PROCESS MODELLING AND CONTROL
LABORATORY MANUAL

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November, 2002

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CHAPTER 1

Introduction

The document gives an overview of the different components associated with the implementation of a data acquisition and control system, to enable the control of the experimental setups with the use of the computer. This was achieved through the centralised implementation of an analog to digital (A/D) and digital to analog (D/A) conversion instrumentation called the OPTO22 SNAP I/O range.

Certain protocols or methods were accordingly defined to standardise the implementation of the physical wiring and the software used, and this document discusses these methods. Some practical issues surrounding the implementation an control system on an experimental setup is also discussed.

The document is divided into the following chapters:

Chapter 2 gives an overview of the different issues surrounding the measurement and control of a "real" process.

Chapter 3 discusses the different software components, and their interaction, used in the acquisition of the data and the control of the different experimental setups.

Chapter 4 defines the protocols and methods used for the analog wiring of the instrumentation.

Chapter 5 discuss the different documentation types used in documenting the data acquisition and control system as well as the data base that was developed to store the relevant information.

CHAPTER 2

Measuring and control devices

The different issues surrounding the measurement and implementation of an analog control system is discussed. This includes the filtering of noise, the analysis of instrument error and a generic procedure for the calibration of the instrument.

A theoretical discussion on cold junction compensation for thermocouple measurement is also given.

2.1 Noise and filtering

Noise is characterised by high frequency disturbances with a zero net effect on the measurement and arises from a number of sources such as (Seborg et al., 1989:538):

i) the measuring device,

ii) electrical equipment such as a.c. power circuits, generators and turbines,

iii) that inherently part of the process (i.e. boiling liquid level measurement).

The *noise* generated by these sources degrades the signal condition that is used for the control of the process. This will cause a decrease in controller performance, especially for controllers that use an approximation of the derivative error. The *noise* can however be removed from the incoming signal as it contains no valuable information (Marlin, 2000:389) for control. Noise is mainly reduced by using proper shielding and grounding or *filtering*.

Two types of filters can be identified (Richardson & Peacock, 1994:539) and are *analog filters* or *digital filters*. The *analog filters* are implemented as electrical networks and is used to *condition* (i.e. to remove or minimize the noise) continuous signals. *Digital filters* are implemented as software on the computer and *condition* sampled data signals (Richardson & Peacock, 1994:539). The theory on which both filters are based, are the same although the implementation may differ.

The filter calculation usually employed in the chemical processing industry is a first order lag or *low pass filter* (Marlin, 2000:390). Its operation can be described by an differential equation of the form:

$$\tau_f \frac{dy(t)}{dt} + y(t) = x(t) \tag{2.1}$$

with $x(t)$ the data to be filtered, $y(t)$ the raw measurement and τ_f the filter time constant. The equivalent transfer function description is:

$$\begin{aligned} x(s) &= \tau_f y(s)s + y(s) \\ \therefore \quad y(s) &= \frac{1}{\tau_f s + 1} x(s) \end{aligned} \tag{2.2}$$

The gain of the filter is one as the filter must not influence the measurement other than reducing the high frequency noise.

The discrete implementation of the filter can be derived and is known as an *exponential filter* (Seborg et al., 1989:539):

$$\begin{aligned} x_n &= \tau_f \frac{y_n - y_{n-1}}{\Delta t} + y_n \\ \therefore \quad y_n &= \frac{\Delta t}{\tau_f + \Delta t} x_n + \frac{\tau_f}{\tau_f + \Delta t} y_{n-1} \end{aligned} \tag{2.3}$$

The general exponential filter can be written by defining:

$$1 - \alpha \triangleq \frac{\tau_f}{\tau_f + \Delta t} \tag{2.4}$$

to give,

$$y_n = \alpha x_n + (1 - \alpha) y_{n-1} \tag{2.5}$$

A frequency plot (Bode plot) of the *low pass filter* shows (figure 2.1) how the fact that the magnitude drops rapidly can be used to reduce the effects of noise by ensuring that the filter gain is small at the frequencies where noise is encountered.

The filter time constant is used to determine the magnitude at the specified frequency. The filter time constant can, for example, be increased to filter lower frequency noise.

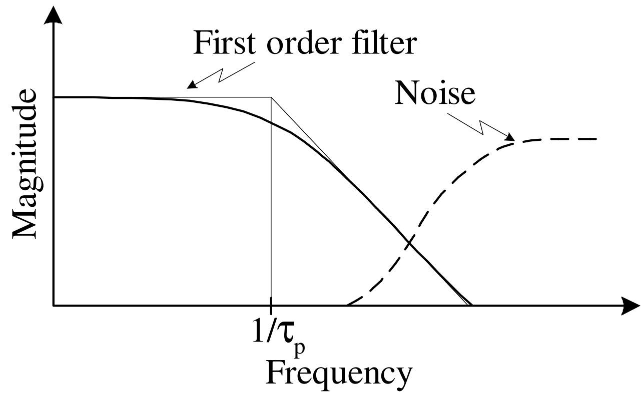


Figure 2.1: Low pass filter

Example 2.1: *A sinusoidal noise measurement with a frequency of 10 rad/s and amplitude of 0.1 is shown in figure 2.2. A low pass filter can therefore be designed to reduce this noise.*

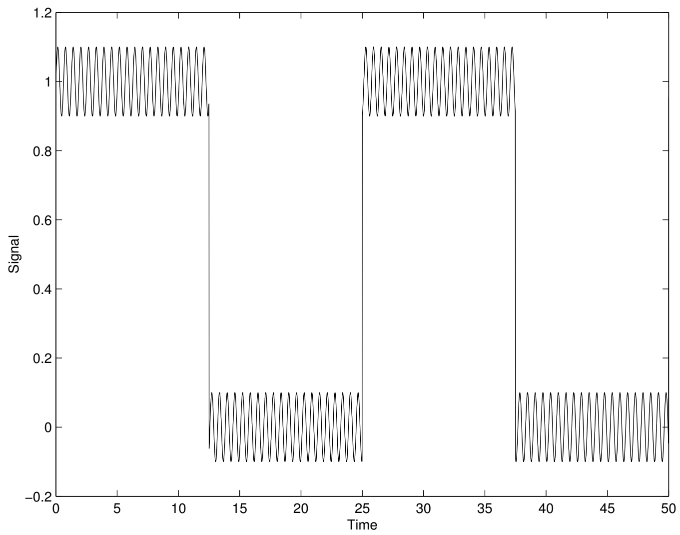


Figure 2.2: Raw measurement data

A filter that will reduce the noise by 80% is developed by firstly specifying the filter gain (G_f):

$$\frac{x(s) - y(s)}{x(s)} = 0.8$$

$$\therefore \quad G_f = \frac{y(s)}{x(s)} = 0.2$$

and secondly determine the filter time constant (τ_f), using the magnitude frequency response of the filter transfer function:

$$G_f = \frac{1}{\sqrt{1+\omega^2\tau^2}}$$

$$\therefore \quad \tau_f = \frac{\sqrt{(\frac{1}{G_f})^2 - 1}}{\omega} = \frac{\sqrt{(\frac{1}{0.2})^2 - 1}}{10} = 0.5$$

to give the low pass filter:

$$G_f = \frac{1}{0.5s+1}$$

The filter can accordingly be placed in series with the measured data to condition the signal and the resultant output signal can be seen in figure 2.3. It can

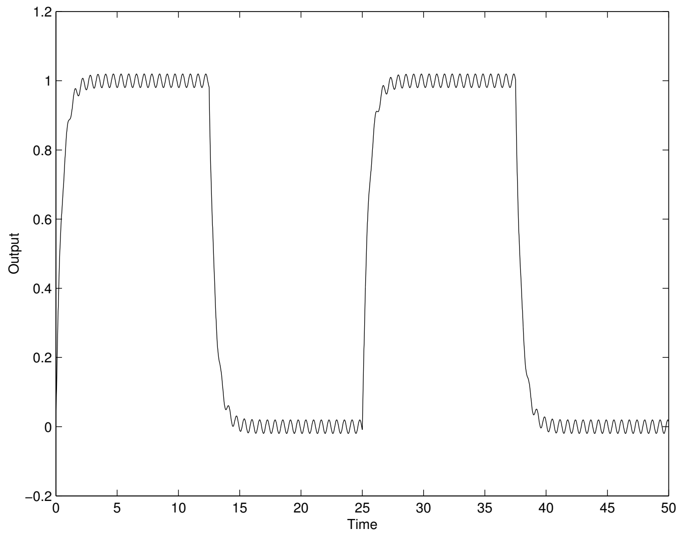


Figure 2.3: Filtered data

be noted that the filter will, however, slow the response of the signal measurement and is slowed more as the signal is filtered more. The degradation of the measured signal due to noise and that due to the implementation of the filter must therefore be optimised.

Signals used for compressor surge control will, for example, not be filtered as rapid large changes can occur that needs immediate action, while level measurement of a storage tank can be filtered more as the process dynamics are slow. ■

2.2 Sensor and actuator calibration

A sensor or actuator is usually calibrated by adjusting the low range output value or *zero* as well as the *span* of the measurement or control. A generic procedure for the calibration of a measuring or control device is given, but it should be noted that the different manuals for the instrumentation should be consulted for more specific details.

