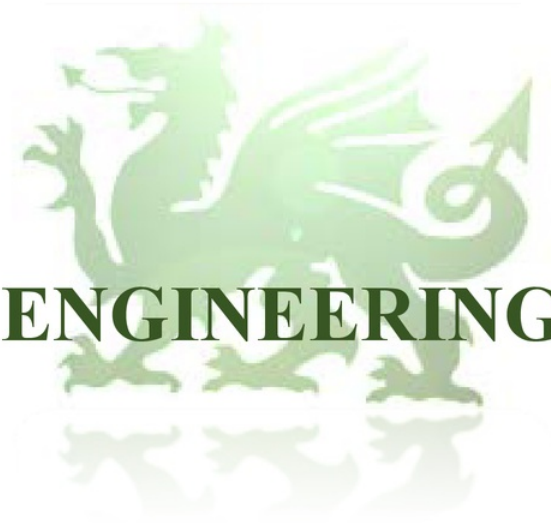


Final Report

by Joshua Coles

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KCS ENGINEERING LTD

BSc (Hons) Electrical & Electronic Engineering
PSDE6019: Major Project

Joshua Coles

Final Report: Automatic Pressure Calibrator

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Industry Supervisors: Saul Coles

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Abstract

This project details the process of designing and creating an automatic pressure calibrator for calibrating a -250 millibar (mBAR) to +250 mBAR pressure transmitter. The standard method used for calibrating a pressure transmitter is to generate pressure against the transmitter using a manual hand pump. This manual method introduces human error into the calibration and can lead to false readings. The purpose of this project was to create an automatic method that removes human error from the process and provide a method to calibrate the transmitter to a tolerance of $\pm 0.25\%$.

The system hardware and software was designed and implemented against a specification set out by the industrial supervisor. The system was tested against a set of test tables and evaluated on the performance. The system achieved all the specification criteria and performed as required repeatedly. The prototype is complete and could be developed further to provide a product capable of use in industry. Recommendations and critical analysis were carried out to provide feedback on the project performance and areas of the prototype that could be engineered to perform better.

Concise abstract given which does fairly reflect the project undertaken

Acknowledgements

I'd like to acknowledge the opportunity my father; Saul Coles, gave me to be able to reach this point in my career. Thanks to him I have been able to gain technical experience in many industries.

I'd like to acknowledge my college lecturers for giving me support with the LabVIEW program and for the further guidance given during the project.

Very brief set of acknowledgements

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1.0 Introduction & Background Research

1.1 Introduction

The aim of this project is to design and build an automatic low-pressure calibrator prototype. The objective of the prototype is to overcome the issues and human errors that are introduced into the manual process of calibrating a pressure transmitter.

The project was given to me by my industrial supervisor; Saul Coles of KCS Engineering Ltd (KCS). KCS is a contracting company that specialises in instrumentation and calibration. KCS work in a number of industries, including: Power stations, Food processing factories, NHS facilities, Car manufacturing plants etc.

Current calibration methods for pressure instruments require a technician to use a manual hand pump to generate pressure or draw vacuum. From experience, it can take up to twenty minutes to calibrate an instrument. The amount of time varies depending on the accuracy and sensitivity of the instrument. Human error is introduced into the results when manually calibrating a device. The signal from the instrument has a transient effect when pressure is varying; therefore if results are recorded before a signal has reached steady state then the true performance of the instrument is not measured.

The project is being undertaken to build a working prototype that must remove the errors from manually calibrating an instrument. Once the prototype is complete, the device will be developed further to provide a product that could potentially be manufactured to sell into industry. The budget required for this project is set at £1,000.

Good, clear introduction to the project

1.2 Background Research

1.2.1 Pressure & Vacuum

Pressure and vacuum are defined as molecules within a gas or liquid impacting on their surroundings. The magnitude depends on the force over a defined area; i.e. pounds per square inch (PSI). Pressure refers to molecule impacts that provide results greater than atmospheric results. Vacuum refers to molecule impacts that provide results lower than atmospheric results (Laboratory, 1998).

Gauge pressure defines atmospheric pressure as 0 BAR, vacuum would provide a negative result up to -1 BAR; -1 BAR gauge is absolute vacuum and cannot be achieved; absolute vacuum is only present in space. *Absolute* (ABS) pressures uses absolute vacuum as the zero point, starting at 0 BAR ABS. *Absolute* pressure includes the atmospheric pressure in the results and as such is unaffected by the slight variances from day-to-day fluctuations in the atmospheric pressure (SA Instrument & Control, 2001).

Recording and monitoring pressure and vacuum is vital in modern processes. To generate pressure in a power station many variables need monitoring for quality and safety reasons. These variables can include feed water pressure, steam pressure, oil pressure and air flow; which is a differential pressure (Forbes Marshall, 2003).

1.2.2 What is calibration?

Calibrating an instrument is done to prove the accuracy of the instrument across its scale. The type of calibration performed depends on the instrument; for pressure, a known sample pressure is applied on the input port of the instrument and the output signal is measured, the two pressure readings are then compared (SETRA, 2016). For temperature, a temperature source; such as a hot-box or hot-bath, is used to simulate a static temperature, the temperature probe is then submerged and the displayed temperature from the probe is compared to the source temperature. For conductivity, the conductivity probe is sterilised and then submerged in a known conductivity fluid, the displayed conductivity reading is then compared to the conductivity solution. The methods of calibration may differ between instrument types, but the same principle is used to calibrate; compare the probe being calibrated to a fixed known sample to ensure the reading is within a certain tolerance and adjust the zero and span point if required.

1.2.3 Manual Calibration

Figure 1 shows the setup of manually calibrating a Siemens transmitter with a Druck manual pressure calibrator. The Druck unit is a pressure calibrator that generates pressure by using a hand-pump. This pressure is sent to the calibrated unit and a signal feedback is produced and measured on the Druck. The Druck then compares the returned signal with actual pressure (GE, 2015).



