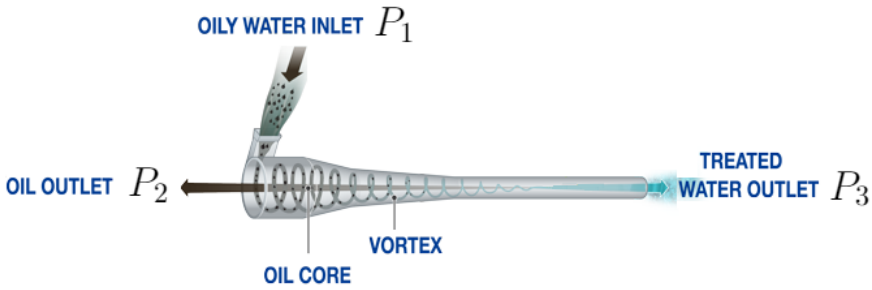


Figure 2.12: HC illustration with description and variable names [24].

The supplier of the HCs, eProcess, recommends that the PDR is kept between 1.5 and 2.5 for optimal separation efficiency [11].

2.4.2.4 Oil Concentration

The Master thesis [1] states that the SAS shall be implemented with an indirect calculation of the oil concentration. This can be conducted by using the density measurement from the Coriolis flow meter, and clean water at 1000 kg/m^3 as the

reference for the calculation. The oil concentration is defined as

$$\alpha_o = \frac{\rho_w - \rho_{ow}}{\rho_w} \tag{2.2}$$

where α_o is the mass fraction of the oil in water, ρ_w is the water density reference, and ρ_{ow} is the measured density of the oily water.

2.4.2.5 Pressure Control of Emergency Line

The purpose of the emergency line (EL) is to depressurize the CSL if the upstream pressure exceeds the CSLs inlet pressure limit of 27 bar. The EL can be activated through the SAS or by a mechanical pressure switch, which is further explained in Section 2.4.2.8. The Master thesis [1] designed an atmospheric reservoir system, and for that reason, a choke valve is placed in the EL to bleed down the pressure to atmosphere. During an ESD of the CSL, it is convenient for the operator to have automatic pressure control of the EL, instead of manually reducing the pressure. As a result, pressure control shall be implemented in the SAS, which is illustrated in the P&ID in Figure 2.2.

Another essential point in this pressure control loop is the conversion of units. There are several ways to implement the unit conversion, for example inside the controller parameters, or outside the controller. The controller parameters are usually easier to find if the unit conversion is placed outside the controller. In this case, there is no auto-tuning of the controller, hence the conversion of units is placed outside the controller. The unit conversion for converting pressure to voltages is defined as

$$V_c = \frac{V_h - V_l}{P_h - P_l}(P_m - P_l) + V_l \tag{2.3}$$

where V_c is the converted voltage value, V_h is the highest voltage range value, V_l is the lowest voltage range value, P_h is the highest pressure range value, P_l is the lowest pressure range value, and P_m is the measured pressure. The same principle can be used to convert other units, by replacing the all the P and V in (2.3) with the desired units.

The controller for the EL is selected as a Proportional-Integral (PI) controller. A PI controller will be more than fast enough to operate the choke valve when the control parameters are tuned correctly. Furthermore, the PI controller must be able to switch smoothly between `auto` and `hand`, in addition to data entry limits on the setpoint of the controller. This will protect the reservoir system towards unintended pressurization. The PI control algorithm is defined as

$$u = K_p(e + \frac{1}{T_i}\int_0^t e\ dt) \tag{2.4}$$

where the error $e = r - y$, r is the setpoint, y is the process value, u is the control variable, K_p is the gain, and T_i is the integral time.

2.4.2.6 Control Algorithms

The control algorithms for the CSL shall be developed by PhD Candidate Sveinung Johan Ohrem and is not part of the Master thesis scope of work. A discussion about implementing old or well-proven control algorithms was conducted with supervisor Christian Holden. The discussion resulted in that no control algorithms shall be implemented in the SAS. This is because the CSL can easily be tested with manual control, in addition, to the unnecessary work to remove the algorithms before the new algorithms can be implemented in the SAS.

2.4.2.7 Alarms and Monitoring System

The main objective of the alarm and monitoring system is to warn the operator of abnormal situations and conditions in the plant. The alarms shall be relevant, indicate priority, and be easy to understand [6]. After considering all Phases of the CSL process, the following alarm and priority levels is defined and presented in Table 2.7. Each alarm level has its own color code so that the operator can easily prioritize and manage the alarms. Priority 1 is the highest priority level and priority 3 is the lowest priority level.

Table 2.7: Alarm and priority level.

Alarm Level	Alarm Color	Alarm Priority
High High (HH)	Red	Priority 1
High (H)	Yellow	Priority 2
Low (L)	Yellow	Priority 2
Low Low (LL)	Red	Priority 1
Inspect (I)	Purple	Priority 3

Table 2.8 presents the alarm tags, alarm priority and process limits for the CSL. The alarm tags are built on the same tag system introduced in the specialization project [11], see Appendix D, except the underscore and the alarm priority, which is added to the tag. The process limits for the HH alarms are defined by the safety-critical operating conditions, which is defined in the Master thesis [1]. The H alarms are set 5 bar lower than the HH alarms, such that the operator has time to manipulate the system and avoid the HH alarm. "Low Low" (LL) and "Low" (L) alarms are not used in Phase 1, but shall be used for the CFU in Phase 2. Inspection (I) alarms have the lowest priority level and shall be used for inspection of the HCs PDR, when the PDR is outside the normal operation limits. The alarm limits for 1-PT-301 is not final and must be re-evaluated based on the limits of the finalized pump and reservoir system.

The alarms will be presented to the operator in an alarm list. This list will consist of three columns, where the first column contains the time when the alarm where

Table 2.8: Process alarm list for the CSL Phase 1.

Alarm Tag	Alarm Level	Process Limit
1-PT-101_HH	HH	27 bar
1-PT-101_H	H	22 bar
2-HC-100_I_PDR_greater	I	PDR >2.5
2-HC-100_I_PDR_less	I	PDR <1.5
2-HC-200_I_PDR_greater	I	PDR >2.5
2-HC-200_I_PDR_less	I	PDR <1.5
1-HC-300_I_PDR_greater	I	PDR >2.5
1-HC-300_I_PDR_less	I	PDR <1.5
2-TT-101_HH	HH	$50°C$
2-TT-101_H	H	$45°C$
2-TT-102_HH	HH	$50°C$
2-TT-102_H	H	$45°C$
2-TT-202_HH	HH	$50°C$
2-TT-202_H	H	$45°C$
1-TT-302_HH	HH	$50°C$
1-TT-302_H	H	$45°C$
1-PT-301_HH	HH	6 bar
1-PT-301_H	H	4 bar

activated. The second column contains the tag of the component that triggered the alarm, and the third column contains the status of the alarm, i.e., its priority. An example of how an alarm will look is presented in Table 2.9. In addition to the shown setup, the alarm row will be color coded as specified in Table 2.7, making it easier for the operator to swiftly distinguish between the different levels of the alarms and take action based on the severity of the alarms.

Table 2.9: Example of an H pressure alarm.

Time	Tag	Status
11:31:10 AM	1-PT-101	H

When an alarm is triggered, a sound activates to indicate the alarm, and there will be two different alarm sounds for H and HH alarms. The operator shall be able to activate or deactivate the sound-generating system in the HMI, in case the operator leaves the operating station and need a way to detect alarms while not monitoring the HMI.

The alarm system shall also have a disable function, but only for a specified amount of time, that is limited by a maximum value. After that time has elapsed the alarm system is automatically activated, to ensure that the alarm system cannot be permanently deactivated. The alarm system deactivation is implemented with

regards to the start-up of Phases 2, where LL alarms are present.

When the reason for an alarm has been identified and the operator wishes to continue normal operation of the CSL, alarms can be acknowledged by pressing a `Acknowledged` button directly adjacent to the alarm list. This will remove the color overlaying the alarm text in the list and turn off the alarm sound. This way, if a new alarm is triggered after the user has acknowledged previous alarms, only the new alarms will be overlaid by color and the operator can easily distinguish between old and new alarms. When all the alarms in the list have been acknowledged by the operator, the alarm list can be cleared of all alarms by pressing a `Clear` button directly adjacent to the `Acknowledged` button.

2.4.2.8 ESD System

The alarms and causes were defined in the previous section and now the effects of the alarms must be defined. Only HH alarms shall be linked to the ESD shutdown level. The effect shall be to open the safety valve, 1-SV-101. The HH alarms will automatically activate the ESD, while the software ESD button will be placed on HMI Screen 2 for manual ESD activation. The cause and effect (C&E) diagram for Phase 1 of the CSL is presented in Figure 2.13.

Cause & Effect				Note	
Compact Separator Laboratory				Description	Depressurization through EL.
				P&ID	Phase 1
				Tag	1-SV-101
				Action	Open
Description	**Tag**	**P&ID**	**Note**		
Pressure HH	***1-PT-101_HH***	Phase 1			x
Temperature HH	***2-TT-101_HH***	Phase 1			x
Temperature HH	***2-TT-102_HH***	Phase 1			x
Temperature HH	***2-TT-202_HH***	Phase 1			x
Temperature HH	***1-TT-302_HH***	Phase 1			x
Pressure HH	***1-PT-301_HH***	Phase 1			x
Software ESD button	***0-ESD-001***	Phase 1			x
Pressure Switch	***1-PS-101***	Phase 1			x

Figure 2.13: C&E diagram for Phase 1 of the CSL.

Since there are some uncertainties regarding the design of the reservoir system and its pressure capability, the flow control valves are kept in their current position when the ESD level is activated. This will depressurize the HCs in a safe and slow manner, such that the pressure in the EL can be controlled. Note that if the reservoir system is designed to handle the full pressure of the CSL, the choke valve on the EL and the flow control valves could just as well be set to fully open during an ESD.

The shutdown logic (SDL) diagram is a graphical representation of the shutdown level hierarchy within a plant [6], and is normally displayed on the HMI screen. In this case, the SDL is small and there are no valve position indicators for feedback, so the necessity of SDL on the HMI is not present. The SDL diagram for Phase 1 of the CSL is presented in Figure 2.14.

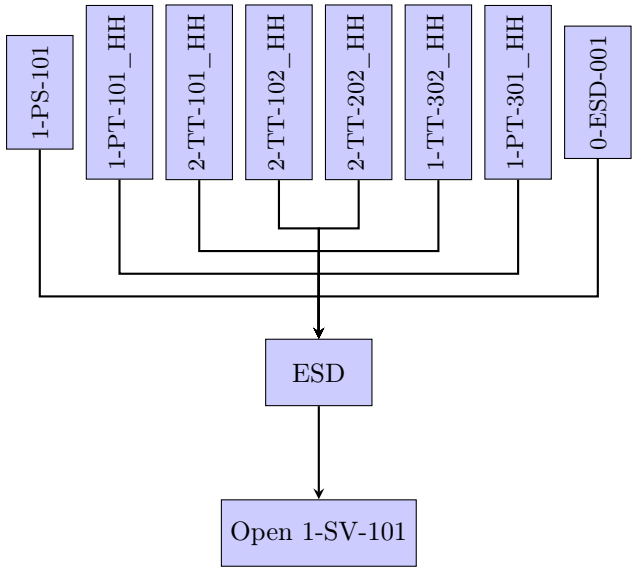


Figure 2.14: Shutdown logic diagram for Phase 1 of the CSL.

2.4.2.9 Real-Time Data Display

The real-time data display will provide the operator with an ability to monitor the development of process parameters in a plotted graph format. The graphs will be divided into different tabs, such that each graph will cover as much of the HMI screen as possible. The tabs will be divided by type of signal and presented in the same style as illustrated in Figure 2.11. The alternative to this solution would be to view all the graphs at the same time, which would imply that each graph had to be very small to fit the HMI Screen 2.

In each tab, there will be only one graph, and for each graph, the operator will be able to select what specific data to plot, by selecting from a list positioned directly adjacent to the graph. Each graph will show a 20 s trend of the process data(s)

chosen by the operator. In addition, a scrolling function will give the operator the opportunity to view recent data without having to access logging files.

2.4.2.10 Alarm Logging and Real-Time Data Logging

The operator shall be able to activate and deactivate a real-time logging system under the logging system part of the HMI Screen 2. Raw data will then be logged to a comma-separated values (CSV) file stored on the operating personal computer (PC). The alarms will be logged to an Excel file continuously as long as the LabVIEW program runs, and cannot be deactivated. The alarms in the log file will be presented in the same format as seen in Table 2.9.

2.4.2.11 Further Software Expansion

Since the new control algorithms will be developed and simulated in MATLAB, it is very convenient to convert the MATLAB code to C code and directly implement this in LabVIEW by the use of Formula nodes. The Formula node can read and evaluate C code and define inputs and outputs for integrating the graphical part of the LabVIEW software program [10]. A simple example of using the Formula node in LabVIEW is shown in Figure 2.15, where the calculation of the oil concentration percentage from Section 2.4.2.4 is used.

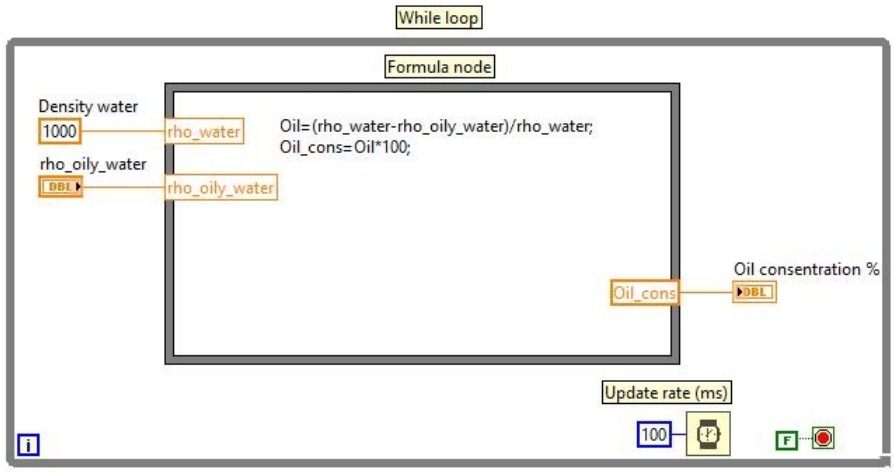


Figure 2.15: Example of Formula node in LabVIEW block diagram.

The *MATLAB Coder* application can be used to convert MATLAB code to C code for scripts [17], while Simulink diagrams can be converted to C code by choosing *Embedded Coder Quick Start* in the drop down menu of the *Build Model* icon [18].

2.5 Commissioning

2.5.1 Flushing

It is absolutely essential that the CSL piping and tubing are completely cleared of any debris from the construction process before mounting the HCs and running the CSL. This is achieved by flushing the CSL with fresh water. This procedure does not require high pressure, hence the water supply system in the workshop shall be able to handle the task. The water feeding system operates at approximately 5.5 bar, according to Section 2.2.2, which is enough pressure to properly flush out any debris inside the piping.

It is recommended to flush the CSL after running with oily water, such that the CSL is kept clean and maintained for operation for many years.

2.5.2 Leak Test

Leak testing is a very common method to test the integrity of the welds, flanges and fitting connection by using compressed gas. The leak test is normally performed at the maximum operational pressure of the system, which gives the final confirmation that the system is leak free and ready for operation.

A discussion was carried out whether to choose air or nitrogen as the test medium. Nitrogen is the standard test medium for hydrocarbon systems. This is because the nitrogen reduces the oxygen content which implies that the explosive mixture of hydrocarbon and air is reduced. Since the CSL shall be operated with simulated oil, and implementation of Phases 2-4 will fill the CSL with air, nitrogen is not necessary at this stage. However, since a nitrogen regulator already have been bought for Phase 2, it is cheaper to use nitrogen because of the high cost of purchasing a new air pressure regulator.

2.5.2.1 Leak Test Calculations

The combined gas law is used to calculate how many liters of nitrogen is needed to pressurize the CSL at the maximum operational pressure of 25 bar. The combined gas law is defined as

$$\frac{P_{CSL}\, V_{CSL}}{T_{CSL}\, Z_{CSL}} = \frac{P_B\, V_B}{T_B\, Z_B} \tag{2.5}$$

where Table 2.10 presents the variables and data.

Solving (2.5) for V_B gives

$$V_B = V_{CSL} \frac{P_{CSL}\, T_B\, Z_B}{P_B\, T_{CSL}\, Z_{CSL}}. \tag{2.6}$$

The compressibility factor is found by the use of pseudo reduced temperature and pressure, to find the most relative behavior of the gas.

Table 2.10: Variable and data descriptions for (2.6).

Variable	Descriptions	Data
P_{CSL}	Leak pressure of the CSL.	25 bar
P_B	Pressure in nitrogen bottle.	200 bar
V_{CSL}	Volume of the CSL.	93.4 l
V_B	Volume in nitrogen bottle.	50 l
T_{CSL}	Room temperature of the CSL.	$18°C$
T_B	Temperature in nitrogen bottle.	$15°C$
Z_{CSL}	Compressibility factor for the CSL.	0.99
Z_B	Compressibility factor for the nitrogen bottle.	1.04

The resulting calculations indicate that one pressure build-up to 25 bar in the CSL, needs 11.9 l of compressed gas at 200 bar. Hence, one bottle of 50 l, 200 bar compressed nitrogen gives at least four pressure build-ups of the CSL, which is convenient if several pressure build-ups must be conducted due to leaks. The detailed calculations of the gas volume are presented as a MATLAB script in Appendix B.

2.5.2.2 Leak Test Procedure

A 50 l, 200 bar bottle of nitrogen shall be connected through tubing and fittings to a drainage point on the CSL. End caps will seal all the out- and inlets to the CSL. A gradual pressure build-up, with step-wise stops every 5 bar up to 25 bar, shall make the leak test more safe to perform for the operators. The following leak test procedure shall be followed during the leak test:

1. Check that all drain valves and sampling points valves are closed.
2. Check that 1-MV-201 or 1-MV-202 are open.
3. Open the safety valve 1-SV-101 and the choke valve 1-CH-101.
4. Slowly open the pressure regulator and monitor the manometer to increase the pressure with 5 bar in the CSL.
5. All flanges and connections shall be coated with a soapy solution, which begins to bubble if a leak is present. If a leak is detected, the CSL shall be depressurized before any repairs is carried out. In addition, listen for audible pressure loss.
6. Go back to step 4 until 25 bar is reached, then continue to step 7.
7. After repairing any potential leakages, the maximum operational pressure of 25 bar shall be hold for 30 min for a successful leak test.
8. Open the drain valves to depressurize the CSL.

If the CSL is to be serviced or for any reason dismantled, the CSL has to be leakage tested again before any high-pressure operation. The packers used in between flanges do not withstand opening and re-tightening, and for that reason, the packers must be replaced in case of de- and re-assembly of the CSL.

2.5.2.3 Leak Test of Pneumatic Supply System

Since all actuators are actuated pneumatically, the pneumatic supply system of the CSL needs to be as reliable as possible. The pneumatic actuators operate at a maximum of 7 bar [20]. To ensure that the pneumatic supply system is leakage free, the system shall be tested with pressurized air at the maximum operating limit of 7 bar.

2.5.3 Testing of Instrumentation and Automation System

The testing of the SAS shall be conducted in two parts; Factory Acceptance Test (FAT) and Site Acceptance Test (SAT), which is a common way to test automation systems.

2.5.3.1 Factory Acceptance Test

The FAT is a demonstration of the automation system. It is performed before the system can be installed on site. The FAT ensures the system owner that the automation system meets the requirements and specification of the contract. A formal FAT/SAT procedure must be prepared, which shall be followed during the FAT. After the FAT is conducted, the owner of the system must give their approval, such that the vendor can proceed with on-site installation. The FAT shall be performed at the student offices with a simulated test setup of the CSL, which shown in Figure 2.16. [22]

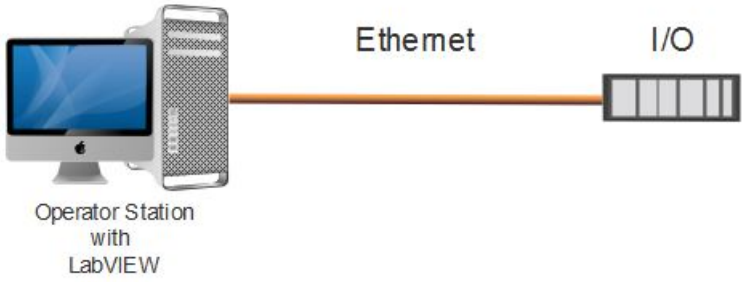


Figure 2.16: FAT setup.

2.5.3.2 Site Acceptance Test

The SAT is basically the same as the FAT, except that the SAT is performed on site with all the equipment and interfaces in its working environment [22].

Loop testing of each instrument is incorporated into the FAT/SAT procedure and will be performed in cooperation with the SAT and the leak test. The loop testing procedure is not optimal, due to the lack of testing equipment. A discussion was carried out with supervisor Christian Holden on this topic and the conclusion was to not buy the loop testing equipment due to the high cost.

The SAT shall be performed at the laboratory facilities with the test setup shown in Figure 2.17.

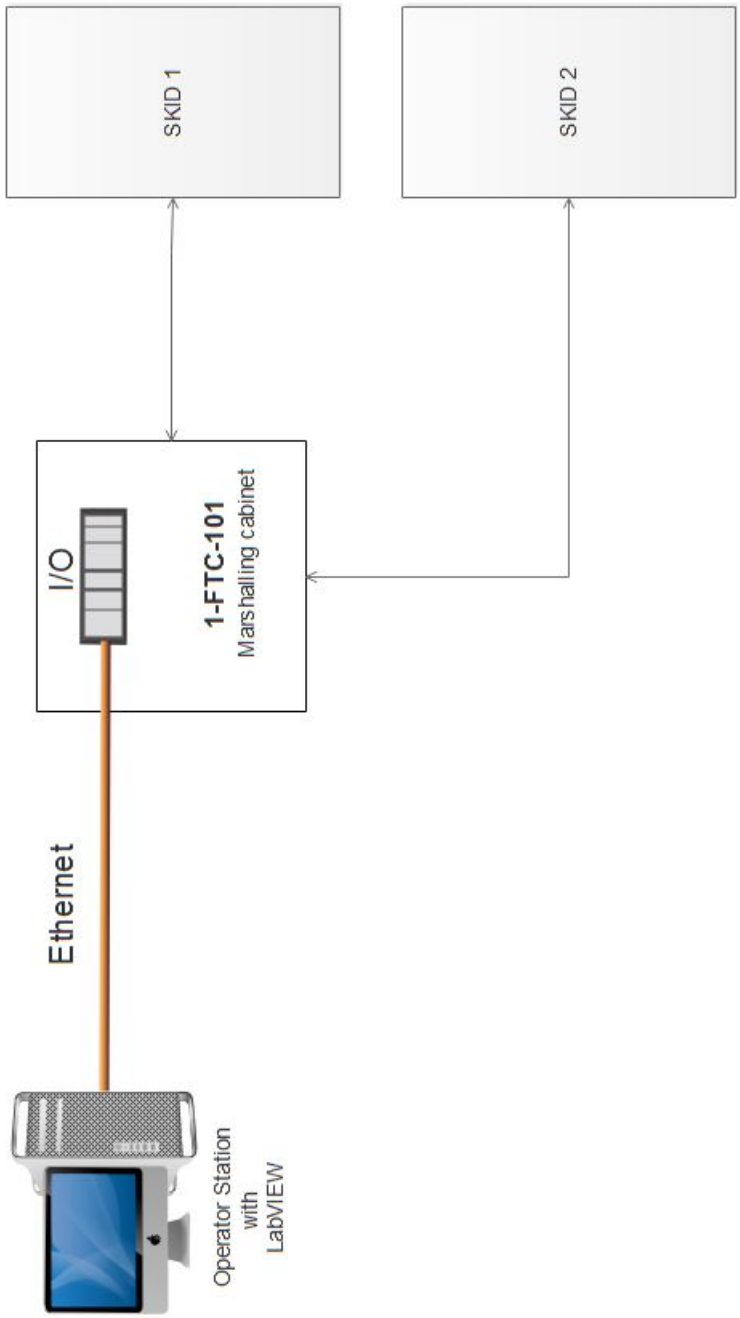


Figure 2.17: SAT setup.

Chapter 3

Construction Phase

The construction phase will be a continuation of the construction phase in the specialization project [11], and will only cover installation subjects which remain to complete the construction of Phase 1 of the CSL.

3.1 Structure

3.1.1 Painting of Structure Frames

To prevent corroding of the structure frames and to improving the looks of the CSL, the frames are painted with steel lacquer. Since the CSL is supposed to emulate a subsea structure, the skids are painted in subsea-yellow with color coding RAL-1018. Figure 3.1 presents the painted structure frames of the CSL.

3.1.2 Structure Frame for Marshalling Cabinet

The marshalling cabinet was originally supposed to be wall mounted, but since the CSL will be relocated when the Department of Mechanical and Industrial Engineering changes premises, a more mobile solution was preferred. In order for the marshalling cabinet to be as mobile as possible, it was mounted on a steel frame. This frame was constructed based on the design specified in the specialization project [11]. The structure frame raises the bottom of the marshalling cabinet 70 cm above floor level, which gives an excellent working height inside the marshalling cabinet. Figure 3.2 shows the welded structure frame for the marshalling cabinet.

Figure 3.1: Structure frames after painting.

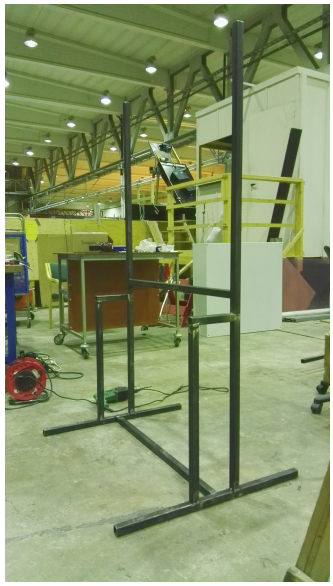


Figure 3.2: Steel frame for marshalling cabinet.

