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## **CONTROL NARRATIVE, CNG IN A BOX™**

**FOR**

**BAKKEN COLD WEATHER MOD  
GE OIL & GAS  
24 APRIL 2014**

**REVISION A**

## TABLE OF CONTENTS

<b>1</b>	<b>GENERAL .....</b>	<b>5</b>
1.1	PURPOSE.....	5
1.2	SCOPE .....	5
1.3	REFERENCES.....	5
1.4	GENERAL INFORMATION .....	5
<b>1.5</b>	<b>REVISIONS.....</b>	<b>6</b>
<b>2</b>	<b>EQUIPMENT.....</b>	<b>7</b>
2.1	COMPRESSOR CONTAINER .....	7
2.2	DRYER .....	7
2.3	COMPRESSOR PACKAGE.....	8
2.4	COMPRESSOR BLOWDOWN & RECOVERY SYSTEM .....	8
2.5	RELIEF VALVES.....	8
2.6	INLET ISOLATION VALVE.....	8
2.7	GAS AFTERCOOLERS.....	9
2.8	COMPRESSOR LUBRICATION .....	9
2.9	CNG BUFFER TANKS .....	9
2.10	CONTROL SYSTEM .....	10
2.10.1	CONTROL PANEL.....	10
2.10.2	VALVES.....	11
2.10.3	INSTRUMENTATION .....	11
2.10.4	DISPENSER & CARD READER .....	11
<b>3</b>	<b>CONTROL PHILOSOPHY.....</b>	<b>13</b>
3.1	OVERALL CONTROL.....	13
3.2	DRYER .....	13
3.3	COMPRESSOR.....	13
3.4	BLOWDOWN .....	14
3.5	BUFFER TANKS .....	15
3.6	DISPENSING .....	16

<b>3.7</b>	<b>COMPRESSOR LUBRICATION .....</b>	<b>16</b>
3.7.1	CRANK & BEARING LUBRICATION.....	16
3.7.2	CYLINDER & PACKING LUBRICATION .....	17
<b>3.8</b>	<b>ELECTRICAL .....</b>	<b>17</b>
3.8.1	REMOTE POWER PANEL .....	18
3.8.2	JUNCTION BOX #930 .....	19
3.8.3	CONTROL PANEL.....	19
<b>3.9</b>	<b>ALARMS &amp; TRIPS .....</b>	<b>21</b>
<b>4</b>	<b>OPERATOR INTERFACES.....</b>	<b>22</b>
4.1	REMOTE POWER PANEL.....	22
4.2	CONTROL PANEL .....	22
4.3	GAUGE PANEL.....	22
4.4	MISC INTERFACES.....	22
<b>5</b>	<b>SEQUENCE OF OPERATION.....</b>	<b>23</b>
5.1	NORMAL STARTUP .....	23
5.1.1	VERIFY UTILITIES & ISOLATION.....	23
5.1.2	VERIFY OIL LEVELS .....	23
5.1.3	TURN ON POWER.....	23
5.1.4	VERIFY CONTROLLER STATUS .....	23
5.1.5	INPUT OPERATING PARAMETERS.....	23
5.1.6	START THE SYSTEM .....	26
5.1.7	AUTOMATED PROCESS.....	26
5.1.8	MONITOR OPERATION .....	30
5.1.9	UNATTENDED OPERATION.....	30
5.2	BACKGROUND CONTROLS .....	30
5.2.1	GAS TEMPERATURE .....	30
5.2.2	AIR DIRECTION.....	30
5.2.3	WARM WEATHER OPERATION .....	31
5.2.4	COLD WEATHER OPERATION .....	31
5.2.5	LOUVER DE-ICE & GAS DETECTION.....	31
5.2.6	SPACE HEATER .....	31
5.2.7	EQUIPMENT TEMPERATURE MONITORING.....	32
5.2.8	OIL COOLER.....	32
5.3	NORMAL SHUTDOWN.....	32
5.3.1	PERFORM SHUTDOWN.....	32
5.4	CONTROL SYSTEM INITIATED EMERGENCY SHUTDOWN .....	33
5.4.1	GAS DETECTION.....	33
5.4.2	COMPRESSOR DISCHARGE PRESSURE HIGH.....	33
5.4.3	POWER LOSS .....	33
5.4.4	OTHER SHUTDOWN ALARMS.....	33
5.5	EMERGENCY SHUTDOWN.....	34
5.5.1	CONTROL POWER SWITCH .....	34
5.5.2	ESD PUSHBUTTONS .....	34

5.5.3	LEL GAS MONITOR .....	34
5.5.4	FIRE DETECTION .....	34
5.5.5	PLC RELAY CR-901 .....	34
5.6	MAINTENANCE MODE.....	35
5.6.1	ACCESS .....	35
5.6.2	TESTING.....	35

## **1 GENERAL**

### **1.1 PURPOSE**

The purpose of this document is to describe the CNG IN A BOX™ equipment, control strategy, operator interfaces, and typical sequences of operation for compressing and dispensing compressed natural gas (CNG) for use as vehicle fuel.

### **1.2 SCOPE**

This document covers equipment supplied by Guild Associates as well as interfaces with various peripheral equipment supplied by others. Limited information may be included pertaining to equipment by others, but only to the extent of connections to the Guild equipment.

Warnings and trips are NOT covered in this document. Refer to the P&ID and Alarm & Trip List for information pertaining to software and hardware interlocks, description of alarms, response to alarms, and other details that define how alarm conditions are handled. The P&ID includes software interlock "diamonds" (i.e. I113) that correlate to the applicable instrument and the Alarm & Trip List.

### **1.3 REFERENCES**

Refer to the latest revision of these documents for the discussions below.

P&ID	MG120-00010
One Line Diagram	MG120-00905
Network Diagram	MG120-00906
Alarm & Trip List	MG120-00907

### **1.4 GENERAL INFORMATION**

The overall system is designed to dry, compress, and dispense pipeline natural gas for use as vehicle fuel.

Major equipment provided by Guild includes: Compressor Container and Remote Power Panel.

Equipment supplied by others and peripheral to the Guild supplied systems includes: 460VAC power service to the site, field plumbing and electrical equipment, dispensers, point of sale equipment, internet/telephone connection, and roof with signage.

The first priority of the system is to dispense CNG to retail customers as quickly and safely as possible. Next, when applicable, would be to slow fill a fleet of vehicles. And finally to minimize the starting and stopping of the compressor by using buffer tanks with a cascade filling sequence.

More detailed discussions are provided below. Section 2 provides a brief description of the equipment. Section 3 covers the control philosophy for the overall system as well as each sub-system. Section 4 describes the operator interfaces. And section 5 details various sequences of operation for different scenarios.

### **1.5 REVISIONS**

REV 0 Started with MG109-00950 revD dated 9 Jan 2014. See modifications in **BLUE** for changes relating to the Bakken cold weather modifications.

REV A Started with MG120-00950 rev0 dated 20 March 2014. Update per final design review & GE feedback. See modifications in **ORANGE, MAGENTA, & GREEN** for changes.

## **2 EQUIPMENT**

The Guild supplied equipment includes the Compressor Container and Remote Power Panel. Refer to the referenced drawings above for the following discussions.

### **2.1 COMPRESSOR CONTAINER**

The compressor container consists of a 20-foot modified ISO container which houses the inlet natural gas dryer, 400 HP CNG compressor, blow down tanks, crankcase oil makeup tank, cylinder oil supply tank, gas and oil coolers, oil heater, and a used oil tank. The container is equipped with access doors, removable louvered panels, ventilation, a control system interlocked LEL (Lower Explosive Limit) monitor, fire detection temperature switches, and mounting provisions. The container is furnished with an instrument and control panel door and an adjacent personnel door for maintenance. One end wall contains **electrically actuated** louvered panels to allow air ingress for cooling. The roof of the container also consists of corrugated steel above which the buffer vessels are mounted. The area above the compressor/motor package houses the gas cooler with electrically actuated louvers outside the container that open when the cooler fan starts and closes when the fan stops. **For cold weather operation, a smaller fan is added near the 400 hp motor access panel. This fan draws outside air backwards down through the main gas cooler to help heat the container interior. Included in the cold weather package kit are exterior insulated panels and a 20 kW space heater.**

These components are fully integrated in the compressor container so that only power, instrument and control wiring, utility, and dispenser interface connections need be provided in the field. The ISO container has been modified for air-cooling the compressor and providing access to all components. A description of the major components is provided herein.

### **2.2 DRYER**

The system features a model NG-SV-21-4 single tower molecular sieve dryer supplied by PSB Industries. This dryer is an externally regenerable system with a capacity of 21 MMSCF at 7#H<sub>2</sub>O/MMSCF inlet water content. The desiccant vessel is custom designed to a height of 87-inches for installation in the compressor container. The system comes replete with the 3A adsorbent vessel, piping, filters, and digital dew point meter as indicated below. A 4-inch flange facilitates connection to the gas supply. Features are:

- A single adsorber vessel designed, manufactured, and stamped per ASME code Section VIII and -20°F MDMT,
- Stainless steel desiccant screens,
- A high efficiency pre filter and after filter and four (4) inlet/outlet manual isolation valves with lockable handles, a drain valve, and remote-mounted DP, (Differential Pressure) indicators located on the gauge panel.
- An initial charge of Type 3A high capacity molecular sieve desiccant to minimize co-adsorption of mercaptans,

- Piping designed, manufactured and tested per ASME B31.3 and using Sizes 4” SA234WPB fittings and SA105 flanges with schedule 40 SA-53B /SA106B seamless pipe,
- A Dew Point analyzer with digital indicator provides an analog 4-20mA signal to the controller for trending, alarming, and shutdown.