Figure 1 - Manual Calibration Process

A similar unit to the Druck is the Beamex unit. The Beamex unit can calibrate from -0.95 BAR (Vacuum) to 100 BAR (Beamex, 2016). If a technician wants to calibrate higher pressures then an additional external transducer attachment is required. These external transducers add weight to the equipment carried around by the technician and can cost a similar amount to the individual base unit.

1.2.4 Semi-Automatic Calibration



Figure 2 - WIKA CPC2000 Calibrator (WIKA, 2013)

Figure 2 shows the WIKA CPC2000 pressure calibrator (WIKA, 2013). The device operates by the user entering a desired pressure into the display and starting the process. The pressure is then generated by an internal pump. The operation of the device can be seen in Figure 3, the target pressure is used to control the pump. Any adjustments are then made based on pressure feedback.

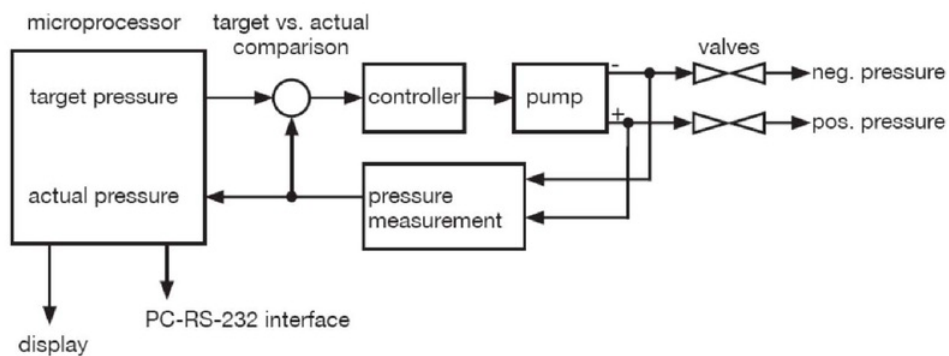


Figure 3 - WIKA CPC2000 Process (WIKA, 2013)

Good background research showing what equipment is available at present

2.3.3 Current Automatic Pressure Calibration

Why 2.3.3 and not 1.2.5?



Figure 4 - Additel Calibrator (Additel, 2018)

Figure 4 shows the Additel automatic pressure calibrator (Additel, 2018). The Additel device is capable of calibrating between -75 mBAR and +75 mBAR. The device is able to power a transmitter, read information from the device using the HART protocol and read voltage and current signal inputs. The cost of the device is \$9,750. The device has a limited range and an excessive cost, the aim of this project is to create a device that can calibrate across a wider range with the budget of £1,000.

1.3 The Problem

The issue with manually calibrating an instrument is the human error that can enter the process. When generating pressure using the calibrating device, the signal output from the device lags behind the injected pressure. If the lag is not accounted for and the technician takes a reading before the signal has reached steady state then the calibration results will not represent the actual transmitter performance. Another issue is the amount of time spent manually calibrating a pressure transmitter. Depending on the accuracy and scale of the instrument, the total time can be significant.

An automated pressure calibrator will be designed and a prototype built to overcome these issues. A basic block diagram for the system can be seen in Figure 5. A system processor will control a pressure generating rig, this rig will send pressure to a reference and calibrating transmitter. The feedback from these transmitters will then be fed back into the system processor, allowing the system to measure and control the process.

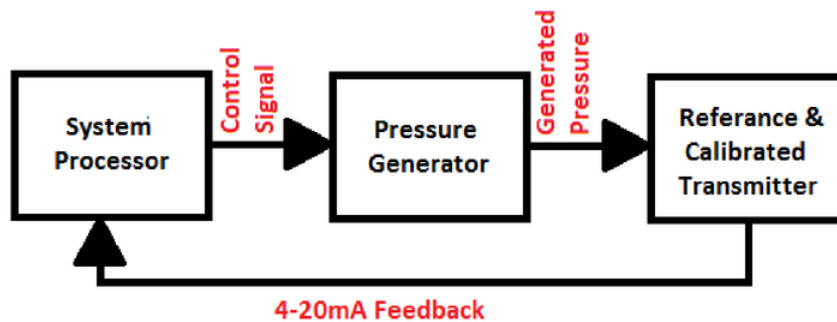


Figure 5 - System Block Diagram

Good explanation of what the problem is that the project will attempt to alleviate

2.0 Literature Review

2.1 Potential Solutions

2.1.1 Solution A



Figure 6 - NI myDAQ (National Instruments, 2017)

The control system for this solution would use the National Instruments (NI) myDAQ device shown in Figure 6 (National Instruments, 2017). The myDAQ device is a data acquisition device that can input and output analogue signals, digital signals and provide power supplies. The device is small and lightweight. The device also houses a multi-meter that could be used for fault finding on the calibrated instrument or its transmission cables. The myDAQ device can be plugged into a laptop or computer and accessed by using the NI LabVIEW program. The NI LabVIEW engineering software is used for designing control systems that can be integrated into hardware. The software provides drag and drop interfaces to be able to easily visualise the input control signals from the hardware. This solution would use a laptop as the HMI for the prototype. The myDAQ does not have an inbuilt processor and therefore needs the processor of a computer to run the program.

2.1.2 Solution B



Figure 7 - NI myRIO (National Instruments, 2017)

The control system for this solution would use the NI myRIO embedded reconfigurable I/O device (National Instruments, 2017). The myRIO device uses the NI LabVIEW software. The board has an inbuilt processor and FPGA, therefore when the programming computer has been disconnected, the software board can still operate. A HMI touch-screen display would be required for a user to operate the software. The myRIO-1950 model provides four analogue inputs, two analogue output and 16 digital I/O pins that can also be used for PWM supply. The digital outputs uses a 3.3VDC signal, a transistor circuit will be needed to trigger the solenoid valves. The analogue signals from the transmitters will require converting from 4-20mA to a DC voltage. This solution would also use the NI LabVIEW software to integrate the hardware into the software.