3.2 Instrumentation

3.2.1 Valves

3.2.1.1 Control Valves

During the specialization project [11], temporary dummy valves were constructed and installed due to long delivery time of the valves. After the valves were delivered, the temporary dummy valves were removed and the control valves were installed and bolted to the pipe flanges with packers in-between. Figure 3.3 shows an example of the dismounted dummy valve, while Figure 3.4 shows an example of the installed control valve.

3.2.1.2 Drain Valves

A total of six needle valves were installed in order to drain and depressurize the CSL according to the P&ID in Figure 2.2. Three valves were installed at low points of the CSL, while the remaining three valves were installed at the bottom of each vessel housing. Since the CSL operates at high pressure, the outlet tubing of the drain valves is pointed downwards to avoid any damage to personnel while draining. Furthermore, a hose can be clamped on the outlet tubing and routed down to either trench underneath the CSL or a tank, depending on the type of process fluid. For safety reasons, it was considered installing ball valves in series with the needle valves. It was decided not to buy any extra ball valves due to both economic factors and that the ball valves would be redundant. Figure 3.5 shows an example of a low drainage

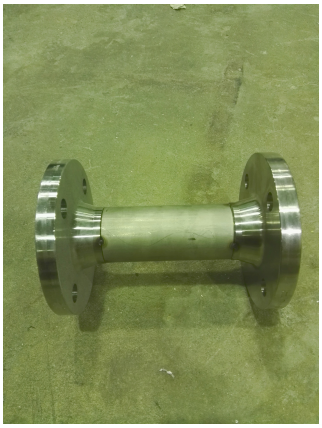


Figure 3.3: Example of dismounted dummy valve.

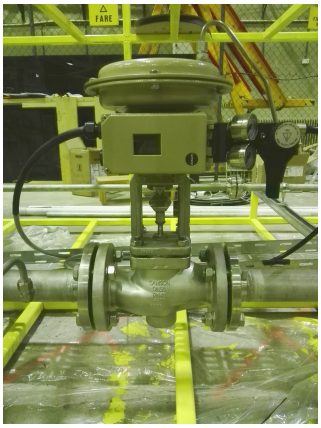


Figure 3.4: Example of installed control valve.

point after HC1 in the CSL.

Figure 3.5: Example low drainage point in the CSL.

3.2.2 Flow Meters

Electromagnetic Flow Meter

The electromagnetic flow meters are grounded to the process piping according to Section 2.3.1.1. Figure 3.6 shows an example of an installed electromagnetic flow meter with process grounding.

Figure 3.6: Installed electromagnetic flow meter with black wiring for process grounding.

3.2.3 Differential Pressure Transmitters

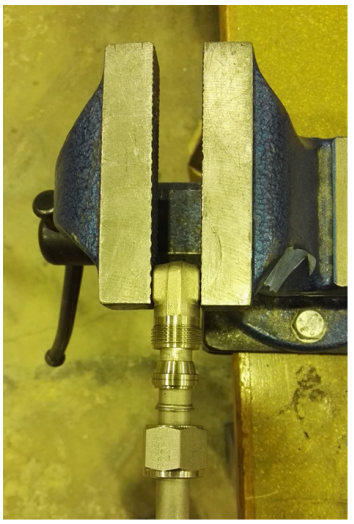
Six pressure differential transmitters (PDT) were installed according to the P&ID in Figure 2.2. The installation procedure for the PDTs was designed in the specialization project [11] and involves installing the PDTs above the process piping and connecting the tubing to the pipe by the use of weld fittings. This is done so that the tubing is automatically drained if the process piping is drained.

Mounting brackets were made out of 30x30x3 mm steel profiles and then welded to the top deck or middle deck of the structure frames. The PDT transmitters were installed onto the mounting brackets by the use of u-shaped clamps.

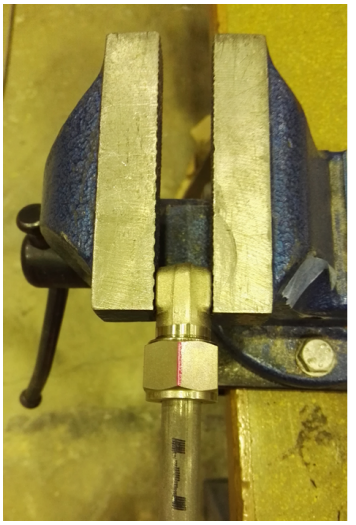
The PDTs were purchased by the 2016 summer students and were ordered with M20 process connection, which is a rather uncommon process connection to use in combination with tubing. However, M20 to 1/2" BSP thread adapters were purchased and installed with o-rings and polytetrafluoroethylene (PTFE) tape, to ensure good sealing.

The tubing length from the PDT process connection to the weld fittings on the process piping was measured, such that the tubing could be cut into the correct lengths and bent with a pipe bending wrench. After bending the tubing, the tubing was installed to check the compatibility between the transmitter and the weld fitting. If the tubing passed the compatibility test, the tubing was dismantled and the fittings were installed in a table vice, which is presented in Figure 3.7. The nut of the fitting is then tightened by hand until a wrench is needed for further tightening, then tighten 5/4 turn with a wrench, such that the ferrules are fastened to the tubing. The fittings are then reopened and the tubing is installed in the CSL, which is presented in Figure 3.8. Note that if the ferrules are already fastened to the tubing, the nut shall only be re-tightened 1/4 turn after hand-tightening the nut.

The same method for installing tubing and fittings are used for all the instruments



(a) Visual inspection of ferrules.



(b) Tightened fittings.

Figure 3.7: Installation of fittings in vice.

in this report.

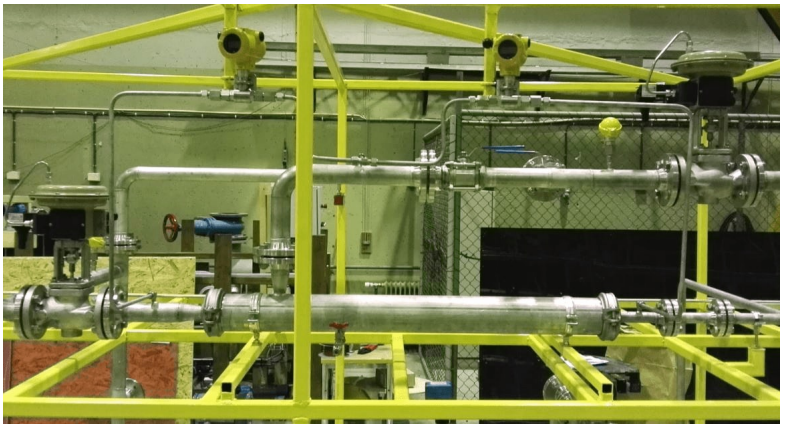


Figure 3.8: Example of installed PDT on the third vessel housing.

3.2.4 Absolute Pressure Transmitters and Manometer

Two absolute pressure transmitters (PT) and two pressure indicators (PI) were installed according to the P&ID in Figure 2.2. The PT and PI were installed in the same manner as the PDT in Section 3.2.3. Figure 3.9 shows a pressure transmitter and a pressure indicator installed on the oily water inlet of the CSL.

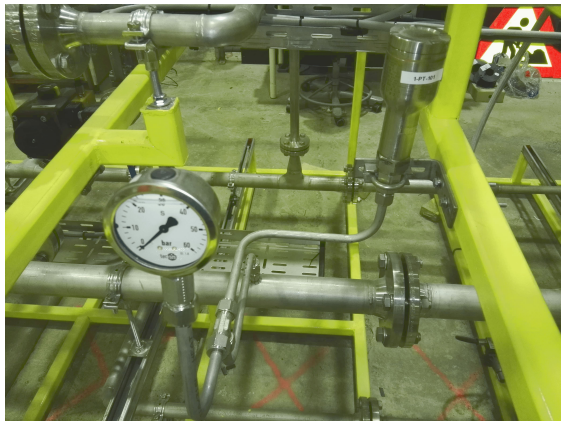


Figure 3.9: Example of installed PT and PI on the inlet process pipe.

3.2.5 Temperature Transmitters

Four temperature transmitters (TT) were installed according to the P&ID in Figure 2.2. The installation procedure for the TTs was designed in the specialization project [11], such that the end of the thermocouple is placed in the middle of the process pipe. The method consists of connecting the TT to a 1/2" BSP female tubing adapter, which is then fastened to the weld fitting located on the process piping. Figure 3.10 shows an example of an installed temperature transmitter.

Figure 3.10: Example of installed temperature transmitter in the CSL.

3.2.6 Pressure Switch

The mechanical pressure switch (PS) was installed according to the P&ID in Figure 2.2. The pressure switch was designed in the specialization project [11] as a safety function that will prevent the pipe from bursting by opening the safety valve

when the process fluids exceed 27 bar. The PS was installed in the same manner as the temperature transmitter in Section 3.2.5. Figure 3.11 shows the installed pressure switch.

Figure 3.11: Installed pressure switch in the CSL.

3.2.7 Sampling Points

3.2.7.1 Mounting and connection to process

A total of three sampling points were installed in the CSL according to the P&ID in Figure 2.2. A T-shaped steel base for the sampling points was welded together by two 5x80x300 mm plates. The plates were then welded to an L-shaped bracket in the CSL. The result is presented in Figure 3.12.

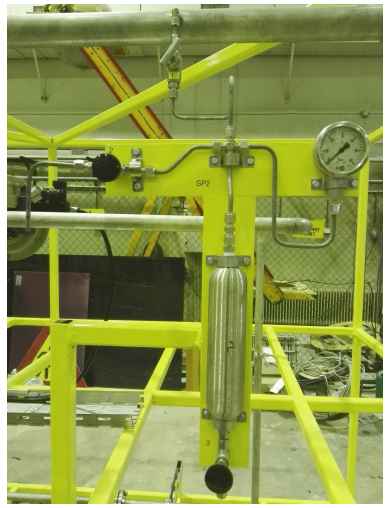


Figure 3.12: Example of installed sampling point after HC2.

In addition to fulfilling their function as sampling platforms for process parameter, such as oil content, the sampling points also acts as additional drainage points. An operational procedure for operating the sampling point is presented in Section 4.1.

3.2.8 Cable Trays

The cable trays were installed according to the routing in Section 2.3.3. The cable trays were cut with an angle grinder and mounted together with either t-bends, elbow-bends, or a flexi-riser. In order to securely fasten the cable trays, bolts were used to fasten the cable trays to the structure frames. Figure 3.13 show the installed cable trays for Skid 2.

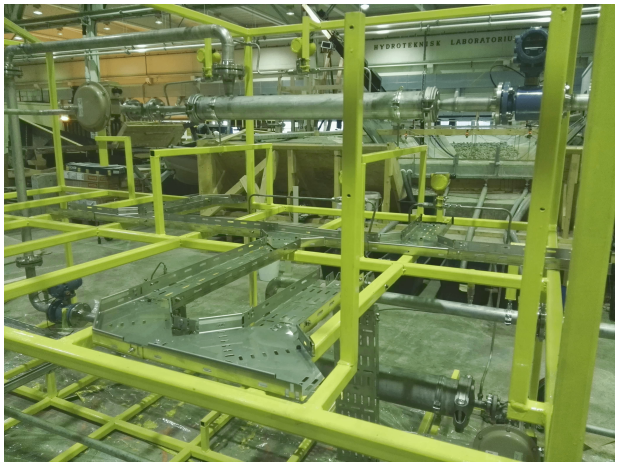


Figure 3.13: Example of cable trays for Skid 2.

After the installation of the cable trays, all the sharp edges, which potentially could cause damage to the cables, where fitted with protective lists. Figure 3.14 shows an example of cable trays fitted with protective lists.

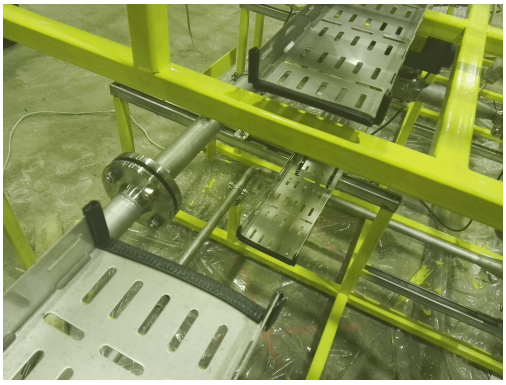


Figure 3.14: Protective lists on cable trays between Skid 1 and Skid 2.

3.2.9 Junction Boxes and Cabling

The cabling system was designed in the specialization project [11], and all the cables and junction box were installed according to the topology in Figure 3.15.

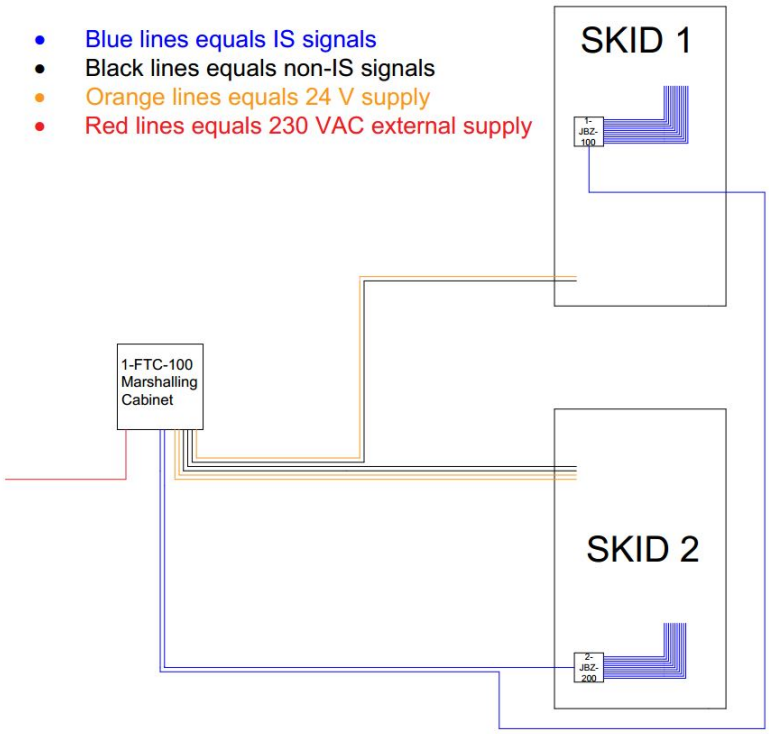


Figure 3.15: Installed field cable topology for the CSL [11].

3.2.9.1 IS Field Junction Boxes

Mounting brackets for both junction boxes were made by 30x30x3 mm steel profiles and welded to the middle deck of the structure frames. The junction boxes were bolted to the brackets in a working height of 1.6 m above ground level, as shown in Figure 3.16.

3.2.9.2 IS Field Cables

The IS field cables, RFOU(I) 1x2x0.75 mm^2, were pulled from the instruments to the junction box, where the protective sleeves and the armor were stripped off in both ends. All instrument cables were installed with a small coil of cable at the instrument so that instruments can be relocated. Next, cable shoes were installed on each core element of the cable, before the cables were fitted with blue heat shrinking sleeves which mark IS signals. The cable screen was isolated at the instrument, and fitted

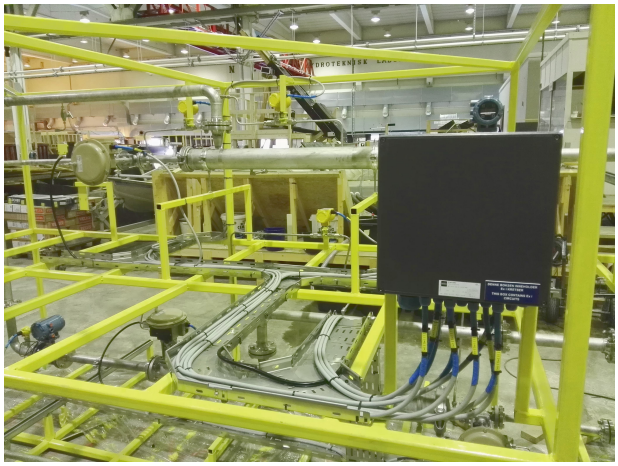


Figure 3.16: Cabling and installed IS junction box on Skid 1.

with yellow and green earthing sleeves at the junction boxes. Finally, the cables were terminated and tested according to the loop diagrams in Appendix G and continuity tested according to Section 2.3.4. Figure 3.16 shows the IS cabling of Skid 2.

The IS field cables were fitted with cable tags at the instrument and at the junction box. Figure 3.17 show the inside and outside cable tagging of the junction box mounted on Skid 1.

3.2.9.3 IS Multicore Cable

The two IS multicore cables, RFOU(I) 16x2x0.75 mm^2, were installed in the same way as the IS field cables in Section 3.2.9.2. In addition, cable pair numbering was installed, and a 5 m coil of cable was placed outside the marshalling cabinet for each multicore cable. This means the marshalling cabinet can be re-located without pulling new multicore cables.

3.2.9.4 Non-IS Field Cables

The six non-IS cables, RFOU(I) 1x2x0.75 mm^2, were installed in the same way as the IS field cables in Section 3.2.9.2, with some minor changes due to being non-IS classified. The heat-shrinking sleeves are black to indicate non-IS, *Ex d* glands were installed at the instrument, and the cables were pulled directly to the marshalling cabinet to avoid any segregation issues in the field junction box. In addition, a 5 m coil of cable was placed outside the marshalling cabinet for each cable, such that the marshalling cabinet can be re-located without pulling new cables.

The installation of the *Ex d* glands is more difficult than installing normal glands. The armor of the cable was locked inside a locking mechanism in the gland before the wires were packed with two compound mass and fitted in a rubber pot. After the two component mass had dried, an inspection of the integrity of the mass was conducted.

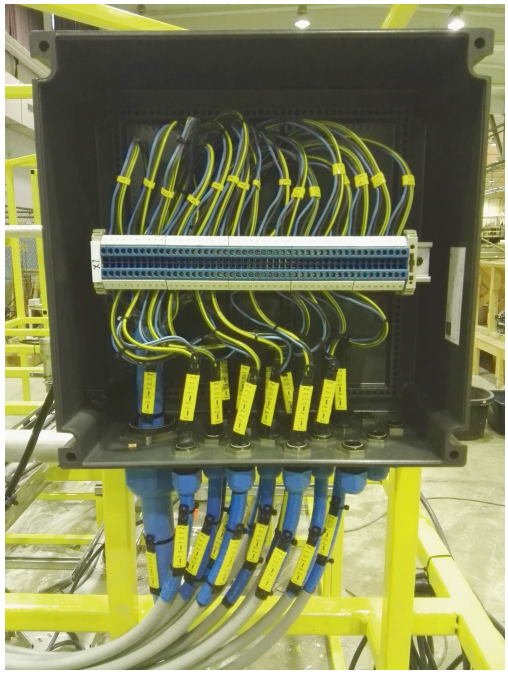


Figure 3.17: Mounted IS multicore in junction box on Skid 1 with tagging and cable pair numbering.

If the mass showed no signs of holes or cracks, the gland could be installed at the instrument. Figure 2.6 shows the cross section of an correctly installed *Ex d* gland.

3.2.9.5 230VAC External Power Cable

The external power cable to the marshalling cabinet, PSFP 1x2x0.75 mm^2, were installed in the same way as the IS field cables in Section 3.2.9.2, except that the end of the cable was fitted with a socket plug.

3.2.10 Pneumatic Supply System

3.2.10.1 Pressure Regulator

The P32E air pressure regulator [19] in Figure 3.18, provides accurate pressure regulation of the pneumatic supply system of the CSL. In addition, the regulator has the option of air-filtering, if sensitive pneumatic components are to be installed in Phase 2-4.

Figure 3.19 shows the custom made mounting bracket for the air pressure regulator. The bracket is mounted such that the pneumatic connections, the regulator valve, and the manometer is not obstructed in any way.

Figure 3.18: P32E air pressure regulator.

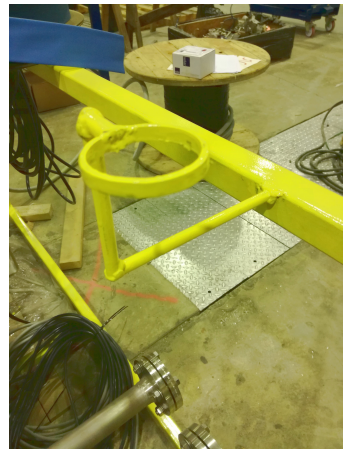


Figure 3.19: Mounting bracket for air pressure regulator.

3.2.10.2 Pneumatic Supply Distribution

When a valve is actuated, the supply system will experience a pressure drop, for that reason the air distribution routing, seen in Figure 3.20 and Figure 3.21, is installed in such a way that the total volume of the pneumatic cabling is as small as possible, in order to reduce the pressure drop to a minimum as a result of actuation of valves.

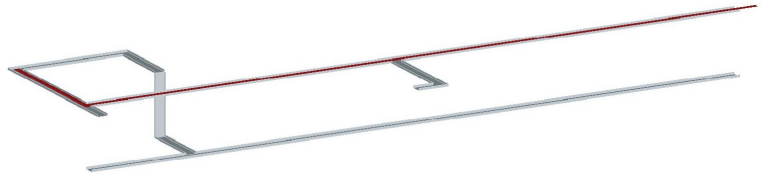


Figure 3.20: Pneumatic routing skid 1.

Figure 3.21: Pneumatic routing skid 2.

12 mm pneumatic T-fittings seen in Figure 3.22 are used to merge the pneumatic tubing and distribute airflow between the pneumatic actuators in the CSL.

Figure 3.22: 12 mm Pneumatic T-fitting.

3.2.11 Tagging of Equipment

The following equipment and pipes were tagged in the CSL:

- Piping inlets and outlets.
- Instruments.
- Vessel housing for HCs.
- Cables.

The engineering numbering system (ENS) was developed in the specialization project [11] and can be found in Appendix D. All the tags were made with an industrial label maker and glued on to the equipment, expect the cables, were a letter construction kit where used to build the tag signs.

3.3 Automation

3.3.1 Hardware

3.3.1.1 Marshalling Cabinet

Table 3.1 describes the racks installed in the marshalling cabinet. DIN rails and cable ducts were mounted on a steel plate, as seen in Figure 3.23, which can easily be rearranged in case of major modifications to the setup. The steel plate also functions as the main earth, where each individual earth distribution system where connected

to main earth. The marshalling cabinet was installed with three earth systems, intrinsically safe earth (ISE) bar, instrument earth (IE) bar and protective earth (PE) bar to minimize the noise on the measurement signals [11].

Table 3.1: Rack description of the marshalling cabinet.

Rail	Description
X1	192 knife terminals for termination of IS field cables.
X2	32 slots for safety barriers or galvanic isolators.
X3	192 non-IS feed through terminals with optional resistance for converting 2-10 V tol 4-20 mA.
X4	36 fuse modular terminal blocks for 24 V and 36 feed through terminals for 0 V.
X5	8-slot chassis, power supply and three 16 A fuses for 230 VAC supply

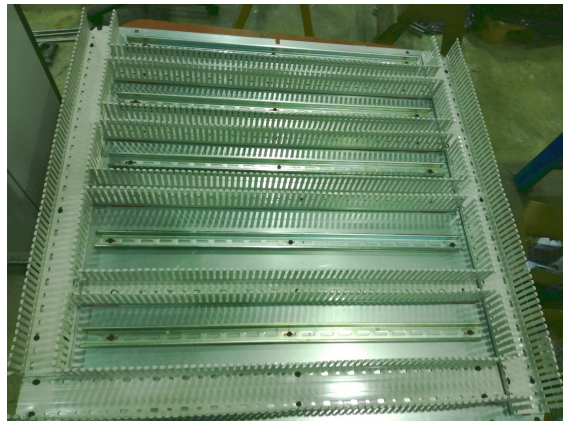


Figure 3.23: Steel plate for marshalling cabinet with DIN rails and cable ducts.

The marshalling cabinet was designed to handle at least 64 signals, both IS and non-IS. As a result, two termination lists X1 and X3 were installed, where X1 is IS termination list and X3 is the non-IS termination list. The blue marker on the cable duct lid, shown in Figure 3.24, were installed to mark the duct for IS signals only.

Ex barriers were installed in rack X2 for converting IS signals to non-IS signals or vice versa, while a 24 V power distribution system was installed in rack X4 for supplying the I/O chassis, barriers and LED light in the marshalling cabinet. Rack X5 was installed with the I/O chassis and a 16 A fuse, which also functions as the main power switch in the marshalling cabinet.

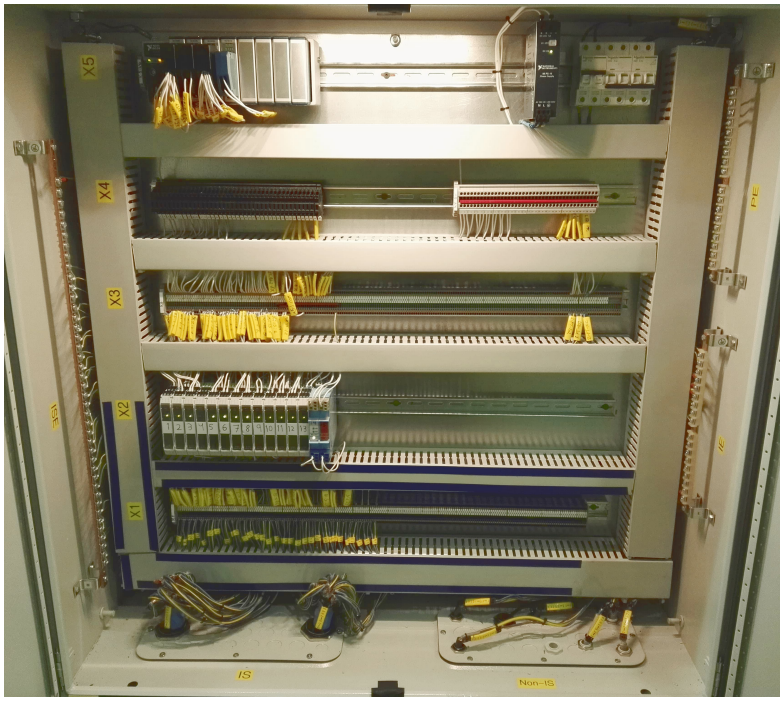


Figure 3.24: Marshalling cabinet with installed content.