### **2.3 COMPRESSOR PACKAGE**

The compressor is direct-driven through a flexible metallic coupling with a 400HP 460VAC 3PH GE motor.

The natural gas feed will be compressed by a GE H304 high-speed reciprocating compressor. The compressor assembly contains the following additional items; pulsation bottles on stage 2 inlet & outlet, oil/gas filtration inter-stage and product, automated pre-lube pump system, oil cooler with thermostatic bypass, lube oil heating, vibration transmitters, divider block monitoring of cylinder oil flows, pressure transmitters for the compressor suction and at the discharge of each stage, two blow-down tanks, temperature transmitters and pressure gauges with isolation on the outlet of each stage, inter-stage and post compression cooler, and lube oil. The compressor depressurization and filter draining is performed by skid-mounted solenoids. The piping is fabricated in accordance with ASME B31.3.

The package is designed to operate from 0F to 110F at a maximum of 3300’ elevation with a suction pressure varying from 10 PSIG to 35 PSIG and a 4700 PSIG discharge pressure. The flows will vary with inlet temperature, pressure and elevation. However the design basis is 875 SCFM at sea level with a 35 PSIG at the compressor suction flange pressure at 1780 RPM.

### **2.4 COMPRESSOR BLOWDOWN & RECOVERY SYSTEM**

This system includes a depressurization gas recovery system to depressurize the compressor for restart. The recovery system includes a 250 gallon ASME 250 psig-rated blowdown tank, filters, drain valves, isolation valves, pressure transmitter, and supply regulator.

### **2.5 RELIEF VALVES**

The relief valves for the compressor package are sized using API RP521 Part 1 & 2 and are of carbon steel construction and ASME marked. The final discharge relief valve is stainless steel. The outlets are pre-piped to one of two vent headers, which exhaust through dedicated vent stacks located on the top of the compressor container.

### **2.6 INLET ISOLATION VALVE**

In accordance with NFPA 52 8.11.9, a self-closing globe valve is installed on the inlet to the compressor. This valve also acts as the compressor inlet pressure control valve.



## **2.7 GAS AFTERCOOLERS**

Each of the four (four stages) compressed gas aftercoolers are ASME marked and is designed for a 20 degree approach. The four cooler cores are combined into a single unit, with one fan, which is mounted in the roof of the container above the compressor. This allows for container ventilation and directs the low level noise upward. The fan is driven by a 15HP 480VAC 3PH motor via belt drive.

## **2.8 COMPRESSOR LUBRICATION**

The single-oil lubrication system provides for crankcase and cylinder lubrication and is comprised of the makeup oil tank with level sensing and makeup valve, crank case oil pan, prelube and coupled pumps, aftercooler, heater, thermostatic valve, filter, and temperature and pressure monitoring signals wired back to the controller. Lubrication of the high pressure cylinders and packing draws oil from the crankcase. This system includes used oil tank, high pressure pump, divider blocks, GFCI protected heat tracing, and level and flow sensing.

## **2.9 CNG BUFFER TANKS**

The rationale for specifying the buffer vessel configuration was to choose the smallest buffer tank capacity necessary to balance the highest potential demand with compressor capacity while limiting the compressor to not more than 10 starts per hour. The objective was to reduce capital cost and buffer vessel footprint to facilitate easier transportability. Three 5500 SCF cascade buffer vessels will satisfy this need. The gas buffer tank configuration chosen for this application is an assembly of 3 seamless pressure vessels mounted horizontally on top of the compressor container. The vessels meet the following specifications:

Three seamless pressure vessels to ASME UPV Code Section VIII, Division 1, Appendix 22, Safety Factor 3 to 1 for dry gas, non-corrosive service.

Design temperature: -40 °F to +200 °F

Vessel material is SA372 Grade J, Class 70

Vessel Size: 20" OD x 1.303" MW x 11' 6" Long

Design Pressure: 5500 psig

Assembly Water Volume: 48.0 ft<sup>3</sup>

Assembly Capacity: 16,239 scf CNG @ 4500/4200/4200 psig

The three high-pressure buffer vessels are mounted horizontally in a modular frame with seismic cross bracing, which is secured to the top of the container. Each vessel includes a 5% notch ultrasonic inspection. Each vessel is equipped with a ¾" manual process isolation valve, a safety relief valve, a ¼" drain valve, and a ¼" bleed valve installed inside of the compressor container. Relief outlets are connected to vent header 2. Drain valve outlets are routed to the blowdown tank. And the bleed valves are plumbed to vent header 2. Pressure transducers and gauges are provided to monitor pressure in each buffer vessel. Normally closed isolation solenoid valves are installed between each buffer vessel and the dispensers. The valves are wired to the

emergency stop circuit to comply with NFPA 52. The control panel is located in the compressor container along with the slow fill connection mounted to the back of the control panel.

## **2.10 CONTROL SYSTEM**

The Remote Power Panel is shipped loose and is to be field mounted away from the compressor container in a non-hazardous location. This panel contains: main breaker and control power disconnect with exterior lockable handle, soft starter with bypass contactor, circuit breakers, small motor starters, control power transformers, UPS, emergency stop pushbutton, lockable control power switch, and miscellaneous electrical components. Field electrical connections to this panel include: main power feed from a 800A 460V 3PH service, 460V circuit from the soft start to the compressor motor, 460V field connections to small motors via a junction panel located in the compressor container, 120V power/emergency shutdown (ESD)/control/communication wiring to the control panel located in the compressor container, and power/communication/ESD wiring to the dispensers. Normal operations with this panel are limited to resetting ESD button and turning on the control power switch and main breaker.

The soft start is a GE Model QT20460U11MS wall mount digital starter.

Additional features include:

- Circuit breaker integrated with the door-mounted handle & under voltage latch
- Digital display/keypad (inside the panel)
- Off/Auto selector switch
- Emergency stop pushbutton
- "Control Power On" (white) pilot light
- Control power transformers (460:120Vac), breakers.
- Full HP rated integral bypass (air) contactor.
- Cooling fan w/filter controlled by thermostat.

### **2.10.1 CONTROL PANEL**

The Control Panel is mounted in the compressor container. The panel is rated NEMA4 weather tight with all internal electronics marked and approved for operation in a Class 1 Division 2 Group D hazardous location. The panel contains power supplies, fuses, control relays, PLC, I/O modules, network switch, and the operator interface touch screen. The panel is also equipped with an emergency stop and light switch on the panel door. Skid mounted instrumentation and control circuits are pre-wired into this panel and tested at the factory. Field electrical connections to this panel are limited to 120VAC power, start/status signals (**dry contact AND ethernet communications to VFD**) to/from the remote power panel, provisions for additional site ESD circuitry, and Ethernet to the internet (by others).

The PLC is an Allen Bradley Compact Logix model 1769-L30ER that acts as the "brain" of the system. The embedded program provides for automated control of the

compressor, soft starter, smaller motors and heaters, buffer prioritization, direct fill, slow fill, interface via touch screen, system monitoring, alarm warnings and trips, and communications for remote internet access. Automatic operations are provided for startup, normal shutdown, emergency shutdown, and process upset. Interface with instrumentation is via analog and discrete I/O modules from the Allen Bradley 1769 series. Interface to the touch screen is via the multi-channel Ethernet switch. The switch also provides network connection to the internet for remote access. The touch screen is a model QTERM-A7/3654R from Beijer.

Normal operations with this panel include resetting the ESD and starting the system via the touch screen. The touch screen provides all operator interfaces for: start/stop, slow fill, warning and trip alarm indication, and manual mode operation during troubleshooting and maintenance.

### 2.10.2 VALVES

A number of piloted solenoid valves are also provided for automatic operation of the compressor blowdown and buffer tank functions. All come with 120 VAC coils to reduce the burden on the 24VDC power supply. All fail closed so as to stop all gas flow during power outage or ESD. Control is via dry contact relay within the control panel thereby providing electrical isolation between the 120VAC and 24VDC circuitry.

### 2.10.3 INSTRUMENTATION

Located throughout the skid package are various sensors connected to the Control Panel providing for automatic operation of the system. Pressures are monitored with 4-20mA loop power, factory sealed pressure transmitters. The hazardous location protection technique for these devices is explosion-proof with factory sealing thereby precluding the need for a conduit seal. Temperature transmitters are also two-wire 4-20mA loop powered, provided with thermo-wells, and are marked and approved for Division 2 non-incendive operation. The compressor and motor vibration transmitters are also 4-20mA loop powered and are marked and approved for Division 2 non-incendive operation. The dewpoint analyzer transmitter is located inside the control panel with the sensor element located out on process piping. This unit requires 120VAC and is also marked and approved for Division 2 locations. The LEL provides two relay signals, one for hi warning and a second for hi trip, along with a 4-20mA signal for monitoring, trending, and controller initiated shutdown. The hi warning relay is used as a discrete input to the PLC to indicate a warning. The LEL hi trip relay is hard wired into the ESD circuitry for safety. The LEL uses explosion-proof as the protection technique. Temperature switch TSHH-900 and TSHH-901 are provided for system shutdown if the compressor container temperature rises above 190 degrees F an indication of a fire. Discrete signal (switches) explosion-proof devices are also provided for compressor makeup and supply oil levels and low oil flow monitoring.