Step 1: Set the measured property or the actuator to its minimum input. A tank can, for example, be emptied if a level measurement device is calibrated or a thermocouple can be placed in ice it the temperature measurement is calibrated. The minimum signal output (i.e. 4 mA or 1 VDC) is set by adjusting the ZERO setting of the instrument.

Step 2: Set the measured property or the actuator to its maximum input (i.e. fully fill the tank for level measurement calibration) and adjust the RANGE setting to obtain the correct maximum output (i.e. 20 mA or 5 VDC).

Step 3: Set the measured property or the actuator to half of its maximum input and check the output to see if the output is linear or non–linear.

Step 4: Obtain a mathematical correlation for the sensor or actuator output to the measured property should Step 3 show that the measurement or actuator output is non–linear. This is done by setting the measured property or actuator at different values between the maximum and minimum values and tabulating the corresponding output values.

2.3 Sensor and actuator characteristics

A brief description of the more important characteristics of measurement and control instrumentation, follows. The definitions of theses characteristics is of great importance when deciding on the type of instrument to be purchased, or identifying some current control issues for the task at hand.

2.3.1 Range, span and turndown

Range is the region over which a quantity may be measured (input range) or transmitted (output range) and is defined by stating the lower and upper range values.

Span is the magnitude of the range of the instrument (i.e. the difference between the upper and lower range values).

Turndown is the ratio of the upper range value to the lower range value (Richardson & Peacock, 1994:529).

2.3.2 Sensitivity

The *sensitivity* of a measuring instrument or actuator is the ratio of the change in magnitude of the output signal corresponding to the change in the magnitude of the input; after a steady state has been reached(Richardson & Peacock, 1994:529).

Example 2.2: *Consider a typical thermocouple for which the voltage output, E, is given by the following expression:*

$$E = \beta_0 + \beta_1 T + \beta_2 T^2$$

where T is the temperature and β is the temperature coefficient. The sensitivity of the thermocouple can therefore by derived, by differentiation, to obtain:

$$\frac{dE}{dT} = \beta_1 + 2\beta_2 T$$

and shows that the sensitivity of this instrument is a linear function of temperature.■

2.3.3 Resolution

Resolution is the minimum difference in the values of a quantity that can be discriminated by a device. Care should be taken to specify instrumentation with the correct for the application at hand, as more sensitive equipment invariably costs more—but effective control cannot be obtained with a measurement that has a too low *resolution*.

2.3.4 Repeatability

Repeatability gives an indication of the closeness of agreement among a number of consecutive measurements for the same value of input conditions, under the same operating conditions and approached from the same direction for the full range of the instrument (Richardson & Peacock, 1994:530). The direction of approach must be specified as the instrument might have *hysteresis* where there is a difference in the measurement of the device for the same input condition depending on whether the measurement is increasing or decreasing (figure 2.4).

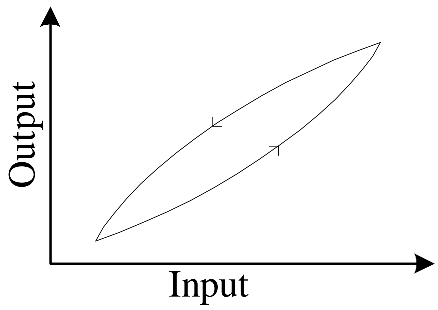


Figure 2.4: Hysteresis of a measuring device

2.3.5 Measurement error

Measurement error of an instrument is the difference between the actual measurement and the true value. The measurement error of instrumentation can usually be described with a Gaussian or normal distribution that relates the frequency of the error measurement to the measurement error (figure 2.5).

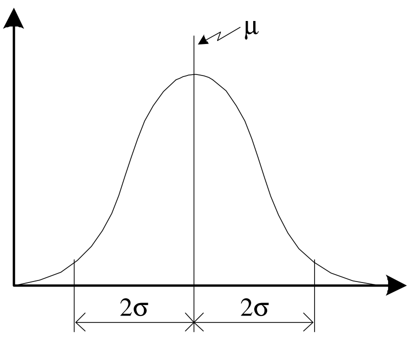


Figure 2.5: Standard deviation and confidence intervals of a measuring device

The *confidence interval* gives an indication of the maximum deviation expected for a certain percentage of measurements. The confidence interval usually used is $\pm$ 2 σ from the norm and corresponds to 95% of the measured data readings that is expected to lie within the defined bounds.

> **Example 2.3:** *The true heights and outputs are tabulated for given a sensor that is used to measure the liquid height in a tank. The true measurement (y) can be calculated if it is assumed that the measured output (y_m) of the sensor should increase linearly with liquid height (H) over a range of 4 to 20 mA.*

$$
\begin{aligned}
& y = mH + c \\
\therefore \quad & y = 0.53H + 4
\end{aligned}
$$

Table 2.1: Liquid height measurement

Height (cm)	0	5	10	15	20	25	30
Output (mA)	4.1	6.3	8.9	12.5	14.5	17.1	19.8

The standard deviation (σ) can then be calculated as a function of the measured (y_m) and outputs (y), where N is the amount of measured samples (Johnson, 1994:25):

$$\sigma^2 = \frac{\sum (y_m - y)^2}{N-1}$$
$$\therefore \quad \sigma = \sqrt{\frac{0.01 + 0.12 + 0.16 + 0.3 + 0.01 + 0.02 + 0.01}{6}}$$
$$\therefore \quad \sigma = 0.33$$

If it is assumed that the measurement error can be described with a Gaussian distribution, as is the case for most measurements, the measurement error can be presented by $y_m \pm 2\sigma = y_m \pm 0.7mA$ for a 95% confidence interval. This corresponds to a 3.5% error margin in the measured output. ∎

2.3.6 Dead band

Dead band is the range over which the input to the instrument can be varied without the responding to the output. This a characteristic of control valves that are "sticking". A typical response curve for an instrument that has *dead band* can be seen in figure 2.6.

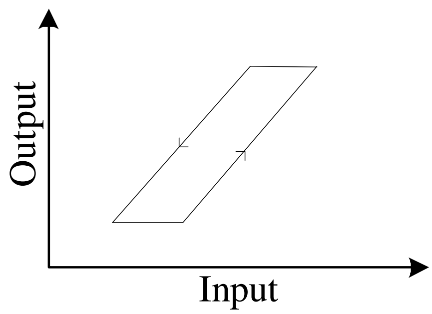


Figure 2.6: Dead band response of a measuring device

2.4 Cold junction compensation

2.4.1 Background

Two materials (X and Y) with different thermo-electric properties will generate a potential difference, termed a *Seebeck voltage*, if the two junctions of the materials are at different temperatures (figure 2.7). This thermo-electric effect can be used to infer temperature by measuring the potential difference (E_{XY}).

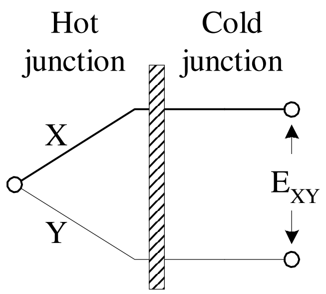


Figure 2.7: Thermocouple description

Five laws of thermocouple behaviour can be listed (Richardson & Peacock, 1994:469):

i) The emf depends only on the temperatures of the junctions and is independent of the temperatures of the wires connecting the junctions. The leads that joins the measurement (hot) and the reference (cold) junction may experience temperature fluctuations without effecting the reading.

ii) If a third metal Z is inserted between X and Y then, provided that the two new junctions are at the same temperature the emf is unchanged. A measuring device such as a voltmeter can be placed in the circuit without affecting the emf.

iii) If a third metal Z is inserted between X and Y then, provided that the new junctions XY and ZY are both at the same temperature the emf is the same. The connections can accordingly be soldered or brazed.

iv) If the emf obtained using the metals X and Y is E_{XY} and that using metal Y and Z is E_{YZ} the emf obtained employing X and Z will be (Law of intermediate materials):

$$E_{XY} = E_{XY} + E_{YZ} \tag{2.6}$$

v) If a thermocouple produces a emf $E_{XY}^{T_1,T_2}$ when its junctions are at T_1 and T_2 respectively and $E_{XY}^{T_2,T_3}$ when its junctions are at T_2 and T_3 then it will produce and emf (Law of intermediate temperatures):

$$E_{XY}^{T_1,T_3} = E_{XY}^{T_1,T_2} + E_{XY}^{T_2,T_3} \tag{2.7}$$

when the junctions are at T_1 and T_3. This property is used extensively for thermocouple compensation.

Thermowell

The thermocouple must be protected against the abrasive materials that is measured. The thermocouple is subsequently placed in a *thermowell* (figure 2.8) to protect the thermocouple. It should be noted that the thermowell will influence the temperature measurement.

