

# **The Control of an Oil Injected Screw Compressor Package Deployed in a Naphtha Cracking Process**

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## **Abstract**

Oil injected screw compressors are now commonly used in oil and gas applications. The nature of these applications is such that the end users require a package that is not only safe and reliable but also efficient. While the mechanical engineers strive to derive marginal gains from this maturing technology huge efficiency savings can be lost from a poorly controlled package or worst still: a package running in “manual” mode.

This paper first describes the problem faced by outlining the desired control philosophy from the end users perspective. The paper then leads onto an in-depth description of each major component within the control system so an understanding of how each of the individual components work can be gained. As the final location of the package is in an extremely hazardous environment, a highly corrosive marine environment, and the compressor itself is compressing highly combustible hydrocarbon gas, the protection methods employed by the instruments to prevent explosion is then discussed.

The multiple communications networks that allow the condition monitoring system to send its values to the package control system and to the client’s distributed control system are also discussed. This discussion includes how the measured values make their way from the stand alone machine condition monitoring system to the compressor control system and how the two systems integrate with each other to protect the package before annunciating the system status to the client's distributed control system. The subsequent part explains how these individual components are then controlled by the package control system to achieve the desired philosophy with a focus on tuning the automatic pressure control system.

## **Desired Control Operation**

This paper details the control philosophy for the Howden low pressure methane compressor package being supplied to CTCl Corp for the CPC number 6 Naphtha Cracker project at the Linyuan refinery in Taiwan. This compressor package consists of a screw compressor; associated lube oil system; main drive motor; safe area Unit Control Panel (UCP) and a skid edge pressurised Local Control Panel (LCP). This screw compressor package was installed late in 2013 and successfully commissioned in early 2014.

The number 6 naphtha cracker at the Linyuan refinery is used primarily in the production of olefins (ethylene / ethene, propylene / propene and butadiene). Before the construction of the number 6 naphtha cracking plant, the self-sufficiency rate of ethylene in Taiwan was only 38%. As a direct result of this project, the self-sufficiency rate is now above 90%. The compressor package in this paper is deployed to take low pressure methane gas from a vessel within the process, compress it, and send it forward into the process fuel gas line. A recycle line, joining the discharge pipework to the suction pipework will be crucial to the stable operation of the machine.

Under normal operating conditions, the compressor control system is configured to operate to maintain a set suction pressure after having first performed a prestart sequence by getting the oil system up to the correct pressure and temperature. To achieve the desired suction pressure the compressor control system first measures a process variable which in this case is the suction pressure transmitter. Depending on the pressure value measured the control system then has to operate a recycle control valve and a compressor slide valve.

The re-cycle control valve functions as a trimming valve under programmable logic controller (PLC) proportional, integral and derivative (PID) loop control during compressor running and as an equalising valve alongside the solenoid activated unloading valve when the compressor is not running. The unloading valve is triggered when the package is stopping or tripping to de-pressurise both the suction and discharge lines. The recycle control valve, which is located between the suction and discharge lines, fully opens to allow the pressure in both the lines to equalise.

The suction pressure set-point along with the PID gains can all be inputted to the PLC via the supervisory control and data acquisition (SCADA) system supplied with the package. To test the operation of the recycle control valve, the SCADA system operator can put the valve into manual mode and manually input a valve position set-point in %. An operator in the field can then visually verify if the valve moved to the desired position before putting the valve back into automatic control.

Once the compressor has started running and the main drive motor has reached full speed, the recycle control valve will automatically start to control the suction pressure. If the suction pressure is below the set-point the recycle control valve, under the control of the PID block within the PLC, will start to open to feed some of the high pressure discharge gas back to the suction side to allow the suction pressure to build up. As the pressure builds back up the recycle valve will start to close again [1].

During normal compressor running conditions, the recycle control valve operates in conjunction with, but provides finer control and operates with a tighter dead-band than, the compressor slide valve. The compressor slide valve regulates the gas flow of the compressor when it is running.