2.1.3 Solution C

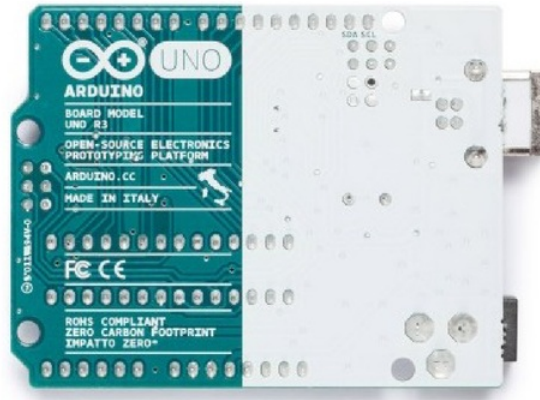


Figure 8 - Arduino Uno Rev 3

The control system for this solution would use the Arduino Uno Rev 3 board (ARDUINO, 2017). The Arduino board is a microcontroller board based on the ATmega328P. The board has several digital I/O and several analogue inputs, the board has zero analogue inputs. The software used for programming the board is the Arduino IDE software. The Arduino starter kit contains the mentioned board and relevant software for just over £70.

2.1.4 Solution Comparison

	COST	CONSTRUCTION COMPLEXITY	USER SIMPLICITY	ANALOGUE I/O	DIGITAL I/O	DATA LOGGING	TESTING FACILITY	TOTAL
Potential Score	5	5	5	5	5	5	5	100%
myDAQ	3	4	4	3	3	4	5	74.29%
myRIO	3	3	4	4	4	4	3	71.43%
Arduino UNO REV 3	5	2	4	1	3	2	0	48.57%

Table 1 - Solution Comparison

Table 1 shows a comparison of different elements of each solution and assigns a score depending on how well each solution met the requirement. Each element was scored from 0 to 5; the higher value being the better result. The numerical value was totalled and converted to a percentage to make choosing the final solution simpler.

The cost of the solution wasn't a major constraint; as long as the solution cost less than £1,000 total. The myDAQ and myRIO controllers both cost £400, therefore they scored lower than the Arduino board that costs £70.

The construction complexity of the myRIO and myDAQ solutions would be fairly easy to complete for an experienced technician, therefore they both scored a higher. The construction of Solution C would be more complex as the on-board memory of the Arduino UNO REV 3 board would need replacing for the required storage, therefore the solution scored lower.

The user simplicity of this project is a huge requirement, the idea is for a user to be able to connect an instrument, start the sequence and then obtain results without intervention. All three solutions are capable of achieving this with varying levels of construction complexity. Ideally, the only complicated part of the solution for the end user will be the connecting of the calibrated instrument.

The analogue I/O is a major requirement in the project. The analogue inputs will be used to measure the feedback signals from the two transmitters. The analogue outputs aren't necessary. However, they could be used as a method of simulating the transmitters and testing the program. Both the myDAQ and myRIO contain adequate analogue I/O. However, the Arduino UNO REV 3 has no analogue outputs, therefore the solution scored lower.

The digital I/O is a major requirement. The digital I/O would be used for controlling the solenoid valves and the micro-pump. Each solution provided more than enough configurable digital I/O, therefore each solution scored similarly.

The data logging of the results is one of the biggest requirements of the project. The results need to be recorded to prove the calibration of the instrument. The myDAQ and myRIO are capable of exporting data to Microsoft Excel, therefore data logging is made simple. The Arduino UNO REV 3 board requires data extraction after each calibration. This isn't a massive issue; however it is an inconvenience, therefore this solution scored lower.

The testing facility section was an additional criteria added for the extra facilities each solution could supply. The priority of this requirement is low as it is not necessary for it to allow the project to work. The myDAQ houses a multi-meter capable of measuring current, voltage and resistance. The multi-meter is an essential part of a technician's tool-kit for fault finding on equipment. The multi-meter could be used for detecting wire shorting, lost earth paths, loss of power etc. Solution B can use the analogue output terminals to be able to simulate the pressure readings of the transmitter, allowing the logic to be tested before integrating into the hardware, therefore solution B scored 3. The Arduino UNO REV 3 board has no on-board testing facilities or analogue outputs for self-simulation, therefore solution C scored a 0.

2.2 Chosen Solution

The chosen solution for this project is solution A. The NI LabVIEW software is ideal for designing a user interface that will provide achieved results and display a graph. The results can either be printed at the end of a test or directly exported to Microsoft Excel to log results on a spreadsheet. The myDAQ hardware provides more than enough I/O to achieve the project and also has the advantage of the built in multi-meter.

For solution B, the device can operate without the use of a computer. If the prototype was designed to operate constantly then the myRIO device would have been ideal. However the prototype will only operate during testing, therefore the myRIO board is too excessive for this project. For solution C, the Arduino Uno Rev 3 board has a lack of memory for storing results and would have to be connected to a laptop for the results to be stored. The device would also require a HMI for the user to be able to operate the software. Having to use two displays to operate the solution is an inconvenience to the user.

3 potential solutions noted, a realistic comparison table produced and a good, reasoned choice made as to which solution to take forward

3.0 Specification & Testing Plan

3.1 Specification

The following list shows the specification for the hardware and software of the prototype.

Hardware

- The prototype must automatically calibrate a pressure transmitter.
- The prototype must generate pressure up to 250 mBAR & draw vacuum to -250 mBAR.
- The prototype must be able to read a 4-20mA signals from two pressure transmitter simultaneously.
- A transmitter must be installed for control and to record and reference pressure.
- The prototype must be able to pump in increments of 20% along the pressure range and hold the pressure/vacuum inside of a small tank.
- Any transmitters used in this prototype must be calibrated externally before installing onto the prototype.
- The supply to each component must be fused.
- The prototype must be portable.
- The main controller for this prototype must be the NI myDAQ.

Software

- The program controlling the prototype must have a form of HMI.
- The program must have interlocks that prevents the prototype from damaging itself.
- The prototype must be capable of storing the results achieved and determining if the pressure transmitter has passed or failed the calibration depending on a tolerance.
- The program controlling the prototype must have a structured sequence.
- The prototype must be able to test a pressure transmitter within a tolerance of 0.25%
- The software must alert the user if the instrument goes out of tolerance.
- The software must produce results in a table and graph format.