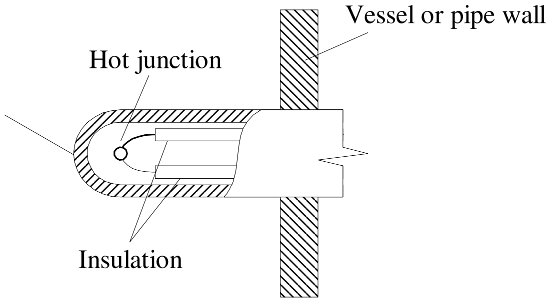


Figure 2.8: Thermocouple placed inside a thermowell

Thermocouple compensation

The thermocouple reading (emf) is a function of both the measurement (T_1) and reference (T_2) temperatures (i.e. emf = $E_{XY}^{T_1,T_2}$). The a change in T_2 will therefore have an effect on the emf and will subsequently cause measurement errors. $E_{XY}^{T_1,T_2}$ must accordingly be compensated for, by negating the effect of (T_2). This is accomplished through the use of the Law of intermediate temperatures that can be written for the reference temperature:

$$E_{XY}^{T_1,0} = E_{XY}^{T_1,T_2} + E_{XY}^{T_2,0} \tag{2.8}$$

where $E_{XY}^{T_2,0}$ varies with the reference temperature (T_2), that is usually another thermocouple reading (i.e. the measurement and reference temperatures are the same to give an emf = $E_{XY}^{T_2,0}$).

The implementation of an automatic reference junction compensator circuit can be seen in figure 2.9. The compensation can be implemented in the electrical circuit (i.e. reference emf is connected in series with the reading) but is inefficient if a large number of thermocouple is used as each of the readings must be compensated for on the electrical circuit. A more efficient configuration for a system that uses a large number of thermo-

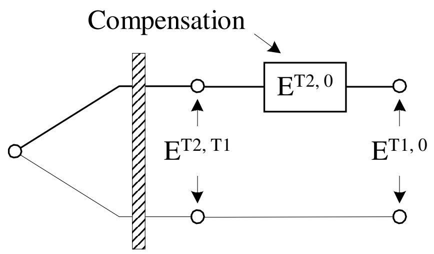


Figure 2.9: Thermocouple compensation configuration

couples is to do the compensation with software (i.e. the measurement emf is added to the reference emf reading).

CHAPTER 3

Distributed control system

The different data acquisition architectures are discussed in this chapter and the implementation of a control system using in the Simulink environment is shown. The location of the different software components are also given.

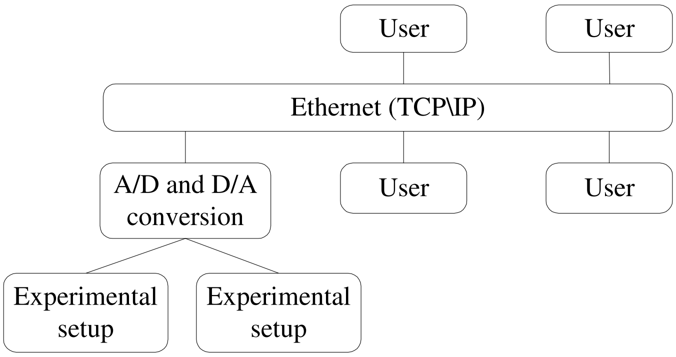
3.1 Distributed data acquisition and control

A schematic of the different *distributed control systems* that can be implemented in the process control laboratory is shown in figures 3.1(a) to 3.1(c).

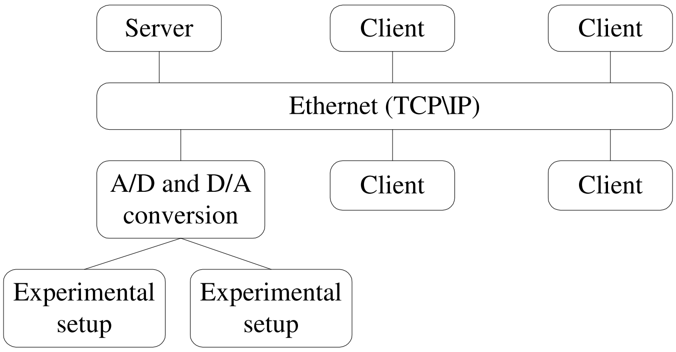
The analog measurements is converted to a digital signal and is sent across the ethernet using the *TCP/IP* format, which is a well accepted protocol defined specifically for use with the ethernet. The control signals originating from the computers connected to the ethernet is converted back to a analog signal and sent to the actuators of the process. The different architectures regarding the interaction of the different computers on the ethernet is subsequently discussed.

Distributed data acquisition and control . The analog measurements are sent directly to the user computers through the ethernet connection and the process receives the digital control signal from the user computer via the same route.

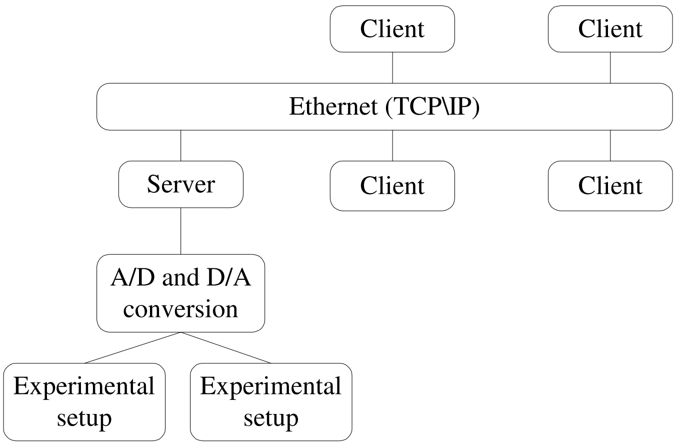
A great advantage of this approach is that any user can be used for the control of any unit should one user fail, but data integrity is at risk as there is no central data archiving device. The user computer is therefore responsible for both data acquisition and control, hence the name *distributed data acquisition and control*.



(a) Distributed digital control system



(b) Supervisory digital control system



(c) Clustered supervisory control system

Figure 3.1: Different digital control configurations

Supervisory data acquisition and control A server is placed on the ethernet highway for the control configuration, and is responsible to give access to the different users or clients of the control system, store the data and check the variables for alarm management.

The fact that the clients must log onto the server before the control system can be used gives greater security and control over the different experimental setups.

Clustered supervisory data acquisition and control The server is connected directly to the A/D and D/A instrumentation. This increases data integrity as the data to the server is not transmitted of the ethernet connection. The *bandwidth* (indication of ethernet use) of the ethernet is also reduced.

3.2 Software and communication protocols

The different software used (and their interaction) for the control of the experimental setups is shown in figure 3.2. The schematic shows that there are two ways or routes to communicate with the experimental setups from Simulink, which is the software used to implement the control algorithms in the process control laboratory.

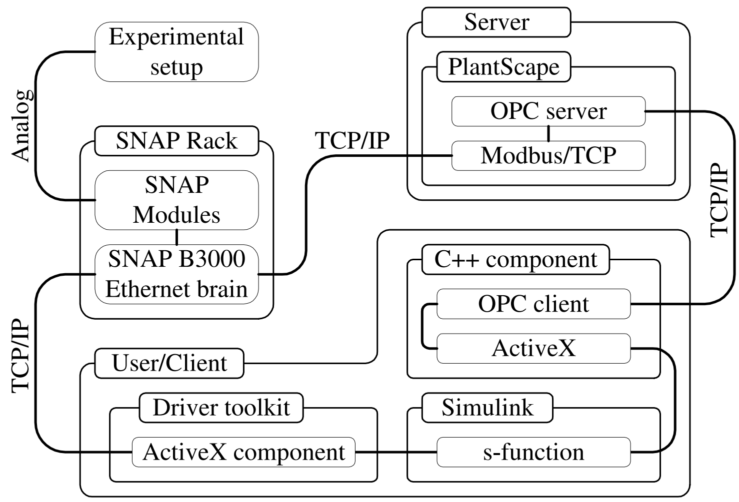


Figure 3.2: Software protocols used

The first route can be with the use of the *driver toolkit* from OPTO22 that utilises *ActiveX*, which is a protocol defined for interfacing different software programs in the Windows environment, to communicate directly with the A/D and D/A conversion devices (SNAP B3000 brain, etc.).

The second route is with the use of a server and specific *SCADA* (Supervisory Control and Data Acquisition) software that uses *MODBUS/TCP*, a protocol defined for instrument interfacing over a ethernet connection, to communicate with the A/D and D/A conversion devices. A custom *C++ component* was developed in-house to enable that utilises *ActiveX* to communicate with the server using *OPC*, another control protocol defined for inter controller communication via ethernet connections.

Figure 3.2 shows further that the *Driver Toolkit* and the *C++ component library* must be installed on the user or client computer. The software can be found on \\groa\lab\Opto for the *Driver Toolkit* and \\groa\lab\PlantStar fot the *C++ component library*.

The s–function needed for the interfacing of *Simulink* with the experimental setups can be obtained from \\groa\lab\Rigs. More information on the development of the s–function can be obtained from the in–house *Matlab Opto22 driver manual*.

The *Real time clock* block is used to force the *Simulink* simulation to run at real time and must therefore be included on the model of the control algorithm used for control. The block icon can be seen in figure 3.3. The s–function and model of the *real time clock* can be found at \\groa\lab\Matlab\Rtclock and must be included in the current *Matlab* path to run.