The slide valve is moved by a double acting hydraulic cylinder. The cylinder is controlled using two load and two unload solenoid valves. The solenoid valves which control the slide valve cylinder are supplied from the compressor lube oil system for hydraulic power.

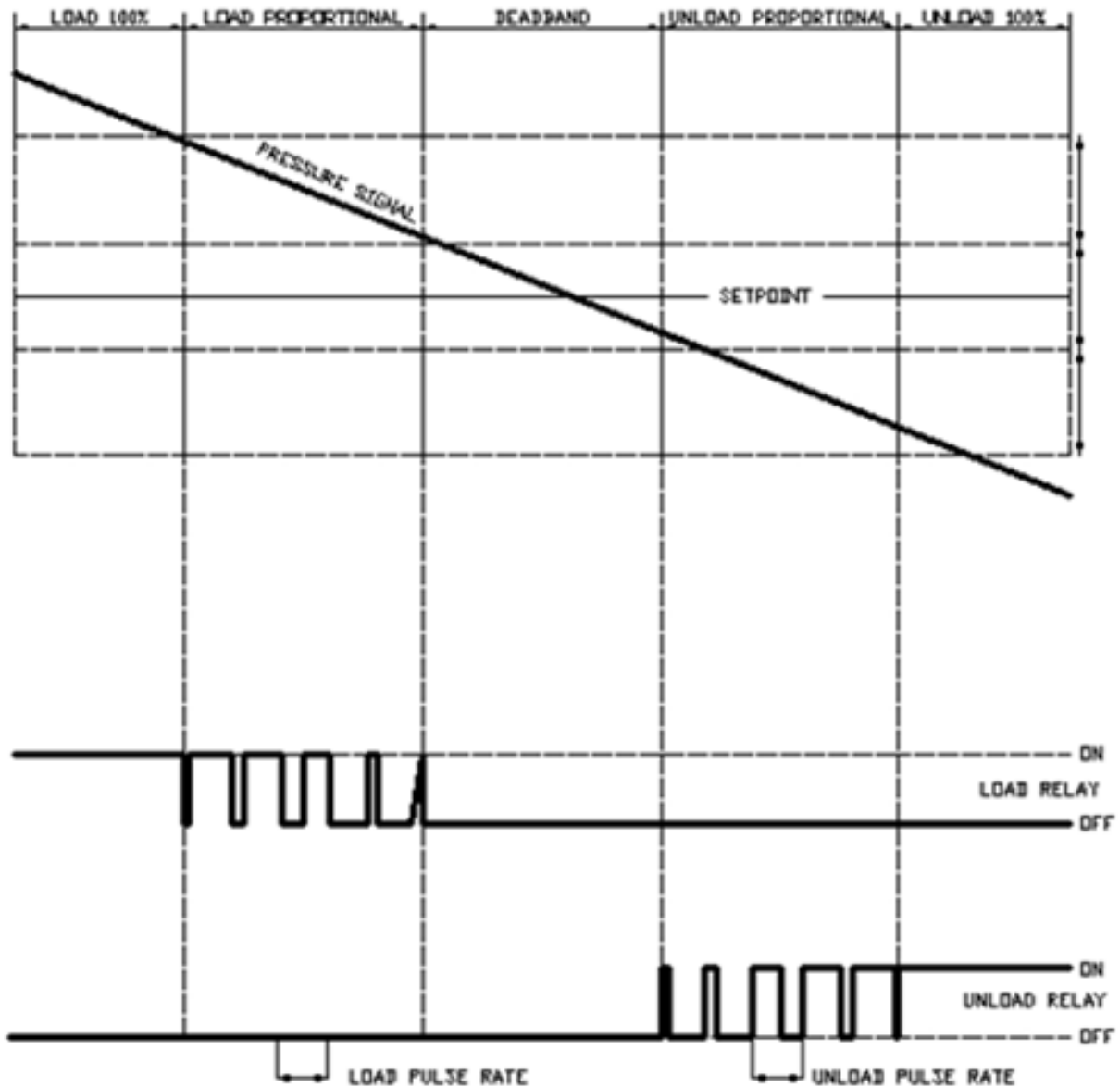


Figure 1: Slide valve loading and unloading pulse rate varying with a pressure signal error

The slide valve operates in conjunction with, but provides coarser control and operates with a wider dead-band than, the recycle control valve and again the main drive motor must be running before automatic pressure control using the slide valve is enabled.