Cross wiring with cable shoes was pulled and connected to the terminals in the racks and marked with yellow signs, which indicate the destination of the cross wiring between the racks. Because of the different magnitudes of the current running through the different cables, the power- and signal cables have different dimensions. Power cables are 1.5 mm^2, signal cables are 0.75 mm^2. In addition, as seen in Figure 3.24, all racks, earth bars and cable entries are marked with labels, so it is easy to modify the marshalling cabinet. A complete list of the equipment installed in the marshalling cabinet can be seen in Appendix E.

3.3.2 Software

The construction of the software will only describe the functionality of the SAS and not the logic itself. The logic behind the functionality can be explored in the electronic appendix "Safety and Automation System in LabVIEW", a list of the electronic appendixes can be found in Appendix K.

3.3.2.1 Network Configuration

The National Instrument (NI) Measurement and Automation Explore (MAX) was used to configure the network settings for the NI cDAQ-9188 Ethernet chassis. The Ethernet chassis must obtain a static IP address, because of a network monitoring

system which is further explained in Section 3.3.2.5. The following procedure must be used to configure the network and set a static IP address for the Ethernet chassis [14]:

1. Open NI MAX.
2. Right click on `Network Devices`, then select `Find Network NI-DAQmx Devices`, as shown in Figure 3.25.

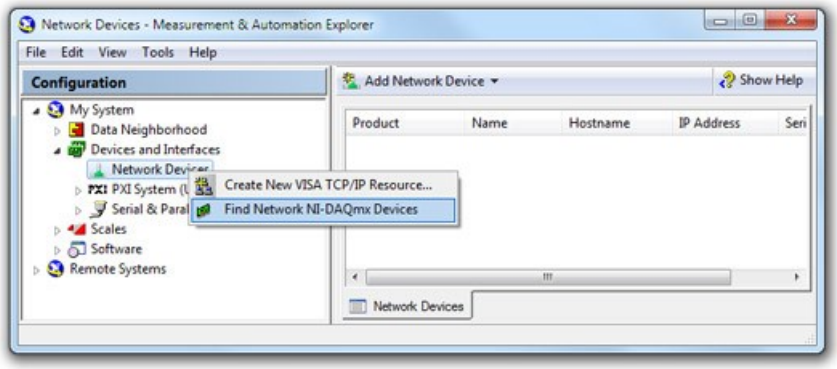


Figure 3.25: Find network devices in NI MAX.

3. Select your device and click `Add Selected Device`. The device will appear under `Network Devices` with all the I/O modules in the chassis, as shown in Figure 3.26.

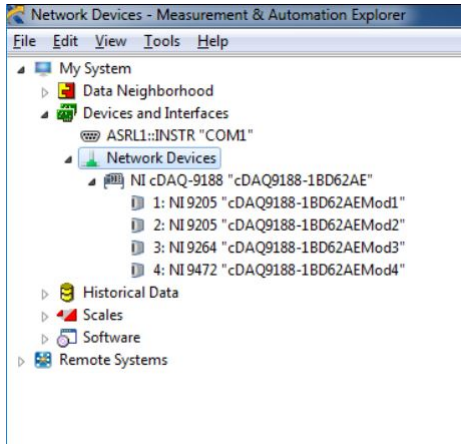


Figure 3.26: Devices has appeared under Network Devices in NI MAX.

4. Selected your device under `Network Devices` and go to `Network settings` to configure the IP address. Selected `Static` from the drop-down menu and set the IP address to `169.254.98.166`, then click `Save`.

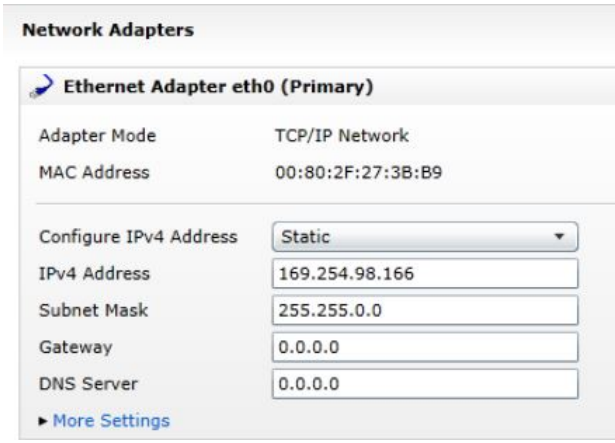


Figure 3.27: Set IP address to Static.

5. Click on `Self-Test` to verify that the network status is OK.

The network configuration is now complete and the NI MAX will remember the implemented settings.

3.3.2.2 LabVIEW Project Explorer

The CSL software project was built and managed in the Project Explorer in LabVIEW. The Project Explorer uses a folder structure where all the files related to the project are located. The folder structure in the Project Explorer consists of the following main folders:

- ***MainVI:*** The main software for control and monitoring of the CSL.
- ***SubVI:*** Location of all the sub programs called from the main program.
- ***Equipment:*** Location of all stored default values in the main program.
- ***NI cDAQ-9188:*** Location of all the configured I/O channels linked to tags in the Ethernet chassis.
- ***Unit conversion:*** Location of conversion files from hardware range to software range. An overview of all the range conversion linked to the tags is located in Appendix F.
- ***Documentation:*** Location of all the documentation related to the CSL, datasheets, layout drawings, loop diagrams, operation procedures and I/O signal list.

Figure 3.28 shows the Project Explorer structure for the CSL.

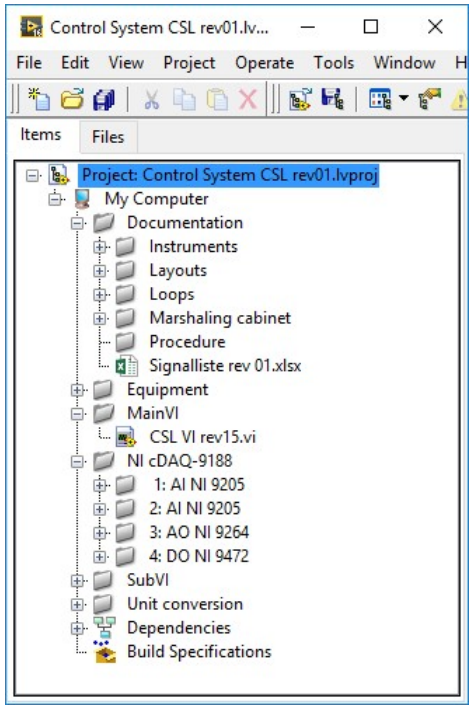


Figure 3.28: Project Explorer for SAS.

3.3.2.3 Process Control System

The process layout for HMI Screen 1 presented in Figure 3.30, was built on the specification in Section 2.4.2.2. Standard numeric indicators were used to display all measurements from the CSL, with a corresponding gray LED to indicate the point of measurement. All LEDs associated with HH and H alarm tags, see Table 2.8, blinks with 0.5 s interval whenever an alarm is active, where the alarm blinking colors is given in Table 2.7. However, when an I alarm in Table 2.8 is activated, the LED will not blink, just light up, because it is a less important alarm. Additionally, when an alarm is activated, the tag name appears underneath the LED, so that it is easy to correlate the tag in the alarm list to the process layout.

The automatic pressure control of the EL was built on the specifications in Section 2.4.2.5. Figure 3.30 shows the main controls of the EL, where the operator can select `Auto` or `Hand`, and select the pressure setpoint of the EL. When `Auto` is selected, the manual numeric position controller of the choke valve will be disabled and function as a numeric position indicator. When `Hand` is selected, the operator can use the manual numeric position controller to set the desired position of the choke valve. The setpoint of the controller can, of course, be adjusted in `Hand` mode, such that the setpoint can be changed before switching back to `Auto`. The default setup for the pressure control of the EL is `Auto`. The controller gain and integral time are normally adjusted and set once, so it is not necessary to show these parameters to

the operator all the time. As a result, the controller parameters are placed in a subVI which pops-up when pressing the DCSS symbol PC-001, as shown in Figure 3.30. Figure 3.29 shows the pop-up window of the controller parameters, where the derivative time is selected as zero, to get a PI controller. The program will always remember the last controller parameters chosen by the operator. In addition, the controller was implemented with smoothly switching between `Auto` and `Hand`, and vice versa.

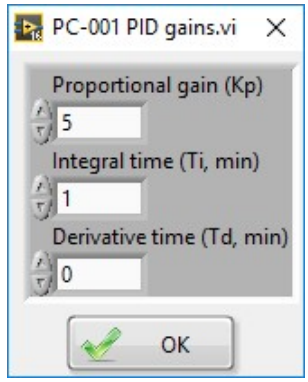
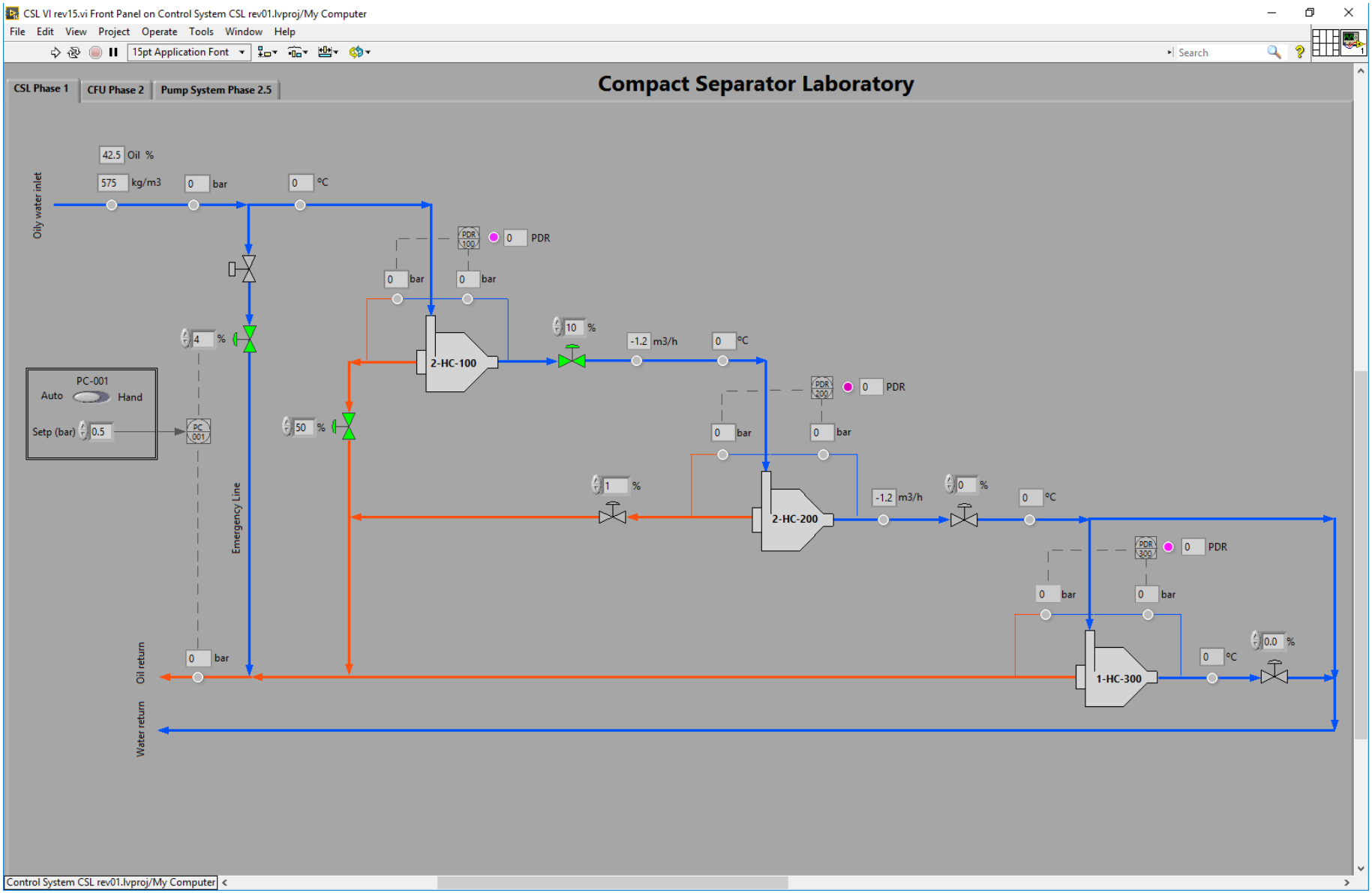


Figure 3.29: PID gains pop-up window.

Standard graphical valves were chosen from the LabVIEW library and placed inside the flow lines of the process layout. The valves were defined as open at 3 %, corresponding to a green valve, while defined as closed under 3 %, which corresponds to a gray valve.

As seen in Figure 3.30 the layout is clean and simple, and has no unnecessary distracting animations. Tabs for Phase 2 and the pump and reservoir system were also implemented.


CSL VI rev15.vi Front Panel on Control System CSL rev01.lvproj/My Computer
File Edit View Project Operate Tools Window Help
15pt Application Font
Search
CSL Phase 1
CFU Phase 2
Pump System Phase 2.5
Compact Separator Laboratory
Oily water inlet
42.5 Oil %
575 kg/m3
0 bar
0 °C
PDR 100
0 PDR
0 bar
0 bar
4 %
10 %
-1.2 m3/h
0 °C
2-HC-100
PC-001
Auto
Hand
Setp (bar) 0.5
PC 001
50 %
Emergency Line
PDR 200
0 PDR
0 bar
0 bar
1 %
2-HC-200
-1.2 m3/h
0 %
0 °C
PDR 300
0 PDR
0 bar
0 bar
0.0 %
0 °C
1-HC-300
0 bar
Oil return
Water return
Control System CSL rev01.lvproj/My Computer

See Figure 3.30 on page 49.

Figure 3.30: HMI Screen 1.

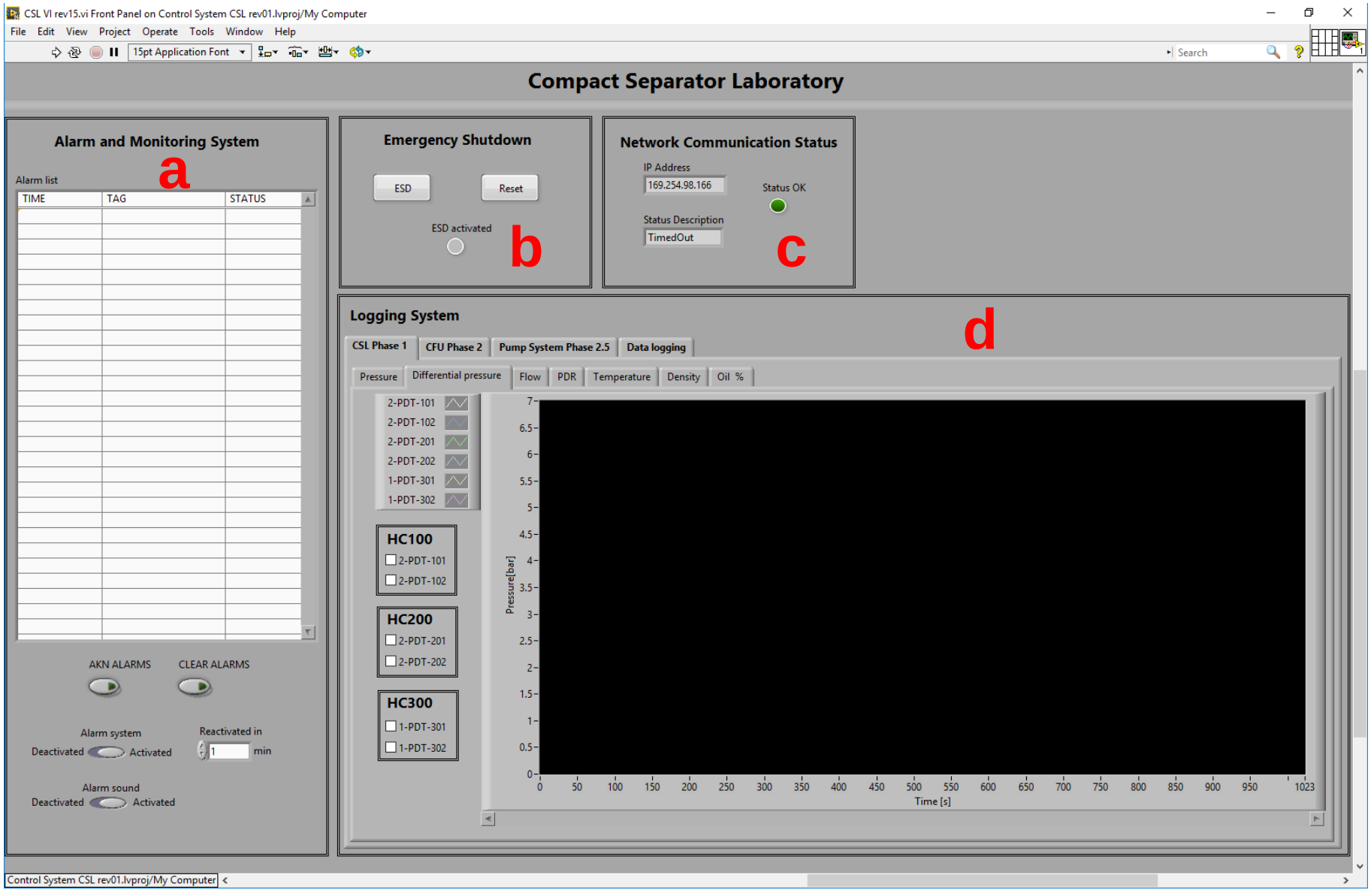
3.3.2.4 ESD System

The ESD system presented in Section (b) in Figure 3.31, was built on the specifications presented in Section 2.4.2.8. The manual activation of the ESD system is located on HMI Screen 2 and the corresponding LED will light red whenever the ESD system is activated through an HH alarm or the manual ESD button. The activation of the ESD system will open the safety valve and automatically set the pressure control of the EL into `Auto` mode. To reset the ESD system, all HH alarms must be out of active state and the ESD button must be deactivated. In addition, the safety valve must be closed manually from the HMI before normal operation can be achieved. This works as an extra safety feature.

3.3.2.5 Alarm and Monitoring System

The alarm list is presented in a table format as shown in Section (a) in Figure 3.31. The program inserts a text string, as illustrated in Table 2.9, into the top row of the table each time a signal value passes from a non-alarm state to an alarm state. If an alarm is activated after another alarm has been activated, the program inserts an empty row on top of the alarm table, such that the text string containing the newest alarm can be inserted into the top of the table. In order to clear the alarm list, all alarms in the list have to be acknowledged, as specified in Section 2.4.2.7. This ensures the awareness of the operator to any active or unacknowledged alarms, such that any alarms that have not been noticed can not be cleared.

The network monitoring system is shown in Section (c) in Figure 3.31 checks the network status between the NI cDAQ-9188 Ethernet chassis and the operator station. A green LED is lid whenever the network is up and running. The network status is not connected to any shutdown function, so the system only notifies the operator that the communication is lost.


CSL VI rev15.vi Front Panel on Control System CSL rev01.lvproj/My Computer
File Edit View Project Operate Tools Window Help
15pt Application Font
Search
Compact Separator Laboratory
Alarm and Monitoring System
a
Alarm list
TIME
TAG
STATUS
AKN ALARMS
CLEAR ALARMS
Alarm system
Deactivated
Activated
Reactivated in
1
min
Alarm sound
Deactivated
Activated
Emergency Shutdown
ESD
Reset
ESD activated
b
Network Communication Status
IP Address
169.254.98.166
Status OK
Status Description
TimedOut
c
Logging System
d
CSL Phase 1
CFU Phase 2
Pump System Phase 2.5
Data logging
Pressure
Differential pressure
Flow
PDR
Temperature
Density
Oil %
2-PDT-101
2-PDT-102
2-PDT-201
2-PDT-202
1-PDT-301
1-PDT-302
HC100
2-PDT-101
2-PDT-102
HC200
2-PDT-201
2-PDT-202
HC300
1-PDT-301
1-PDT-302
Pressure[bar]
Time [s]
Control System CSL rev01.lvproj/My Computer

See Figure 3.31 on page 51.

Figure 3.31: HMI Screen 2.

The following list describes the sections in Figure 3.31:

(a): Alarm and Monitoring System.

(b): Emergency Shutdown.

(c): Network Communication Status.

(d): Logging System.

3.3.2.6 Real-time Data Display

The real-time data display presented in Section (d) in Figure 3.31 was built on the specification in Section 2.4.2.9. The operator can choose the graph where the desired signal(s) is located and choose the signal by clicking the correct check-box. Additionally, over the check-boxes, a plot legend displays the colors of the selected signals. The default time scale of the x-axis is 20 s, but this can be changed by the operator by clicking the x-axis and inserting the desired value. The y-axis displays the signal value and varies for each signal. The y-axis can be changed in the same way as the x-axis. Additionally, by right-clicking on the axis of a graph, the scale of the axis can be changed to auto-scale.

3.3.2.7 Alarm Logging and Real-time Data Logging

The alarm system will log all occurring alarms to Excel as long as the program is running and the alarm system is not temporarily deactivated.

Logging of the real-time signal data is activated and deactivated in the `Data Logging` tab, which is located in the logging system, presented in Section (d) in Figure 3.31. A green led indicates whether the signal logging program is writing to an Excel-file or not.

The operator can select the path directory for where both alarms and data signals shall be logged on the operator station PCs hard drive.

3.3.2.8 Structure of the Block Diagram

The structure of the block diagram in LabVIEW is divided into several blocks running in parallel. Each block in Figure 3.32 represent a (while) loop, which is used to execute a code repeatedly until the program is stopped [13]. Additionally, all (while) loops are implemented with a clock function which sets the update rate of the each (while) loop. The update rates vary from each (while) loop, such that important loops has

high update rate, while less important loops have a lower update rate. This is done to reduce strain on the Central Processing Unit (CPU) of the operator station PC.

The block diagram structure in LabVIEW consist following main features:

- ***Analog inputs and logging:*** Logic for retrieval of all measured input signals from the NI cDAQ-9188 chassis and logic for logging each input signal to Excel. Filtering of input signals in order to remove noise.
- ***Analog Output:*** Logic for sending software signals to the analog output module of the NI cDAQ-9188 chassis.
- ***Digital output:*** Logic for sending software signals to the digital output module of the NI cDAQ-9188 chassis.
- ***Pressure control for EL:*** Control algorithms for pressure control of the EL located on HMI screen 1.
- ***Valve LED color:*** Logic to set the open and close colors for the control valves on HMI screen 1.
- ***ESD logic:*** Logic for initiation of ESD system.
- ***LED alarm colors:*** Logic to set the alarm colors on the corresponding LEDs to numeric indicators on HMI screen 1.
- ***Network communication status system:*** Logic for checking the network status between the operator station and the NI cDAQ-9188 chassis.
- ***Alarm and Monitoring System:*** Logic for monitoring of the process values and displaying alarms in the alarm list on HMI screen 2.
- ***Plot:*** Logic for displaying process values in the graphs on HMI screen 2.

The text descriptions in Figure 3.32 can also be found in the block diagram of the software program, with additional description inside each loop, to help the operator to easily understand the logic of the program.

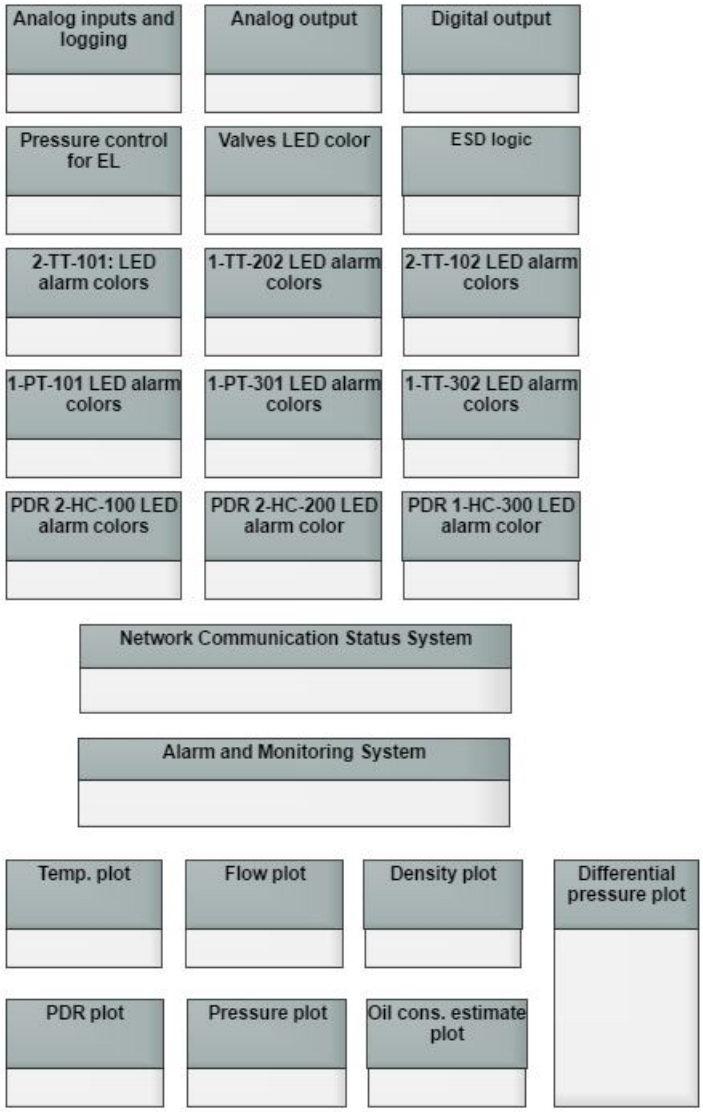


Figure 3.32: Structure of the block diagram in LabVIEW.