General specification given which is detailed and realistic

3.2 Testing Plan

Test	Pass Requirement	Pass / Fail	Comment
Use the Druck DPI pressure hand pump to pressurise the system to test for air leaks.	Pressure loss is negligible after system pressure settles.		
Use the Druck DPI pressure hand pump to draw vacuum from the system to test for air leaks.	Vacuum loss is negligible after system pressure settles.		
Inject 4-20 mA into the AX-ABC card to test for voltage output.	The voltage output is 2-10 VDC for 4-20 mA linearly.		
Inject appropriate signals into each component using the calibrated Fluke 724 process meter and the Fluke 789 multi-meter.	Each component operates as expected from manufacturers specification; i.e. Solenoid Valves open, The pump operates etc.		
Measure voltage off each power supply using the calibrated Fluke 789 multi-meter.	Correct Voltage level outputted from each power supply.		
Use the inbuilt multi-meter to measure varying voltage values.	The multi-meter is capable of use from the panel connections and varying voltage readings are reading expected values.		

Table 2 - Preliminary Test Table

Table 2 shows the preliminary test to be carried out on the prototype. The preliminary tests are designed to test the individual components in the prototype before the main tests are carried out.

Good pre-test table noted to test the equipment before main test begins

Test	Pass Requirement	Pass / Fail	Comment
Run the program in normal condition multiple times.	The results must be inside of tolerance for each program operation, this proves the operation, repeatability and reliability of the prototype.		
Whilst the program is running, observe the reference transmitter display	Both the dial and numerical display show the same reading of pressure / vacuum		
Whilst the program is running, observe the calibrated transmitter display	Both the dial and numerical display show the same reading of pressure / vacuum		
Whilst the program is running, observe the operation of the indicators.	Relevant indicators for valve direction, pressure condition and results recording illuminate when required.		
Operating the start button.	The program sequence moves from the 'initialise' state to 'state 0' and the prototype begins to operate.		
Operate the stop button.	The program sequence moves from its current state to the 'manual stop' state, stopping the operation of the system.		
Operate the program with the adjustable tolerance set at 0.25% and 2%.	The program detects the adjustment of the tolerance and adjusts the tolerance logic as required.		
Whilst the program is running, observe the pressure difference display.	The display shows a pressure reading throughout the operation.		

Table 3 - Main Test Table

Table 3 shows the main test table used to test the operation of the prototype. These tests are designed to test the main operation of the prototype, the prototypes reliability and the operation of the LabVIEW program.

Very good set of tests to be carried out on the main sequence with a 'pass requirement' noted

4.0 Safety, Sustainability, Environment, Professionalism, Maintenance & Reliability

4.1 Safety

When the system does go into fault, the program must leave its current position in the sequence, turn off the pump and drain the generated pressure to atmosphere. This will allow the user to maintain the prototype without the danger of the stored pressure.

A point of work risk assessment (POWRA) will be carried out before undertaking the project to ensure the work area is safe. Should the circumstances change at any point the POWRA will be reviewed. *Where is the POWRA?*

4.2 Sustainability

The components used in the prototype will be 'standard off-the-shelf' components that have a long operating life. The pressure generated in the prototype is from atmosphere, therefore there are no gases or liquids that need supplying to the prototype; hydraulic and nitrogen calibration processes have been avoided.

4.3 Environment

Any waste created during the course of this prototype will be recycled where possible. If the prototype was taken further and developed into a product to sell, the UK guidance on 'Electrical & Electronic Equipment (EEE): Producer Responsibilities' must be used, where old equipment that is being replaced must be taken from the customer and disposed of correctly.

The project will not produce any harmful emissions or by-products during operation. The noise pollution of the prototype is minimal as the pump generates less than 25 decibels of noise; below the tolerance for hearing protection.

4.4 Professionalism

This project will have the industrial supervisor; Saul Coles, acting as a customer, therefore all relevant company policies and procedures will be followed in the production, testing and supplying of the prototype. This includes the 'KCS Quality Policy' and the 'KCS Environment Policy'.

Very good detail noted on Safety, Sustainability, Environmental protection & Professionalism

4.5 Maintenance

A wiring drawing will be provided with the prototype to help technicians fault find and test the prototype when necessary. Each component has been fused individually to make fault finding simpler, as the faulty component will be easily identified by the blown fuse.

Annually, the reference transmitter will need to be calibrated against external standards, this will ensure the instrument is within a specified tolerance against national standards.

4.6 Reliability

The components used in this project are all manufactured 'off-the-shelf' components. These components have a long operating life, therefore component faults are unlikely as long as the prototype is used within the specified pressure range. The reference transmitter has been calibrated against national standards within a set tolerance, therefore instruments calibrated on the prototype can be traced back to national standards as well.