As with the recycle control valve, the slide valve controller parameters are modified on the SCADA system.

When slide valve control is indeed enabled and all the interlocks are satisfied the PLC will automatically adjust the slide valve position by switching the load and unload solenoids to maintain the discharge pressure within the controller dead-band. As the slide valve moves in and out to adjust the gas flow through the machine a linear position indicator (LPI) detects the slide valve position, in %, and feeds it back to the PLC for display on the SCADA screen. A slide valve is described as being “fully open” or “totally unloaded” at 0% whereas at 100% it is described as “fully closed” or “totally loaded”.

During the compressor pre-start sequence the recycle control valve is driven fully open by the PLC and the slide valve unload solenoids are energised to drive the slide valve fully open. Once the LPI detects the slide valve is less than 5% the solenoids are de-energised. This is to ensure when the compressor starts it is starting unloaded and not trying to send any gas forward against a head which would increase starting torque and main drive motor current.

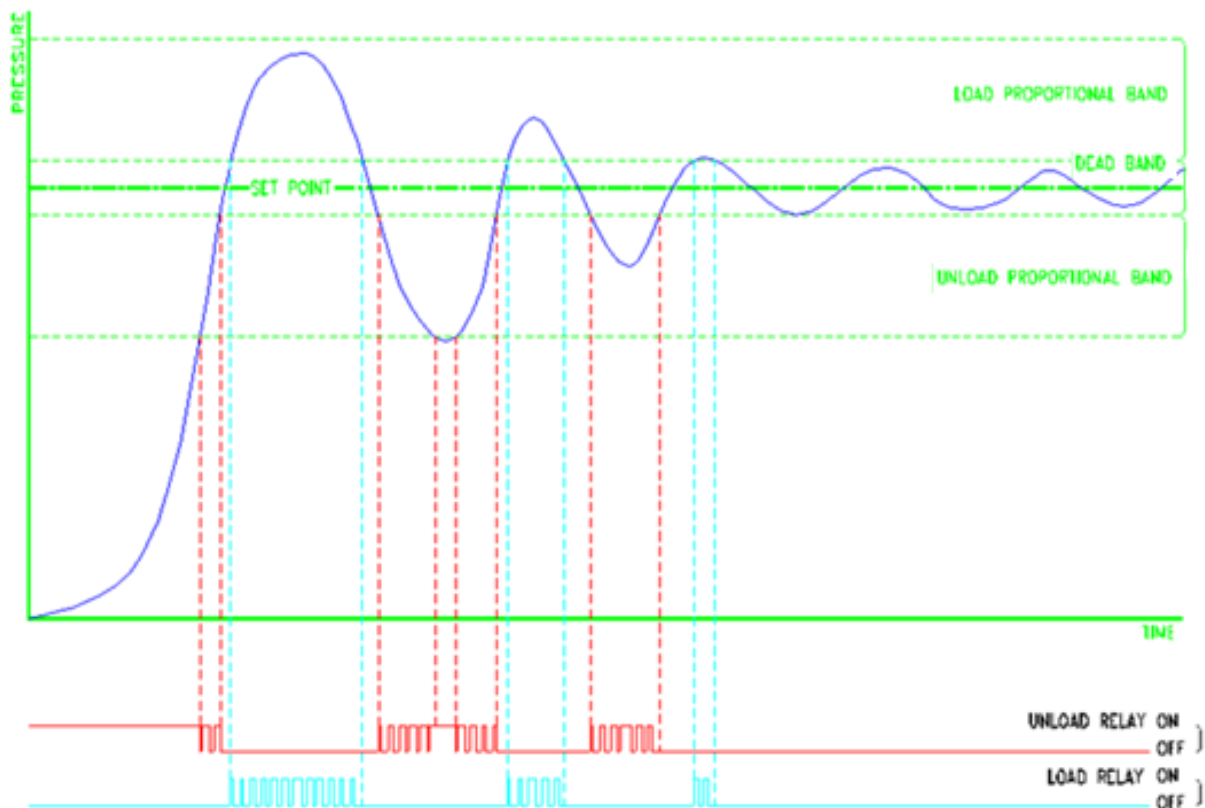


Figure 2: Slide valve load and unload signals in relation to a modulating suction pressure

Once running in automatic control the slide valve controller in the PLC software compares the input signal from the pressure transmitter with the set point value. The loading and unloading relays are energised depending on the outcome of the comparison.