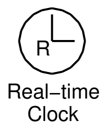


Figure 3.3: Real time clock icon

Example 3.1: *The of the s–function block using the ActiveX component calls for the level and flow control loop can be seen in figure 3.4, and shows that two inputs for the control valves (4–20 mA) and two outputs (-20–20 mA) for the liquid level and liquid flow are available for the implementation of a control algorithm.*

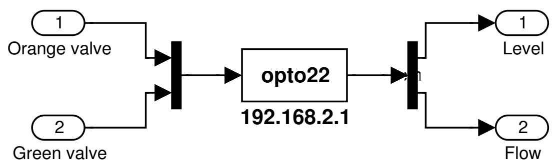


Figure 3.4: s–function implementation of the level and flow model

CHAPTER 4

Analog and digital signal transmission

The different issues surrounding the implementation of the analog wiring system in the process control laboratory is discussed. This includes the layout design of a *junction box* for each individual *experimental setup* as well as the box used to house the A/D and D/A converter instrumentation. The different protocols with regard to the different cables used in the wiring of the analog system are also given.

4.1 Signal component installation

An overview of the analog and digital signal transmission configuration as implemented in the control laboratory can be seen in figure 4.1.

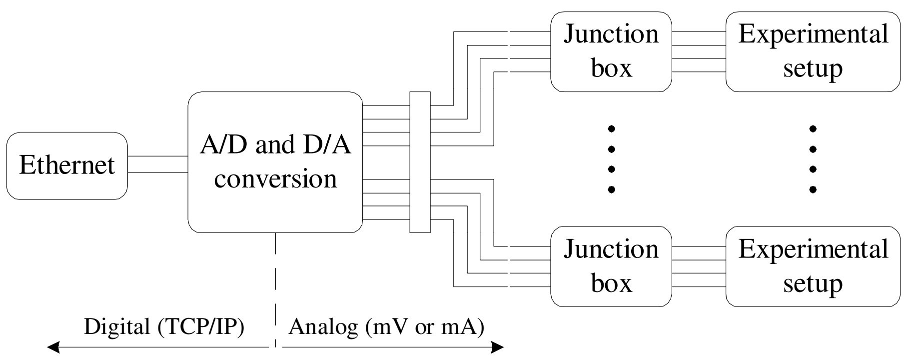


Figure 4.1: Analog and digital implementation

The analog to digital and digital to analog converters is used to transform the analog signals to a digital networking protocol called (TCP/IP) and *vice versa*. All the transmission lines of the experimental setups is routed to a centralised case or box (referred to as the *Opto box*) where the A/D and D/A conversion instrumentation is situated. The box is used to protect the expensive instrumentation as well as the open connections from dust and spills and the implementation thereof can be seen in figure 4.2.

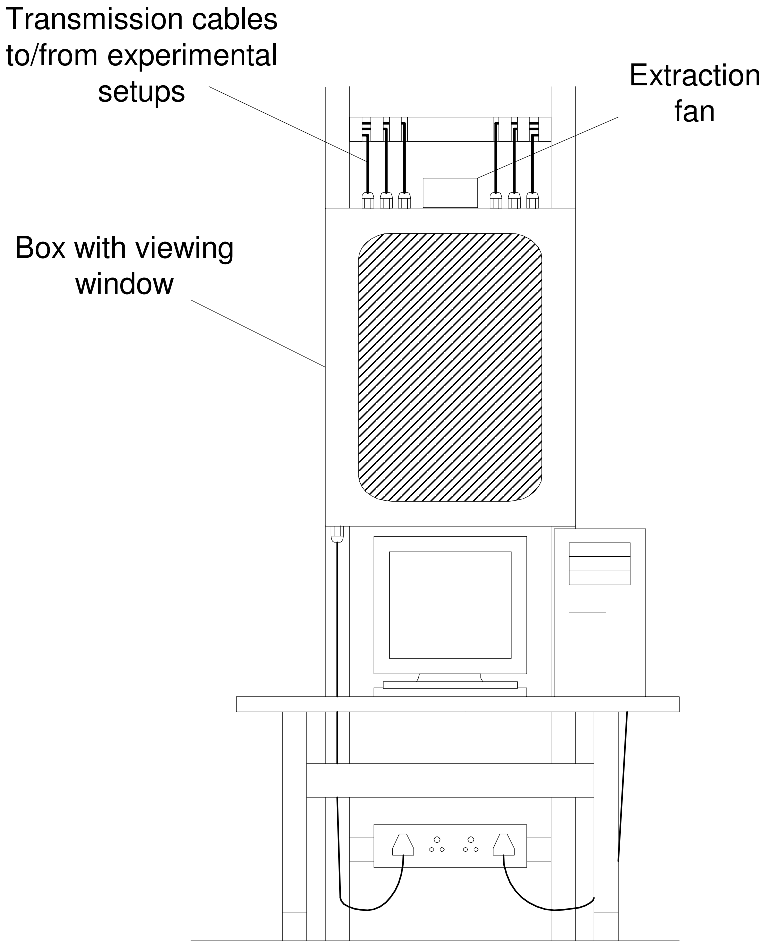


Figure 4.2: Opto box installation

The *junction box* is inserted between the A/D and D/A converters and the instrumentation of the experimental setup and is used to:

- house the different power supplies needed for the instrumentation.
- create a physical connection point between the transmission lines in the trunking and that used to wire the experimental setup.
- protect the instrumentation by inserting fuses in the transmission lines.
- create a save environment for the open connections and power supplies.

The *junction box* is installed against the wall at each experimental setup together with the associated computer of the experimental setup. A graphical representation of the implementation of the *junction box* can be seen in figure 4.3.

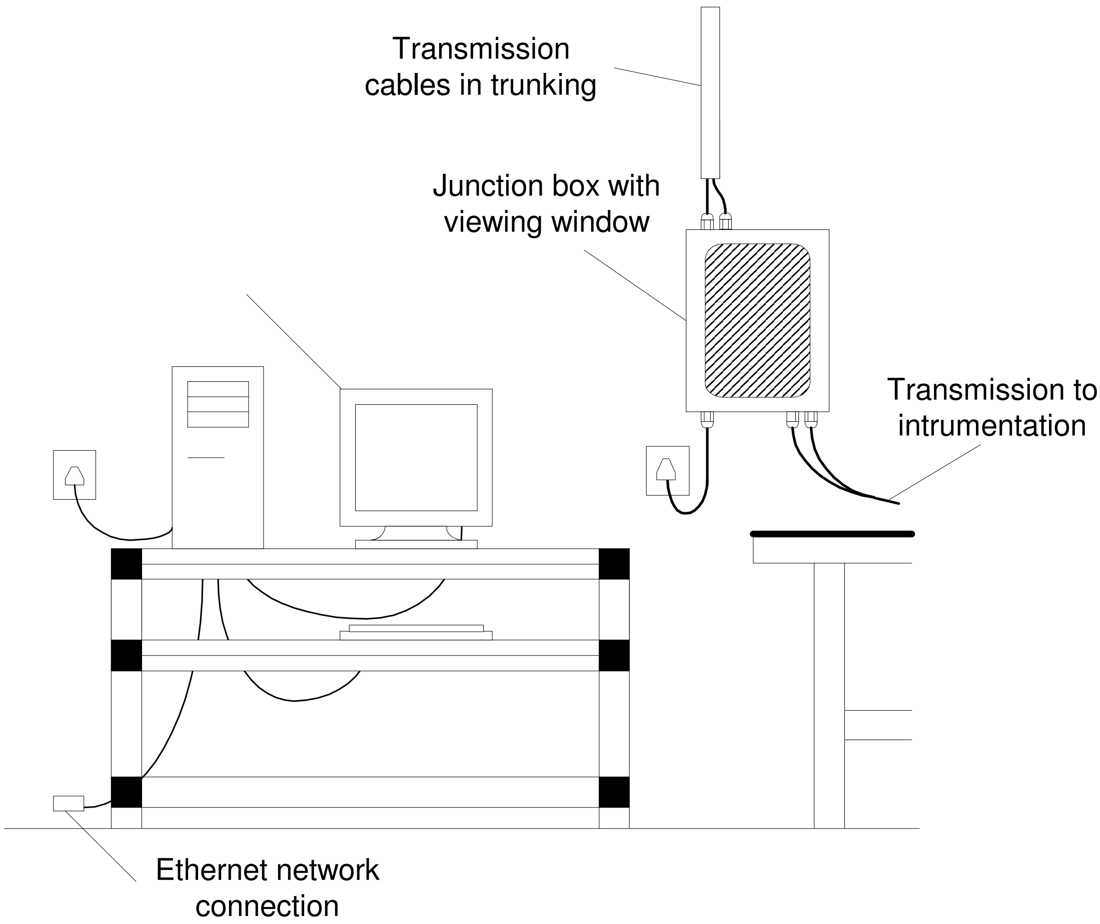


Figure 4.3: Junction box installation

The cables from the *Opto box* is situated in trunking (to keep the appearance of the process control laboratory neat) and enters the box at the top using cable glands to seal the box from dust and spills. The power cable and the cables that connects the instrumentation of the experimental setup to the junction box is separated to reduce noise contamination of the high voltage power cable on the measurement cables.