Maintenance & Reliability taken into consideration in relation to equipment used

5.0 Project Design

5.1 Pneumatic Hardware

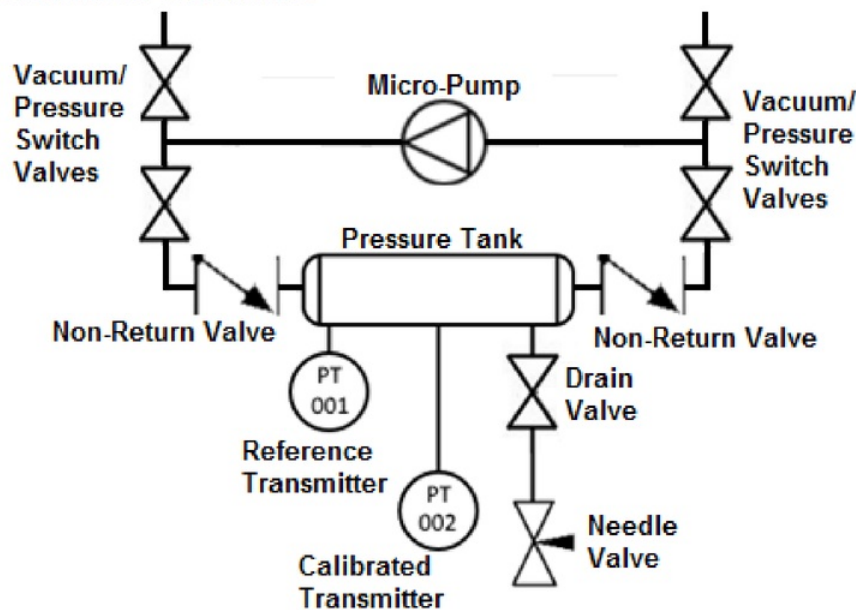


Figure 9 - Pneumatic Hardware

Figure 9 shows the layout of the pneumatic hardware in the prototype. The micro pump in the centre is responsible for generating the pressure and drawing the vacuum. There are 4 single direction solenoid valves that control whether the tank is being pressurised by the pump or vacuum is being drawn from the tank. The pressure tank is the vessel that will hold the pressure or vacuum that is being generated. The non-return valves attached to the pressure tank isolates the air to the tank when the pump switches off, this then reduces the likelihood of pressure being lost from leaks across the solenoid valves. The reference and calibrated transmitters are directly attached to the pressure tank. The drain valve and needle valve combination will allow the system to slowly bleed pressure as required.

5.1.1 Generating Pressure Method

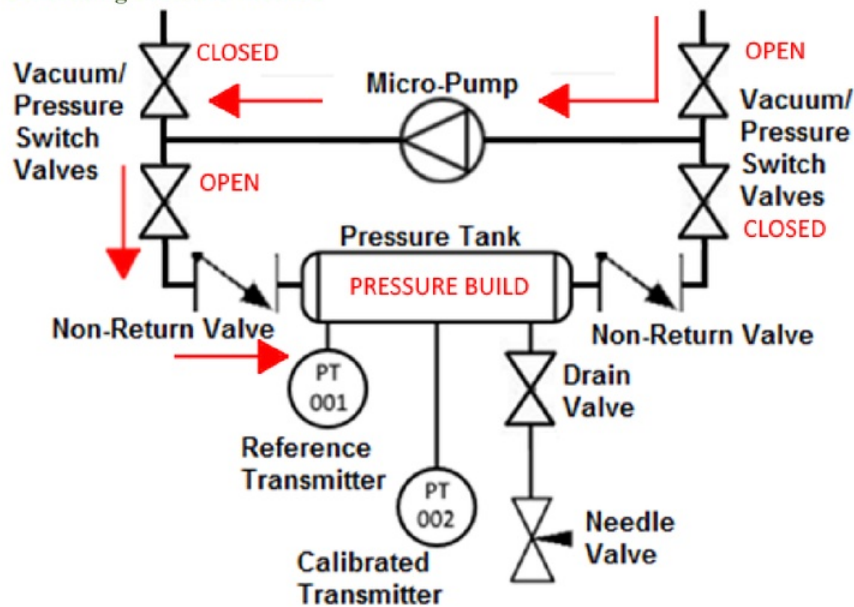


Figure 10 - Building Pressure Setup

Figure 10 shows the method the prototype will use to build pressure against the instrument. The red lines indicate the path of the airflow through the open solenoid valves. Air will be drawn from atmosphere, through the first open solenoid valve, through the micro-pump and then through the second solenoid valve, directing the air into the pressure tank. The non-return valves will isolate the generated pressure in the pressure tank. When the pressure needs draining the drain solenoid valve will open, allowing air to bleed out through the needle valve.

5.1.2 Drawing Vacuum Method

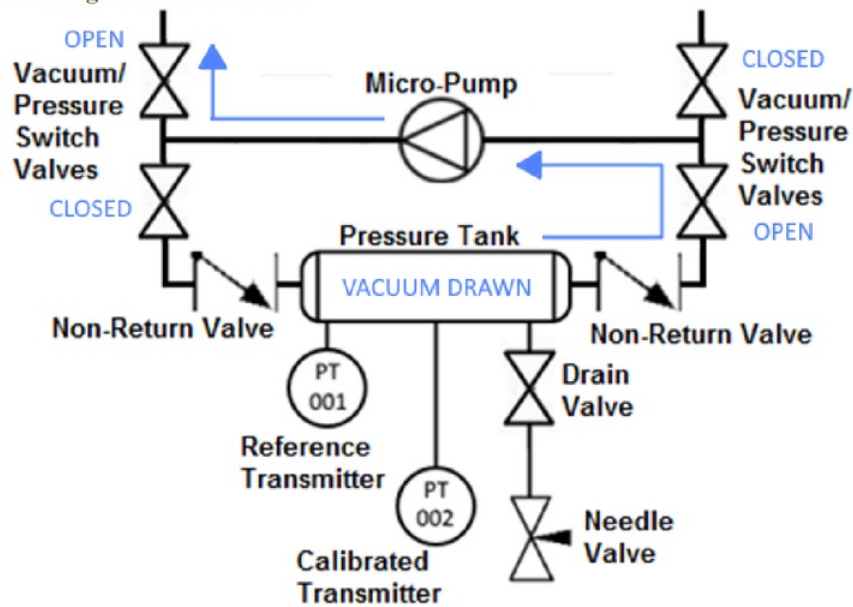


Figure 11 - Project Concept Drawing Vacuum

Figure 11 shows the prototype drawing vacuum from the instrument. Vacuum is drawn from the tank, through the non-return valve, then through the first open solenoid valve, then through the micro-pump and the air is then pushed out the second open solenoid valve to atmosphere. The orientation of the isolation valves and the closed solenoid valves prevents air from returning into the tank. When vacuum needs to be reduced the drain valve can be opened to allow air to pass through the needle valve and into the tank.

Excellent series of block diagrams and explanations which clearly shows how the project is to be designed

5.2 Electronic Hardware

5.2.1 Control

The main controller for this project is the National Instruments myDAQ. The myDAQ has several digital outputs that'll be implemented in this project, however the myDAQ is only capable of outputting 4 mA for powering the digital output. That level of current won't be adequate to drive the components selected for the project, therefore an external buffer relay is required.