### 2.10.4 DISPENSER & CARD READER

The dispenser and card reader are supplied by GE Wayne or Other brand. It will contain solenoid valves for fast and efficient filling using a cascade sequence from the 3 buffer tanks.

#### 2.10.4.1 Dispenser

The interface with the remote power panel includes 120 vac power for the dispensers and an RS485 communications link, HMI, and PLC. This link allows the PLC to gather important data from the dispensers to be used during the buffer/vehicle filling process.

#### 2.10.4.2 ESD Buttons

An emergency stop button is required to be located near the dispensers. Another ESD, is required near the personnel access point of the perimeter wall or fence. These ESD's are to be wired into the emergency stop circuit supplied with the remote power panel and compressor container.

### **3 CONTROL PHILOSOPHY**

#### **3.1 OVERALL CONTROL**

The purpose of the system is to dry and compress pipeline natural gas to approximately 4500 psig and store the gas in three high pressure buffer vessels. These vessels are connected to dispensing units for retail sale of compressed natural gas (CNG) as vehicle fuel. The system is controlled by a single programmable logic controller (PLC) that provides for automatic operation of the drying, compression, and buffer tank functions. The following sections will cover in more detail the control of each sub-system.

#### **3.2 DRYER**

There is no automatic control by the PLC of the drying system. The operator simply positions manual valves according to the P&ID and the process is completely passive. The dewpoint analyzer is provided for monitoring dryer product moisture level, warning the operator that the dryer adsorbent material will require regeneration soon, and shutting down the compressor system if the dewpoint rises above the setpoint based on location (city, state).

#### **3.3 COMPRESSOR**

The compressor is a 4 cylinder 4 stage reciprocating compressor driven by a 400 HP motor. Various components are provided along the flow path to control the compression process. Lubrication of the compressor is covered in a separate section below.

From the dryer the gas enters the compression phase through an inlet forward pressure (or pressure reducing) regulator PCV-319. This is a piloted control valve that is manually adjustable and uses upstream gas pressure from the dryer inlet as the motive force to move the regulator stem. A small solenoid valve FY-319 is energized to connect the motive gas to the downstream pressure sensing pilot regulator PCV-3191. When FY-319 is de-energized, the motive gas is vented to the vent stack and the regulator closes due to lack of motive gas. This configuration allows for PLC open/close control of the regulator and provides the shutdown isolation of the inlet gas required by NFPA 52. The PLC monitors compressor suction pressure and temperature for high or low warning and shutdown via pressure transmitter PT-320 and temperature transmitter TT-320.

In addition, stage 2 is provided with pulsation bottles. Flow orifices (FE's) are located at the first stage suction and discharge, second stage pulsation bottle inlet, second stage discharge and pulsation bottle outlet, third stage suction and discharge, and fourth stage suction and discharge. Each stage of compression has discharge pressure transmitters & gauges, and pressure relief valves (PSV's).

Each stage discharge temperature & pressure is monitored by the PLC via temperature & pressure transmitters (TT's and PT's). These sensors provide for various control functions covered below, as well as high and low warnings and shutdowns. They are 24 vdc 2-wire loop powered devices with temperature sensors

all scaled for -50 to 400 deg F. Pressure transmitter ranges are: compressor suction (PT-320) 0-200 psig, first stage discharge (PT-326) 0-300 psig, second stage discharge (PT-336) 0-2000 psig, third stage discharge (PT-346) 0-3000 psig, fourth stage discharge (PT-358) 0-8000 psig, Buffer tanks (PT-362, PT-366, PT-370) 0-8000 psig, Blowdown tank (PT-391) 0-200 psig, and oil pressure (PT-532) 0-200 psig.

A four core air cooled heat exchanger provides discharge gas cooling for each of the 4 stages. [Two fans are used to move air through this cooler based on ambient temperature and other sensors and setpoints. Refer to section 5.2 for detailed description of the control logic for these fans.](#)

Four coalescing filters are provided on the discharges to collect oil carryover and for particulate removal. The solenoid valves at the bottom of each filter, used during the blowdown process covered later, also drain the oil collected in the filter bowls to the blowdown tank for periodic manual draining. The valves are piloted 120 VAC coil fail closed valves automatically controlled by the PLC during the blowdown process. In the unlikely event of the compressor running for an extended period, there exists the possibility that oil will fill the filter bowls beyond capacity. To preclude this, the PLC will periodically and automatically, based on the cycle counts of the divider block oil flow switches FSLL-539 & 539, pulse the solenoid valves open for a short time to move the oil to the blowdown tank, then close the valves and resume normal operation. The compressor will continue to run during this valve pulsing process.

The final stage 4 discharge is provided with a block HV-360 and bleed HV-3601. These are also manual devices with no automatic control. The valve handles are lockable in the open or closed position providing isolation from the buffer tank and safe lockout tagout during compressor maintenance.

### **3.4 BLOWDOWN**

After the compressor has completed a vehicle fill and pressurized the buffer tanks it will turn off. At this time there is pressurized gas trapped in the compressor. It is not possible to restart the compressor up against these pressures. Therefore an automatic blowdown process is provided to depressurize the compressor to allow for restart, and save this gas in blowdown tank.

Both the inlet regulator PCV-319 and the blowdown regulator PCV-394 are closed. The same four solenoid valve used for oil draining as discussed above, are also used for the blowdown process. After the compressor stops, the first stage blowdown valve FV-329 is opened and the stage 1 discharge pressure PT-326 minus the blowdown pressure PT-391 is monitored by the PLC. When the difference of pressures reaches a preset value (adjustable via the touch screen HMI) the controller assumes the first stage discharge has effectively finished depressurizing. The PLC then closes FV-329 and opens the second stage blowdown valve FV-339. Again the difference of pressure between stage 2 discharge PT-336 and the blowdown tank pressure PT-391 is monitored to determine finishing the step. This sequence is repeated for the third then

the forth stages. The blowdown process is now finished, the gas is stored in the blowdown tank, and the compressor can be restarted.

Regulator PCV-394 is similar to the inlet regulator PCV-319 discussed above. This is a piloted control valve that is also manually adjustable and uses downstream gas pressure as the motive force to move the regulator stem. A small solenoid valve FY-394 is energized to connect the motive gas to the downstream pressure sensing pilot regulator PCV-3941. When FY-394 is de-energized, the motive gas is vented and the regulator closes due to lack of motive gas. This configuration allows for PLC open/close control of the regulator. When the compressor restarts, regulator PCV-394 opens first to allow gas to flow from the blowdown tank to the compressor inlet. The PLC again monitors the drop in pressure via PT-391. When this pressure reaches a preset level (typically 10 psig, adjustable via the touch screen), the PLC closes PCV-394 and opens PCV-319 to now draw gas from the pipeline. Depending on the speed at which these valves operate, some overlap with both valves open may be required to prevent shutting the compressor down on low suction pressure.

Additionally, if the pressure in the blowdown tank rises while the compressor is running on pipeline gas, it may be that one of the solenoid valves is leaking. If the leak is significant, the system will warn and trip on high blowdown pressure. However, if the leak is small, the PLC will automatically draw this gas from the blowdown tank by temporarily closing PCV-319 and opening PCV-394 until the blowdown pressure PT-391 drops below the setpoint (typically 10 psig). Then the PLC will close PCV-394 and open PCV-319 to continue running on pipeline gas. Some overlap between opening and closing these two valves may be required to prevent trip on low inlet pressure.

Finally, blowdown tank pressure transmitter PT-391 is also monitored for high and low pressure warning and shutdown alarms.

### **3.5 BUFFER TANKS**

Three high pressure vessels are provided for buffer tanks of the CNG400. The high, medium, and low pressure buffer vessels allow for cascade vehicle tank filling by the dispensers. Use of buffer volume reduces excess starting and stopping of the compressor. The automated buffer filling processes are covered below.

If it is determined that gas is needed (because buffer tank pressures are low or GE Wayne dispenser configuration has initiated a pre-emptive start) the compressor starts. The PLC will first send gas to Direct Filling then monitor the buffer tank pressures to decide where to send the gas. Fail closed solenoid valves and check valves are provided for automatic control of flow to buffer tanks. Priority one is to Direct Fill with FV-374, then to fill the high buffer tank by opening solenoid FV-362 until high buffer tank pressure PT-362 reaches a preset stop pressure value (typically 4500 psig, adjustable via the touch screen). The compressor continues to run, FV-362 closes, and FV-366 opens to fill medium buffer tank. Again, when that buffer vessel reaches the stop pressure, valves are switched to fill low buffer tank. If there is no gas being dispensed, slow fill is not enabled, and all three buffer vessels are full, the compressor stops and performs a blowdown sequence.

As vehicles are filled, gas is drawn from buffer tanks and pressures will drop. The dispensers will draw from the low buffer tank first, then the medium buffer tank, and finally top off the vehicle with the high buffer tank. This results in the low buffer tank having the lowest pressure on up to the high buffer tank with the highest pressure. If all three buffer tanks pressure drops below the adjustable start pressure setpoints (typically 3600 to 3800 psig) the compressor will start again and repeat the prioritized buffer tank filling.