4.2 Analog and digital input output instrumentation

The instrumentation used for the A/D and D/A conversion is the *SNAP ETHERNET I/O range* from OPTO22 and consist out of different individual components each with a specific function. A schematic of the interaction of the different components can be seen in figure 4.4. Two different input modules are used for general process measurement

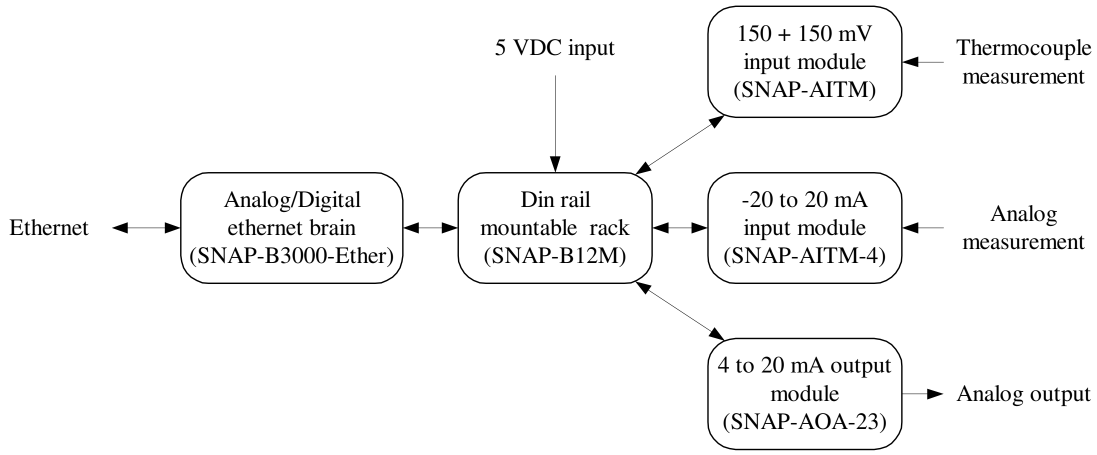


Figure 4.4: Component specification of the SNAP I/O range

(AITM–4) and thermocouple measurement (AIMA). One output module (AOA–23) is used for the manipulation of the actuators. The *AIMA* and *AOA–23* model has two channels while the *AITM–4* has four channels per module. The modules slot onto the *B12M rack* that is capable of housing a total of twelve modules. A breakdown of the different modules used can be seen in table 4.1 and shows that two racks are needed to house the twenty four modules

Table 4.1: Module breakdown

Module name	Channels	Modules
SNAP–AITM–4	18	5
SNAP–AIMA	21	11
SNAP–AOA–23	15	8
Total	54	24

Every rack needs one *B3000 brain* and is used to convert the digital signal to the *TCP/IP* format, a protocol used to transfer data across the *ethernet*. The brain can be interfaced with:

Modbus which is a generic protocol devised for interfacing with third–party hardware and software.

OPC (object linking and embedding for control), a control protocol specifically devised for third–party software interfacing. The brain acts as an *OPC server* that can be interfaced with OPC and DDE clients.

ActiveX (object linking and embedding for Windows) that was developed for third–party software interfacing

HTML that is a generic web based protocol used extensively as a communication medium on the *internet*

4.3 Loop power

The measuring equipment and actuators need electrical power to convert the physical properties of the process to an electrical signal that can be used for digital control and monitoring. The electricity is obtained either from the inputs used for the measurement output or as a different input supply. The use of the electrical power from the measurement signal is commonly referred to as *loop power*.

A power supply must accordingly be used to power the signal transmission, but it is impractical to use one power supply for one measuring device. The power supply (ES) is therefore placed in parallel to the instruments (XI) requiring the power supply as can be seen in figure 4.5. The A/D or D/A device (OP) is placed in series with the measuring instrument or actuator as it must measure or manipulate the signal.

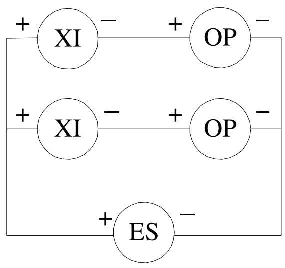
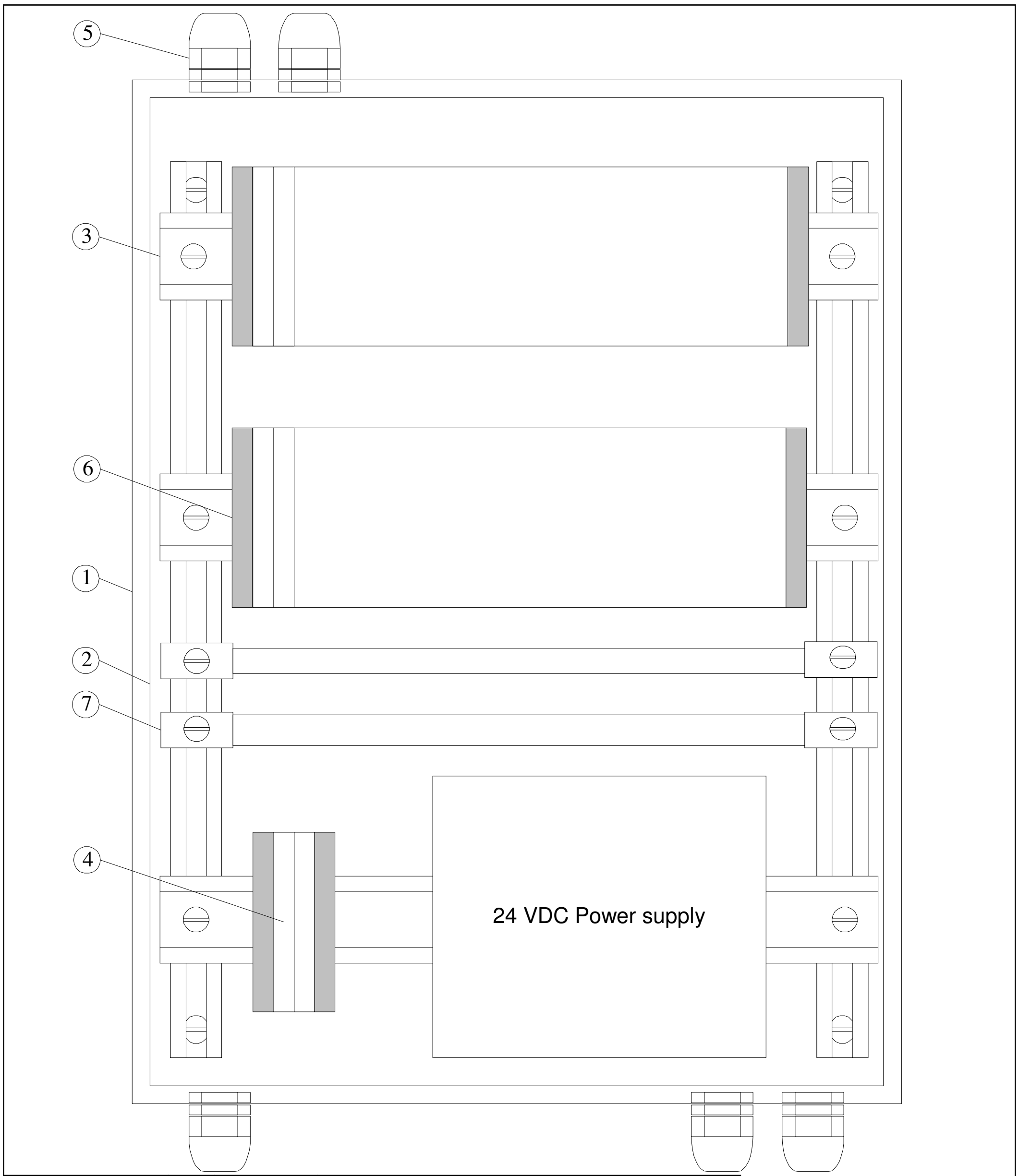


Figure 4.5: Power supply implementation

4.4 Junction box layout

The *junction box* is a powder painted mild steel case with a sealed hinged door with an IP55 rating (resistant to dust). A polycarbonate window was inserted into the door for illustrative purposes. A stainless steel base plate is inserted at the bottom of the box. Two C–rails are place vertically onto the base plate with bolts(see figure 4.6).

The *DIN rails* and *bus bars* are mounted onto the rails and tightened with bolts. The *bus bars* and *DIN rails* can therefore move freely once the bolts are loosened to give a larger degree of freedom to the box layout. The fused and normal *connectors* are specifically designed to “clip” onto the DIN rail and is used to connect two cables. The power supply is also placed onto the DIN rial and ensures the easy removal of the device



ITEM	QTY.	PART NO.	DESCRIPTION
1) Enclosure	1	EB 1556.600	Hinged door (IP 65), sheet metal, size: 400 x 300 x 120
2) Chassis	1		Zinc plated, size: 385 x 275 x 25
3) Din rail	2		Size: 245 x 35
4) Connector: Normal	41		To fit 4 mm cable
Fused	9		To fit 4 mm cable
5) Cable glands	7		
6) End stops	6		
7) Bus bar	2		Size: 245 x 10

Date: 03-10-2001	**Distillation junction box**	Author: Lourens du Plessis
		Type: Wiring diagram

Figure 4.6: Junction box layout

as the base plate with all the other components need not be removed. The cables that enter the box at the top and bottom is sealed using *cable glands*.