A suction pressure measurement lying above the load proportional band setting results in a continuous load signal being produced. As the pressure measurement passes into the load proportional band the load signal begins to pulse off and as the pressure measurement continues to fall, the mark space ratio of the load signal reduces linearly until, at the edge of the dead band, the control action is nil. If the suction pressure measurement is within the dead-band no slide valve control is enabled with all pressure control being done by the recycle control valve. If the pressure measurement falls into the unload proportional band the unload signal begins to pulse on and as the pressure measurement continues to fall, the mark space ratio of the unload signal increases linearly until, at the edge of the unload proportional band it is always on.

When the package comes to a normal stop the following actions are performed automatically by the PLC: The unload solenoids drive the slide valve back to its minimum position. Once the slide valve is at minimum position (or a pre-determined timer has timed out, if minimum position not reached), the PLC system will open the stop signal to the MCC for the main motor. The suction pressure alarm is inhibited then the compressor unloading valve is now automatically opened by the PLC system to remove the high discharge pressure and prevent reverse rotation of the machine. The PLC system will fully open the gas recycle valve and the oil/gas differential pressure trip bypass circuit is enabled and associated alarm inhibited. The lube oil manifold circulating valve is now automatically opened and the manifold isolation valve closed by the PLC system to allow the lubrication oil to get back to the primary separator rather than into the compressor working chamber. The PLC system will lock the oil/gas differential pressure control valve at the 50% position then open the compressor drain valve to allow oil to drain from the working chamber back to the primary separator. The PLC system will re-enable the oil heater circuit. The oil is now being heated and circulated around the system again (duty lube oil pump will still be running) in preparation for a machine restart.

In the event of an automatic process trip occurring, the PLC will be latched in the trip state. This latched state can be re-energised by pressing the trip reset button on the annunciator, after all relevant trips have been returned to the healthy state. Tripped states are also automatically reset during the start sequence prior to starting the main drive motor.

When activated by one of the safety trip circuits, the main motor 'Stop' signal to the motor

control centre (MCC) will become open circuited thus stopping the main motor instantaneously. In addition to the hard-wired trip action, the PLC system will immediately activate the following sequence of events: Initiate the compressor stop sequence, detailed previously, then the PLC system will trigger the relevant trip message on the HMI PC and annunciator on the LCP. After the shutdown logic has been initiated, the PLC will prevent a reset of the trip circuit for a pre-determined time period. After this period has elapsed and the associated trip alarms have returned to the healthy state, the operator can then reset the trip circuit by pressing the trip reset button on the LCP's annunciator controls. After any faults or trips associated with the shutdown have been fully investigated and rectified, the operator will be free to restart the compressor. The oil is now being heated and circulated around the system again (duty lube oil pump will still be running) in preparation for a machine restart. This completes the trip shutdown sequence.

An emergency shutdown can be initiated by the local package emergency stop or the client control room emergency stop by the PLC control system within the safe area control panel. When activated by the PLC, the main motor start request signal to the MCC will become open circuited thus stopping the main motor in a controlled manner. The PLC system will trigger the relevant emergency stop message on the HMI PC and annunciator on the LCP.

### **Control System**

The compressor package, incorporating the local control panel, is designed for use in a Zone 2 hazardous area according to IEC 60079-10-1, the unit control panel is designed for use in a safe area. The end user has classified the zone as a zone 2 environment which, according to IEC 60079-10-1 is a place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only [2].