A slow fill option is also available for long overnight filling of a fleet of vehicles like trucks or buses. This mode can be scheduled, enabled, or disabled via the touch screen. If slow fill is disabled then FV-378 will remain closed. If enabled, the PLC will continue to perform normal fast fill to vehicles as the first priority. Additionally during periods when no retail sales are required, the PLC will continue to run the compressor and open FV-378 to fill a fleet of vehicles to the slow fill pressure setpoint. This setpoint is temperature compensated based on compressor discharge temperature TT-358.

Included on the three connections to the dispensers, located inside the compressor container, are three fail closed solenoid valves wired to the emergency stop circuit that will close if: someone hits an ESD (Emergency Shut Down) button, the gas monitor detects the presence of gas above 25% of the lower explosion limit (LEL), or either of the two compressor container temperature switches open if the container temperature rises above 190 degrees F. This fulfills the requirement from NFPA 52 for automatic isolation between buffer tanks and dispensing during an emergency shutdown. During normal operations these valves remain open.

A modbus RS485 serial communications link is provided between the touch screen and the dispenser(s). The touch screen will display and log relevant dispenser data and will provide the PLC with information as to the number and sizes of tanks that are about to be filled. The PLC can then use this data and the current level of buffer tanks to preemptively start the compressor and/or switch to direct fill to expedite the filling process.

### **3.6 DISPENSING**

The dispensers are supplied by others so this discussion is limited to the interfaces to the Guild equipment.

Three pipe (or tube) connections from the buffer tanks system supply the dispenser. The dispenser handles the automatic cascade filling of the vehicle as well as point of sale and credit card approval. As discussed above, a serial communications link provides the touch screen and PLC with useful data for display and filling. 120 VAC 1 PH power for the dispenser comes from the remote power panel.

### **3.7 COMPRESSOR LUBRICATION**

#### **3.7.1 CRANK & BEARING LUBRICATION**

Oil supply for crank and bearing lubrication is the makeup oil tank V-536 and the compressor crank case oil sump that holds nominally 7.5 gallons of oil. Level switch



L5LL-530 is connected to the PLC to provide alarm trip on low oil level. Oil flows from the oil sump to two gear pumps, one motor driven for prelube P-511 and one directly coupled P-513 to the compressor. The prelube pump is controlled by the PLC via relay on a 120VAC circuit to the motor starter and will run most of the time with the oil heater to help keep the oil warm. Three way valve FV-526 will divert oil back to the crankcase during this oil warming phase. Prior to starting the compressor the oil temperature must be between 70 and 170 degrees F and the program must not be in the six minute start delay. Then FV-526 will switch to divert oil to the bearings for at least 30 seconds, after which oil pressure will be checked as a permissive to start the compressor. A spill back regulator PCV-511 set to 10-15 psig will allow excess oil to flow back to the inlet of the pump.

Oil cooling is provided by an air cooled heat exchanger HX-520 with a 1/3 HP fan driver that is also controlled by the PLC **using a two setpoint deadband approach**. The thermostatic valve TCV-523 is a passive device with no PLC control that will divert oil around the oil cooler until it warms to >150 degF. The electric oil heater H-525 with integral thermostat will heat the oil as required to 120 degF. Power to this heater will turn on anytime the prelube pump OR compressor is running. There is no direct PLC control of the oil heater. Temperature transmitter TT-528 provides for PLC high or low oil temperature warning or shutdown. This sensor is also used as a permissive for starting the compressor.

Oil is then filtered by F-529 and the oil pressure at the bearings is monitored by the PLC via PT-532. Again, the PLC will monitor for high or low oil pressure warnings and shutdowns, and use this pressure as a permissive for starting the compressor. Oil filter F-529 restriction is indicated on pressure differential indicator PDI-529 located on the gauge panel. PDI-529 reads roughly 15 psid with a new filter.

### 3.7.2 CYLINDER & PACKING LUBRICATION

Oil supply for cylinder & packing lubrication is provided **by the compressor oil pan**. Oil feeds to compressor coupled high pressure oil pumps P-537A&B.

The high pressure oil then flows from the pumps to the divider blocks where it is split up and sent to the four cylinders and packing as indicate on the P&ID. The divider blocks have no control by the PLC but work off the oil pressure itself to move "shuttles" back and forth within the divider block. Flow switches F5LL-538 and F5LL-539 are connected to the divider blocks and will cycle its electrical contacts along with the divider block shuttles to indicate flow. The PLC monitors for proper lubrication by measuring the time between the flow switch contact closures. If this time is greater than the shutdown setpoint time for three consecutive cycles OR the time exceeds 3 x the shutdown setpoint, the compressor is shutdown to prevent damage due to loss of cylinder/packing lubrication. A warning is indicated on the touch screen anytime the cycle time exceeds the shutdown setpoint one or two times in a row.

## 3.8 ELECTRICAL

As covered in the equipment section above, there are three electrical panels provided to house the various electrical components: Remote Power Panel, Junction Box #930,

and Control Panel. This section covers the control of these devices. Refer to drawing MG120-00905 One Line Diagram for electrical systems discussions below.

### 3.8.1 REMOTE POWER PANEL

Main power from a 800A 460V 3PH service enters the remote power panel and connects to the line side of main breaker CB-910. This breaker is equipped with an under-voltage latch mechanism to provide for remote PLC, LEL, temperature switch, and/or emergency pushbutton ESD actuation of the main breaker. This emergency stop circuit is a hard wired system that operates independently from the PLC software program. An under-voltage trip of the main breaker will require someone to be at the site to physically reset the breaker. A white control power light is also provided to indicate the main breaker can be turned on.

Power from the main breaker is first fed to the compressor motor reduce voltage soft starter RVSS-330. This is a fixed speed start/stop control system only. As buffer tanks or filling gas pressure is required, the PLC sends a start command via dry contact relay to the soft starter inputs terminals. After the motor starts the soft start sends a run status dry contact signal back to the PLC for run verification. After the speed ramp is complete and the motor is at full speed, the soft start automatically energizes a bypass contactor and turns off the soft starter solid state power transistors (SCRs). This is done to reduce the heat generated by the voltage drop across these transistors. A six minute delay between starts limits starting the compressor to a maximum of 10 starts per hour. This is done to prevent overheating the large motor by starting it too often. A 200 watt motor space heater is wired to normally close auxiliary contacts on the bypass contactor to keep the motor interior warm when it is off to prevent condensation.

Power from the load side of the main breaker is then run to six 60A class J fuses. Three of these fuses provide power to the external dryer regeneration system. The other three provide current limiting to the branch breakers there by increasing the overall short circuit rating (SCCR) of the Remote Power Panel to 65KA. Powers from these three fuses connect to a power distribution bus bar that feeds a row of miniature molded case circuit breakers. These breakers provide short circuit protection of the conductors to the smaller motors and heaters. The load side of these breakers is connected to the line side of motor starter contactors with 120 vac coils. Motors are protected with overload relays wired in series with the contactor coil circuit. The PLC controls starting and stopping of the different motors via 120VAC 1PH circuits through 24VDC coil interposing relays located in the control panel.

Breaker CB-930 is a 2 pole breaker that feeds a 480/120 single phase control power transformer T-930 that supplies power for a dispenser, oil circuit heat tracing, motor space heater, oil heater thermostat, the remote power panel cooling fan, control panel heaters, and compressor container lighting. Transformer T-930 secondary over current protection is provided by breaker CB-931.

A second control power transformer T-920 with primary & secondary breaker protection, is fed from the LINE SIDE of the main breaker, provides 120VAC for the

UPS, ESD circuit, power supplies, and the control panel inputs and outputs. The UPS supplies roughly 25 minutes of PLC, LEL, and ESD power to allow for automatic restart of the compressor system after a brief power outage. This second transformer source is supplied by the LINE SIDE of the main breaker so that power is supplied to the PLC, and LEL, to allow them to boot up and verify there are no faults prior to energizing the under voltage latch which then permits turning on the main breaker.

Emergency shutdown buttons (ESD), fire detection temperature switches, LEL, or a few PLC initiated trips will drop out the main breaker via the under-voltage latch thereby cutting the power source to all outputs. Motors will stop, heaters will turn off, valves will fail close, and compressor container lights will turn off. The PLC, LEL, and all input sensors remain powered as long as there is utility power OR, during a power outage, until the UPS batteries are depleted.

### 3.8.2 JUNCTION BOX #930

This panel is located in the compressor container mounted to the back right of the control panel. This panel has NO control function or interface with the PLC. It is simply a single point for conveniently field connecting the smaller 460V loads. It contains a row of terminal blocks that are pre-wired through rigid conduit to the smaller motors and the oil heater located inside the compressor container.

### 3.8.3 CONTROL PANEL

This panel houses various 120VAC and 24VDC devices used to automatically control the system. The control philosophy behind these devices is covered in detail below.

#### 3.8.3.1 Power Supplies

There are two power supplies used. The first PWS-921 is the Allen Bradley Compact Logix supply used for the PLC and I/O modules. It supplies the 24V and 5V DC power for the Logix backplane. The second PWS-922 is rated for 60 watts output and is used to convert 120VAC to 24VDC. The 24V is then used to power input instrumentation and small interposing relay coils.