Chapter 4

Operation Procedures

4.1 Procedure to Operate Sampling Points

The following procedure must be followed when using the sampling points. Figure 4.1 shows a sampling point and the valve numbering which are used in the following procedure:

1. Check that the sampling bomb is drained and de-pressurized.
2. Open inlet valve (1) until the pressure in the sampling bomb matches the process pressure, then close inlet valve (1).
3. Open vent valve (2) until the pressure in the sampling bomb is at atmospheric level.
4. Extract sample from sample valve (3).
5. Fully drain the sampling bomb, then close sample valve (3) and vent valve [2].

Figure 4.1: Sampling point at water outlet HC2.

4.2 Start-up Checklists

4.2.1 Mechanical

The following mechanical checks must be conducted before the CSL is ready for operation.

	Start-up Checklist	Check
1.0	**Mechanical**	
1.1	Check that all six drain valves are closed, see Figure 2.2	
1.2	Depending on whether or not HC3 is going to be used, check that either 1-MV-201 or 1-MV-202 are open, see Figure 2.2	
1.3	Check that all three sampling points inlet valves (1) are closed, see Figure 4.1.	
1.4	Check that the pneumatic supply hose is connected to the pressure regulator.	

1.5	Check that the pressure is regulated to 7 bar in the pressure regulator.	
1.6	Check that all flow control valves (FV) are in open position, see Figure 2.2	

The checklist must be updated when future Phases of the CSL is integrated with Phase 1.

4.2.2 Automation

The following procedure must be followed to ensure a safe start-up of the software and hardware of the automation system.

	Start-up Checklist	Check
2.0	**Automation**	
2.1	Turn on the power switch fuse 1 in 1-FTC-100/X5.	
2.2	Check that all green power LEDs for the safety barriers(1-FTC-100/X4) and I/O rack (1-FTC-100/X5) are turned on.	
2.3	Boot the operation station.	
2.4	Open NI MAX and run a software self-test which verifies the I/O and network communication.	
2.5	Open project folder and run the main VI.	

Chapter 5

Commissioning Phase

5.1 Flushing

The workshop water feeding system was connected to the CSL through the drain valve of 2-HC-200, shown in Figure 5.1. Before flushing the CSL, all flanges and fitting connection were tightened to avoid any unnecessary water leaks in the laboratory facilities. The flushing was carried out for 30 min with open drain valves and open sampling points, to ensure that any debris was flushed out of the CSL.

Figure 5.1: Workshop water feeding system connected to the CSL.

After flushing the pipes, the HCs were installed into the vessel housings. Installation of the HCs in the vessel housing 2-HC-200 and 1-HC-300 was a fairly simple operation, due to the flexibility of the piping, but 2-HC-100 was more demanding to install. Installing 2-HC-100 required dismantling a small pipe section of the piping, in addition to. a valve to get access to the vessel housing. To ensure that the operation would not damage the valve or the actuator, a small pulley lifting system was installed

and used during the operation.

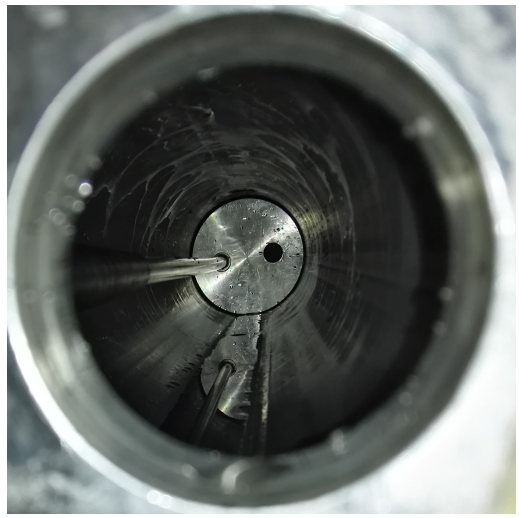


Figure 5.2: Flushed and clean vessel housing with one liner installed.

Figure 5.2 shows the inside of the flushed 2-HC-100 with one of two HCs installed. Next, the second HC was installed, and the hold-down plate was mounted to ensure no movement of the HCs in the vessel housings during operation. Then, the pipe and valve could be lifted back up again with the pulley system, before the pipe section could be bolted to flanges and clamped on to the vessel housing with the pipe clamps.

5.2 Leak Test

5.2.1 Leak Test of the CSL

In order to carry out the leak test, a bottle containing 50 l of compressed nitrogen at 200 bar, as specified in Section 2.5.2.1, was connected to one of the CSLs drainage points, via a pressure regulator. This way, the leak test could be carried out as specified in Section 2.5.2.2. Since the CSL is rated for pressure number 40 bar, and the SAS activates the ESD when the pressure in the CSL reaches 27 bar, the authors decided to leak test to 30 bar instead of 25 bar. Figure 5.3 shows a plotted curve of data read from 1-PT-101 during the leak test. No major leakages were detected during the test, only minor leakages that were easily fixed on the spot. As seen in Figure 5.3, the CSL did not suffer from any pressure drop that could have indicated any major leakages. This was backed up by testing all flange connections, tubing fittings or threaded fittings with leakage spray. The curve from 1500 s in Figure 5.3 shows a slight pressure drop, which had not occurred at any of the steps prior to reaching the 30 bar step. This is due to the six needle drain valves, which has a very small leak at high pressures. However, due to the fact that the CSL is leak free at

the maximum operational limit of 25 bar, the CSL is considered leak free.

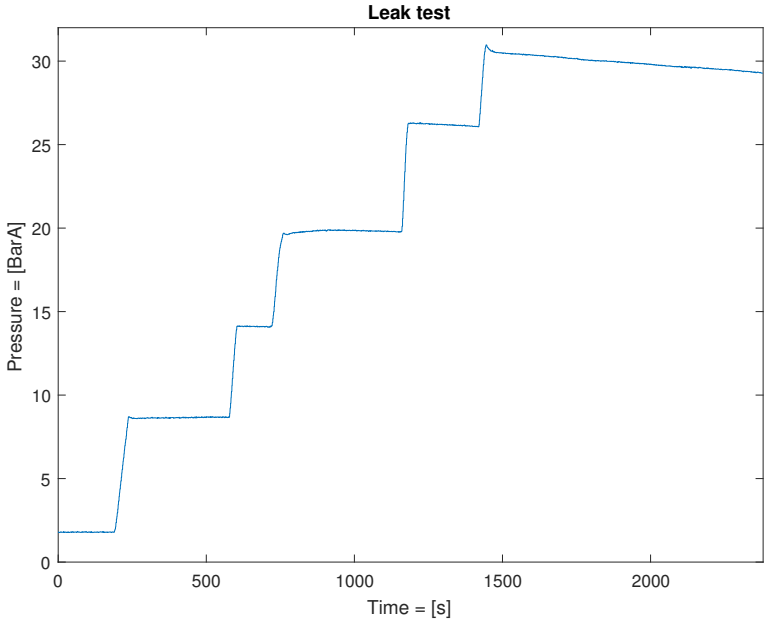


Figure 5.3: Leak test of the CSL.

5.2.2 Leak Test of Pneumatic Supply System

The pneumatic supply system was tested according to the procedure in Section 2.5.2.3. The system did not have any significant leakages or faults, and proved its functionality when the valves were successfully tested.

5.3 Testing of Instrumentation and Automation System

5.3.1 Factory Acceptance Test

The FAT were conducted with the FAT setup in Section 2.5.3.1, and the FAT results are presented in the FAT procedure in Appendix C.

5.3.2 Site Acceptance Test

The SAT was conducted with the SAT setup in Section 2.5.3.2, and the SAT results are presented in the SAT procedure in Appendix C.

The SAT test revealed that the analog output (AO) controlling the control valves was not working as intended. The control valve loop designed in the specialization

project [11] is based on converting a voltage signal to a 4-20 mA signal, by the use of 500 Ω resistances. After troubleshooting the loop, the issue reviled to be that the loop had more resistance than first anticipated. Therefore, the NI9264 AO voltage module could not deliver the operating voltages and at the same time deliver the correct current signal.

NI were contacted and the they recommend the NI9265, 4 channel current output modules with external 24 V power supply. Two NI9265 modules were then purchased and installed in the marshalling cabinet. In addition, the corresponding loop diagrams, marshalling cabinet layout and 24 V distribution diagram were updated. These can be found in Appendix G, Appendix H, and Appendix J respectively.

The PC in operator station of the CSL was donated by the Department of Mechanical and Industrial Engineering at NTNU. This was a previously used PC that was originally supposed to be trashed. When running the SAS the PC lagged and did not preform as desired. Even though the communication between the CSL and the operator station worked the PC lacked the capacity to smoothly run the SAS. After running the first round of the SAT, there was an incident where the PC lost power while being in sleep mode. This caused a software failure which resulted in a loss of network communication between the PC and the NI cDAQ chassis. The authors were not able to fix the software fault, so the Information Technology (IT) responsible at the Department of Mechanical and Industrial Engineering at Valgrinda offered the authors another previously used PC.

The PC was then installed in the laboratory facilities, and the network communication in Section 3.3.2.1 was once again configured. As a result, the network communication was up and running once again, and the flow control valves were successfully tested according to the SAT procedure in Appendix C.

Chapter 6

Project Cost

The project cost for each discipline is presented in Table 6.1, which includes the following sub categories:

- ***Structure:*** Steel profiles and paint.
- ***Piping:*** Vessel housing, welding of pipes, pipes, flanges, elbows and miscellaneous piping equipment.
- ***Instrumentation:*** Instruments, tubing, fittings, pneumatic supply system, valves, junction boxes, and instrument cables.
- ***Automation:*** Marshalling cabinet, I/O modules, cDAQ chassis, terminals and miscellaneous automation equipment.
- ***Electrical:*** Power supply, power cables and fuses.
- ***Commissioning:*** Leak testing equipment.
- ***Miscellaneous:*** Travel expenses from the Master thesis [1].

Note, that the commissioning discipline is an estimated value, due to the fact that no invoice is received before the hand-in of this Master thesis.

In the specialization project [11], a total budget of NOK 1,990,665.00 was estimated for the construction of Phase 1. Table 6.2 shows the remaining budget for Phase 1. These funds are reserved for purchasing oil in water (OIW) sensors and a flow control valve. Hence, the available space marked by flanges on the water outlet of 1-HC-300, the water outlet of 2-HC-100, and on the oil outlet of 1-HC-300 in Figure 2.2.

Table 6.1: Project cost for Phase 1.

Discipline	Cost including VAT
Structure	NOK 21,440.01
Piping	NOK 285,218.00
Instrumentation	NOK 581,959.67
Automation	NOK 138,158.14
Electrical	NOK 3675.00
Commissioning	NOK 2000.00
Miscellaneous	NOK 9341.50
Total cost	NOK 1,038,882.32

The authors can not cite any specific prices since most vendors tend to prefer confidentiality regarding the price of their equipment. Most of the remaining budget will be used when acquiring two OIW sensors.

Table 6.2: Remaining budget for Phase 1.

Total	Cost including VAT
Budget	NOK 1,990,665.00
Cost	NOK 1,038,882.32
Remaining budget	NOK 951,782.68

Chapter 7

Discussion, Conclusion and Recommendations for Further Work

7.1 Discussion

The laboratory facility does not have a dedicated system for managing and documenting equipment. Therefore, the authors have consistently throughout the report used summary tables for documenting the selected equipment. Managing the parts and equipment used in the laboratory is very important with regards to further maintenance and expansion.

In order to execute a proper flow test of the CSL, in addition to step testing both actuators and transmitters, a temporary water pump system was desired prior to the construction of the permanent pump and reservoir system in Phase 3. After considering many options, these being presented in Section 2.2.1, it was decided that the most convenient of these options for getting a temporary pump system was buying a single pump for testing the CSL with water. The largest setback of buying a new pump is obviously the cost, a factor that becomes relevant when a pump and reservoir system is designed and constructed later. The authors advice doing a FEED study based on the design of a pump and reservoir system in the Master thesis [1]. If a pump had been bought, which later proved unusable in the pump and reservoir system, an extra pump would have to be bought. Therefore, the authors decided not to buy a single pump prior to that FEED study.

To operate the CSL, a used PC was donated by the Department of Mechanical and Industrial Engineering at NTNU in the fall of 2016. The PC had been formatted prior to being handed over to the authors. Only programs that are necessary to run the CSL were installed, in order for the PC to operate as smooth as possible. During

testing of the SAS, the PC crashed multiple times, in addition to general lagging during testing operations. The authors would like to express their concern regarding further development of the SAS and implementation controller algorithms. One does not know if, or at what point this PC will become unable to handle the tasks of running and controlling the CSL.

Originally, the NI9264 voltage output module was selected as the AO module that would control the flow valves in the CSL. The voltage applied by the NI9264 module coupled in parallel with a resistor would transform the voltage signal to a current signal. This did not work as predicted in the specialization project [11], due to the fact that the NI9264 could not deliver both the operating voltage and the control current required to operate the flow control valves. The flow control valves had a higher load resistance than the authors were aware of, and therefore, the NI9265 current output module was purchased in order to replace the NI9264 module. This way the resistor coupled in parallel with the AO module could be removed from the circuits, and the flow control valve would be supplied with the current signal needed to operate. The NI9264 voltage output module was initially chosen instead of a current output module due to the fact that it was less expensive. Luckily, buying two extra NI9265 current output modules did not prove to be too costly.

For the reader to get the full scope of what this Master thesis revolves around, the authors recommend browsing trough the electronic appendix "Images of the CSL", a list of the electronic appendixes can be found in Appendix K. In addition, the specialization project [11] can be found as an electronic appendix.

7.2 Conclusion

This Master thesis is aimed towards completing the construction of the CSL, including constructing and designing the SAS. It would have been fortunate to have the opportunity to test the CSL with water flow directly after the commissioning phase, but this can not be done due to the lack of a pump.

Variations in types of fittings and connections being used to connect tubing, instrumentation and process piping to each other are undesirable. Every fitting or connection that needs a transition to be spliced creates an extra weak point in the CSL, regarding leakages. For the most part, the fittings and connection types used in the CSL have been consistent, although not on all the threading types. Therefore, being consistent throughout the selection process will spare further expansions of the CSL for leakages and weak points that may occur as a consequence of adapter connections. Even though there were some adapter connections used throughout the CSL, the different connections, fittings, and threading mostly fitted directly together. This proved to be fortunate for the integrity of the CSL during the leak test in Section 5.2. Some minor leakages occurred during the steps of the test, but all occurring leakages were repaired on the spot by tightening the leaking fitting or connection. The leak

test proved that the CSL was completely sealed and leakage free after the first and only test.

The authors recommend buying a new PC for the CSL operator station. If not right away, at least prior to operation of the CSL with oily water, and the implementation of control algorithms in the SAS, which require a stable and reliable PC. It seems unwise to use an old and partly unfit PC for the task, as the hub for the entire control system for the CSL with a budget of this magnitude. Especially since a new PC is a fairly low-cost procurement compared to the rest of the instrumentation and equipment in the CSL.

The FAT, presented in Section 5.3.1 was successfully conducted. So was the SAT, presented in Section 5.3.2. Initially, all elements of the SAT except testing of the flow control valves were successfully executed. After exchanging the NI9266 module with the NI9265 module, as described in Section 5.3.2, the remainder of the SAT was successfully conducted. This was the last piece of the puzzle, which made the authors able to deliver a CSL that fulfills all requirements set in the Master thesis task description.

7.3 Recommendations for Further Work

At some point, the new student(s) or PhD candidate(s) are going to take over the CSL. For that reason, the authors would like to give their recommendations for future development of the CSL.

7.3.1 Tuning PI Controller

The PI controller located on the EL in the SAS needs to be tuned according to the process parameters. This cannot be done prior to testing the CSL with a high pressurized liquid flow. Therefore, this must be done before operation of the CSL involving hydrocarbons.

7.3.2 Maintenance of the Vessel Housing

In case the vessel housings for some reason needs to be opened, the rubber packers sealing the clamp fittings at both ends of each housing have to be lubricated with grease prior to re-installation. This is because the packer sealing will expand when the pressure is rising inside the vessel housing and shrink when the pressure decreases. If the packer sealing is not properly lubricated, the packers seals could disintegrate.

7.3.3 Further Development of the Software

Future student(s) or PhD candidate(s) working on the CSL for further development of the SAS needs to familiarize themselves with the current setup before making

any alterations or adding new logic. By browsing the LabVIEW block diagram and looking at the comments throughout the program, an understanding of its setup and functionality can be obtained. This, of course, presupposes that the person supposed to alter or expand the program have a certain degree of knowledge about LabVIEW and its functionality. Either way, the authors recommend reading Section 2.4.2 before making any alterations to the program.

7.3.4 Pump and Reservoir System

Based on the reviews done in Section 2.2.1, the authors recommend running an independent FEED study based on the pump and reservoir system designed in the Master thesis [1].

7.3.5 Position Verification of the Safety Valve

During installation of the process piping and valves, the welders that welded the pipes also installed the safety valve (1-SV-101), see Figure 2.2, without knowing whether the valve was in open or closed position. This means that, in order to know the position of the valve, it have to be tested when a pump system is connected to the CSL, prior to any operation. The testing could, for example, be done by closing all control valves and manual valves in the CSL, followed by a pressure build up on the CSLs inlet. Opening 1-CH-101 and monitoring if 1-PT-301 transmits the same pressure as 1-PT-101 will indicate if the current position of the safety valve is open. If 1-PT-101 transmits the applied pressure and 1-PT-301 transmits the same pressure as the CSL had prior to the pressure build up, the safety valve is closed.

Currently, the pressure switch (1-PS-101) controlling the safety valve is wired to be normally open, see Figure 7.1, such that the pressure switch does not transmit any power to the safety valve unless it has tripped. That means the valve is, presumably, closed until it is powered by either the pressure switch or by the SAS.

If the test reveals that the valve is open when in the position shown in Figure 7.1, the operator simply have to turn the solenoid valve, seen in Figure 7.2, that actuates the safety valve, 180° in order to reverse the default position of the safety valve. This is easily done by removing the 2 screws holding the solenoid valve to the side of the safety valve, turning the solenoid 180°, then fastening the 2 screws.

7.3.6 Air Drainage Valves

During start-up and operation of the CSL, air or gas may be in the system. Most of the air will flow through the process piping, but some may accumulate in the vessel housings and the highest elevated pipe. For that reason, a needle valve on top of each vessel housing, and on top of the highest elevated pipe may be a smart investment. This way excess air may be drained, not to disturb any oily water flow through the HCs while the CSL is in operation.

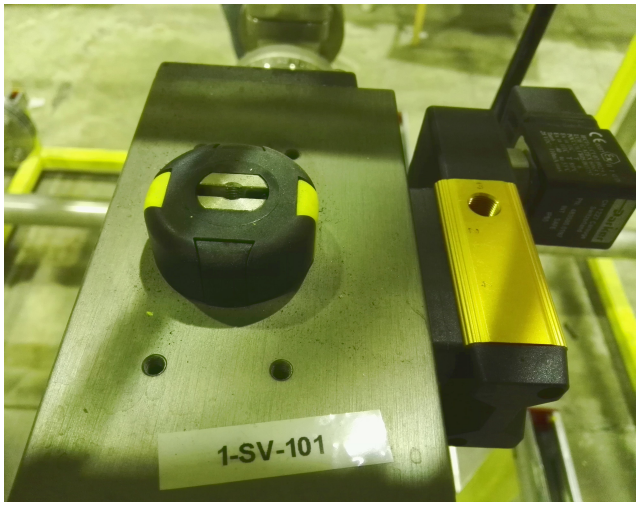


Figure 7.1: Safety valve presumably in closed position.

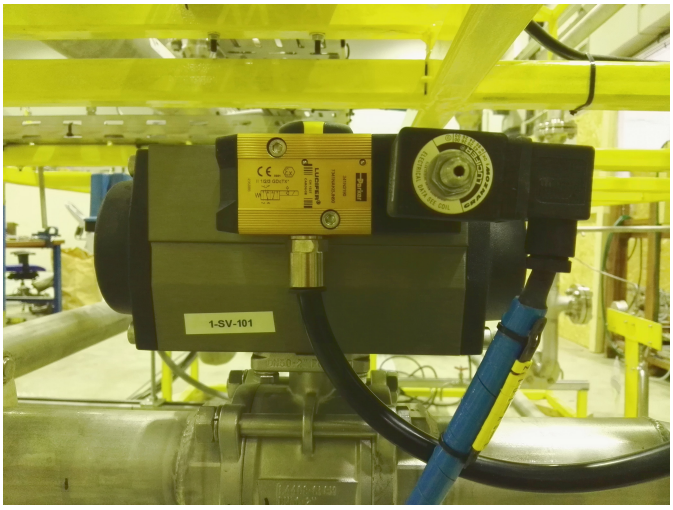


Figure 7.2: Safety valve with solenoid valve.

7.3.7 Calibration of Flow Control Valves

In case any of the flow control valves become inaccurate after some period of time, the Samson 3730 electro-pneumatic positioner controlling the position of the stem, has an auto calibration function [21]. The auto-calibration may be executed by accessing the control button which is available inside the cover of the positioner display. This way the valves can be re-initialized to the default settings.

7.3.8 Oil in Water Sensor

The authors recommend properly testing the CSL with a pump and reservoir system to ensure that it is functioning as intended, prior to purchasing the two planned OIW sensors. Especially due to the high cost of the OIW sensors.

7.3.9 Updating Documentation for Future Phases

All documentation, i.e drawings, diagrams, lists, and models are located in a Dropbox folder which follows the CSL. Anyone working with the CSL is given access and may view and/or modify any documentation. It is important to be consistent regarding methods for writing and archiving documentation for all Phases of the CSL.

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Appendix A

IS Calculation

New IS calculation for pressure transmitters provide by Statoil, 1-PT-101 and 1-PT-301.

Verification of Intrinsically Safe Circuits

	Manufacture	Type	Description	Certficate	Authority	U_i [V]	I_i [mA]	P_i [mW]	R_i [Ω]	C_i [nF]	L_i [mH]
TRANSMITTER DATA	**Druck**	**PTX 7900**	**2-Wire Pressure Transmitter**	**BAS01ATEX1254**	**EECS**	**28.0**	**180**	**1000**		**55**	**0.36**

	Manufacture	Type	Description	Certficate	Authority	U_o [V]	I_o [mA]	P_o [mW]	R_o [Ω]	C_o [nF]	L_o [mH]
BARRIER DATA	**STAHL**	**9160/23-11-10**	**Galvanic isolation**	**03 ATEX E 010 X**	**DMT**	**27**	**88**	**576**		**90**	**2.3**

CABLE DATA				
Manufacture:	**Draka**	Wires:	**2**	
Type:	**RFOU(i)**	Size [mm^2]:	**0.75**	
Description:	**Instrument cable**	Max Length, L_{max} [m]:	**318**	
		Capacitance, Cc [nF/km]:	**110**	
		Inductance, Lc [mH/km]:	**0.67**	
		Resistance [Ωkm/wire]:	**26.3**	

$I_o \leq I_{i(min)}$	**OK**
$V_o \leq V_{i(min)}$	**OK**
$P_o \leq P_{i(min)}$	**OK**
$C_i+C_c \leq C_0$ [nF]	**OK**
$L_i+L_c \leq L_0$ [mH]	**OK**

The circuit is approved for : EEx ia IIC

	Tag
IS calculation valid for	1-PT-101 1-PT-301

U_i [V] Maximum voltage that can be applied to the intrinsically safe circuits.

I_i [mA] Maximum current that can be applied to the intrinsically safe circuits.

P_i [mW] Maximum input power in an intrinsically safe circuit that can be dissipated without invalidating intrinsic safety.

R_i [Ω] Resistance in the intrinsically safe circuits.

C_i [nF] Total equivalent internal capacitance of the apparatus which is considered as appearing across the connection facilities of the apparatus.

L_i [mH] Total equivalent internal inductance of the apparatus which is considered as appearing across the connection facilities of the apparatus.

U_o [V] Maximun output voltage in an intrinsically safe circuit that can appear under open-circuit conditions.

I_o [mA] Maximum current in an intrinsically that can be taken from the connection facilities.

P_o [mW] Maximum electrical power in an intrinsically safe circuit that can be taken from the apparatus.

R_o [Ω] Maximum load resistance.

C_o [nF] Maximunm capitance in an intrinsically safe circuit that can be connected to the connection facilities.

L_o [mH] Maximunm inductance in an intrinsically safe circuit that can be connected to the connection facilities.