There is one single location for starting and stopping the package: from the skid edge LCP. Sequence control can be initiated from only the skid edge LCP. This allows the operator to initiate compressor pre-start or compressor start/stop sequences via the local control panel push buttons. Maintenance functions, such as manual control of the pumps and heater can also be selected from the LCP. The LCP also features LCD indication of the major process values, such as suction, discharge and oil pressures and temperatures, to enable the operator in the field can evaluate the performance of the package without contacting the control room to interrogate the SCADA system. An alarm annunciator window is also installed to highlight process alarms and trips to the local operators, again without having to contact the control room.



Figure 3: Showing the IEC 60079-2 Ex p pressurised local control panel with maintenance functions

Additionally, maintenance functions can also be selected from the HMI allowing control operators to stroke the package control valves (Recycle control valve, suction isolation valve, discharge isolation valve and the oil-gas differential pressure control valve) as required during plant maintenance checks.

An Invensys Trident triple modular redundant fault tolerant series PLC and a RSView powered HMI PC are supplied with the control panel to provide automation control and operator interface, and to gather information from the machine monitoring system and provide a communication interface point with the DCS.

A Bently Nevada 3500 system monitors the main motor bearing temperature; the compressor casing vibration; compressor bearing temperatures and the compressor rotor axial displacement and initiates a hard-wired trip of the package if any of these parameters

exceed the shutdown limits. The machine monitoring system signals, alarms and trips are transmitted to the PLC for display on the HMI and re-transmission to the DCS.

In this particular application there is no need for a dedicated hardwired trip circuit as all trips are adequately handled by the SIL 3 rated PLC system. The PLC continuously monitors the process instrumentation not only for alarm and control but also for display on the HMI and re-transmission to the DCS for operator information.

Again the PLC system is capable of monitoring the package emergency stops in this instance negating the need for a dedicated hardwired emergency stop circuit. Each low voltage motor has its own emergency stop system provided which can be wired back to the motor starter cabinet. A package emergency stop is also provided at the LCP and the DCS.