The ST Microelectronics ULN2803A chip has been used. This chip is a Darlington transistor array chip, the maximum current gain for each channel is 1000.

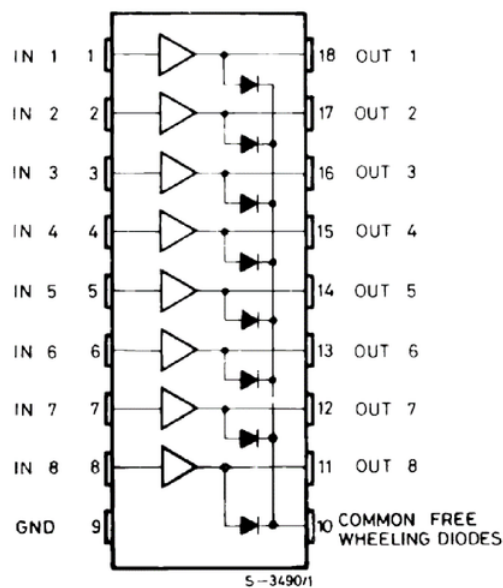


Figure 12 - ULN2803A wiring diagram (ST Microelectronics, 2018)

Figure 12 shows the wiring schematic for the chip. The chip switches the common return from each component. Inputs 1 - 8 are connected to the myDAQ digital outputs. The GND chip is connected to the digital output ground on the myDAQ. Outputs 1 - 8 are connected to the common returns from each individual component. Terminal 10 is connected to the power supply of each component for the free-wheel effect, allowing inductive energy to dissipate. There will be two of these chips installed as the selected pump operates at 6VDC whilst the selected solenoid valves operate at 12VDC.

5.2.2 Micro-Pump

The micro-pump used to generate the pressure in the tank is the TCS Micropumps D3K series pump; shown in Figure 13.

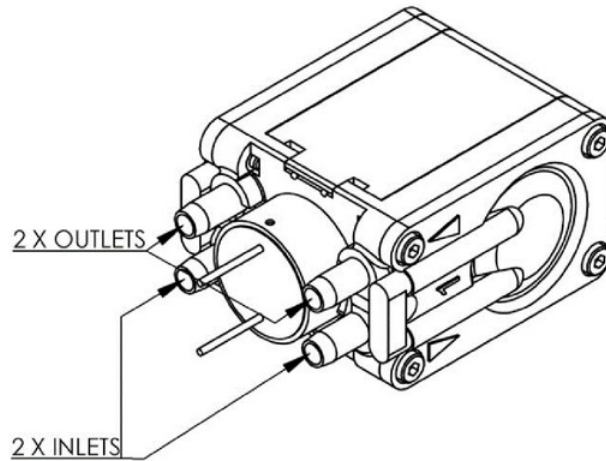


Figure 13 - D3K Micro-Pump (TCS Micropumps, 2014)

The micro-pump has two dual pumping channels. The channels can be connected in series for maximum pressure generation or in parallel for maximum flow. For this project the pump will be connected in series. The pumps maximum working pressure range with a moderate flow rate is -0.5 bar to +0.5 bar with maximum current drawn being 420mA.

5.2.3 Signal Processing

A standard output for instruments in industry is 4-20mA. The NI myDAQ is only capable of reading voltage on the analogue inputs, therefore a current to voltage converter is required. The Axio AX-ABC card was chosen to convert the 4-20mA signal to a 2-10VDC signal.

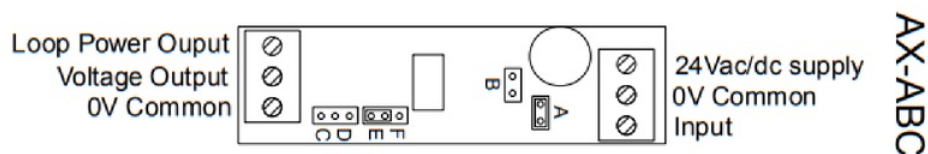


Figure 14 - AX-ABC Card (AXIO, 2011)

Figure 14 shows the Axio card. The card has a 24VDC power supply, a 0VDC common and 4-20mA input terminal. The card then converts this signal into a smoothed voltage and outputs it to the voltage output terminal. The mA signal is read from the loop powered transmitter, therefore the loop output terminal is connected to the positive terminal connected to the transmitter.

I/O selection table – Current input				
Output	Input			
	0-20mA	4-20mA*	0-10mA	10-20mA
	0-10V*	A + F + D	A + E *	A + D
	2-10V	-	A + F + D	-
0-5V	A + B + F + D	-	-	-

* factory default setting 4-20mA input, 0-10V output

Figure 15 - AX-ABC Jumper Setup (AXIO, 2011)

The AX-ABC card will be configured for a 4-20mA input and converted to a 2-10VDC signal, therefore according to Figure 15 the jumpers on the circuit need to be connected to points A, F & D; shown in Figure 14.

5.2.3 Other Components

The solenoid valves used in the project are the Heschen 2/2 way normally closed valves. The ports on the solenoid valves are 1/4". The solenoid operates at 12VDC. To supply the solenoid valves a 230VAC to 12VDC power supply will be installed. To supply the micro-pump a 12VDC to 6VDC power supply will be installed. To supply the signal conditioning cards a 230VAC to 24VDC supply will be installed. Three indicating LEDs will be installed onto the prototype for displaying the condition of the calibration.

All hardware components being used have been researched, referenced and clearly understood

5.3 Software Design

A program was designed that can control the system as required by the specification. The main structure of the program must:

- Control the 4 solenoid valves, switching between vacuum and pressure mode.
- Control the operation of the pump to generate pressure or draw vacuum.
- Read the voltage signal feedback from the AX-ABC card for the pressure feedback.
- Control indication LEDs that will display the status of the calibration.
- Constantly monitor for faults and alert the user to any.

Figure 16 shows the flow diagram for the main program.