The *loop power* supplied by the 24V power supply is installed, in parallel with each measuring or control loop, inside the *junction box* with the use of the *connectors* and the *bus bars*. The details can be seen in figure 4.7 and is based on the wiring diagram in figure 4.5. The *bus bar* is fixed to the C–rail by rubber bands to insulate the bar from the

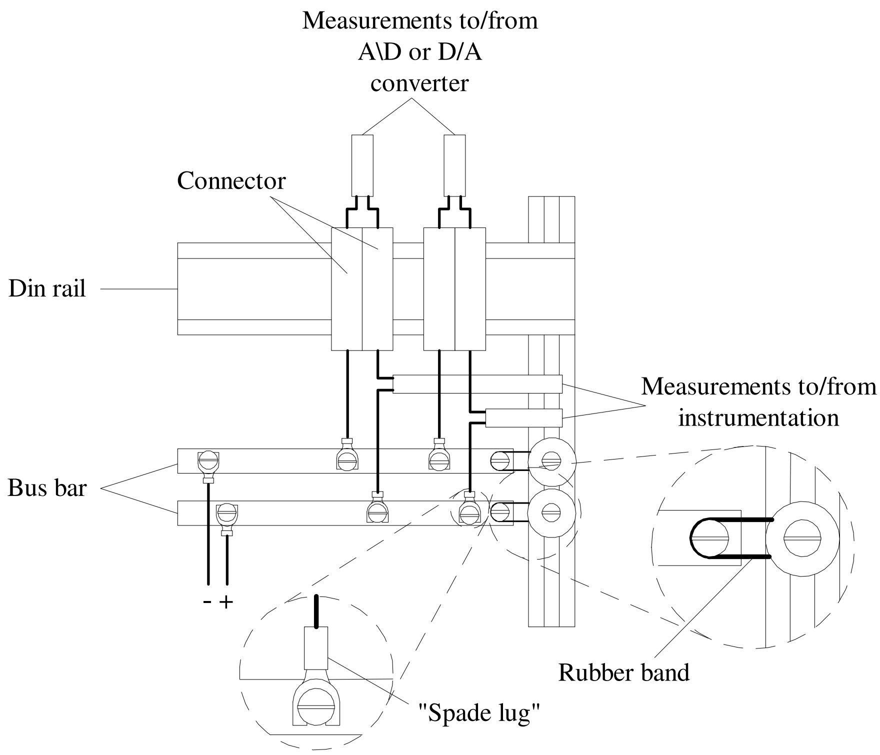


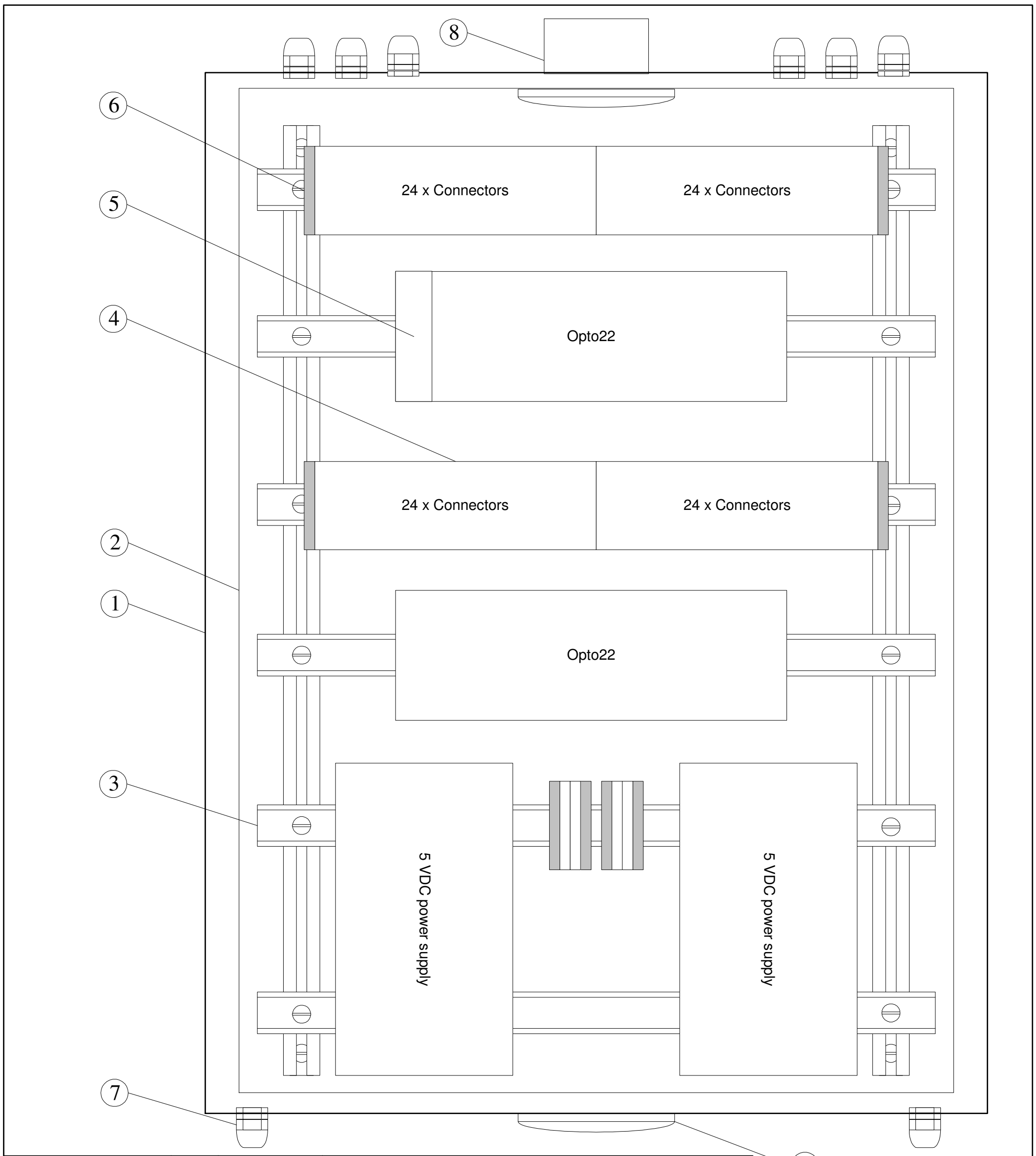
Figure 4.7: Loop power installation

rest of the junction box. The cables can accordingly be fixed onto the *bus bar* with bolts and “spade lugs”.

4.5 Opto box layout

The layout of the *Opto box* is based on the same principles as that of the *junction box*. The A/D and D/A instrumentation (OPTO22) are fitted to the DIN rail using custom clips and the power requirements of the instrumentation are supplied by two 5 VDC power supplies also fixed to the DIN rail.

A 220 VAC extraction fan is installed at the top of the box to remove the heat generated by the instrumentation. An air filter is installed at the bottom to act as the cool air inlet for the flow caused by the extraction fan.



ITEM	QTY.	PART NO.	DESCRIPTION
1) Enclosure	1	EB 1058.600	Hinged door (IP 65), sheet metal, size: 800 x 600 x 210
2) Chassis	1		Zinc plated, size: 770 x 549 x 3
3) Din rail	4		Size: 480 x 35
4) Connector: Normal	116		To fit 4 mm cable
5) Opto 22 module	24		AOA-23 : 8, AIMA-4:4, AITM: 12
6) End stops	16		To fit 35 mm din rail
7) Cable glands	11		
8) Extraction fan	1		
9)Air filter	1		

Date: 03-10-2001	**Opto22 junction box**	Author: Lourens du Plessis
Scale: 1 : 4		Type: Wiring diagram

Figure 4.8: Opto box layout

4.6 Cabling

4.6.1 Communication transmission

The cable used for communication is *twisted pair shielded* cable with the shield placed between the outer and the inner insulation of the two individual conductors (see figure 4.9). This is to shield the signal in the conductors from external noise effects such as generators, heating coils, AC currents, etc. The outer insulation should be gray in colour and the two inner insulated conductors red and blue.

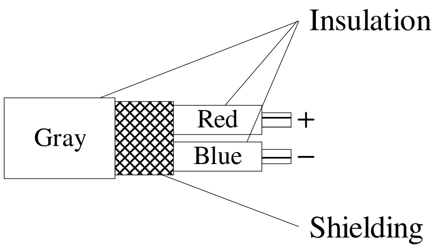


Figure 4.9: Cable used for communication

4.6.2 Thermocouple measurement

The cable used for the transmission of signal originating from thermocouples can be seen in figure 4.10. The colour of the outer insulation is black while the inner insulation differs with the different type of thermocouple used. The colour scheme shown in figure 4.10 is that of a J–type thermocouple. The colour scheme for a K–type thermocouple is blue and yellow.

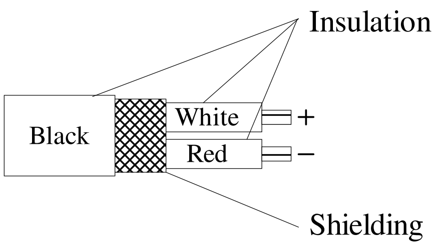


Figure 4.10: Cable used for thermocouple measurement

4.6.3 Power transmission

Certain transmitters requires an extra power input. The cables used for this will therefore not be responsible for communication and must therefore be specified differently from the cable that is used for communication. The cable and colour scheme used for the purpose of power transmission for three and two wire applications can be seen in figure 4.11(a) and figure 4.11(b). No shielding from electrical disturbances is needed as the cable is not used for communication. The voltages transmitted are also higher and are therefore not as susceptible to noise.