#### 3.8.3.2 Fuses

Fuses are supplied to protect individual control circuits including: power supply input & output, 120VAC control circuits to solenoid valves, 120VAC power supply to dewpoint analyzer, discrete 24VDC input circuits (1 fuse shared per bank of 16 inputs), discrete 120VAC inputs via interposing relay (1 fuse shared per bank of 8 relay coils), and 4-20mA loop power analog instruments. Each fuse holder includes a blown fuse LED indicator and a touch safe swing out feature for replacement of the fuse.

#### 3.8.3.3 Controller PLC

The system uses an Allen Bradley Compact Logix series 1769-L30ER programmable logic controller PLC-921 for control of the system process, sensor monitoring for alarm and shutdown functions, controller watchdog & fault detection, and interface to the HMI and dispensers. Programming is written in the IEC 61131-3 compliant structured text language. For discussion of the control sequence, refer to section 5 below. For descriptions of all the alarm functions, refer to section 3.9 below.

#### 3.8.3.4 I/O Modules

Compact Logix 1769 series I/O modules provide analog input and discrete I/O interfaces to the PLC. Analog input AI-921 is a 1769-IF16C module that provides 16 channels connected to pressure, temperature, analyzer, and vibration sensors. Discrete input DI-921 is a 1769-IQ16 module that provides up to 16 channels connected to ESD/LEL/fire detection temperature switches circuits, UPS power loss relay, motor status', and oil level & flow switches. Discrete input circuits connected to systems outside the compressor container (i.e. motor status) include an interposing relay to change the voltage to 120VAC for longer distances, provide electrical isolation, and reduce the load on the 24VDC power supply. Discrete output DO-921 is a 1769-OB16P module for control of outputs permissive relay, motor starting, and solenoid valve control. Electronic over current protection is provided integral to each output, thus precluding the need for fusing. Each output is connected to an interposing relay again for isolation and to reduce DC power supply burden.

#### 3.8.3.5 Relays

As covered above, interposing relays are provided on discrete input and output circuits. These devices are approved for Class 1 Division 2 hazardous locations and include LED indication.

#### 3.8.3.6 Dewpoint Analyzer

The dewpoint analyzer AT-316 power, control, and transmitter devices are located inside the control panel. The sensing element is located in the dryer outlet process pipe. AT-316 requires 120VAC supplied through a fuse, includes LCD display for configuration and display of dewpoint, and provides a 4-20mA signal scaled -148 to 68 degrees F to the PLC for monitor, trending, and alarm & trip functions. The unit is approved for operation in a Class 1 Division 2 area.

#### 3.8.3.7 Network Switch

SW-921 is a Sixnet brand SLX-5ES-2SC model that provides four RJ45 ethernet port connections for networking between the PLC, HMI, internet connection to remote SCADA system, and laptop used for field programming changes. A fiber optic port with SC type connections is also included if a long fiber optic connection is required (max length for copper ethernet is 300 feet).

#### 3.8.3.8 Touch Screen HMI

HMI-921 is a Beijer brand QTERM-A7/3654R that requires 24VDC power, provides ethernet connection to the PLC via network switch, RS485 connection to the soft starter and dispensers, is approved for Div 2, and operates down to -30 degF. Section 4.2 below details the various HMI screens the operator will see and use to monitor and control the compressor system.

#### 3.8.3.9 Pressure Transmitters

The pressure transmitters are all 4-20mA two-wire loop powered device with fixed scaling to the ranges indicated on the P&ID. These are located on the left wall of the control panel mounted via the electrical conduit 1/2" FNPT connection with the wiring routed to fused terminal blocks inside the control panel.

#### 3.8.3.10 Solenoid Valves

The solenoid valves used for blowdown are located near the interstage filter bowls. Valves used for buffer tanks and filling functions are all mounted on the outside of the back wall of the control panel. All of these valves have 120VAC coils. The electrical connection is routed through the back wall then into the control panel where it connects to a control relay dry contact, neutral, and ground. Actuation of these valves is from the PLC through a 24VDC discrete output module signal to the control relay coil. The dry contacts of the relay are fed by a 120VAC fuse for protection of the valve coil.

### **3.9 ALARMS & TRIPS**

Some of the warning and trip (shutdown) alarms have been covered in the sections above. For a complete detailed description of all the warnings and shutdowns refer to the P&ID interlock numbers in the diamonds next to input instruments and drawing MG120-00907 Alarm & Trip List.

## **4 OPERATOR INTERFACES**

### **4.1 REMOTE POWER PANEL**

Operator interfaces on the Remote Power Panel are limited to: lockable handles for turning on the main breaker, control power switch, emergency stop ESD pushbutton, off/auto selector switch for compressor control mode, and an indicator light for control power indication. All other operation functions are provided via the touch screen located on the control panel in the compressor container.

### **4.2 CONTROL PANEL**

The control panel includes a second emergency stop pushbutton that is wired in series with the all field ESDs, remote power panel ESD, compressor container fire detection temperature switches, gas detector LEL, and PLC controlled relay CR-901.

Also provided on the control panel is the operator touch screen HMI (human machine interface). When control power is turned on at the Remote Power Panel, this touch screen will light up and display the Initial Power Up Screen. The operator touches this screen to advance to the "Main Screen". From there the operator can navigate to a number of others screens for control of the compressor system, monitoring of the different systems, indication of the system status (is it ok to start, shutdown for some reason, where is it in the control sequence, etc...), modifying setpoints or operation modes, view trends of sensors, view alarm history, and utilize the maintenance mode feature for testing of individual components during troubleshooting and repair verification without running the entire compressor system. Navigation buttons are of a single consistent color and style to prevent confusion with other buttons.

Refer to the Manual for detailed discussions of all the screens and there functionality.

### **4.3 GAUGE PANEL**

This panel located to the left of the control panel provides visual indication of a number of pressures and differential pressures. Some test and isolation valves are provided for verification of pressure sensor scaling. The cylinder & packing oil supply level indicator is located on this panel above the control panel and oil fill and overflow hand valves are located below the gauge panel. There is NO automatic control interface between the gauge panel and the PLC. These are all manually actuated or passive devices.

### **4.4 MISC INTERFACES**

Also on the control panel is a light switch for the light inside the compressor container. Located behind the end wall double doors is the manual valve used to drain oil from the used oil tank. On the opposite louvers end wall is the blowdown tank drain valve.

## **5 SEQUENCE OF OPERATION**

### **5.1 NORMAL STARTUP**

This sequence covers starting the system under normal conditions. Paragraphs 5.1.1 through 5.1.6, and 5.1.8 cover tasks performed by the operator and paragraphs 5.1.7.1 through 5.1.7.16 cover tasks performed by the PLC.

#### **5.1.1 VERIFY UTILITIES & ISOLATION**

Verify service power available to the Remote Power Panel, main breaker and control power switch are off, process valves are positioned open or closed per the P&ID, and pipeline gas is available at the desired pressure.

#### **5.1.2 VERIFY OIL LEVELS**

Verify the crankcase makeup oil (V-536) located back right of container inside big double doors (top barrel). Add oil if required.

#### **5.1.3 TURN ON POWER**

Verify all ESD buttons are in the out position. Turn the control power switch to the on position. The LEL, fire detection temperature switches, and PLC will power up and if safe to continue the control power indicator will illuminate on the Remote Power Panel. It may take up to a minute for this power up and verification process to complete. After the power indicator comes on, the main breaker can be engaged. Turn the main breaker handle on the remote power panel counter clockwise to approximately "3 o'clock" until a slight "click" is heard. Then rotate handle clockwise to approximately "9 o'clock" to engage the main breaker. Note: the small oil cooler fan will start when the main breaker is engaged.

#### **5.1.4 VERIFY CONTROLLER STATUS**

Verify HMI powered on and displaying the STARTUP SCREEN. Touch the screen to bring up the Main Screen and verify no warning or shutdown trip alarms are indicated. If required, take appropriate actions to eliminate the alarms. Verify the status box indicates Waiting for Start. If the status stays at Verifying ESD, check ESD buttons and fire detection temperature switches. If the status stays at Verifying Main Breaker engage the Main Breaker. If the status displays Inlet pressure too Low or High to Start, use hand valves or maintenance mode to get the inlet pressure within 5 to 35 psig.

#### **5.1.5 INPUT OPERATING PARAMETERS**

Using the HMI touch screen, navigate to the SETUP SCREEN and adjust any parameters as required. Return to the MAIN SCREEN.

See Table 5.1.5 for the allowable range and default values of the various input parameters.