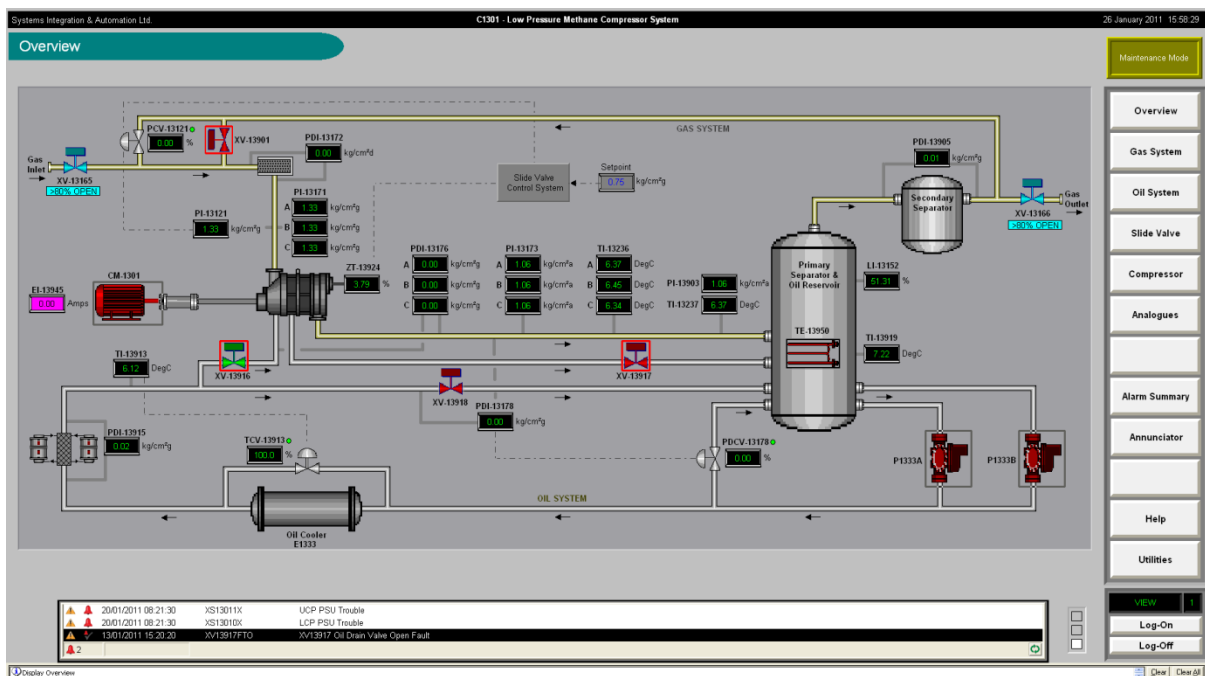


Figure 4: The SCADA system overview screen displaying the main process parameters

The manual Purge of the LCP must be completed before power is applied to the circuits within the LCP. The user is responsible for ensuring that this equipment is not operated in an unsafe condition and the electrical power to these circuits must be isolated, at the point of supply, in the event of clean-air purge supply failure.

### Protection Concepts

Previously mentioned in the text is the zone classification, zone 2, of the area the package is deployed within. As the package contains many instruments and control equipment a few protection concepts were employed in order to prevent a catastrophe. Firstly, all of the



process instruments such as the pressure, level and temperature instruments were all certified Ex d. The lubrication oil pumps and the oil heater were also certified Ex d. A flameproof enclosure (Ex d) is defined as an enclosure in which the parts which can ignite an explosive gas atmosphere are placed and which can withstand the pressure developed during an internal explosion of an explosive mixture, and which prevents the transmission of the explosion to the explosive gas atmosphere surrounding the enclosure [3].

The machine condition monitoring instruments were certified Ex ia. Intrinsically safe protection type (Ex ia) is defined as a type of protection based on the restriction of electrical energy within the apparatus and of interconnecting wiring exposed to the potentially explosive atmosphere to a level below that which can cause ignition by either sparking or heating effects [4].

Lastly the LCP was purged with clean dry air and certified Ex p. Pressurization is defined as a technique of guarding against the ingress of the external atmosphere into an enclosure by maintaining a protective gas therein at a pressure above that of the external atmosphere [5].

## **Communications**

An extensive communication network is installed within the UCP to allow all the information to get to where it needs to go. From Figure 5 it can be seen that the two PLC racks have three interconnect cables transmitting input / output messages, logic power and system power between each rack.

The nature of the PLC installed meant that two of the three cables could be removed or damaged and the PLC would still continue to operate. The information was passed between the two racks on a proprietary protocol.

A redundant communication connection between the PLC and the clients DCS is installed. This comprised of two RS485 physical connections transmitting information between the PLC and the DCS using Modbus RTU protocol. The RS485 standard is a key component in transferring information digital information between control system terminals [6]. Again, if one of the communications links between the PLC and the DCS was removed or damaged, the remaining link will continue to operate. The DCS is configured as the Master, whereby it schedules the messages backwards and forwards between the two nodes, and the PLC is the Slave. The SCADA or HMI terminal is connected using a Cat 5 cable to the PLC through a network switch. It uses TCP/IP protocol to send data back and forth between the SCADA terminal and the PLC. The SCADA software contains an OLE for process control (OPC)

database and the PLC reads and writes information to the address tags within the database allowing the PLC and SCADA to communicate easily.