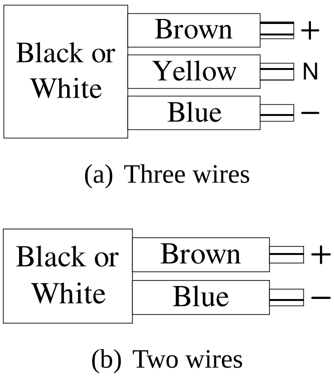


Figure 4.11: Cable used for power transmission

Power cables must be marked clearly with a tag stating the voltage and current type (i.e AC for alternating current or DC for direct current). This is necessary to ensure safe operation by reducing the risk of instrument damage and electrification. An example where a 220 VAC power line is marked can be seen in figure 4.12.

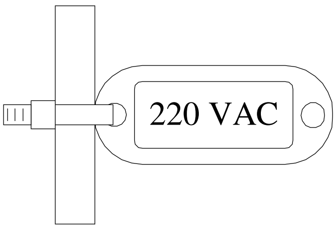


Figure 4.12: Power cable marker

A ferrule, figure 4.13, is placed over the exposed end points of the two conductors in the cables. This is to ensure a good (neat) connection of the cable in the connector; as the wire won't be able to bend because ferrule is rigid.

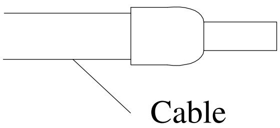


Figure 4.13: Ferrule placed on the end of the conductor

CHAPTER 5

Documentation

Two different types of documentation as well as the corresponding ISA identification numbering used by these documents are defined for used specifically in the process control laboratory. A formal representation of the experimental setups will greatly reduce the amount of time spent on fault debugging and control loop maintenance. The two documentation types used are:

Piping and instrumentation diagrams that are used to describe piping and equipment for the different *experimental setups*.

Loop diagrams that are used to define the wiring of the different instrumentation loops.

5.1 Piping and instrumentation diagrams

A *piping and instrumentation diagram* (P&ID) is a detailed graphic representation of the process flow showing all the piping, the equipment and much of the instrumentation associated with the given process (Mulley, 1993:93). The different equipment and instrumentation is identified using unique numbers called *tag numbers*. The *tag number* of the different instrumentation in the process control laboratory conforms to the *ISA standards* and are defined as follows:

Unit number	Identifier	Loop number

The different unit numbers specified can be seen in table 5.1 while the different identifiers needed to describe the current instrumentation in the process control laboratory is listed in table table 5.2. The loop number is a three digit number, and is unique to each measurement loop. The sensor, transmitter and controller will therefore have the same loop number with different identifiers.

Table 5.1: Unit numbers of the process control laboratory

Number	Setup name
01	Acetone flashing
02	pH
03	Temperature
04	Level and flow
05	Distillation
06	OPTO22 setup

Table 5.2: Different object types

Instrument	Identifier	Instrument	Identifier
Sensors			
Thermocouple	TE	*Other*	
RTD	TE	Analog temperature controller	TC
Differential pressure cell	DP	E/P converter	PY
pH probe	XE	Power supply	ES
Flow sensor	FE	*Junction box*	TB
Level sensor	LE	*Opto box rail*	TS
		SNAP module	OP
Transmitters			
Wheatstone bridge	TT	*Vessels*	
pH transmitter	XT	Tank	TK
Level transmitter	LT	Pump	CP
Flow transmitter	FT	Heat exchanger	HE
		Hand valve	HV
Actuators		Vapour liquid equilibrium	VL
Thyristor	VC		
Control valve	CV		

A list of the different symbols used in the representation of processing equipment is available in the following two references *Chemical Engineering Drawing Symbols* or *Control System Documentation, Applying Symbols and Identifications*.

Example 5.1: *The tag numbering, defined from table 5.2, of the instrumentation and processing equipment used for a simplified pH control loop is listed in table 5.3.*

Table 5.3: Tag number identification

Instrument type	Tag number
pH sensor	02XI001
pH transmitter	02XT001
Analog input channel	06OP235
Control valve	02CV001
I/P converter	02PY001
Analog output channel	06OP208
Tank	02TK001

The P&ID for the pH control system can accordingly be drawn using the different tag numbers of the instrumentation as well as the standard symbols for vessels and instrumentation. The resulting P&ID can be seen in figure 5.1.

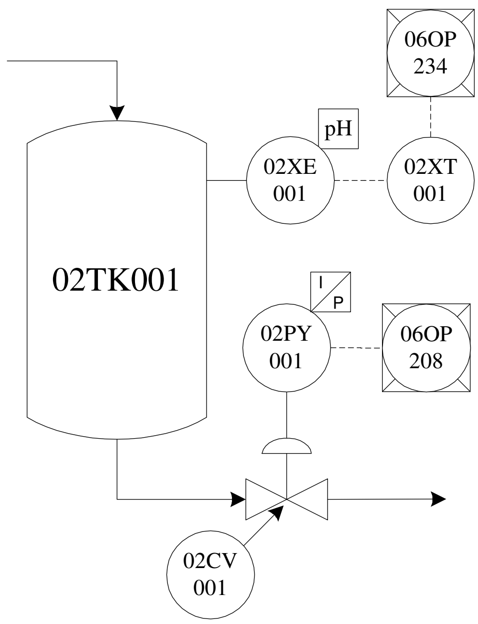


Figure 5.1: Cable marking

The I/P converter and pH sensor have individual identification blocks denoting the conversion and measurement of the different instrumentation. ■

5.2 Loop diagrams

The wiring system has many connections that must be documented in an efficient unambiguous way. The standard format used for the documentation of analog and digital control loops are *loop diagrams*(Mulley, 1993:143). An example of the loop diagram for the two control valves of the pH control loop in the control laboratory can be seen in figure 5.2.

It can be seen that the electrical wiring of the system is shown with the associated instrumentation of the loop. The diagram will therefore greatly assist in the detection and correction of faults or the installation of new instrumentation. The diagram consist further out of four main areas, separated by vertical lines the definition of these areas follows.

Field defines the instrumentation on the experimental setup. The instrumentation usually associated with the field are are sensors, actuators, converters and transmitters.

Junction box defines the wiring inside the junction box. The power supply and connectors with their corresponding identification number or tag are clearly shown. It should be noted however that the full connector number consist out of the number shown on the connector as well as the rail number. The tag number for the connector is therefore 02TBXXX.C with the C denoting either the red (R) or blue (B) wire.

Trunking is the wiring between the *junction box* and the *Opto box*.

OPTO22 is the instrumentation inside the *Opto box*. The connectors are again shown with the *SNAP modules*. The Opto box is allocated unit number six 06, the connector tag number will therefore be 06TSXXX.C. The two opto racks are defined by numbers 1 and 2. The tag number for a specific measurement will therefore be 06OP1XX or 06OP2XX depending on the associated rack of the current model.

5.3 Tag number marking

5.3.1 Cable marking

The numbering of the different cables are affixed to the cable using specific colour coded cable markers. The cable number contains two parts, the connector number from the cable origin and the connector number of the destination connector.

The cable number is affixed on both ends of the cable. The exact source and origin of the cable can accordingly be seen at any end; reducing the effort for maintenance and fault detection. The connectors are marked as well using smaller plastic numbering clips with the same colour scheme as that used for the cables.

The direction of the numbering is always from the *experimental setup* to the *Opto box* with a dash separating the two numbers. An example can be seen in figure 5.3 with the