Table 5.1.5 Operating Parameters Allowable Range and Default Values

Input Parameter	Units	HMI Range	PLC Range	Default
High Buffer Start Compressor SP	Psig	0-4100	500 to (Stop-200)	500
High Buffer Stop Compressor SP	Psig	0-4500	700 to 800	700
Med Buffer Start Compressor SP	Psig	0-3800	500 to (Stop-200)	500
Med Buffer Stop Compressor SP	Psig	0-4200	700 to 800	700
Low Buffer Start Compressor SP	Psig	0-3800	500 to (Stop-200)	500
Low Buffer Stop Compressor SP	Psig	0-4200	700 to 800	700
Slow Fill Stop Compressor SP	Psig	0-4200	500 to 3500	3500
H340 Stage 2 Start SP	Deg F	0-400	230 to 300	240
H340 Stage 2 Stop SP	Deg F	0-400	220 to (Start-10)	220
H340 Stage 3 Start SP	Deg F	0-400	230 to 300	240
H340 Stage 3 Stop SP	Deg F	0-400	220 to (Start-10)	220
H340 Stage 4 Start SP	Deg F	0-400	230 to 300	240
H340 Stage 4 Stop SP	Deg F	0-400	220 to (Start-10)	220
H340 Discharge Start SP	Deg F	0-400	75 to 120	120
H340 Discharge Stop SP	Deg F	0-400	70 to (Start-5)	115
Stage 1 Depressure SP	Psid	N/A	2 to 40	20
Stage 2 Depressure SP	Psid	N/A	2 to 50	25
Stage 3 Depressure SP	Psid	N/A	5 to 60	25
Stage 4 Depressure SP	Psid	N/A	5 to 70	25
Blowdown Tank Empty SP	Psig	N/A	5 to 35	20
PCV391 to PCV319 Overlap Time SP	Sec	N/A	0 to 15	0.5
Dryer Dewpoint SP	Deg F	N/A	-140 to 60	-12
V364 Depressure Rate High SP	Psi/sec	0-400	10 to 200	200
V368 Depressure Rate High SP	Psi/sec	0-400	10 to 200	200
V372 Depressure Rate High SP	Psi/sec	0-400	10 to 200	200
Stage 1 Discharge Leak Rate SP	Psi/min	0-30	1 to 20	10
Stage 2 Discharge Leak Rate SP	Psi/min	0-30	1 to 20	10
Stage 3 Discharge Leak Rate SP	Psi/min	0-30	1 to 20	10
Stage 4 Discharge Leak	Psi/min	0-30	1 to 20	10



Rate SP				
Stage 1 Discharge Temp Low Warning Delay SP	Mins	0-100	5 to 60	30
Stage 2 Discharge Temp Low Warning Delay SP	Mins	0-100	5 to 60	30
Stage 3 Discharge Temp Low Warning Delay SP	Mins	0-100	5 to 60	30
Stage 4 Discharge Temp Low Warning Delay SP	Mins	0-100	5 to 60	30
CW Fan PID SP TT334	Deg F	0-400	225 to 275	250
CW Fan PID SP TT344	Deg F	0-400	225 to 275	250
CW Fan PID SP TT354	Deg F	0-400	225 to 275	250
CW Fan PID SP TT358	Deg F	0-400	75 to 125	100
CW Fan PID SP TT920	Deg F	0-400	10 to 70	40
Hot Mode Temp SP	Deg F	0-400	10 to 60	10
Cold Mode Temp SP	Deg F	0-400	5 to (High-5)	5
Oil Cooler Start SP	Deg F	0-400	105 to 150	140
Oil Cooler Stop SP	Deg F	0-400	100 to (High-5)	100
Space Htr TT313 Start SP	Deg F	0-400	5 to (Stop-5)	10
Space Htr TT313 Stop SP	Deg F	0-400	10 to 50	15
Space Htr TT334 Start SP	Deg F	0-400	5 to (Stop-5)	10
Space Htr TT334 Stop SP	Deg F	0-400	10 to 50	15
Space Htr TT344 Start SP	Deg F	0-400	5 to (Stop-5)	10
Space Htr TT344 Stop SP	Deg F	0-400	10 to 50	15
Space Htr TT354 Start SP	Deg F	0-400	5 to (Stop-5)	10
Space Htr TT354 Stop SP	Deg F	0-400	10 to 50	15
Space Htr TT3542 Strt SP	Deg F	0-400	5 to (Stop-5)	10
Space Htr TT3542 Stp SP	Deg F	0-400	10 to 50	15
Space Htr TT3544 Strt SP	Deg F	0-400	5 to (Stop-5)	10
Space Htr TT3544 Stp SP	Deg F	0-400	10 to 50	15
Space Htr TT358 Start SP	Deg F	0-400	5 to (Stop-5)	10
Space Htr TT358 Stop SP	Deg F	0-400	10 to 50	15
Space Htr TT920 Start SP	Deg F	0-400	5 to (Stop-5)	10
Space Htr TT920 Stop SP	Deg F	0-400	10 to 50	15
Open louvers LEL SP	%LEL	0-100	1.5-5.0	5.0
Close louvers LEL SP	%LEL	0-100	1.0-(Open-0.5)	4.0
Hot Mode TT334 SP	Deg F	0-400	225 to 300	275
Cold Mode TT334 SP	Deg F	0-400	200 to (Up-25)	225
Hot Mode TT344 SP	Deg F	0-400	225 to 300	275
Cold Mode TT334 SP	Deg F	0-400	200 to (Up-25)	225
Hot Mode TT354 SP	Deg F	0-400	225 to 300	275
Cold Mode TT354 SP	Deg F	0-400	200 to (Up-25)	225
Hot Mode TT358 SP	Deg F	0-400	80 to 125	100
Cold Mode TT358 SP	Deg F	0-400	25 to 75	50
Warn 153 SP	Deg F	0-400	(154 SP+1) to 2	-15
Warn 154 SP	Deg F	0-400	-20 to 0	-20

Warn 156 SP	Deg F	0-400	(157 SP+1) to 2	0
Warn 157 SP	Deg F	0-400	-4 to 0	-4
Warn 159 SP	Deg F	0-400	(160 SP+1) to 2	0
Warn 160 SP	Deg F	0-400	-4 to 0	-4
Warn 164 SP	Deg F	0-400	-20 to 0	-4
Warn 167 SP	Deg F	0-400	100 to 125	115
Trip 168 SP	Deg F	0-400	105 to 130	125
Warn 169 SP	Deg F	0-400	-50 to 10	-30

### 5.1.6 START THE SYSTEM

From the MAIN SCREEN press the START button and a verify window will pop up. Press the YES, START button to initiate the automatic operation of the compressor system. At this point the PLC takes over and performs all the process steps automatically based on the status of the compressor system. The following discussions detail these automatic operations.

### 5.1.7 AUTOMATED PROCESS

The following sections cover the automatic steps performed by the PLC. The section title is what appears on the MAIN SCREEN in the Status box. Only step 5.1.7.3 (same as 5.1.6 above) requires operator action, all the other steps are automatic.

#### 5.1.7.1 Verifying ESD Circuit

At this point the system is idle and verifying the ESD circuit. If it stays here check ESD buttons and fire detection temperature switches.

#### 5.1.7.2 Verifying Main Breaker

At this point the system is idle and verifying the main breaker. If it stays here, engage the main breaker.

#### 5.1.7.3 Waiting for Start

At this point the system is idle waiting for some action by the operator. All valves are closed and motors are off. Access to the maintenance mode feature is permitted. If any permissive warnings or trip alarms are active, the START button disappears preventing start. Assuming the system is operable, the operator initiates a start as described above. The PLC will then advance to the [Verifying Temperatures](#) step.

#### 5.1.7.4 Inlet Pressure Too Low To Start

The inlet pressure is too low to start the system. Use hand valve and/or manual mode to get the inlet pressure between 5 and 35 psig.

#### 5.1.7.5 Inlet Pressure Too High To Start

The inlet pressure is too high to start the system. Use hand valve and/or manual mode to get the inlet pressure between 5 and 35 psig.

#### 5.1.7.6 Verifying Temperatures

At this point the system is idle waiting for equipment temperatures TT-313, TT-334, TT-344, TT-354, TT-3542, TT-3544, and TT-358 to warm up above their minimum operating temperatures. The cold weather package has actuated louvers, insulation panels, and a space heater added for this heating of the container interior. After temperatures have been verified, the PLC will turn on the prelube pump and oil heater, then advance to the Determining Status step.

#### 5.1.7.7 Determining Status

During this step the PLC will determine the current status of the system by checking discharge pressure PT-358 against the permissive setpoint.

If the compressor system was shutdown normally or just performed a blowdown, the system should be ready to start so the PLC will advance to the Verifying Buffer Tanks step.

If the process came to this step from the end of a normal buffer tank fill OR was interrupted by something (power loss, ESD, trip alarm...), a blowdown sequence is required because there is pressure left in the compressor cylinders. In this case the PLC will advance to the Blowing Down stage 1 step.

#### 5.1.7.8 Blowing Down stage 1

The PLC will open stage 1 depressurization solenoid valve FV-329. The PLC will then monitor the pressure difference between stage 1 discharge PT-326 and the blowdown pressure PT-391. When this difference is below the setpoint, the PLC closes FV-329 and advances to the Blowing Down stage 2 step.

#### 5.1.7.9 Blowing Down stage 2

The PLC will open stage 2 depressurization solenoid valve FV-339. The PLC will then monitor the pressure difference between stage 2 discharge PT-336 and the blowdown pressure PT-391. When this difference is below the setpoint, the PLC closes FV-339 and advances to the Blowing Down stage 3 step.

#### 5.1.7.10 Blowing Down stage 3

The PLC will open stage 3 depressurization solenoid valve FV-349. The PLC will then monitor the pressure difference between stage 3 discharge PT-346 and the blowdown pressure PT-391. When this difference is below the setpoint, the PLC closes FV-349 and advances to the Blowing Down stage 4 step.