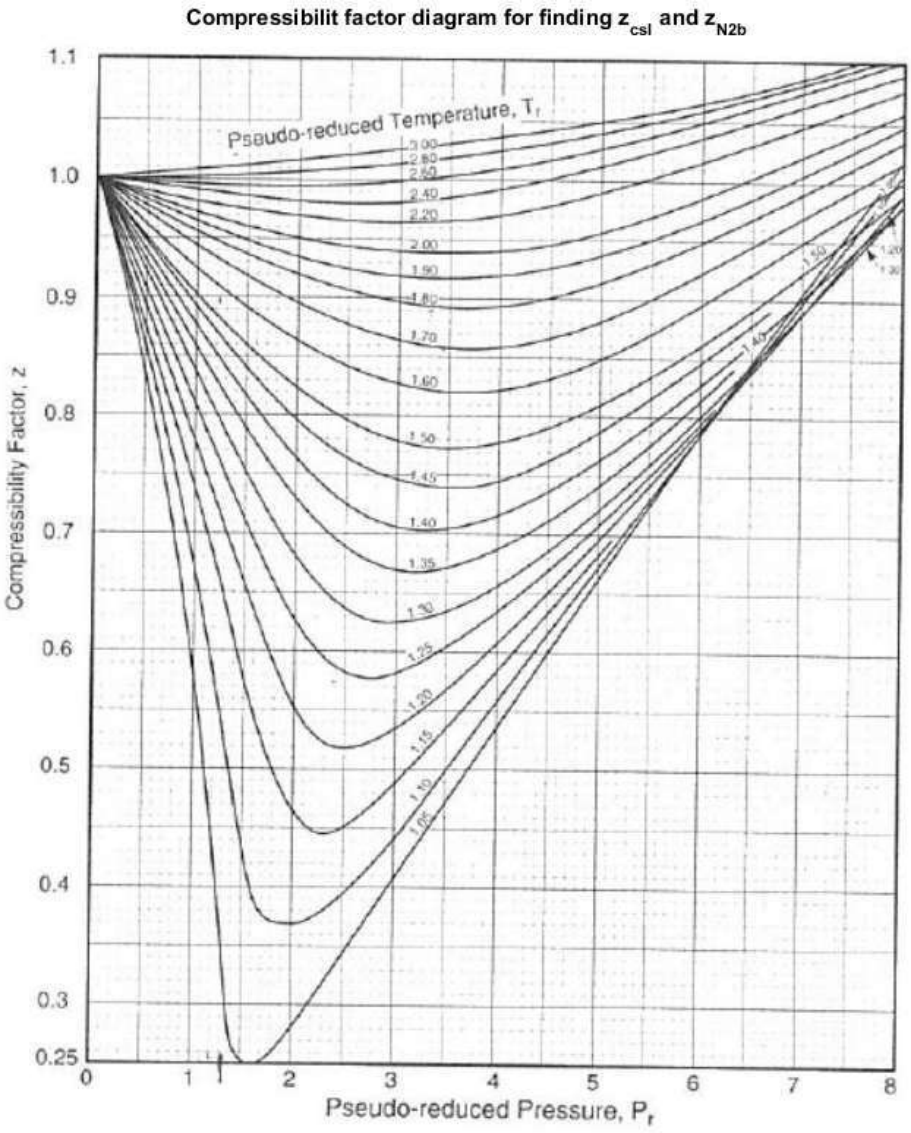
Appendix B

Gas Volume Calculations

```
% Calculation of gas volume for leak testing of the CSL
clear;

% 1" pipe
L1=11;                          %[m]    (Lenght)
OD1=33.4;                       %[mm]   (Outer diameter pipe)
WT1=3.378;                      %[mm]   (Wallthickness pipe)
r1=((OD1*0.001)-(WT1*0.001))/2; %[m]    (Radius pipe)

% 2" pipe
L2=21;                          %[m]
OD2=60.33;                      %[mm]
WT2=3.912;                      %[mm]
r2=((OD2*0.001)-(WT2*0.001))/2; %[m]

% 4" Vessel housing
n4=2;                           %[Number of vessel housings]
L4=1.2;                         %[m]
OD4=114.3;                      %[mm]
WT4=6.02;                       %[mm]
r4=((OD4*0.001)-(WT4*0.001))/2; %[m]

% 6" Vessel housing
L6=1.2;                         %[m]
OD6=168.28;                     %[mm]
WT6=7.112;                      %[mm]
r6=((OD4*0.001)-(WT4*0.001))/2; %[m]

% Total estimated volume of the CSL pipes and vessel housing.
V_csl=(pi*(r1^2)*L1)+(pi*(r2^2)*L2)+((pi*(r4^2)*L4)*n4)+(pi*(r6^2)*L6); %[m^3]

% Pseudo reduced temperature and pressure
Tc_N2=273.15+(-146.96);         %[K]    (Critical temperature Nitrogen)
Pc_N2=33.958;                   %[bar]  (Critical pressure Nitrogen)

T_csl=273.15+18;                %[K]    (Room temperature)
T_N2b=273.15+15;                %[K]    (Temperatur N2 bottle)

P_csl=25;                       %[bar]  (Leak pressure CSL)
P_N2b=200;                      %[bar]  (Compressed gas N2 bottle)

Tr_csl=T_csl/Tc_N2;             %       (Reduced temperature room temperature)
Tr_N2b=T_N2b/Tc_N2;             %       (Reduced temperature N2 bottle)

Pr_csl=P_csl/Pc_N2;             %       (Reduced pressure room temperature)
Pr_N2b=P_N2b/Pc_N2;             %       (Reduced pressure N2 bottle)

 I=imread('C_diagram.JPG');
 imshow(I);
 title('Compressibilit factor diagram for finding z_{csl} and z_{N2b}')

% Using Tr and Pr on the compressibility diagram to find the compressibility factor
z_csl=0.99;                      %      (Compressibility factor for the CSL)
z_N2b=1.04;                      %      (Compressibility factor for the Oxygen bottle)

% Ideal gas law
% V_csl - Volume of CSL
% V_Ob - Volume of compressed gas 200bar

V_N2b=V_csl*(P_csl/P_N2b)*(z_N2b*z_csl)*(T_N2b/T_csl);    % [m^3]
V_N2b_l=V_csl*(P_csl/P_N2b)*(z_N2b*z_csl)*(T_N2b/T_csl)*1000;  % [liter]
fprintf('\n V_N2b = %g m^3 or %g liter for one pressure build-up to 25bar. \n',V_N2b, V_N2b_l)

% Number of N2 bottles needed
V_standard_N2b=50;              % [liter]
n_N2b=V_N2b_l/V_standard_N2b;
```

```
fprintf('\n Number of N2 bottles (50 liter, 200bar) needed is %g per pressure build-up.\n',n_N2b)
```

```
V_N2b = 0.0119012 m^3 or 11.9012 liter for one pressure build-up to 25bar.

Number of N2 bottles (50 liter, 200bar) needed is 0.238025 per pressure build-up.
```



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Appendix C

FAT/SAT Procedure

Table C.1 presents the abbreviations, which are used in the FAT/SAT procedure.

Table C.1: FAT/SAT procedure abbreviations.

Abbreviations	Description
✓	Checked or Corrected
FYI	For Your Information
NA	Not Applicable

	FAT/SAT Procedure Automation System	FAT Check	SAT Check
1.0	**Network Communication**		
1.1	Connect the NI cDAQ-9188 to the operator station and run the NI MAX.	✓	✓
1.3	Run the self-test in NI MAX, and verify that the network status is OK.	✓	✓
1.4	Open the project explorer and run the main VI.	✓	✓
1.5	Verify that the IP address in network status is set to 169.254.98.166. Verify again that the network status led is OK.	✓	✓
2.0	**Logging system**		
2.1	Go to page "Logging Options" and selected the signal logging filename and path.	✓	✓
2.2	Verify that the logging system switch is enabled (by default) and that the corresponding LED is green.	✓	✓
3.0	**Alarm and Monitoring System**		
3.1	Simulate a value between $45 - 49°C$ for each of the following temperature transmitters.		
	• 2-TT-101	✓	✓
	• 2-TT-102	✓	✓
	• 1-TT-202	✓	✓
	• 1-TT-302	✓	✓
	Verify the following:		
	• The corresponding indicator displays the simulated value.	✓	✓
	• The corresponding LEDs are blinking yellow.	✓	✓
	• H alarms are displayed in the alarm list.		
	Enable override of the alarm and monitoring system and simulate the values again.	✓	✓
	Verify the following:		
	• No LEDs are blinking yellow.	✓	✓
	• No alarms are displayed in the alarm list.		

3.2	Simulate a value of $50°C$ for each of the following temperature transmitters.		
	• 2-TT-101	✓	✓
	• 2-TT-102	✓	✓
	• 1-TT-202	✓	✓
	• 1-TT-302	✓	✓
	Verify the following:		
	• The corresponding indicator displays the simulated value.	✓	✓
	• The corresponding LEDs are blinking red.	✓	✓
	• HH alarms are displayed in the alarm list.	✓	✓
	• The ESD is activates.	✓	✓
	• PC-001 of the EL is set to Auto.	✓	✓
	• 1-SV-101 is set to open.	✓	✓
	Reset the ESD. Enable override of the alarm and monitoring system and simulate the values again. Verify the following:	✓	✓
	• No LEDs are blinking red.	✓	✓
	• No alarms are displayed in the alarm list.	✓	✓
	• The ESD is not activated.	✓	✓

3.3	Simulate a value between 22-26 bar for the following pressure transmitter. • 1-PT-101. Verify the following: • The corresponding indicator displays the simulated value. • The corresponding LEDs are blinking yellow. • H alarms are displayed in the alarm list. Enable override of the alarm and monitoring system and simulate the values again. Verify the following: • No LEDs are blinking yellow. • No alarms are displayed in the alarm list.	✓ ✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓

3.4	Simulate a value of 27 bar or higher for each of the following pressure transmitters. • 1-PT-101 Verify the following: • The corresponding indicator displays the simulated value. • The corresponding LEDs are blinking red. • HH alarms are displayed in the alarm list. • The ESD is activates. • PC-001 of the EL is set to Auto. • 1-SV-101 is set to open. Reset the ESD. Enable override of the alarm and monitoring system and verify the following: • No LEDs are blinking red. • No alarms are displayed in the alarm list. • The ESD is not activated.	✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓

3.5	Simulate a value between 4-5bar for the following pressure transmitter. • 1-PT-301. Verify the following: • The corresponding indicator displays the simulated value. • The corresponding LEDs are blinking yellow. • H alarms are displayed in the alarm list. Enable override of the alarm and monitoring system and simulate the values again. Verify the following: • No LEDs are blinking yellow. • No alarms are displayed in the alarm list.	✓ ✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓

3.6	Simulate a value of 6 bar or higher for each of the following pressure transmitters. • 1-PT-301 Verify the following: • The corresponding indicator displays the simulated value. • The corresponding LEDs are blinking red. • HH alarms are displayed in the alarm list. • The ESD is activates. • PC-001 of the EL is set to Auto. • 1-SV-101 is set to open. Reset the ESD. Enable override of the alarm and monitoring system and verify the following: • No LEDs are blinking red. • No alarms are displayed in the alarm list. • ESD is not activated.	✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓

3.7	Simulate a value of 1bar simultaneously for the following differential pressure transmitters pairs, such that the PDR is less then 1.5.		
	• 2-PDT-101	✓	✓
	• 2-PDT-102	✓	✓
	• 2-PDT-201	✓	✓
	• 2-PDT-202	✓	✓
	• 1-PDT-301	✓	✓
	• 1-PDT-302		
	Verify the following:	✓	✓
	• The corresponding indicator displays the simulated value.	✓	✓
	• The corresponding PDR LEDs is purple.	✓	✓
	• I alarms are displayed in the alarm list.	✓	✓
	• PDR is calculated and displayed in the corresponding indicator.	✓	✓
	Simulate again, with a value of 3bar simultaneously, such that the PDR is higher then 2.5.		
3.8	Acknowledge and clear the alarms in the alarm list. Verify that the alarms are logged to Excel.	✓	✓
4.0	**ESD software button**		
4.1	Simulate an ESD with the software button 0-ESD-001.	✓	✓
	Verify the following:		
	• The corresponding LEDs are blinking red.	✓	✓
	• The alarms are displayed in the alarm list.	✓	✓
	• The ESD is activates.	✓	✓
	• PC-001 of the EL is set to Auto.	✓	✓
	• 1-SV-101 is set to open.		
	Reset the ESD.		

5.0	**Simulate flow meters**		
5.1	Simulate a value of between 2-10 V (700-1000 kg/m^3) for the following flow meter. • 1-FT-101 Verify the following: • The corresponding indicator displays the simulated value. • The corresponding oil concentration indicator displays the oil concentration.	✓ ✓ ✓	✓ ✓ ✓
5.2	Simulate a value of between 2-10 V (0-5 m^3/kg) for the following flow meter. • 2-FT-102 • 2-FT-202 Verify the following: • The corresponding indicator displays the simulated value.	✓ ✓ ✓	✓ ✓ ✓
6.0	**Test of the PC EL**		
6.1	Set the PC-001 from auto to hand, and simulate a value between 0-100 % for the choke valve, 1-CH-101. Verify the following: • The valve switch to green when defined open at 3 %. • The regulator switches from auto to hand bumpless.	✓ ✓ ✓	✓ ✓ ✓

6.2	Set the PC-001 to auto, and selected a setpoint of 3 bar. Simulate a value on 1-PT-301, both lower and higher then the setpoint. Verify the following: • The controller opens the choke valve, 1-CH-101, when the simulated value on 1-PT-301 is lower then the setpoint of PC-001. • The controller closes the choke valve, 1-CH-101, when the simulated value on 1-PT-301 is higher then the setpoint of PC-001. • The regulator switches from hand to auto bumpless.	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓
7.0	**Simulate safety valve**		
7.1	Open 1-SV-101. Verify the following: • The valve switch to green to indicate open. Close 1-SV-101.	✓ ✓	✓ ✓
8.0	**Simulate flow control valves**		
8.1	Simulate a value between 3-100 % of the following valves. • 2-FV-101 • 2-FV-102 • 2-FV-201 • 2-FV-202 • 1-FV-301 • 2-FV-302 Verify the following: • The valves switches to green at 3 % (defined open position).	✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓
9.0	**Instrument loop test**	NA	

9.1	Set the following positions, 0%, 50%, and 100%, for each flow control valves: • 2-FV-101 • 2-FV-102 • 2-FV-201 • 2-FV-202 • 1-FV-301 • 2-FV-302 Verify that each flow control valve are set to the desired position, by reading the manual position display on the actuator of the valve.	NA	✓ ✓ ✓ ✓ ✓ ✓ ✓
9.2	Set the following positions for the safety valve, open and closed. • 1-SV-101 Verify that safety valve are open and close by reading the position screw on the actuator. Lask the normally open contact on the pressure switch. • 1-PS-101 Verify that safety valve are open by reading the position screw on the actuator.	NA	✓ ✓ ✓ ✓
9.3	Measure the room temperature in the workshop. Verify that the following temperature transmitters approximates the room temperature. • 2-TT-101 • 2-TT-102 • 1-TT-202 • 1-TT-302	NA	✓ ✓ ✓ ✓

9.4	Check that the following pressure transmitters measures atmosphere pressure, when the CSL is not pressurized. • 1-PT-101 • 1-PT-301 Verify during the leak test, that the pressure transmitters displays the same pressure as the corresponding manometers.	NA	 ✓ ✓ ✓
9.5	Check that the following differential pressure transmitters measures zero differential pressure, when the CSL is not pressurized. • 2-PDT-101 • 2-PDT-102 • 2-PDT-201 • 2-PDT-202 • 1-PDT-301 • 1-PDT-302 Verify during the leak test, that the differential pressure transmitters displays differential pressure over the HCs, just before the pressure equalizes in CSL.	NA	 ✓ ✓ ✓ ✓ ✓ ✓ ✓
10.0	**Logging system**		
10.1	Use the check box for the absolute pressure graph, and verify that the signals are displayed on the graph.	✓	✓
10.2	Use the check box for the differential pressure graph, and verify that the signals are displayed on the graph.	✓	✓
10.3	Use the check box for the flow graph, and verify that the signals are displayed on the graph.	✓	✓
10.4	Use the check box for the PDR graph, and verify that the signals are displayed on the graph.	✓	✓
10.5	Use the check box for the temperature graph, and verify that the signals are displayed on the graph.	✓	✓

10.6	Use the check box for the density graph, and verify that the signals are displayed on the graph.	✓	✓
10.7	Use the check box for the oil % graph, and verify that the signals are displayed on the graph.	✓	✓
10.8	Verify that signal data is logged to Excel.	✓	✓
11.0	**FAT Error list**		
11.1	Critical errors: • No critical errors found.		

11.2	Non-critical errors: • Remove logging status active LED. • Trigging the alarm logging function shall be executed when an alarm is activate, and not by acknowledge button. • Show the tag on the process screen when the corresponding alarm is activated. • Change the override button to alarm on and off. • When the override button is active, and several alarms are triggered simultaneously, only the first alarm will show in the display, not all. Irrelevant, since the override is active. • Implement different frequency sounds for H and HH alarms. • Write alarms to file when the alarms system are disabled. • Choose a lighter purple color I alarm. • Prepare a subVI unit convert block for flow converting for 1-FT-101. • Implement HC tags on the logging graph for differential pressure transmitters. • Set all graphs x-axis to the same time scale by default.	✓ ✓ ✓ ✓ NA ✓ ✓ ✓ ✓ ✓ ✓	

	• Alarm logging file, use comma in the csv file to separate columns. • Check the logging timer, does the logger only log on value change? • New superior logging tab for Phases in the logging system. Logging options moved to superior tab.	✓ ✓ ✓	
12.0	**SAT Error list**		
12.1	Critical errors: • No critical errors found.		
12.2	Non-critical errors: • Logging of alarms to CSV files does not divide the info into separated columns. • 1-PT-101 and 1-PT-301 measurements are 0.5-0.7bar above the correct pressure. The cause may be accuracy issues of the transmitter.		✓ FYI
13.0	**Participants**	**FAT**	**SAT**
13.1	• Magnus Hellem, Stud.techn • Jens Djupvik, Stud.techn • Christian Holden, Associate Professor • Sveinung Johan Ohrem, PhD Candidate	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓

Appendix D

Engineering Numbering System

1 Main Equipment Tag Format

Tag number format for main equipment is shown in Figure 1 (AutoCAD P&ID, 2010).

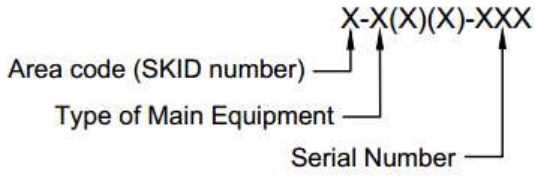


Figure 1: Tag number format for main equipment

An example tag can be 2-HC-100, which gives the area code, type of equipment and the serial number. Table 1 shows some example of typical main equipment for the laboratory (AutoCAD P&ID, 2010).

Component	**Type of Main Equipment**
Hydrocyclone	HC
Compact Flotation Unit	CFU
Pump	P
Tank	T

Table 1: Example of typical main equipment

2 Electrical and Instrumentation Tag Format

Tag number format for electrical and instrumentation is shown equipment Figure 2 (AutoCAD P&ID, 2010).

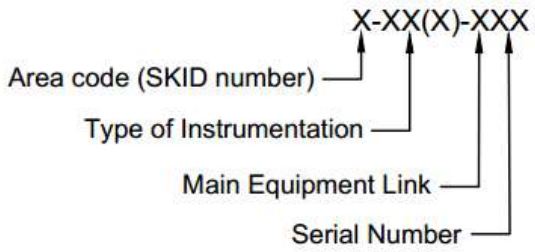


Figure 2: Tag number format for electrical equipment

An example tag can be 2-TT-102. Table 2 shows some example of typical instrumentation for the laboratory (AutoCAD P&ID, 2010).

Component	**Type of Instrumentation**
Temperature Transmitter	TT
Pressure Transmitter	PT
Pressure indicator	PI
Pressure differential transmitter	PDT
Flow meter	FT
Pressure Switch	PS
Oil in water measurement	OIW
Safety valve	SV
Flow Control Valve	FV
Choke Valve	CH
Manual Valve	MV
Junction Box	JB
Sampling point	SP

Table 2: Example of instrumentation equipment

3 Cable Tag Format

Tag number format for cables is shown in Figure 3. The cable tag format is almost identical to the instrumentation format, except for cable type. Table 3 shows some example of cable type for the laboratory.

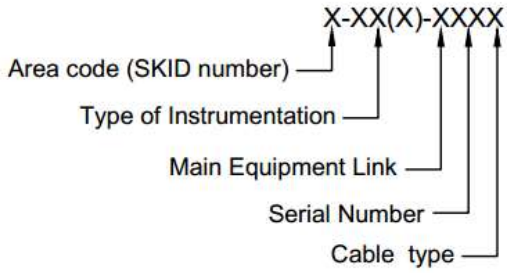


Figure 3: Tag number format for cables

Cable	**Cable type**
Intrinsically Safe	Z
Non Intrinsically Safe	K
Low power	EL
High power	EH

Table 3: Examples of cable types

Appendix E

Marshalling Cabinet Equipment

Table E.1: Marshalling cabinet equipment

Supplier	Type	Description
National Instrument	NI PS-15	Power supply 120 W
National Instrument	cDAQ-9188	NI CompactDAQ 8-Slot Ethernet Chassis
National Instrument	NI9205	32-Ch 200 mV to 10 V, 16-Bit, 250 kS/s Analog Input Module
National Instrument	NI9472	8-Channel 24 V Logic, 100 s, Sourcing Digital Output Module
National Instrument	NI9265	Analog Output, 0-20 mA, 8 Ch Module
Solar Norge	2x1.5 mm^2	Grey Power cable
Schneider	iC60H	Automatic 16 A fuse
Stahl-Syberg	9160/23-11-10	Galvanic isolator for AI circuits
Stahl-Syberg	9165/26-11-11	Galvanic isolator for AO circuits
Norex AS	MTL5525	Galvanic isolator for DO circuits
Norex AS	MTL5512	Galvanic isolator for DI circuits
Phoenix	PT1.5/S-MT BU-3210302	Knife disconnect terminal block
Phoenix	PT1.5/S-MT 3210301	Knife disconnect terminal block
Phoenix	UT4-HESI (5×20)˘3046032	Fuse modular terminal block
Phoenix	UT2.5-3044076	Feed-through terminal block

Appendix F

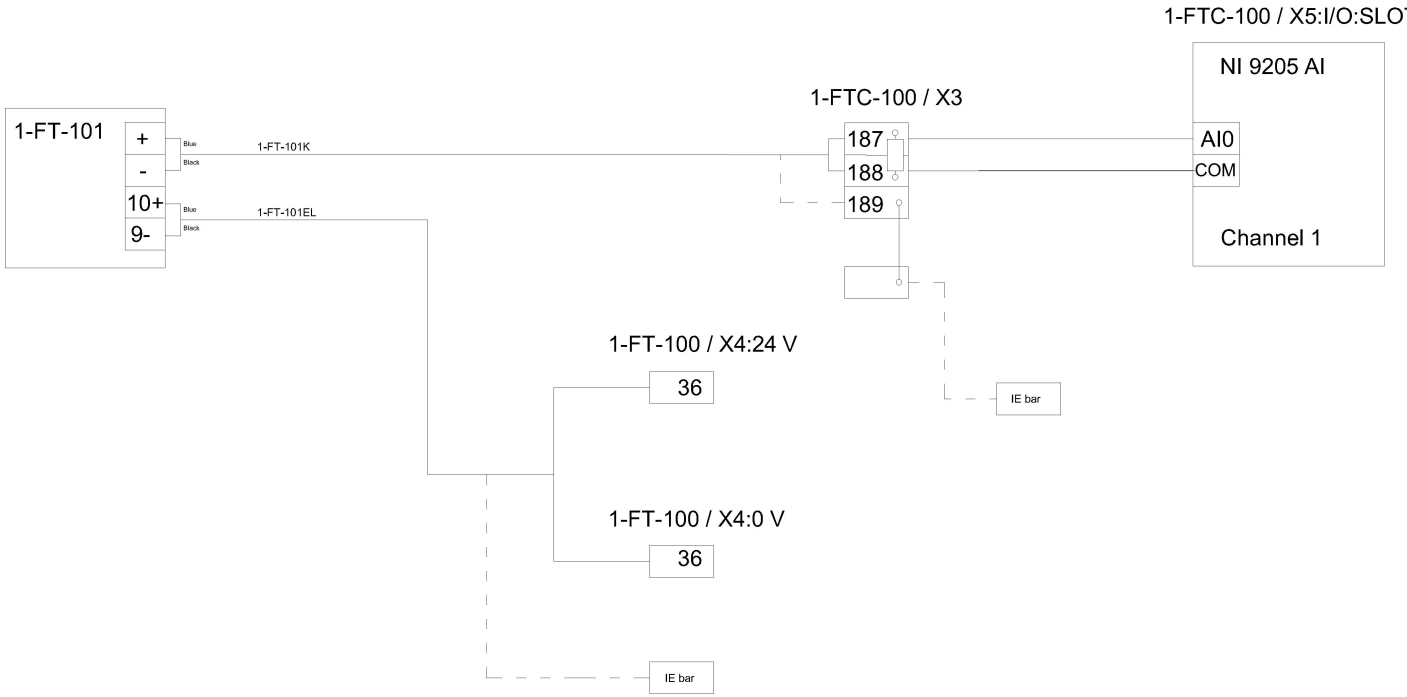
Signal Range Configuration

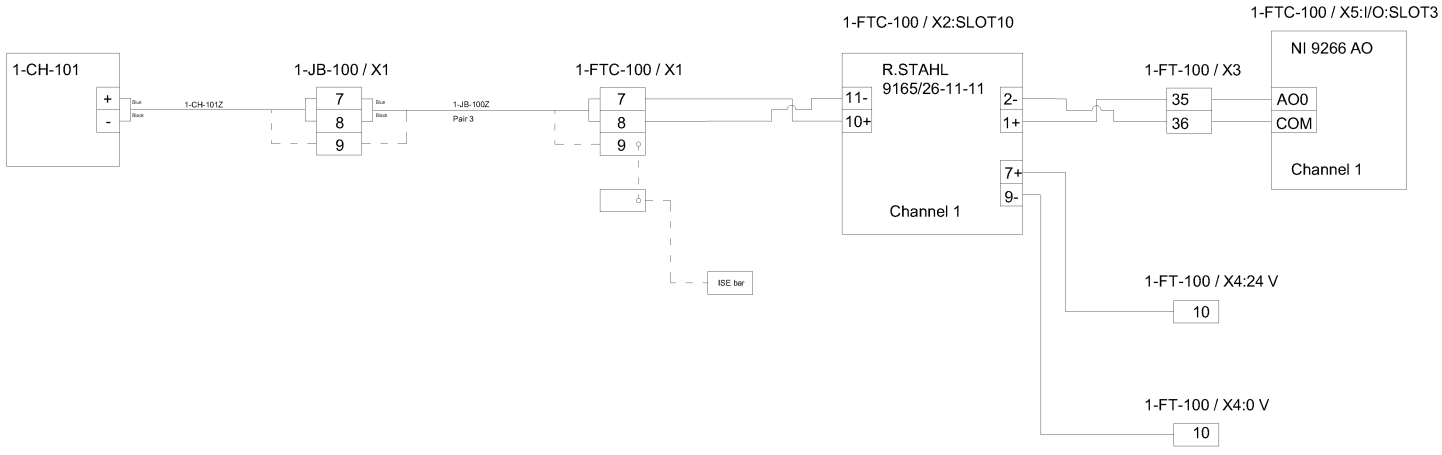
Table F.1: Signal range conversion between input/ouput modules and software.