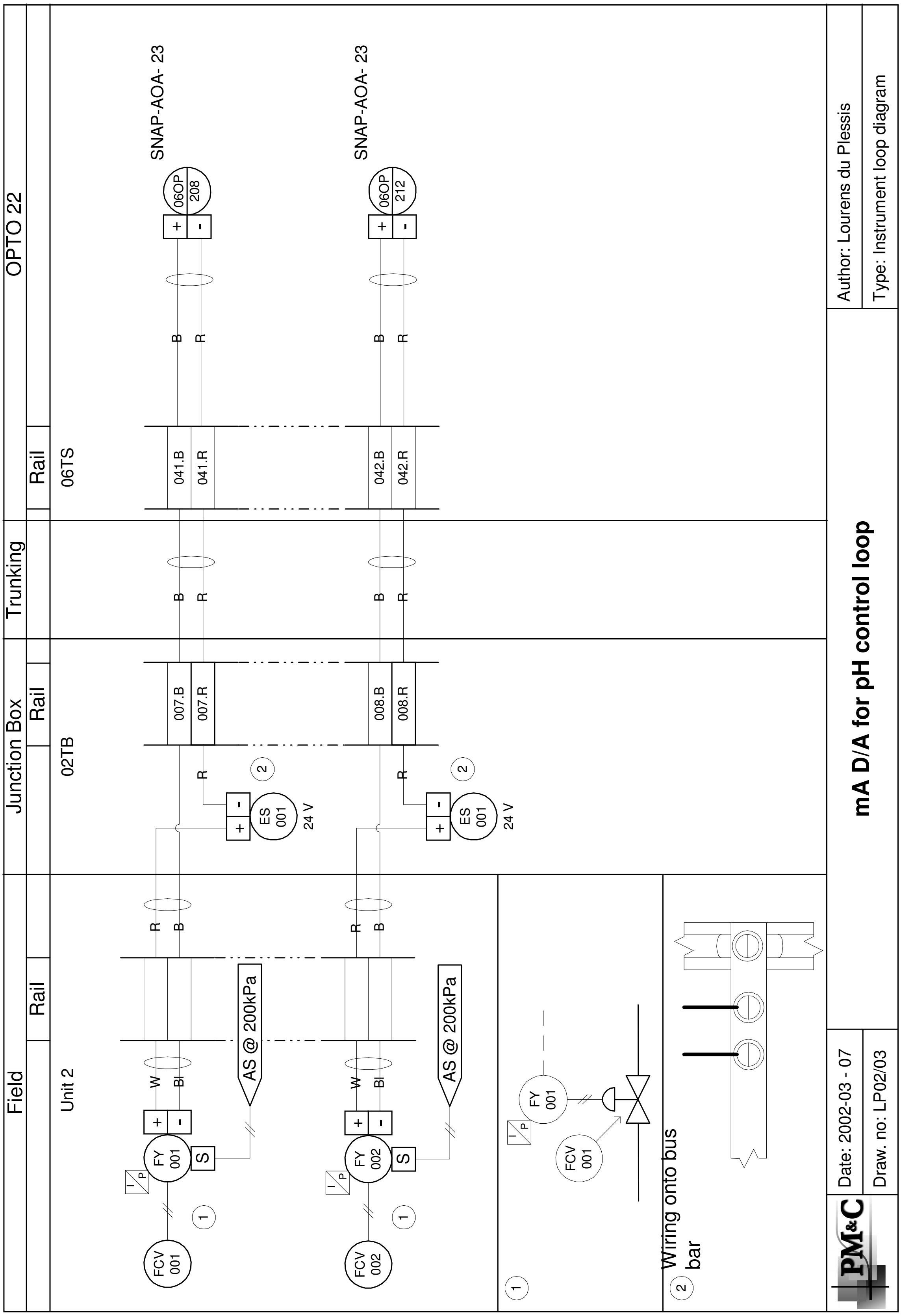


Figure 5.2: Wire diagram of the control valves of the pH control loop

tag numbering flow from the experimental setup (001) to the Opto box (201), which is in this case from left to right.

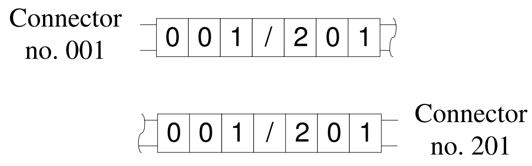


Figure 5.3: Cable marking

5.3.2 Instrument marking

The instrumentation is marked clearly with a tag defining the full tag number of the instrument. "Cable ties" are used to fix the marker onto the instrumentation (see figure 5.4).

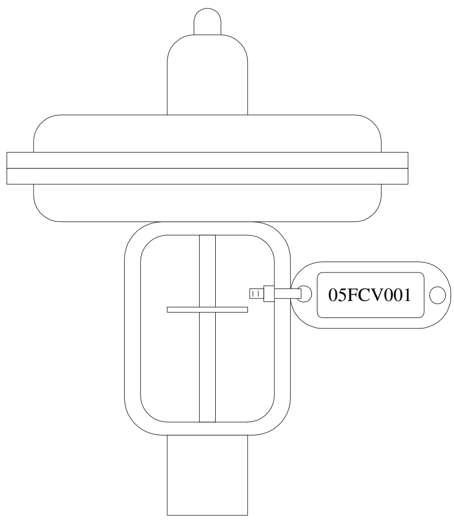


Figure 5.4: Instrument marking

5.4 Equipment Database

To simplify the documentation of the wiring and connectors, an *equipment database* is required. This database tracks each piece of process control equipment and the connections between them. The database can be obtained at \\groa\phpMyAdmin.

The starting point for the database is the rig table, which contains the number and name of all the experimental setups. From here, linked to the rig number an equipment table stores each item's type and number. In addition, data is stored about the date of acquisition and origin of the equipment to simplify maintenance and reordering. To make the database expendable, a table of equipment types is linked to the equipment table, storing the tag extension of the equipment type.

Queries are defined to generate tag numbers in accordance with the standards set out above, by combining the rig number, equipment type extension and the equipment number.

In order to track connections, each equipment record also stores the unique ID of another piece of equipment. The direction of this linked list is defined as away from the final control elements and measuring devices. Therefore, a control valve will link to the *junction box* connector and an OPTO SNAP analog in module will link to the *junction box* connector.

Wire names are generated by a *SQL query*, adding the numbers from the connected pieces of equipment. A list of wire names can be drawn up in a report for wire checking.

To keep the documentation current, the following steps are required when adding new equipment.

Step 1 Collect information The following information is pertinent when installing new equipment:

- What type of signal does the equipment send or receive? This will determine the module on the OPTO that the equipment will be wired to.
- Are there enough connectors in the *junction box* to accommodate the new signal? If not, new connectors must be installed.
- Are there enough OPTO modules of the type required? If not, a new OPTO module must be installed.

Step 2 Add the equipment to the equipment database. Check that the equipment type exist by double clicking the equipment type table. If the equipment type does not exist, add a new type on the last line of the table and close the table view. Open the equipment table by double clicking it. Select the rig and equipment type from the drop down list. Enter a unique number for the equipment in the number field, then select the tag number of the equipment this item is connected to. For instance, a thermocouple would be connected to a connector in the *junction box* for the experimental setup. If there are no free connectors in the *junction box*, follow the same steps as above for two new connectors: one in the *junction box* and one in the *Opto box*.

Step 3 Lay the wiring Open the trunking and lay a new wire between the *Opto box* and the *junction box*, bearing in mind that the wire must be labelled with its wire number. Use the wire number for the wire between the connectors mentioned above. This number is generated automatically by the database in the wire numbers query.

Step 4 Connect the wires The wires are now connected between connectors.

Step 5 Test Before the equipment is used, a signal check must be run. Using a Ohmmeter, check the resistance between the terminals of the new signal. This should be very high. Low values indicate a short circuit.

Step 6 Connect equipment and OPTO The wires are now connected to the equipment and to the OPTO module.

An example of the database interface can be seen in figure 5.5 and shows the different experimental setups of the process control laboratory.

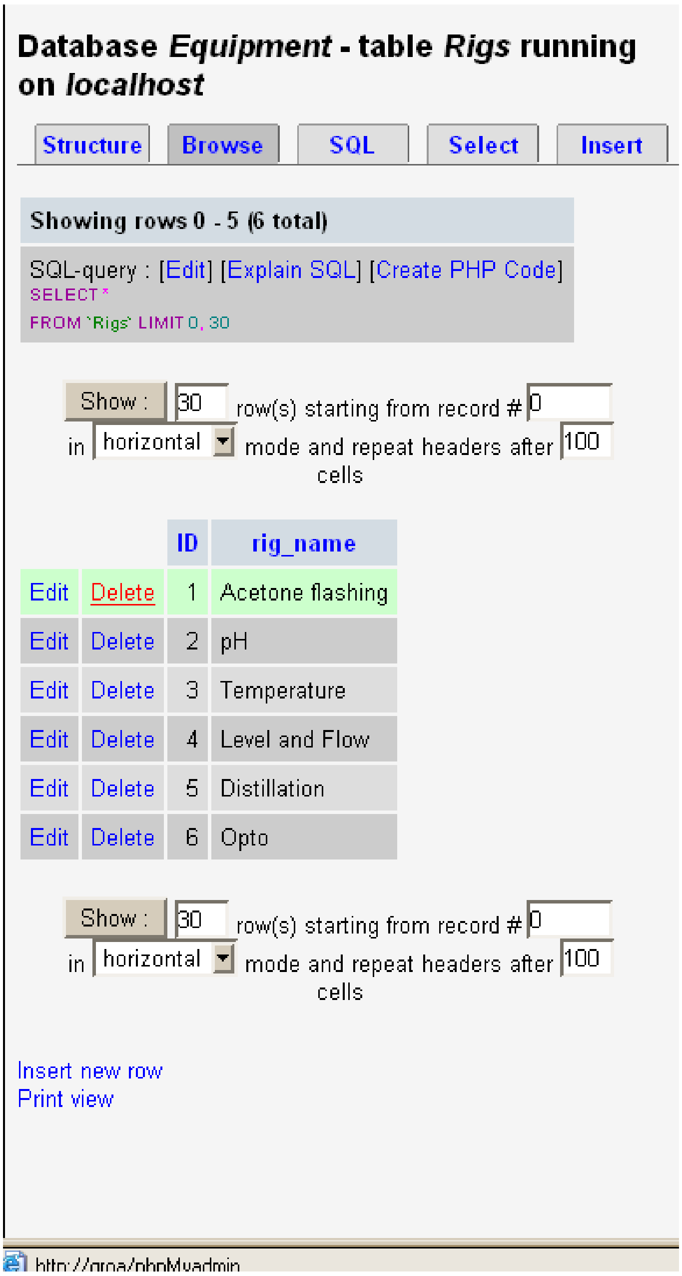


Figure 5.5: Equipment database interface

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