#### 5.1.7.11 Blowing Down stage 4

The PLC will open stage 4 depressurization solenoid valve FV-359. The PLC will then monitor the pressure difference between stage 4 discharge PT-358 and the blowdown pressure PT-391. When this difference is below the setpoint, the PLC closes FV-359. At this point the compressor can be started. However it may be that gas leaked backwards and pressurized the system. So the PLC will go back to Determining Status to make sure the compressor is fully depressurized.

#### 5.1.7.12 Verifying Buffer Tanks (Standby)

The PLC will have advanced to this step from the Determining Status step. The compressor is off, depressurized, and ready to start as needed. The PLC will now decide what to do based on the buffer tank pressures, whether a vehicle has connected to a dispenser and is about to fill, the volume of the vehicle tank(s), and whether the slow fill option is enabled.

If no vehicles are connected, slow fill option is disabled, and ALL buffer tank pressures are above the Compressor Start setpoints, the PLC will stay at this step.

If a vehicle connects to a GE Wayne brand dispenser with communications to the PLC, and this dispenser is drawing gas from the High Buffer Tank, the PLC will compare the amount of gas in the buffer tanks to the vehicle fuel tank volume. If there is enough gas in the high buffer tank to complete the fill, the PLC stays at this step. If the buffer tank pressure is too low to complete the vehicle fill, the compressor is preemptively started to get a head start so as to expedite the vehicle fill. The PLC will advance to the Checking Oil Press & Temp step.

If all of the buffer tank pressures are below the Compressor Start setpoints, they should be topped off so the PLC advances to the Checking Oil Press & Temp step. If slow fill is enabled the PLC advances to the slow filling step.

#### 5.1.7.13 Checking Oil Press & Temp

The prelube pump and oil heater are on warming the oil that is being diverted back to the crankcase oil sump. The PLC will verify the lube oil temperature is between 70 and 170 degrees F and verify not in the 10 starts per hour delay as permissives to continue. If the oil is too cold, the PLC will indicate a warning and stay at this step. If the oil is warm enough, the PLC will switch valve FV-526 to direct oil to the bearings, then check the bearing oil pressure at PT-532 for greater than 10 psig for 30 seconds as a permissive to advance to the Checking Blowdown Pressure step.

#### 5.1.7.14 Checking Blowdown Pressure

Next the PLC will check the blowdown tank pressure. If the tanks have less than the setpoint, typically 15 psig (this situation is abnormal and would happen at initial compressor system startup or after maintenance), the PLC will advance to Direct Filling. Otherwise the blowdown tank needs to be emptied so the PLC advances to the Starting Compressor on Blowdown Gas step.

#### 5.1.7.15 Starting Compressor on Blowdown Gas

If a compressor start was pre-emptive for a GE Wayne dispenser, FV-374 is opened. Otherwise FV-362 is opened. This is so the compressor discharge gas has somewhere to go. The PLC closes PCV-319, opens PCV-394, and starts the compressor, then monitors blowdown pressure PT-391. When this pressure drops below the Blowdown tank empty setpoint (typically 5 psig) the PLC will leave PCV-394 open for the overlap time and advance to the Direct Filling step.

#### 5.1.7.16 Direct Filling

The PLC has advanced to this step because pressures in the three buffer tanks have ALL dropped below the start setpoints OR a GE Wayne brand dispenser is drawing gas from the High Buffer Tank and the PLC has calculated that there is insufficient gas in the High Buffer to complete the vehicle fill. The compressor has been started and FV-374 is open. If the compressor discharge pressure PT-358 rises above the High Buffer stop pressure setpoint or 4700 psig, the PLC closes FV-374 and advances to the Filling High Buffer Tank step. If the GE Wayne dispenser stops drawing gas to check pressure before final top off, the PLC will temporarily open FV-370 to send gas to the Low Buffer Tank and keep compressor running until the dispenser goes back to its final top off.

#### 5.1.7.17 Filling High Buffer tank

The compressor is running. The PLC opens FV-362 then monitors PT-362. If the pressure rises above the high buffer tank compressor stop setpoint, OR compressor discharge PT-358 rises above 4700 psig, the PLC closes FV-362 then advances to the Filling Medium Buffer tank step.

#### 5.1.7.18 Filling Medium Buffer tank

The compressor is running. The PLC opens FV-366 then monitors PT-366. If the pressure rises above the medium buffer tank compressor stop setpoint, OR compressor discharge PT-358 rises above 4700 psig, the PLC closes FV-366 then advances to the Filling Low Buffer tank step. While in this step, if the High Buffer Tank pressure drops more than 100psi, the PLC will jump to the Direct Filling step.

#### 5.1.7.19 Filling Low Buffer tank

The compressor is running. The PLC opens FV-370 then monitors PT-370. If the pressure rises above the low buffer tank compressor stop setpoint, OR compressor discharge PT-358 rises above 4700 psig, the PLC typically closes FV-370, then does a final check of the Medium and High Buffer pressures. Even if these tanks are 99% full, the PLC will jump to their respective filling step to top them off. Otherwise the PLC turns off the compressor, and goes back to Determining Status step to perform a blowdown sequence and get the compressor ready to restart when needed. While in this step, if the High Buffer Tank pressure drops more than 100psi, the PLC will jump to the Direct Filling step.

#### 5.1.7.20 Slow Filling

Other steps will continuously watch for enabling of the slow fill feature. If the system is in the automatic process and the slow option is disabled, the PLC keeps FV-378 closed. If the slow fill option is enabled, the PLC will continue normal operations as usual with retail vehicle filling as the first priority. As the process nears the end of the low buffer tank filling, the PLC will open the slow fill valve FV-378 and monitor the compressor discharge pressure. If the pressure is below the Slow Fill Stop setpoint the compressor will continue to run filling a fleet of vehicles. If any of the buffer vessels drop below the Compressor Start setpoint, the PLC closes the slow fill FV-378 then waits for buffer tanks to replenish before resuming slow fill operations. Once the compressor discharge and all buffer vessels reach the Compressor Stop setpoints, the

compressor stops and the PLC goes back to step Determining Status step to perform a blowdown sequence and get the compressor ready to restart when needed.

#### 5.1.8 MONITOR OPERATION

The operator monitors the system for stable operation. The operator will listen for unusual noises, check the HMI for any warnings, and look for leaks or any other abnormalities. Refer to the Manual for details on monitoring the system as well as period maintenance procedures.

#### 5.1.9 UNATTENDED OPERATION

The systems can now be left alone to run automatically.

## 5.2 BACKGROUND CONTROLS

### 5.2.1 GAS TEMPERATURE

A four core air cooled heat exchanger provides discharge gas cooling for each of the 4 stages. Two fans are used to move air through this cooler based on ambient temperature and other sensors and setpoints. Discussions below cover how air is moved through this heat exchanger.

### 5.2.2 AIR DIRECTION

Temperature sensor TT-921 is used to measure outside ambient temperature. During warmer ambient temperatures the 15 HP motor (M-340) is run to draw air in the end wall louvers, across the container interior, and upward through the gas cooler. Both the end wall and roof louvers are open and the cold weather fan (M-360) is kept off. As ambient temperature drops M-340 will turn off and M-360 will start drawing air backwards down through the gas cooler. The roof louvers are kept open and the end wall louvers will close. This provides warm air to the interior of the container to help keep components above their minimum operating temperatures. The decision to switch air flow direction uses a two-setpoint deadband approach. For example, assume the low and high setpoints are 5 and 10 degF. When TT-921 is greater than 10 degF, upward air flow is used. If the temperature drops below 5 degF, the controls will switch to the downward air flow mode. Not until the temperature rises back above the 10 degF setpoint does the system switch back to upward air flow. This deadband logic prevents short cycling between the two air direction modes.

In addition to the above control method, while operating in Cold Mode, the PLC will run the Cold Mode fan (M-360) by controlling the VFD speed, and will speed up or slowdown in order to maintain the Cold Mode temperature set points associated with TT-334, TT-344, TT-354, TT-358, and TT-920. If the Cold Mode fan is running at 100% speed and ANY of the four compressor temperatures exceeds their respective Hot Mode setpoints, then the Cold Mode fan is not cooling the process gas adequately, so start the Hot Mode fan, turn off the Cold Mode fan and trigger a warning to the HMI "Cold Mode Fan Fail Temp Hi". The Cold Mode fan will be restored after the temperatures have been cooled below all respective Cold Mode setpoints. If sensor TT920 indicates a warning of TT920 Fault (out of range), the Cold

Mode fan control will continue as above, BUT without the use of the TT920 signal. The other 4 sensors are critical equipment temperatures. So for these, an out of range signal will result in a trip.

### 5.2.3 WARM WEATHER OPERATION

The main gas cooler fan, belt driven by a 15 hp motor (M-340) will start and stop automatically based on temperatures TT-334, TT-344, TT-354, and TT-358. This control loop TIC-358 is a simple on/off system with adjustable high (fan on) and low (fan off) setpoints via the touch screen. The logic is such that if ANY of the temperatures rises above its high setpoint, the fan will turn on. When ALL four temperatures drop below their respective low setpoints, the fan will turn off. The high/low setpoints are limited to within alarm setpoints to prevent nuisance warnings or trips. TT-334 setpoint range is from 220 to 300 deg F. TT-344 setpoints range from 220 to 300. TT-354 setpoints range from 220 to 280. And TT-358 setpoints range from 70 to 120 degF. To prevent short cycling the fan motor, the minimum hysteresis is 10 deg with the high setpoint acting as the "master". For example, if the setpoints are 250 and 280 and the operator changes 280 to 255, the low setpoint 250 will be force down automatically to 245. If the low setpoint is changed to 275 it will be force down to 270.