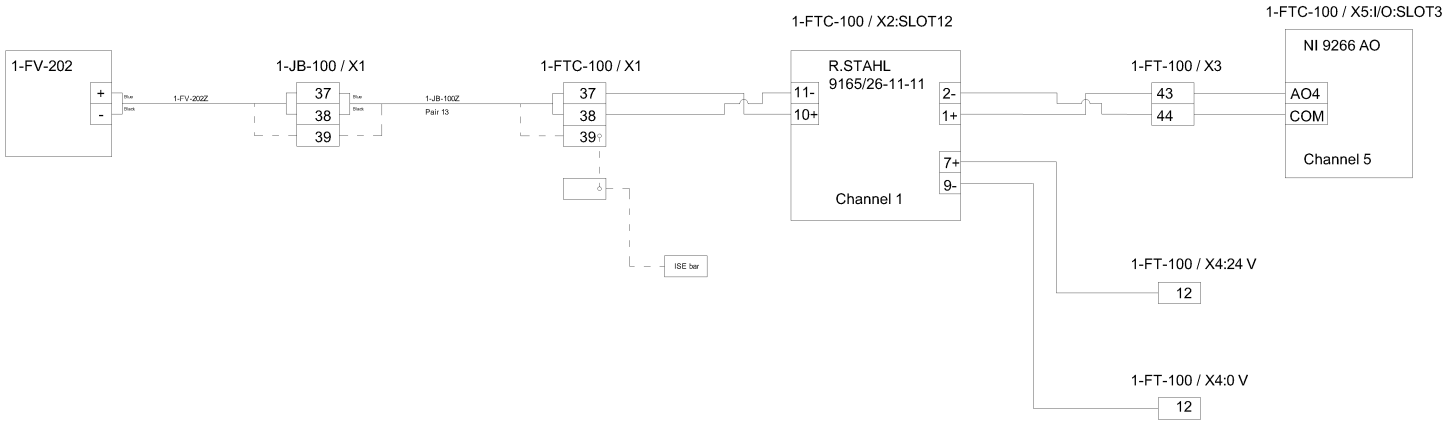
Tag	Signal type	I/O range	Software range
1-CH-101	AO	4-20 mA	0-100 %
1-FT-101	AI	2-10 V	700-1200 kg/m^3
1-FV-202	AO	4-20 mA	0-100 %
1-FV-302	AO	4-20 mA	0-100 %
1-PDT-301	AI	2-10 V	0-70 bar
1-PDT-302	AI	2-10 V	0-70 bar
1-PT-101	AI	2-10 V	0-150 bar
1-PT-301	AI	2-10 V	0-150 bar
1-SV-101	DO	0 or 24 V	0 or 1
1-TT-202	AI	2-10 V	0-50°C
1-TT-302	AI	2-10 V	0-50°C
2-FT-102	AI	2-10 V	0-5 m^3/h
2-FT-202	AI	2-10 V	0-5 m^3/h
2-FV-101	AO	4-20 mA	0-100 %
2-FV-102	AO	4-20 mA	0-100 %
2-FV-201	AO	4-20 mA	0-100 %
2-PDT-101	AI	2-10 V	0-70 bar
2-PDT-102	AI	2-10 V	0-70 bar
2-PDT-201	AI	2-10 V	0-70 bar
2-PDT-202	AI	2-10 V	0-70 bar
2-TT-101	AI	2-10 V	0-50°C
2-TT-102	AI	2-10 V	0-50°C

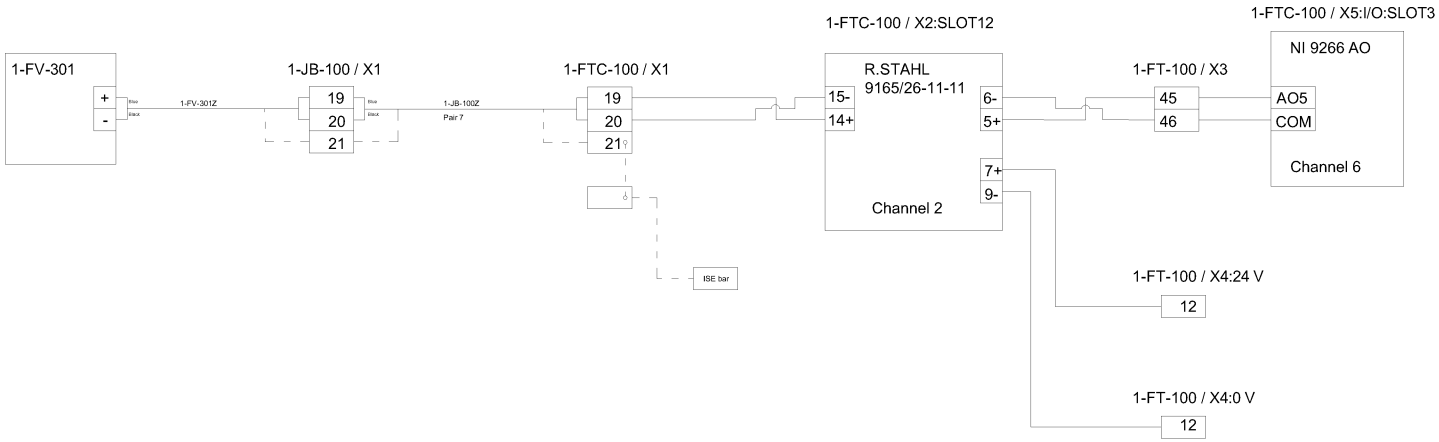
Appendix G

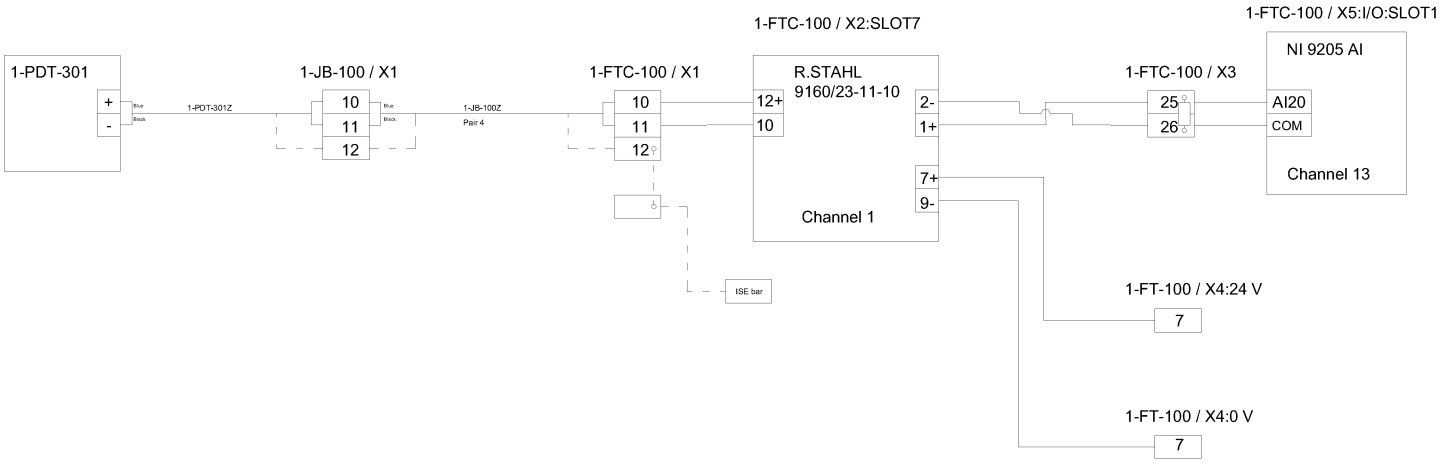
Modified Loop Diagrams

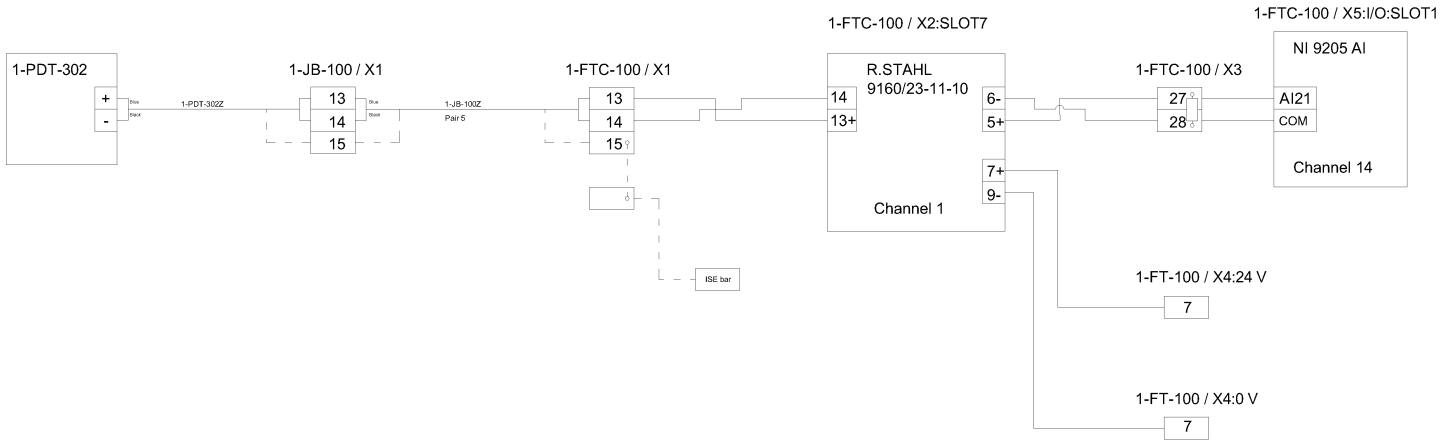

1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI0
COM
Channel 1
1-FTC-100 / X3
187
188
189
1-FT-101
+
-
10+
9-
Blue
Black
1-FT-101K
Blue
Black
1-FT-101EL
1-FT-100 / X4:24 V
36
IE bar
1-FT-100 / X4:0 V
36
IE bar

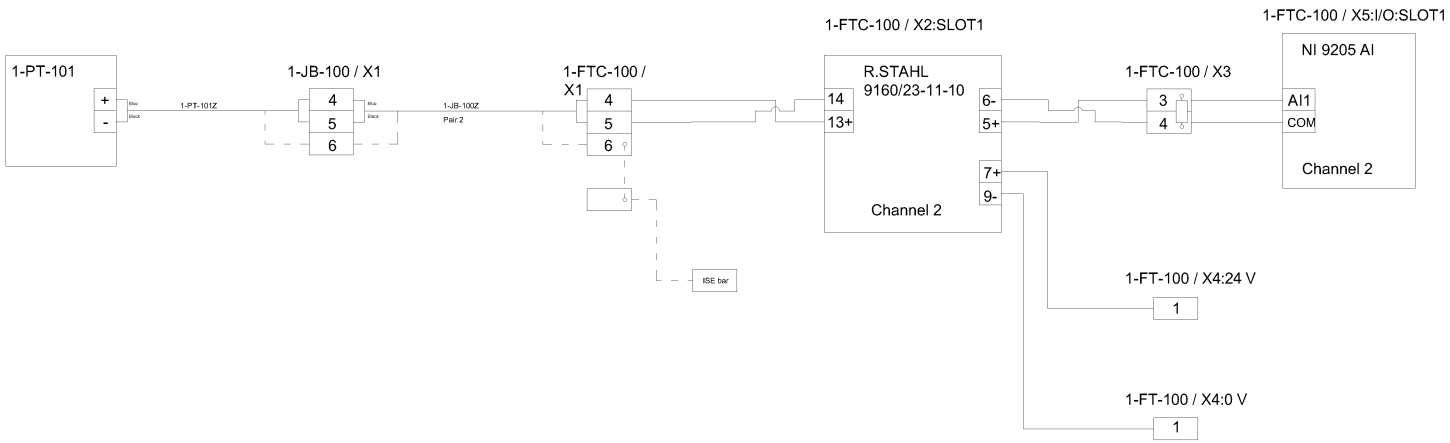

1-CH-101
+
-
Blue
Black
1-CH-101Z
1-JB-100 / X1
7
8
9
Blue
Black
1-JB-100Z
Pair 3
1-FTC-100 / X1
7
8
9
ISE bar
1-FTC-100 / X2:SLOT10
R.STAHL
9165/26-11-11
11-
10+
2-
1+
7+
9-
Channel 1
1-FT-100 / X3
35
36
1-FTC-100 / X5:I/O:SLOT3
NI 9266 AO
AO0
COM
Channel 1
1-FT-100 / X4:24 V
10
1-FT-100 / X4:0 V
10

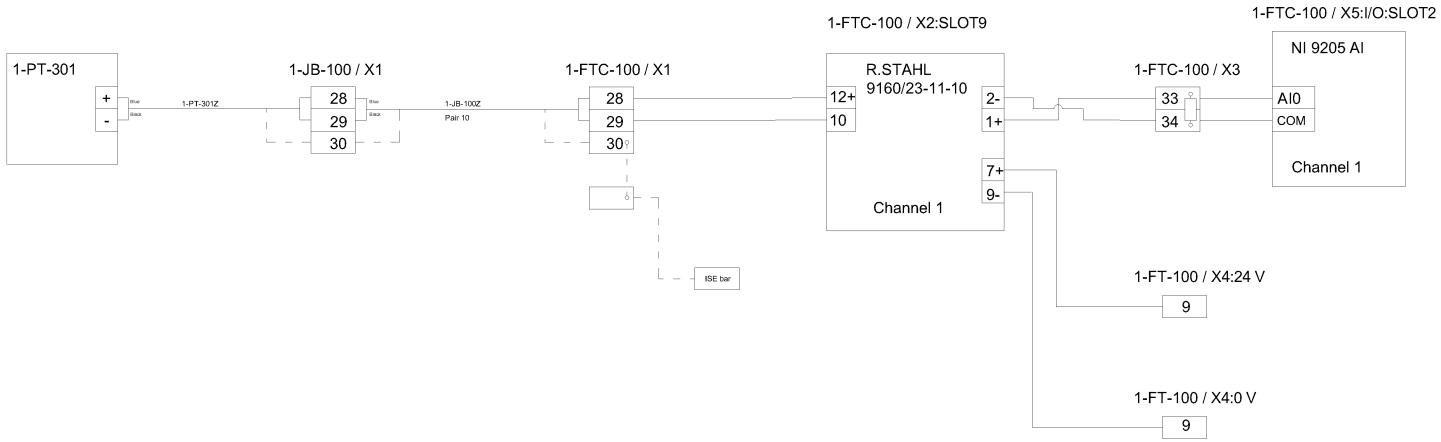

1-FV-202
+
-
Blue
Black
1-FV-202Z
1-JB-100 / X1
37
38
39
Blue
Black
1-JB-100Z
Pair 13
1-FTC-100 / X1
37
38
39
ISE bar
1-FTC-100 / X2:SLOT12
R.STAHL
9165/26-11-11
11-
10+
2-
1+
7+
9-
Channel 1
1-FT-100 / X3
43
44
1-FTC-100 / X5:I/O:SLOT3
NI 9266 AO
AO4
COM
Channel 5
1-FT-100 / X4:24 V
12
1-FT-100 / X4:0 V
12

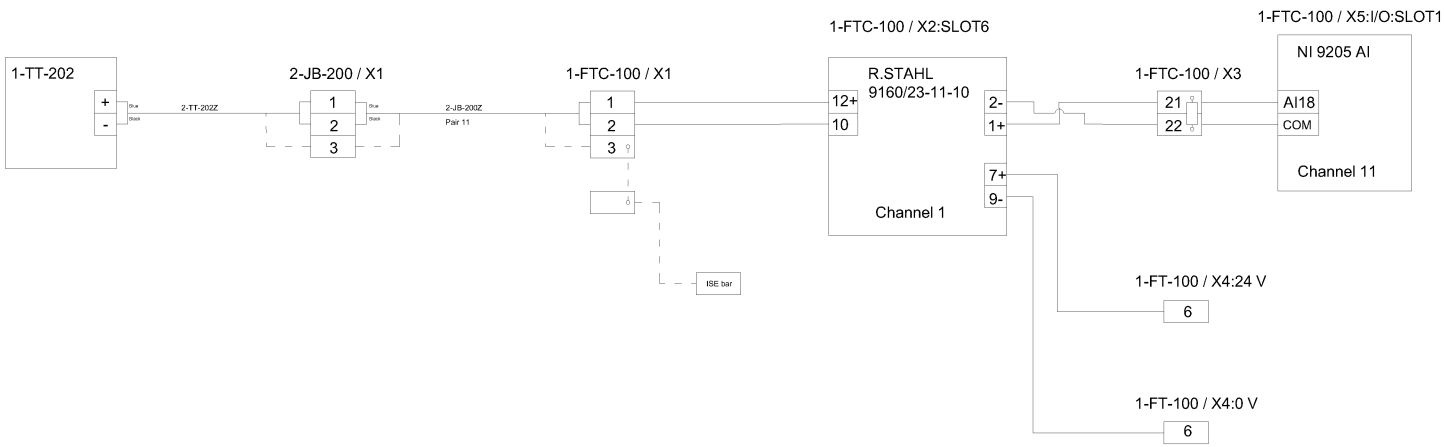

1-FV-301
+
-
Blue
Black
1-FV-301Z
1-JB-100 / X1
19
20
21
Blue
Black
1-JB-100Z
Pair 7
1-FTC-100 / X1
19
20
21
ISE bar
1-FTC-100 / X2:SLOT12
R.STAHL
9165/26-11-11
15-
14+
6-
5+
7+
9-
Channel 2
1-FT-100 / X3
45
46
1-FTC-100 / X5:I/O:SLOT3
NI 9266 AO
AO5
COM
Channel 6
1-FT-100 / X4:24 V
12
1-FT-100 / X4:0 V
12

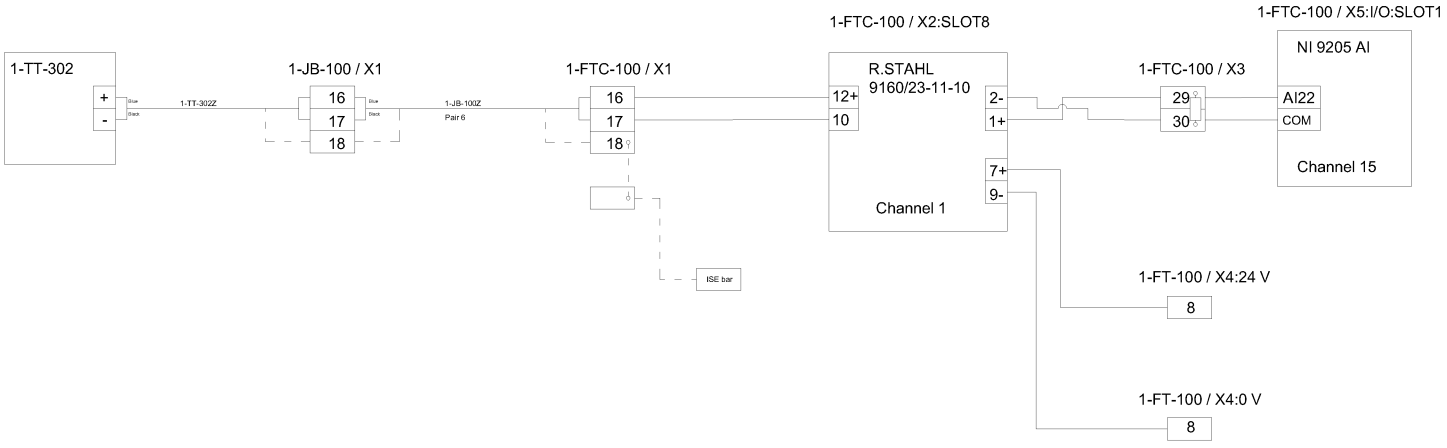

1-PDT-301
+
-
Blue
Black
1-PDT-301Z
1-JB-100 / X1
10
11
12
Blue
Black
1-JB-100Z
Pair 4
1-FTC-100 / X1
10
11
12
ISE bar
1-FTC-100 / X2:SLOT7
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
25
26
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI20
COM
Channel 13
1-FT-100 / X4:24 V
7
1-FT-100 / X4:0 V
7

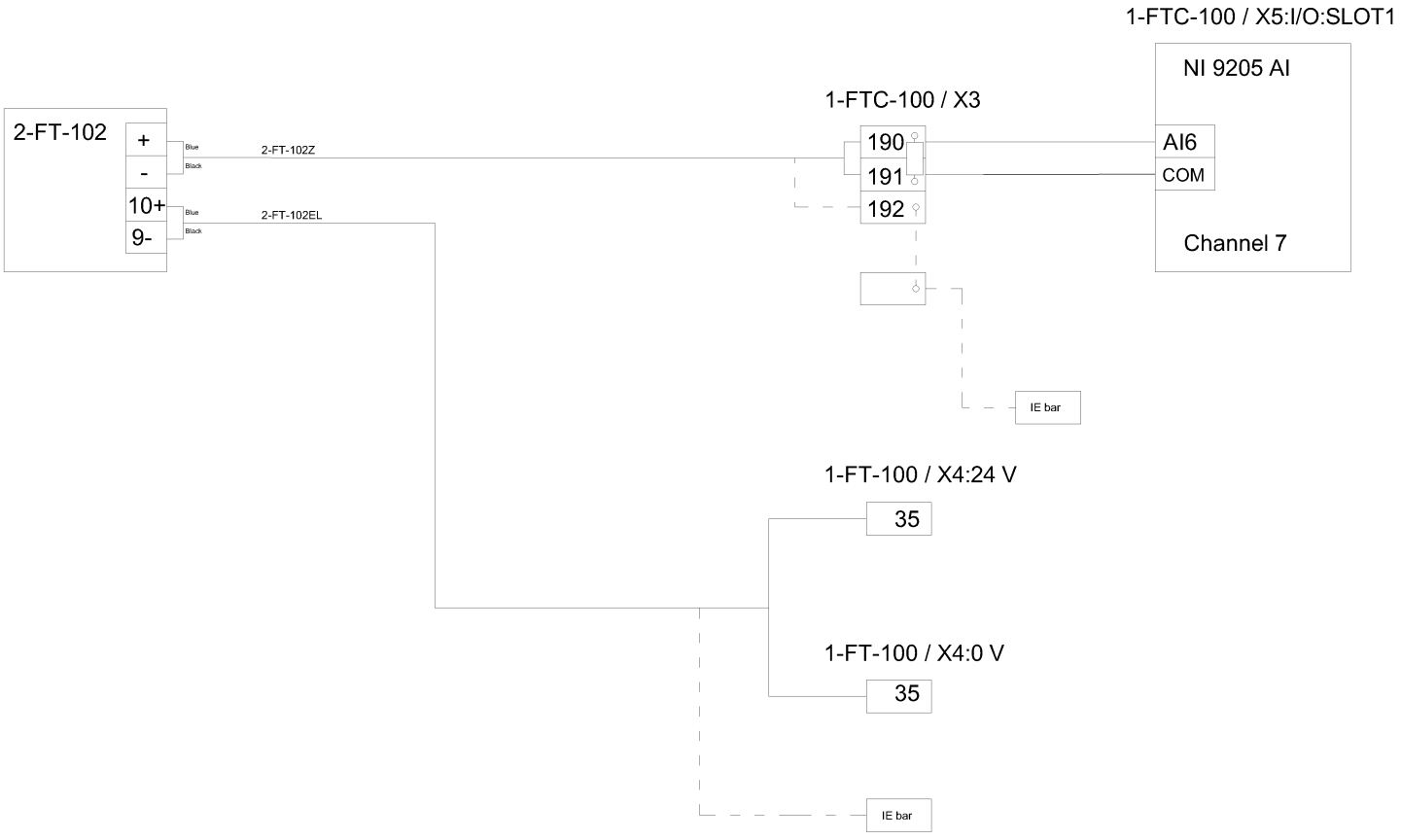

1-PDT-302
+
-
Blue
Black
1-PDT-302Z
1-JB-100 / X1
13
14
15
Blue
Black
1-JB-100Z
Pair 5
1-FTC-100 / X1
13
14
15
ISE bar
1-FTC-100 / X2:SLOT7
R.STAHL
9160/23-11-10
14
13+
6-
5+
7+
9-
Channel 1
1-FTC-100 / X3
27
28
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI21
COM
Channel 14
1-FT-100 / X4:24 V
7
1-FT-100 / X4:0 V
7