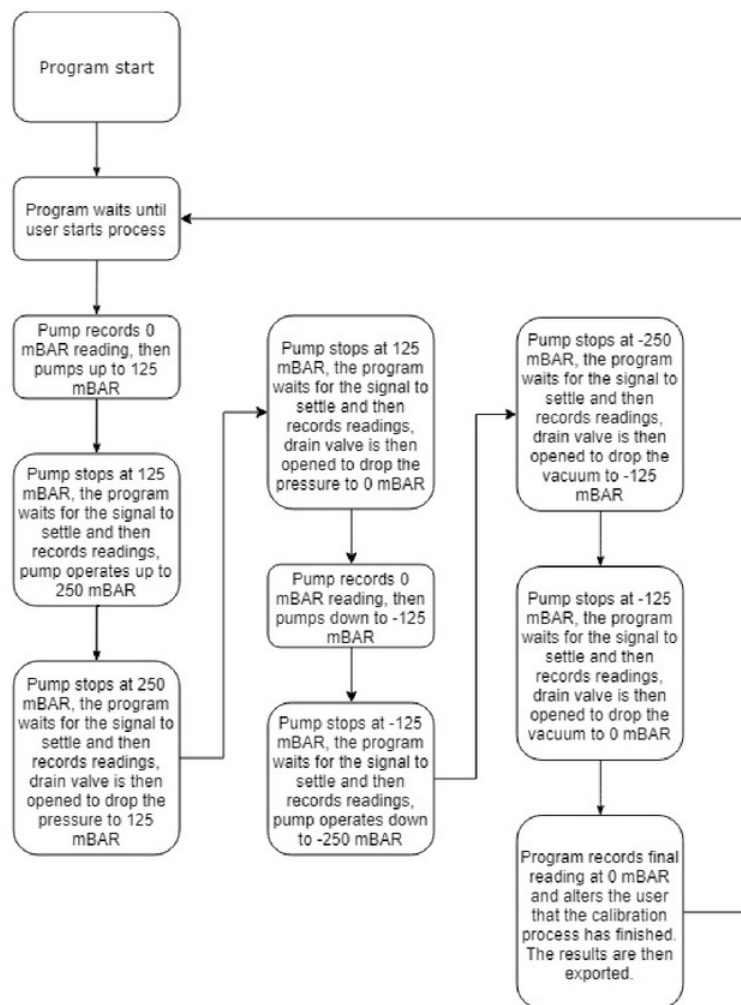


Figure 16 - Program Flow Chart

Very clear design flow chart noted which will help in developing main LabVIEW program

6.0 Project Implementation

6.1 Software Implementation

6.1.1 LabVIEW Program

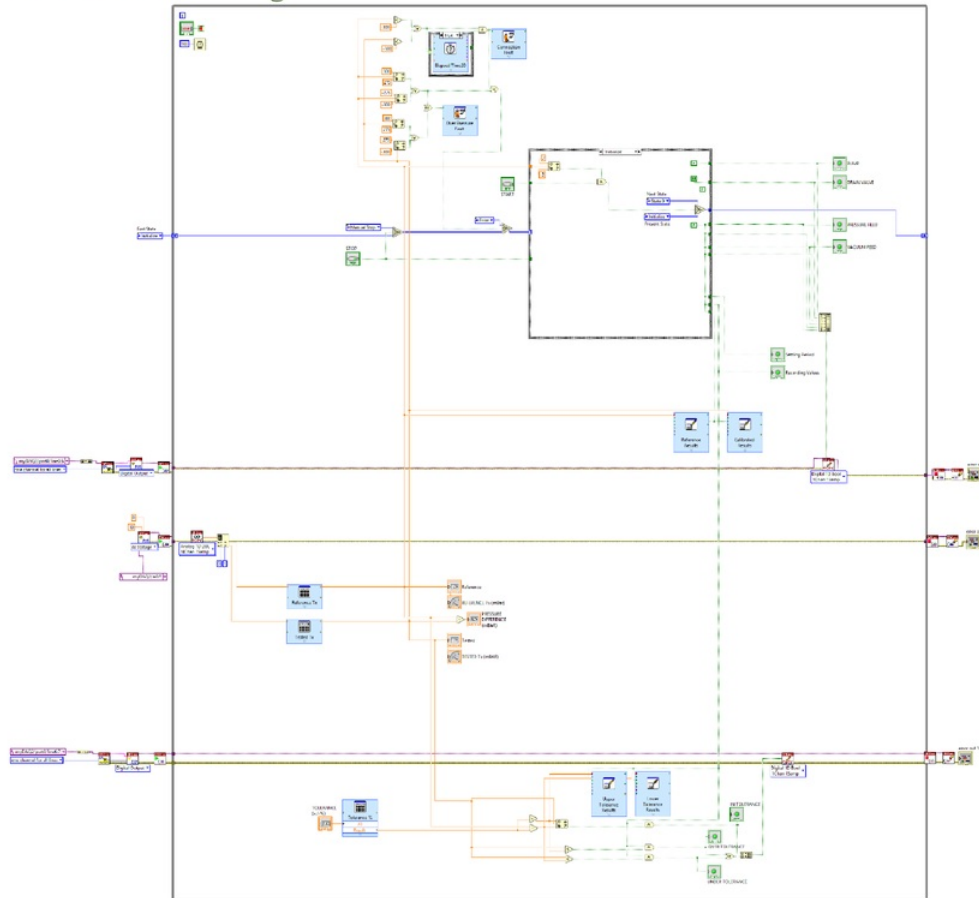


Figure 17 - LabVIEW Program

Figure 17 shows the LabVIEW program developed to control the prototype. The sequence of the program is controlled by the state machine. To minimise the number of input/output tasks that are in the program, arrays have been used to condense multiple inputs or outputs into a single task; for example the top digital output task in Figure 17 processes the six digital outputs that control the pump and solenoid valves in the prototype.