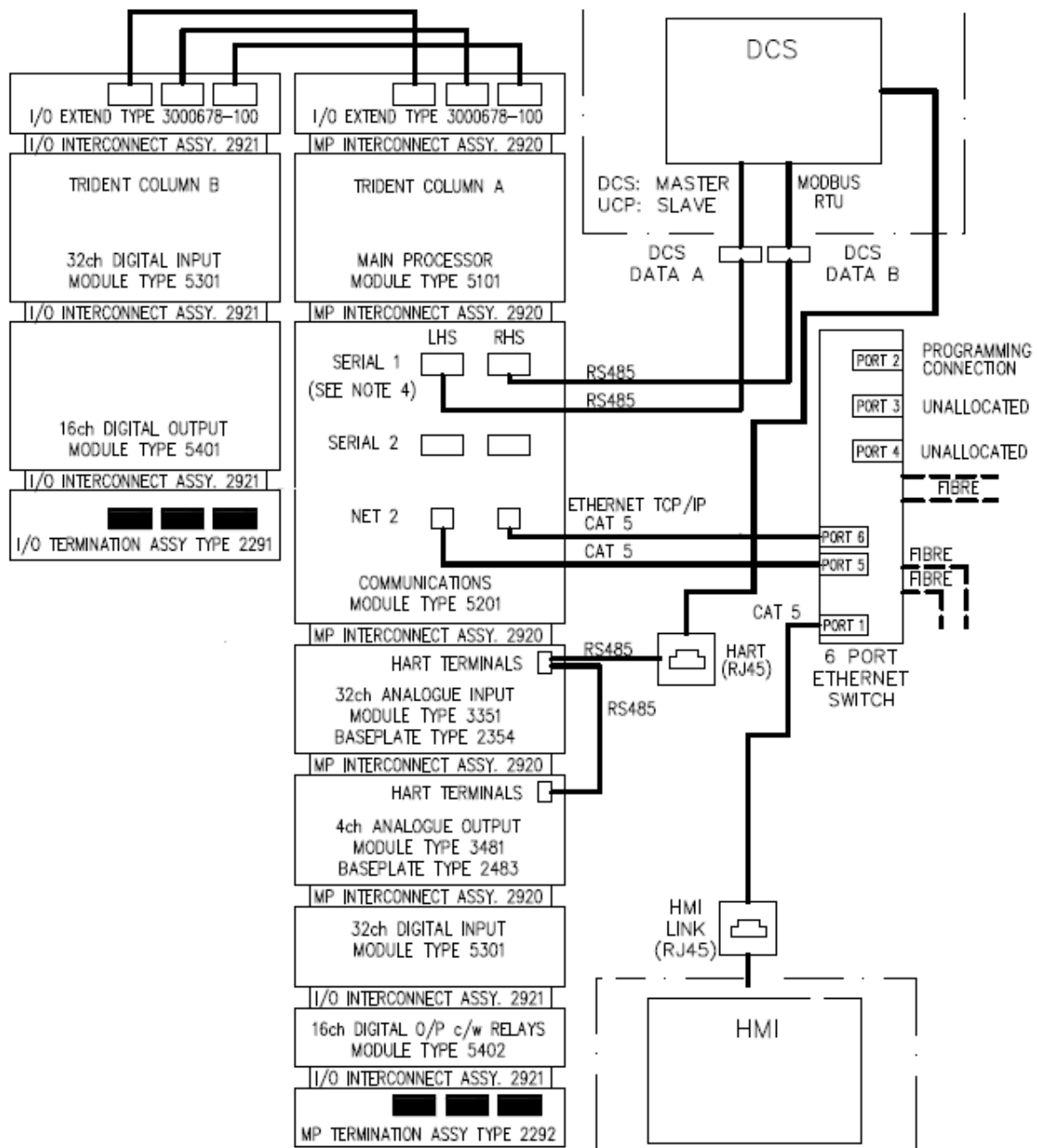


Figure 5: The communications network within the unit control panel

Lastly, a Highway Addressable Remote Transducer (HART) module is installed in the PLC. This communicates with the clients DCS to it to remotely configure and view the health of the process instrumentation connected to the PLC [7]. As this is not a critical application, only one communications link is installed.

## **Conclusion**

This paper first described the control philosophy of the package within the cracker process. The paper then lead onto an in-depth description of the major components within the control system with a focus on the suction pressure control apparatus. The protection methods employed by the instrumentation to prevent catastrophic failure and potentially loss of life, was then discussed.

The multiple communications networks that allow the condition monitoring system to send its values to the package control system and to the client's distributed control system are also discussed. Keeping the above in mind, it should be clear to the reader that the instrumentation and control system used to control a compressor, that compresses hydrocarbon gas in a modern refinery process, is a highly complex system with many critical components vital to a successful installation.

## **Publications:**

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