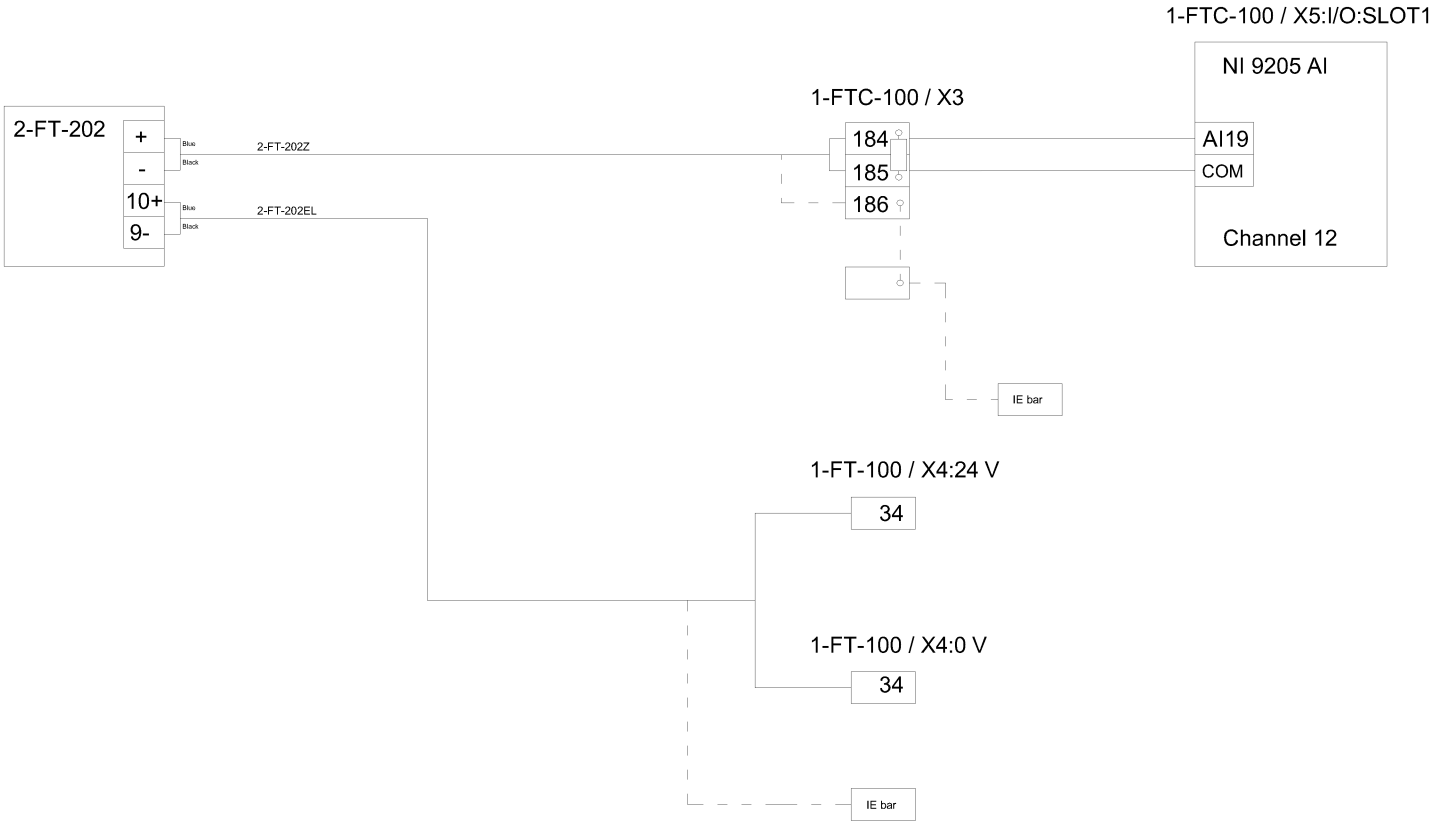

1-PT-101
+
-
White
Black
1-PT-101Z
1-JB-100 / X1
4
5
6
Blue
Black
1-JB-100Z
Pair 2
1-FTC-100 / X1
4
5
6
ISE bar
1-FTC-100 / X2:SLOT1
R.STAHL 9160/23-11-10
14
13+
6-
5+
7+
9-
Channel 2
1-FTC-100 / X3
3
4
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI1
COM
Channel 2
1-FT-100 / X4:24 V
1
1-FT-100 / X4:0 V
1

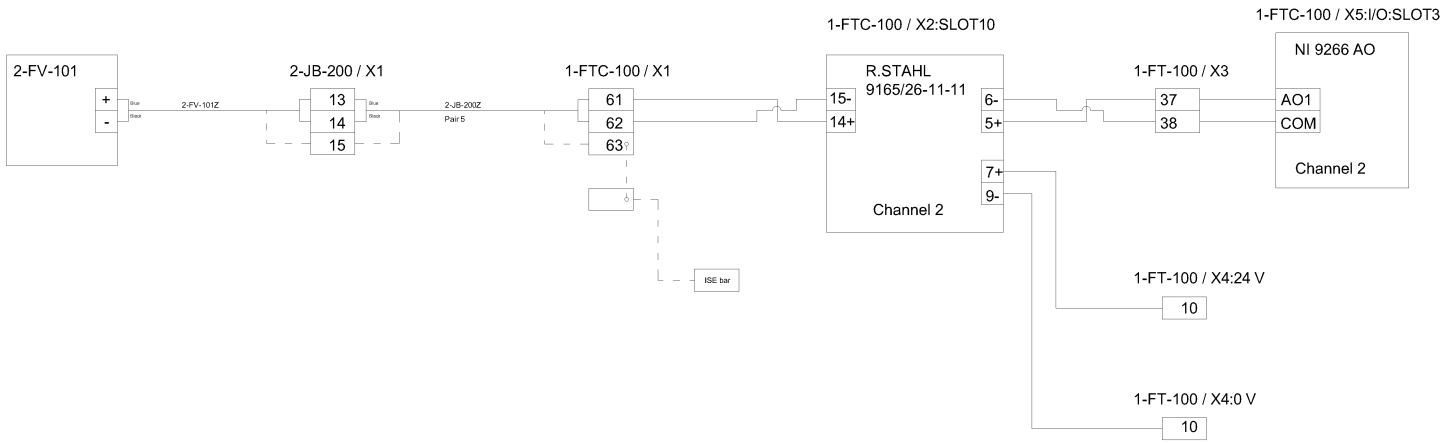

1-PT-301
+
-
Blue
Black
1-PT-301Z
1-JB-100 / X1
28
29
30
Blue
Black
1-JB-100Z
Pair 10
1-FTC-100 / X1
28
29
30
ISE bar
1-FTC-100 / X2:SLOT9
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
33
34
1-FTC-100 / X5:I/O:SLOT2
NI 9205 AI
AI0
COM
Channel 1
1-FT-100 / X4:24 V
9
1-FT-100 / X4:0 V
9

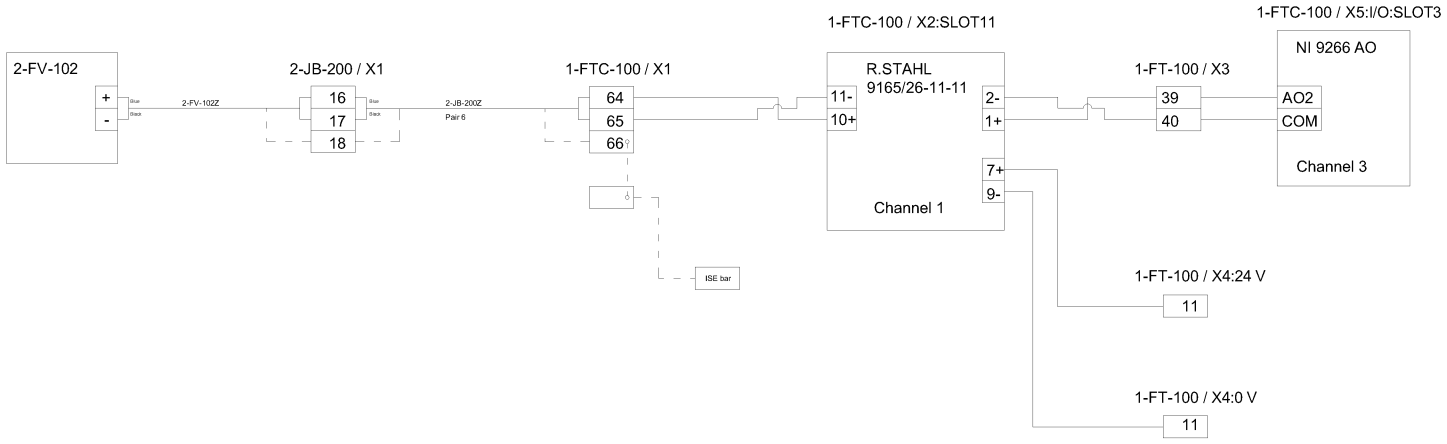

1-TT-202
+
-
Blue
Black
2-TT-202Z
2-JB-200 / X1
1
2
3
Blue
Black
2-JB-200Z
Pair 11
1-FTC-100 / X1
1
2
3
ISE bar
1-FTC-100 / X2:SLOT6
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
21
22
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI18
COM
Channel 11
1-FT-100 / X4:24 V
6
1-FT-100 / X4:0 V
6

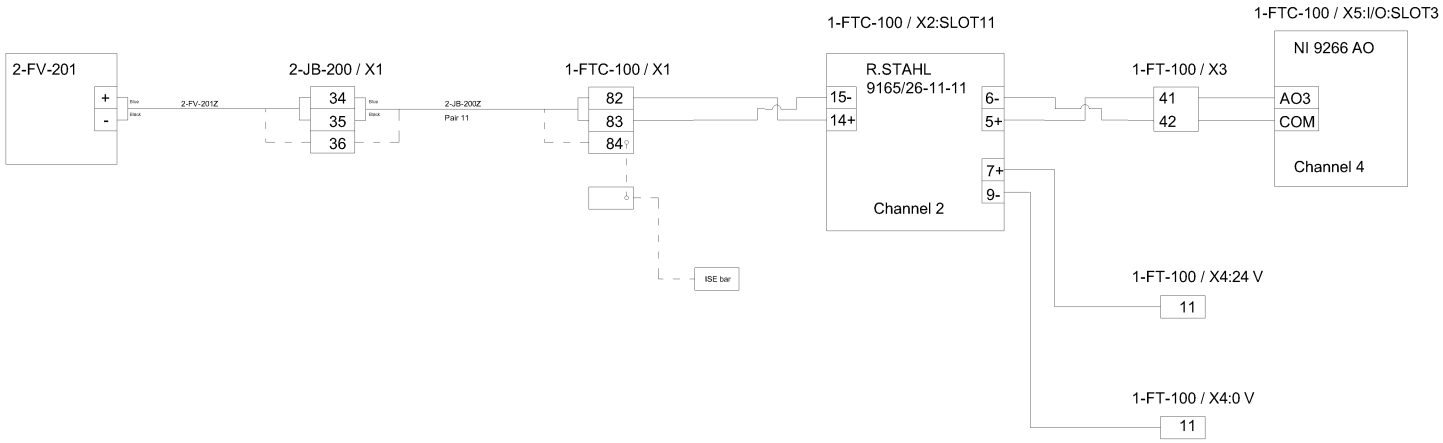

1-TT-302
+
-
Blue
Black
1-TT-302Z
1-JB-100 / X1
16
17
18
Blue
Black
1-JB-100Z
Pair 6
1-FTC-100 / X1
16
17
18
ISE bar
1-FTC-100 / X2:SLOT8
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
29
30
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI22
COM
Channel 15
1-FT-100 / X4:24 V
8
1-FT-100 / X4:0 V
8

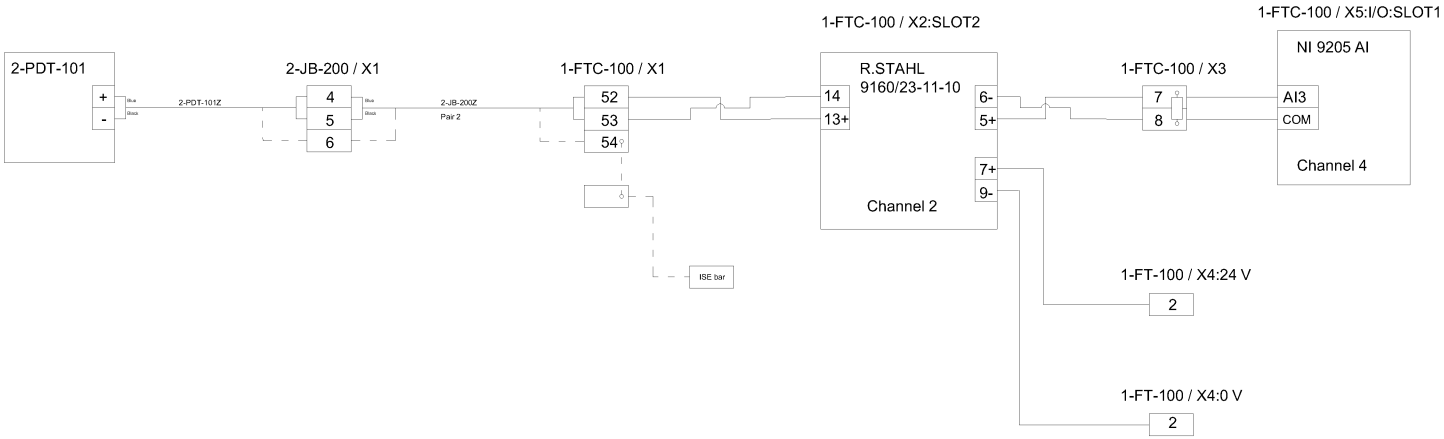

1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI6
COM
Channel 7
1-FTC-100 / X3
190
191
192
2-FT-102
+
-
10+
9-
Blue
Black
2-FT-102Z
Blue
Black
2-FT-102EL
IE bar
1-FT-100 / X4:24 V
35
1-FT-100 / X4:0 V
35
IE bar

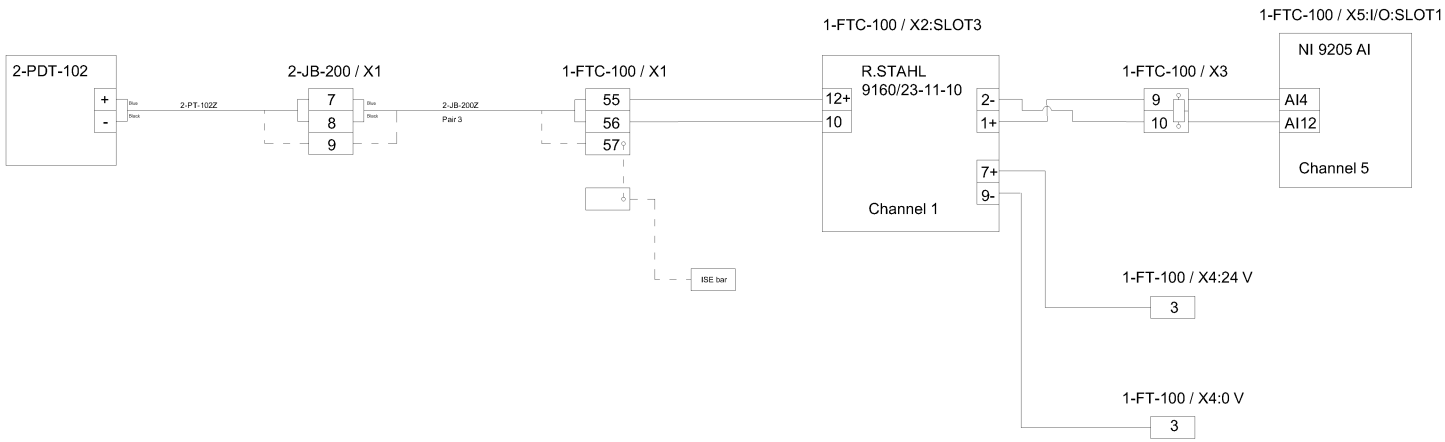

1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI19
COM
Channel 12
1-FTC-100 / X3
184
185
186
2-FT-202
+
-
10+
9-
Blue
Black
2-FT-202Z
Blue
Black
2-FT-202EL
IE bar
1-FT-100 / X4:24 V
34
1-FT-100 / X4:0 V
34
IE bar

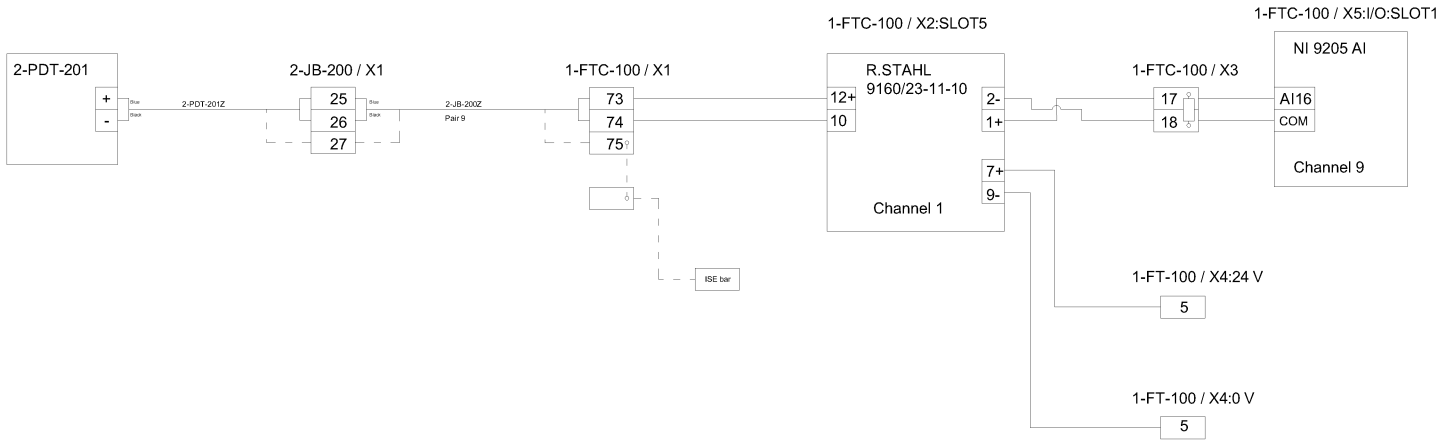

2-FV-101
+
-
Blue
Black
2-FV-101Z
2-JB-200 / X1
13
14
15
Blue
Black
2-JB-200Z
Pair 5
1-FTC-100 / X1
61
62
63
ISE bar
1-FTC-100 / X2:SLOT10
R.STAHL
9165/26-11-11
15-
14+
6-
5+
7+
9-
Channel 2
1-FT-100 / X3
37
38
1-FTC-100 / X5:I/O:SLOT3
NI 9266 AO
AO1
COM
Channel 2
1-FT-100 / X4:24 V
10
1-FT-100 / X4:0 V
10

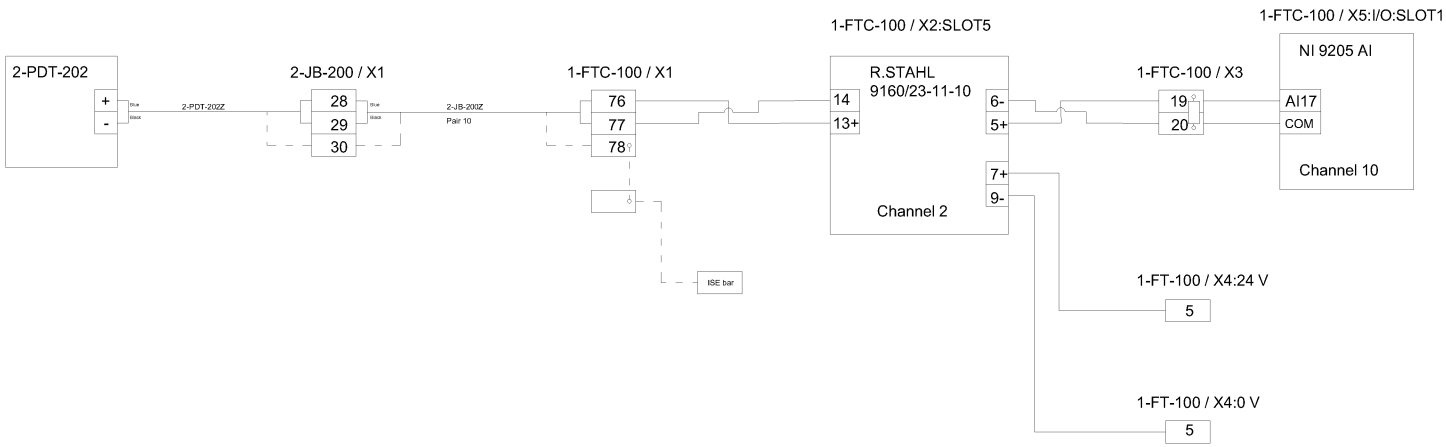

2-FV-102
+
-
Blue
Black
2-FV-102Z
2-JB-200 / X1
16
17
18
Blue
Black
2-JB-200Z
Pair 6
1-FTC-100 / X1
64
65
66
ISE bar
1-FTC-100 / X2:SLOT11
R.STAHL
9165/26-11-11
11-
10+
2-
1+
7+
9-
Channel 1
1-FT-100 / X3
39
40
1-FTC-100 / X5:I/O:SLOT3
NI 9266 AO
AO2
COM
Channel 3
1-FT-100 / X4:24 V
11
1-FT-100 / X4:0 V
11

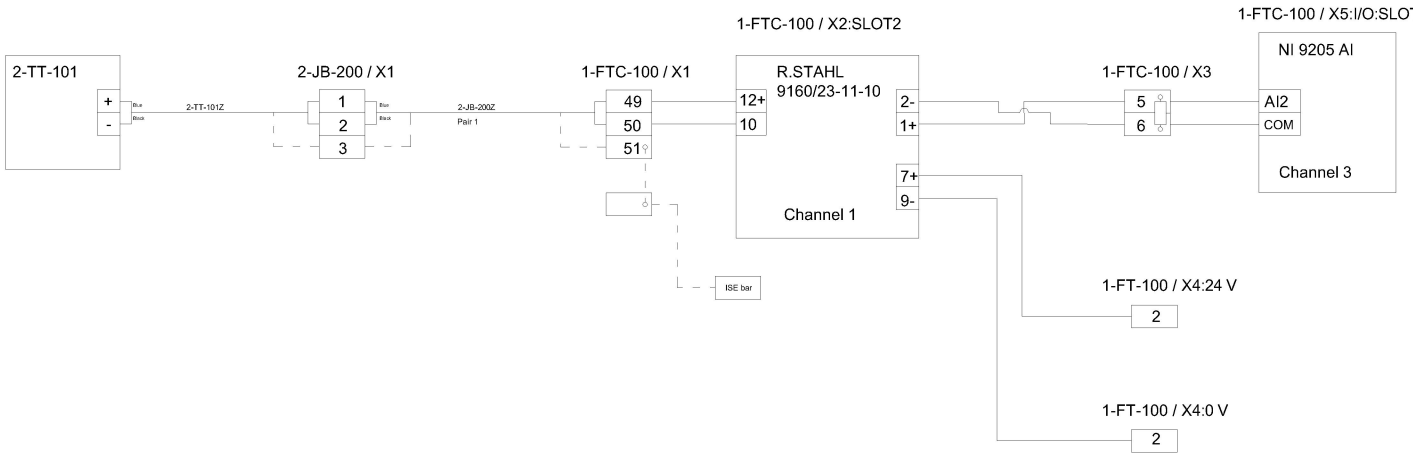

2-FV-201
+
-
2-FV-201Z
2-JB-200 / X1
34
35
36
2-JB-200Z
Pair 11
1-FTC-100 / X1
82
83
84
ISE bar
1-FTC-100 / X2:SLOT11
R.STAHL
9165/26-11-11
15-
14+
6-
5+
7+
9-
Channel 2
1-FT-100 / X3
41
42
1-FTC-100 / X5:I/O:SLOT3
NI 9266 AO
AO3
COM
Channel 4
1-FT-100 / X4:24 V
11
1-FT-100 / X4:0 V
11

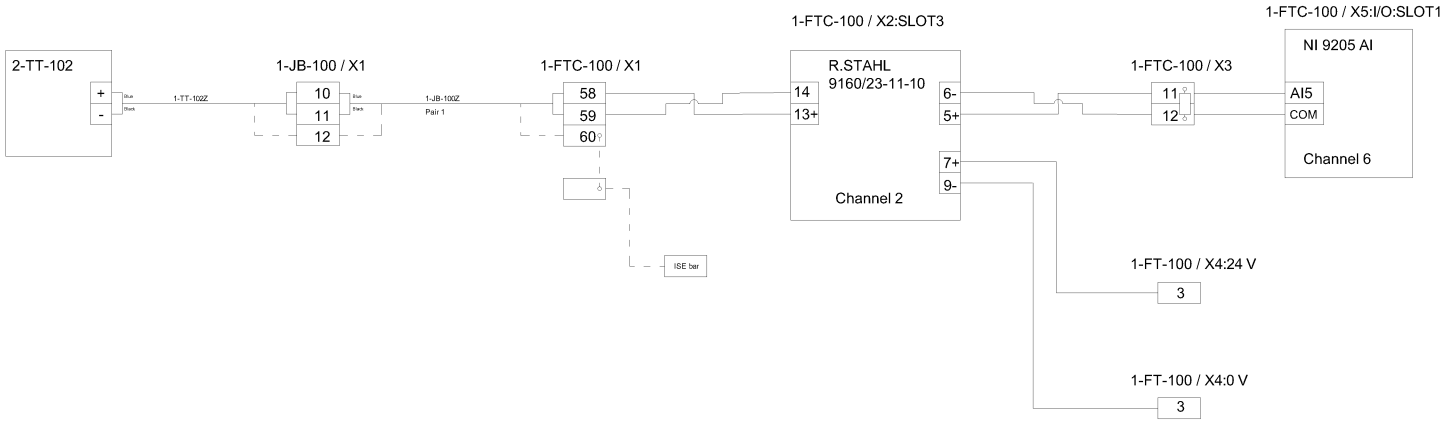

2-PDT-101
+
-
2-PDT-101Z
2-JB-200 / X1
4
5
6
2-JB-200Z
Pair 2
1-FTC-100 / X1
52
53
54
ISE bar
1-FTC-100 / X2:SLOT2
R.STAHL
9160/23-11-10
14
13+
6-
5+
7+
9-
Channel 2
1-FTC-100 / X3
7
8
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI3
COM
Channel 4
1-FT-100 / X4:24 V
2
1-FT-100 / X4:0 V
2