### 5.2.4 COLD WEATHER OPERATION

In this mode the cold weather fan M-360 is used with M-340 kept off and end wall louvers kept closed. This motor is driven by a variable frequency drive (VFD) to allow control of the air flow and thereby control of various temperatures. This variable control is required to prevent potentially over-cooling components during extreme cold operation (i.e. -40 degF). Five PID control loops and a voting system use compressor temperatures TT-334, TT-344, TT-354, TT-358 and the container interior temperature TT-920 for this method. All five of these temperatures will have an associated target setpoint. Each PID control loop will calculate a desired speed of the fan based on "where it is" (temperature) and "where it wants to be" (setpoint). The controls will then use the greatest of the five speeds to actually drive the fan. Basically the temperature control loop needing the most cooling gets the most cooling.

### 5.2.5 LOUVER DE-ICE & GAS DETECTION

The outside ambient temperature is monitored by TT-921. If this temperature drops below 34 degrees F the roof and end wall louvers are periodically cycled open then closed to prevent the buildup of snow and/or ice that may inhibit louver actuation.

Also the PLC monitors the level of methane inside the compressor container via the LEL detector AT-900. Should gas be detected above the high setpoint (typ 5% LEL) the roof and end wall louvers are commanded open to ventilate the compressor container. Only after the level drops below the low setpoint will the louvers resume normal operation.

### 5.2.6 SPACE HEATER

The 20 kW space heater, along with closing end wall louvers and insulation panels, are provided for cold weather operation. PLC control of this heater is provided by a dry

contact relay wired into the thermostat and overtemp circuitry provided with the heater. Eight temperature sensors (TT313, TT334, TT344, TT354, TT3542, TT3544, TT358, TT920) along with high & low setpoints are used in an On/Off deadband control scheme to control the heater. If ANY of the temperatures are below the corresponding low setpoint, the heater is turned on. When ALL temperatures are above their respective high setpoint, the heater turns off. The deadband prevents on & off short cycling the heater. If sensor TT920 indicates a warning of TT920 Fault (out of range), the space heater control will continue as above, BUT without the use of the TT920 signal. The other 7 sensors are critical equipment temperatures. So for these, an out of range signal will result in a trip.

### 5.2.7 EQUIPMENT TEMPERATURE MONITORING

During normal automatic operation between Determining Status and Slow Filling steps, if any of the critical equipment temperatures drops below its warning setpoint and a warning is indicated, compressor starting is disabled and the operation sequence is forced back to the Verifying Temperatures step. Once the equipment has warmed back up and all the low temperature warnings have cleared, normal automatic operations resume.

### 5.2.8 OIL COOLER

While the oil pump OR the compressor is running, oil temperature sensor TT-526 is used along with high & low setpoints for deadband on/off control of the oil cooler fan. The deadband prevents on & off short cycling the cooler motor.

## 5.3 NORMAL SHUTDOWN

### 5.3.1 PERFORM SHUTDOWN

The operator wishes to shutdown the compressor system in an orderly manner. The operator accesses the MAIN screen on the HMI. If the compressor system is operating automatically, the STOP button will appear. The operator presses this button, and the PLC jumps to the Determining Status Step.

#### 5.3.1.1 Stop Compressor

This is actually the Determining Status Step. The PLC turns off the compressor and gas cooler, turns on the prelube, switches FV-526, and closes all other the valves with the exception of the 3 buffer tank isolation valves. FV-365, FV-369, and FV-371 remain open to allow gas to flow from buffer tanks to the dispenser. If there is gas in the compressor a blowdown is required so the PLC advances to a blowdown sequence, then returns here with the compressor blown down. Because a stop was selected the PLC goes back to the waiting for start step.

#### 5.3.1.2 Waiting for Start

This is the exact step covered above. The compressor system is off and the operator can restart anytime or access the Maintenance Mode at will.



## **5.4 CONTROL SYSTEM INITIATED EMERGENCY SHUTDOWN**

The PLC has the ability to shutdown the compressor system by turning off all outputs. The PLC can also trip the main breaker by opening the under-voltage latch circuit with relay CR-901. This provides redundancy to the hard wired ESD circuit. Dropping the main breaker is desired under certain emergency shutdowns.

### **5.4.1 GAS DETECTION**

The hard wired LEL high high trip relay interrupts power to the under voltage latch thereby cutting the main breaker. Along with the LEL hard wired trip relay, the gas monitor provides a 4-20mA analog input signal to the PLC for warning, trending, and PLC initiated shutdown. If the signal rises above the trip setpoint, the PLC will turn off all outputs just like any other trip. The PLC will also de-energize relay CR-901 which will trip the main breaker.

### **5.4.2 COMPRESSOR DISCHARGE PRESSURE HIGH**

Typical high pressure trips will turn off controller outputs that will stop all motors. However, there exists the possibility that the compressor soft start SCRs could short out. This means even though the PLC commands the compressor to stop, it may continue to run. The PLC can detect this by discharge pressure and/or by communications with the soft starter. Should either of these situations indicate the compressor is still running, the PLC will turn off all outputs just like any other trip AND de-energize relay CR-901 which will kill the main breaker.

### **5.4.3 POWER LOSS**

The UPS has a power loss relay that is wired to a PLC discrete input and is used to monitor and react to grid power loss. If the PLC detects a power loss, it will continue to function on UPS power and turn off outputs.

However, to allow for an automatic restart after a short power outage, the PLC will leave the main breaker ON by NOT dropping the under voltage latch via CR-901.

If the power outage is longer than approximately 25 minutes, the UPS batteries will be depleted and the system will power down completely including loss of the main breaker. This will require personnel to physically be at the site to restart the system.

If utility power is restored before the UPS is depleted, the PLC will automatically go back to where it was at the time of the outage. This includes automatically restarting the compressor system if it was in automatic operations mode.

### **5.4.4 OTHER SHUTDOWN ALARMS**

All the other PLC shutdowns will turn off outputs, leave the PLC powered, and leave the main breaker on. Refer to drawing MG120-00907 for detailed descriptions of all the hardware and software interlocks, alarm warnings, and alarms trips.

## **5.5 EMERGENCY SHUTDOWN**

The emergency stop system is a hard wired circuit that operates independent of any controller software. Power source for this circuit is the UPS. Wired in series are the ESD pushbuttons, the LEL trip relay, fire detection temperature switches, and the PLC driven relay CR-901. NOTE: the PLC and LEL remain powered even during an emergency shutdown.

### **5.5.1 CONTROL POWER SWITCH**

If the power switch is off power into and out of the UPS is disconnected. This cuts power to everything except the line side of the main breaker and control power switch. The PLC, all instruments, valves, motors, main breaker, and under voltage latch will turn off.

### **5.5.2 ESD PUSHBUTTONS**

If any of the ESD buttons are pressed, their contacts will open and the main breaker will trip via the under-voltage latch. Permit outputs relay CR-902 coil will be de-energized thereby cutting power to outputs, isolation valves (causing them to fail closed), and the dispenser(s) (or dispenser ESD circuit).

### **5.5.3 LEL GAS MONITOR**

If the LEL detects gas above 25% LEL, its high high trip relay contacts open and the main breaker will trip via the under-voltage latch. Permit outputs relay CR-902 coil will be de-energized thereby cutting power to outputs, isolation valves (causing them to fail closed), and the dispensers. The LEL remains powered up. Once the LEL percentage returns below 10% the LEL gas monitor must be reset by pressing the button below the LEL monitor on the side of the control panel, then the HMI can be re-set.

### **5.5.4 FIRE DETECTION**

Two fire detection temperature switches are provided that are hard wired into the ESD circuit. If either switch detects temperature above 190 degrees F. the main Breaker trips via the under voltage latch.

### **5.5.5 PLC RELAY CR-901**

If the power switch is on, ESDs are out, no high fire detection temperature is detected, no gas is detected above the LEL trip setpoint, and the PLC does not detect any shutdown trips, the PLC will energize CR-901 to allow the engagement of the main breaker. This circuit will also energize the permit outputs relay CR-902 that will connect power to output control circuits. The PLC continues to monitor the system, buffer tank isolation valves remain open, and the dispensers are able to make CNG sales if there is sufficient gas in the buffer tanks. If the PLC detects any ESD fault that requires an emergency trip, it will turn off all output AND de-energize relay CR-901 causing the main breaker to trip via the under voltage latch. CR-902 will also de-energize thereby cutting the power source to outputs. This provides for some redundancy to the PLC turning off the outputs via the I/O module. The PLC remains powered up.

## **5.6 MAINTENANCE MODE**

### **5.6.1 ACCESS**

If the system is at the Waiting for Start step, access to the maintenance mode feature is allowed. During automatic mode of operation, access to this feature is prohibited. This is to prevent manual actuation of valves or motors that are under control of the PLC and need to be left in automatic mode.

### **5.6.2 TESTING**

In maintenance mode, personnel can monitor and test inputs and actuate outputs individually to verify repairs.