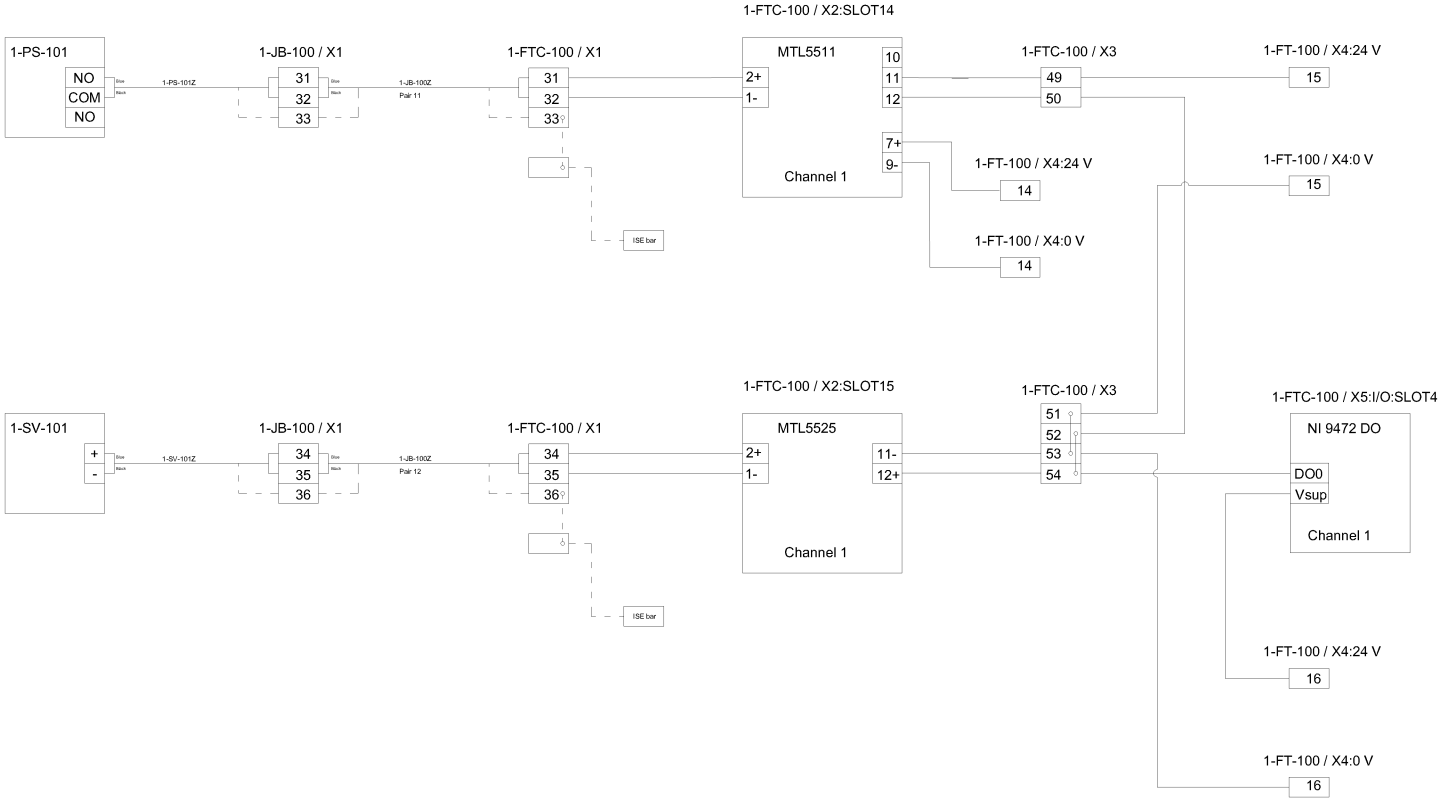

2-PDT-102
+
-
Blue
Black
2-PT-102Z
2-JB-200 / X1
7
8
9
Blue
Black
2-JB-200Z
Pair 3
1-FTC-100 / X1
55
56
57
ISE bar
1-FTC-100 / X2:SLOT3
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
9
10
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI4
AI12
Channel 5
1-FT-100 / X4:24 V
3
1-FT-100 / X4:0 V
3


2-PDT-201
+
-
Blue
Black
2-PDT-201Z
2-JB-200 / X1
25
26
27
Blue
Black
2-JB-200Z
Pair 9
1-FTC-100 / X1
73
74
75
ISE bar
1-FTC-100 / X2:SLOT5
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
17
18
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI16
COM
Channel 9
1-FT-100 / X4:24 V
5
1-FT-100 / X4:0 V
5


2-PDT-202
+
-
blue
black
2-PDT-202Z
2-JB-200 / X1
28
29
30
blue
black
2-JB-200Z
Pair 10
1-FTC-100 / X1
76
77
78
ISE bar
1-FTC-100 / X2:SLOT5
R.STAHL
9160/23-11-10
14
13+
6-
5+
7+
9-
Channel 2
1-FTC-100 / X3
19
20
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI17
COM
Channel 10
1-FT-100 / X4:24 V
5
1-FT-100 / X4:0 V
5


2-TT-101
+
-
Blue
Black
2-TT-101Z
2-JB-200 / X1
1
2
3
Blue
Black
2-JB-200Z
Pair 1
1-FTC-100 / X1
49
50
51
ISE bar
1-FTC-100 / X2:SLOT2
R.STAHL
9160/23-11-10
12+
10
2-
1+
7+
9-
Channel 1
1-FTC-100 / X3
5
6
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI2
COM
Channel 3
1-FT-100 / X4:24 V
2
1-FT-100 / X4:0 V
2


2-TT-102
+
-
Blue
Black
1-TT-102Z
1-JB-100 / X1
10
11
12
Blue
Black
1-JB-100Z
Pair 1
1-FTC-100 / X1
58
59
60
ISE bar
1-FTC-100 / X2:SLOT3
R.STAHL
9160/23-11-10
14
13+
6-
5+
7+
9-
Channel 2
1-FTC-100 / X3
11
12
1-FTC-100 / X5:I/O:SLOT1
NI 9205 AI
AI5
COM
Channel 6
1-FT-100 / X4:24 V
3
1-FT-100 / X4:0 V
3


1-PS-101
NO
COM
NO
1-PS-101Z
1-JB-100 / X1
31
32
33
1-JB-100Z
Pair 11
1-FTC-100 / X1
31
32
33
ISE bar
1-FTC-100 / X2:SLOT14
MTL5511
2+
1-
10
11
12
7+
9-
Channel 1
1-FTC-100 / X3
49
50
1-FT-100 / X4:24 V
15
1-FT-100 / X4:24 V
14
1-FT-100 / X4:0 V
15
1-FT-100 / X4:0 V
14
1-SV-101
+
-
1-SV-101Z
1-JB-100 / X1
34
35
36
1-JB-100Z
Pair 12
1-FTC-100 / X1
34
35
36
ISE bar
1-FTC-100 / X2:SLOT15
MTL5525
2+
1-
11-
12+
Channel 1
1-FTC-100 / X3
51
52
53
54
1-FTC-100 / X5:I/O:SLOT4
NI 9472 DO
DO0
Vsup
Channel 1
1-FT-100 / X4:24 V
16
1-FT-100 / X4:0 V
16

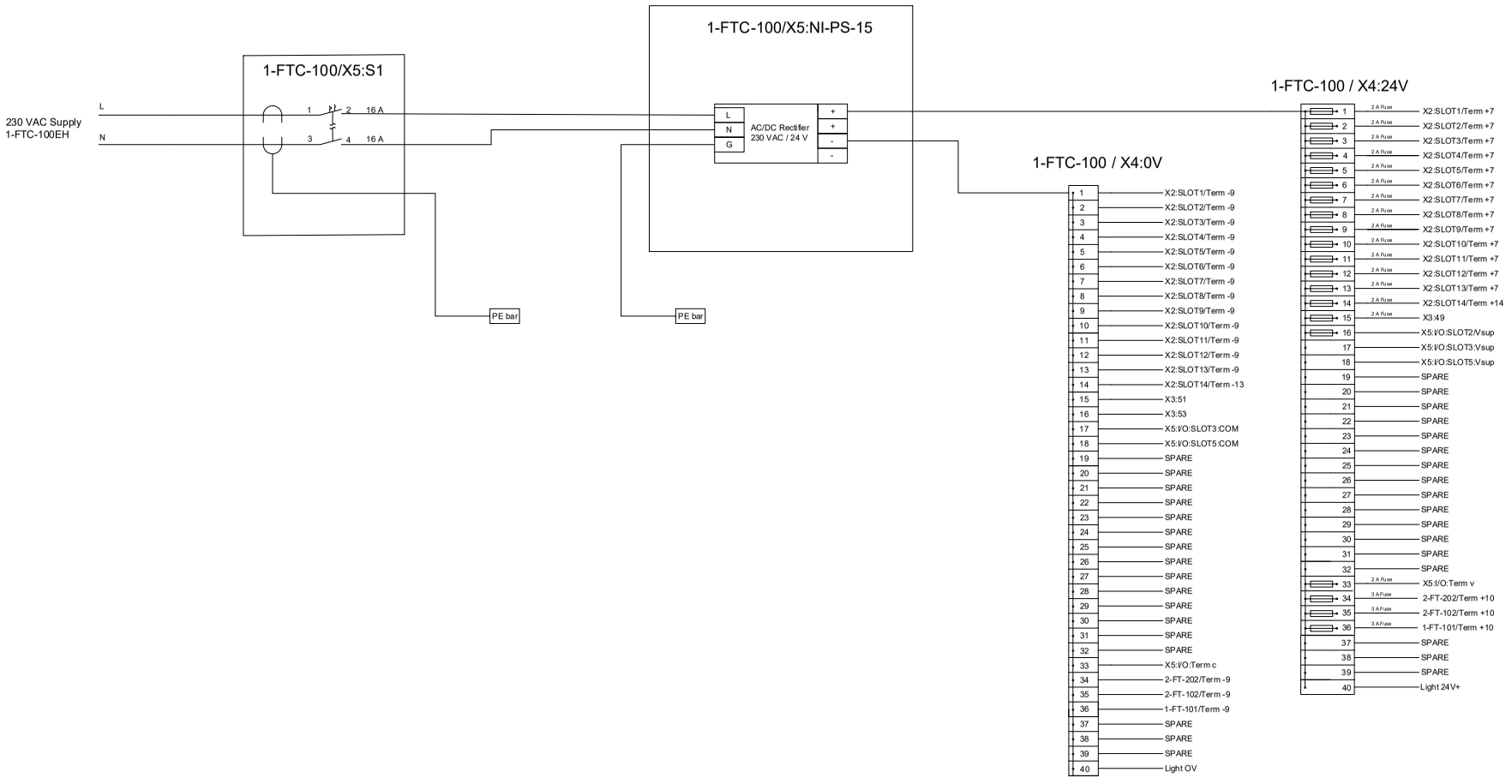
Appendix H

Modified Signal List

Tag	Description	Cable 1 to JB	Termination JB	Term X1 in FTC	Term X2:GI in FTC	Type of barriere	Term X3/X4 in FTC	I/O type	Term I/O Rack
1-CH-101	Choke Vale on Emergency Line	1-JBZ-100	X1:7-9	X1:7-9	X2:GI:SLOT10: 10 and 11	R.STAHL 9165/26-11-10	X3:35-36	AO	X5:I/O:SLOT3:AI0 and COM
1-FT-101	Corliorlis Flow and Density input to HC100	1-FTC-100	NA	NA	NA	NA	X3:187-189	AI	X5:I/O:SLOT1:AI0 and COM
1-FV-202	Flow Control Valve w/IP converter water outlet HC200	1-JBZ-100	X1:37-39	X1:37-39	X2:GI:SLOT12: 10 and 11	R.STAHL 9165/26-11-10	X3:43-44	AO	X5:I/O:SLOT3:AI4 and COM
1-FV-301	Flow Control Valve w/IP converter oil outlet HC300	1-JBZ-100	X1:19-21	X1:19-21	X2:GI:SLOT12: 14 and 15	R.STAHL 9165/26-11-10	X3:45-46	AO	X5:I/O:SLOT3:AI5 and COM
1-FV-302	Flow Control Valve w/IP converter water outlet HC300	1-JBZ-100	X1:22-24	X1:22-24	X2:GI:SLOT13: 14 and 15	R.STAHL 9165/26-11-10	X3:47-48	AO	X5:I/O:SLOT3:AI6 and COM
1-OIW-301	Oil in Water Measurment water outlet HC100	1-JBZ-100	X1:25-27	X1:25-27	X2:GI:SLOT8: 13 and 14	R. STAHL 9160/23-11-10	X3:31-32	AI	X5:I/O:SLOT1:AI23 and COM
1-PDT-301	Differential Pressure Inlet and oil outlet HC300	1-JBZ-100	X1:10-12	X1:10-12	X2:GI:SLOT7: 10 and 12	R. STAHL 9160/23-11-10	X3:25-26	AI	X5:I/O:SLOT1:AI20 and COM
1-PDT-302	Differential Pressure Inlet and water outlet HC300	1-JBZ-100	X1:13-15	X1:13-15	X2:GI:SLOT7: 13 and 14	R. STAHL 9160/23-11-10	X3:27-28	AI	X5:I/O:SLOT1:AI21 and COM
1-PS-101	Safety Pressure Switch	1-JBZ-100	X1:31-33	X1:31-33	X2:GI:SLOT14:1 and 2	MTL5511	X3:49-50	NA	
1-PT-101	Absolute Pressure Inlet HC100	1-JBZ-100	X1:4-6	X1:4-6	X2:GI:SLOT1: 13 and 14	R. STAHL 9160/23-11-10	X3:3-4	AI	X5:I/O:SLOT1:AI1 and COM
1-PT-301	Absolute Pressure Oil outlet HC300	1-JBZ-100	X1:28-30	X1:28-30	X2:GI:SLOT9: 10 and 12	R. STAHL 9160/23-11-10	X3:33-34	AI	X5:I/O:SLOT2:AI0 and COM
1-SV-101	Safety Ball Valve w/Pneumatic Actuator	1-JBZ-100	X1:34-36	X1:34-36	X2:GI:SLOT15:1 and 2	MTL5525	X3:53-54	DO	X5:I/O:SLOT4:DO0 and COM
1-TT-202	Temperature Transmitter water outlet HC200	1-JBZ-200	X1:1-3	X1:1-3	X2:GI:SLOT6: 10 and 12	R. STAHL 9160/23-11-10	X3:21-22	AI	X5:I/O:SLOT1:AI18 and COM
1-TT-302	Temperature Transmitter water outlet HC300	1-JBZ-100	X1:16-18	X1:16-18	X2:GI:SLOT8: 10 and 12	R. STAHL 9160/23-11-10	X3:29-30	AI	X5:I/O:SLOT1:AI22 and COM
2-FT-102	Electromagnetic Flowmeter water outlet HC100	1-FTC-100	NA	NA	NA	NA	X3:190-192	AI	X5:I/O:SLOT1:AI6 and COM
2-FT-202	Electromagnetic Flowmeter water outlet HC200	1-FTC-100	NA	NA	NA	NA	X3:184-186	AI	X5:I/O:SLOT1:AI19 and COM
2-FV-101	Flow Control Valve w/IP converter oil outlet HC100	2-JBZ-200	X1:13-15	X1:61-63	X2:GI:SLOT10: 14 and 15	R.STAHL 9165/26-11-10	X3:37-38	AO	X5:I/O:SLOT3:AI1 and COM
2-FV-102	Flow Control Valve w/IP converter water outlet HC100	2-JBZ-200	X1:16-18	X1:64-66	X2:GI:SLOT11: 10 and 11	R.STAHL 9165/26-11-10	X3:39-40	AO	X5:I/O:SLOT3:AI2 and COM
2-FV-201	Flow Control Valve w/IP converter oil outlet HC200	2-JBZ-200	X1:34-36	X1:82-84	X2:GI:SLOT11: 14 and 15	R.STAHL 9165/26-11-10	X3:41-42	AO	X5:I/O:SLOT3:AI3 and COM
2-OIW-101	Oil in Water Measurment water outlet HC100	2-JBZ-200	X1:22-24	X1:70-72	X2:GI:SLOT4: 13 and 14	R. STAHL 9160/23-11-10	X3:15-16	AI	X5:I/O:SLOT1:AI7 and COM
2-PDT-101	Differential Pressure Inlet and oil outlet HC100	2-JBZ-200	X1:4-6	X1:52-54	X2:GI:SLOT2: 13 and 14	R. STAHL 9160/23-11-10	X3:7-8	AI	X5:I/O:SLOT1:AI3 and COM
2-PDT-102	Differential Pressure Inlet and water outlet HC100	2-JBZ-200	X1:7-9	X1:55-57	X2:GI:SLOT3: 10 and 12	R. STAHL 9160/23-11-10	X3:9-10	AI	X5:I/O:SLOT1:AI4 and COM
2-PDT-201	Differential Pressure Inlet and oil outlet HC200	2-JBZ-200	X1:25-27	X1:73-75	X2:GI:SLOT5: 10 and 12	R. STAHL 9160/23-11-10	X3:17-18	AI	X5:I/O:SLOT1:AI16 and COM
2-PDT-202	Differential Pressure Inlet and water outlet HC200	2-JBZ-200	X1:28-30	X1:76-78	X2:GI:SLOT5: 13 and 14	R. STAHL 9160/23-11-10	X3:19-20	AI	X5:I/O:SLOT1:AI17 and COM
2-TT-101	Temperature input to HC100	2-JBZ-200	X1:1-3	X1:49-51	X2:GI:SLOT2: 10 and 12	R. STAHL 9160/23-11-10	X3:5-6	AI	X5:I/O:SLOT1:AI2 and COM
2-TT-102	Temperature Transmitter water outlet HC100	2-JBZ-200	X1:10-12	X1:58-60	X2:GI:SLOT3: 13 and 14	R. STAHL 9160/23-11-10	X3:11-12	AI	X5:I/O:SLOT1:AI5 and COM
NA	NA	1-FTC-100	NA	NA	NA	NA	1-FTC-100/X5:S1	NA	NA
NA	NA	1-FT-101	NA	NA	NA	NA	1-FTC-100/X4:24V/0V:36	NA	NA
NA	NA	2-FT-102	NA	NA	NA	NA	1-FTC-100/X4:24V/0V:35	NA	NA
NA	NA	2-FT-202	NA	NA	NA	NA	1-FTC-100/X4:24V/0V:34	NA	NA

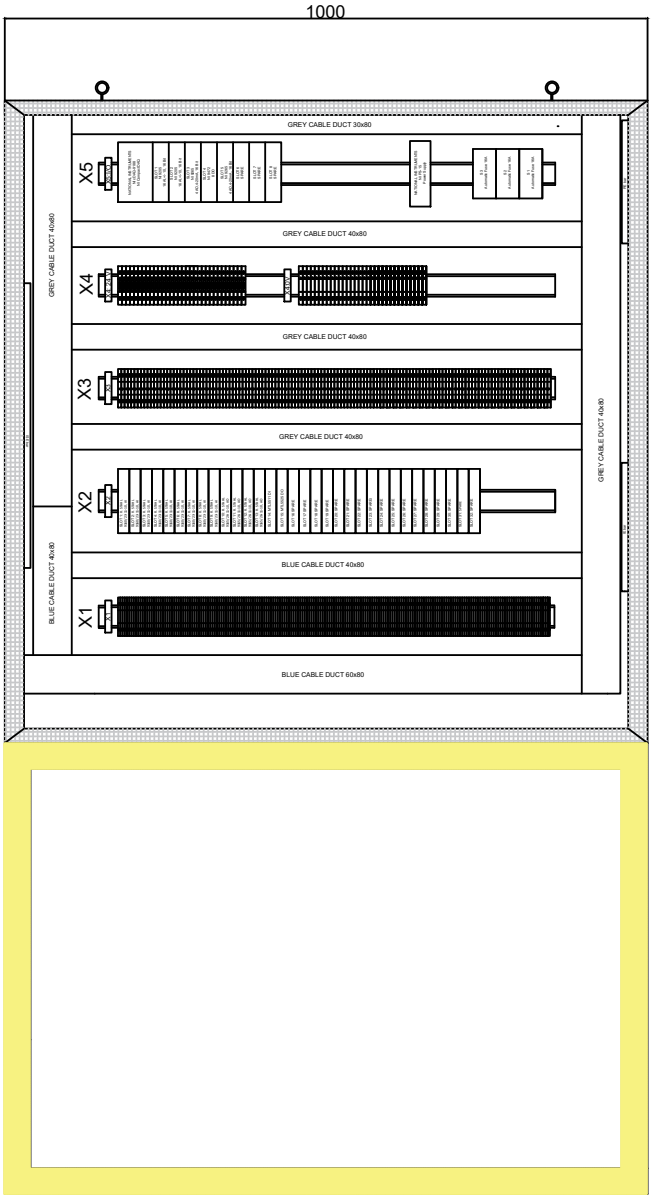
Appendix I

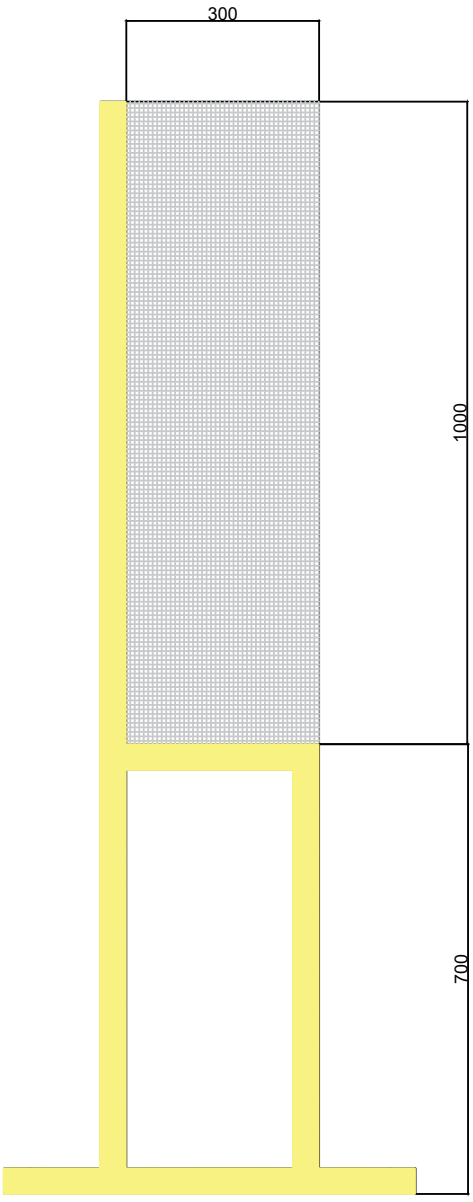
24 V Power Distribution


1-FTC-100/X5:S1
1-FTC-100/X5:NI-PS-15
230 VAC Supply
1-FTC-100EH
L
N
1
2
16 A
3
4
16 A
L
N
G
AC/DC Rectifier
230 VAC / 24 V
+
+
-
-
PE bar
PE bar
1-FTC-100 / X4:0V
1 X2:SLOT1/Term -9
2 X2:SLOT2/Term -9
3 X2:SLOT3/Term -9
4 X2:SLOT4/Term -9
5 X2:SLOT5/Term -9
6 X2:SLOT6/Term -9
7 X2:SLOT7/Term -9
8 X2:SLOT8/Term -9
9 X2:SLOT9/Term -9
10 X2:SLOT10/Term -9
11 X2:SLOT11/Term -9
12 X2:SLOT12/Term -9
13 X2:SLOT13/Term -9
14 X2:SLOT14/Term -13
15 X3:51
16 X3:53
17 X5:I/O:SLOT3:COM
18 X5:I/O:SLOT5:COM
19 SPARE
20 SPARE
21 SPARE
22 SPARE
23 SPARE
24 SPARE
25 SPARE
26 SPARE
27 SPARE
28 SPARE
29 SPARE
30 SPARE
31 SPARE
32 SPARE
33 X5:I/O:Term c
34 2-FT-202/Term -9
35 2-FT-102/Term -9
36 1-FT-101/Term -9
37 SPARE
38 SPARE
39 SPARE
40 Light OV
1-FTC-100 / X4:24V
1 2 A Fuse X2:SLOT1/Term +7
2 2 A Fuse X2:SLOT2/Term +7
3 2 A Fuse X2:SLOT3/Term +7
4 2 A Fuse X2:SLOT4/Term +7
5 2 A Fuse X2:SLOT5/Term +7
6 2 A Fuse X2:SLOT6/Term +7
7 2 A Fuse X2:SLOT7/Term +7
8 2 A Fuse X2:SLOT8/Term +7
9 2 A Fuse X2:SLOT9/Term +7
10 2 A Fuse X2:SLOT10/Term +7
11 2 A Fuse X2:SLOT11/Term +7
12 2 A Fuse X2:SLOT12/Term +7
13 2 A Fuse X2:SLOT13/Term +7
14 2 A Fuse X2:SLOT14/Term +14
15 2 A Fuse X3:49
16 X5:I/O:SLOT2/Vsup
17 X5:I/O:SLOT3:Vsup
18 X5:I/O:SLOT5:Vsup
19 SPARE
20 SPARE
21 SPARE
22 SPARE
23 SPARE
24 SPARE
25 SPARE
26 SPARE
27 SPARE
28 SPARE
29 SPARE
30 SPARE
31 SPARE
32 SPARE
33 2 A Fuse X5:I/O:Term v
34 3 A Fuse 2-FT-202/Term +10
35 3 A Fuse 2-FT-102/Term +10
36 3 A Fuse 1-FT-101/Term +10
37 SPARE
38 SPARE
39 SPARE
40 Light 24V+

Appendix J

Marshalling Cabinet Layout


1000
GREY CABLE DUCT 30x80
X5
GREY CABLE DUCT 40x80
X4
GREY CABLE DUCT 40x80
X3
GREY CABLE DUCT 40x80
X2
BLUE CABLE DUCT 40x80
X1
BLUE CABLE DUCT 60x80
GREY CABLE DUCT 40x80
BLUE CABLE DUCT 40x80
GREY CABLE DUCT 40x80


300
1000
700

Appendix K

Electronic Appendices

The electronic appendices can be found in DAIM with the following numbering:

[1] Documentation of the CSL.

[2] Safety and Automation System in LabVIEW.

[3] Images of CSL.

[4] Specialization project: Construction of Compact Separator Laboratory.