The main LabVIEW program Block Diagram could have been clearer

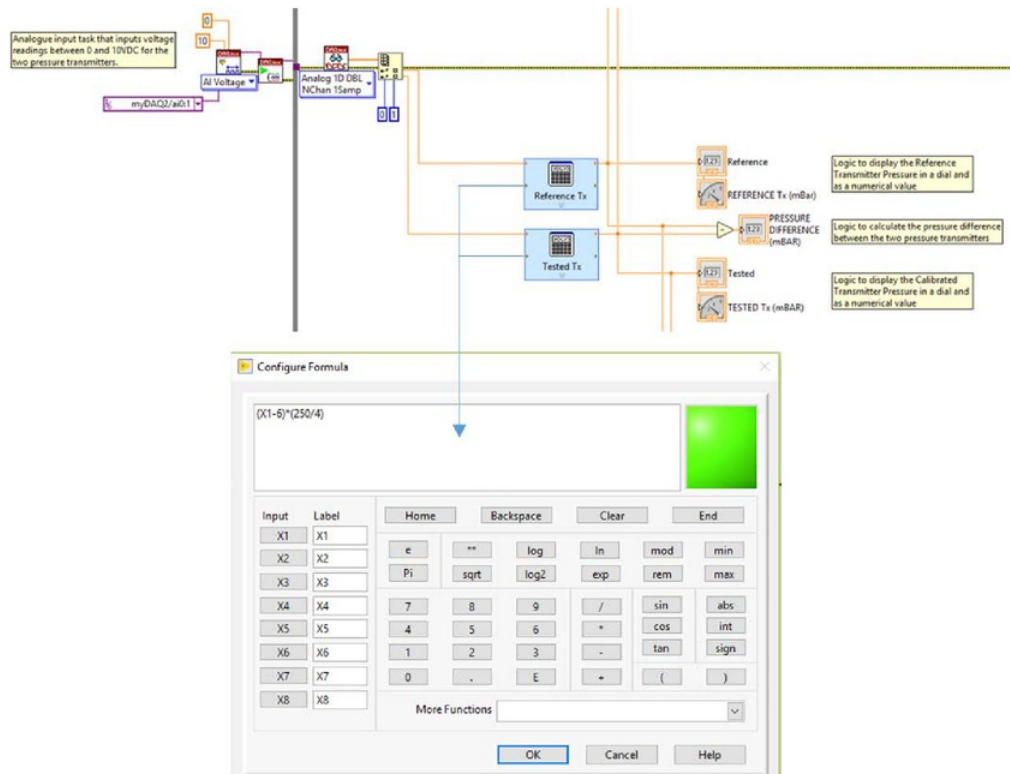


Figure 18 - Pressure Signal Input

Figure 18 shows the logic that is responsible for reading the voltage signal from the AX-ABC card, converting the voltage into a pressure reading and displaying the pressure to the user. The analogue input task has been set up to accept analogue signals between 0 and 10 VDC on channels AI0 and AI1 on the myDAQ. The values are stored inside an array in the task, the signals in the array are read by using the 'Index Array' block, this block converts the array into two usable signal ports. Each channel is then inputted into a formula block. The equation in the formula block is designed to convert a 2-10VDC signal into a -250 mBAR to +250 mBAR signal.

Very good detail on how the analogue inputs are converted in to pressure in mBAR

X1 (Voltage)	Pressure (mBAR)
2	-250
3	-187.5
4	-125
5	-62.5
6	0
7	62.5
8	125
9	187.5
10	250

Table 4 - Voltage to Pressure Conversion

Table 4 shows the result of converting the whole voltage range using the equation in the formula node, where X1 is the voltage input. After the signal is converted into a pressure reading, both channels are displayed on the front panel of the program numerically and in a dial.

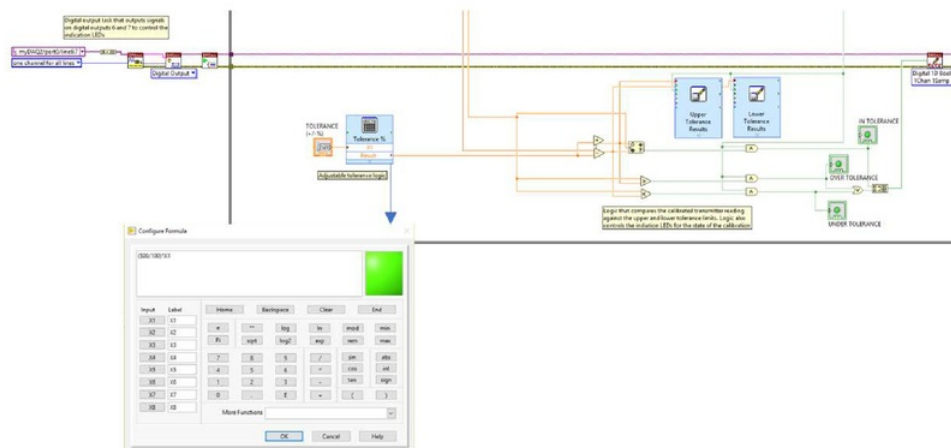


Figure 19 - Adjustable Tolerance Logic

Figure 19 shows the logic that controls the adjustable tolerance. The user enters a tolerance value between 0.25% and 2% on the front panel, this value is then inserted into the formula node called 'Tolerance %'. The equation converts the full scale range of 500 mBAR into a percentage, then multiplies the user percentage by this to give a +/- mBAR tolerance. The tolerance value is then added and subtracted from the reference transmitter readings to create a small pressure range. This pressure range is then fed into an 'In Range?' node, the calibrated transmitter signal is then compared to the small pressure range. If the calibrated

transmitter is in tolerance the 'In Range?' node will output a high signal. The following AND gate has an input from the signal recording node, therefore the indicators for in tolerance and out of tolerance will only illuminate if the tolerance condition and recording conditions are true. Two comparison gates compare the calibrated signal to the upper tolerance limit and lower tolerance limit. Should the pressure go over tolerance or under tolerance then the respective comparison gate will output a high signal. The over-tolerance and under-tolerance nodes are fed into an OR gate to give an out-of-tolerance signal. The out-of-tolerance and in-tolerance signals are then fed into an array, this array condenses the signals into a single digital output task that outputs the signals on the myDAQ on digital channels 6 and 7.

Excellent detail

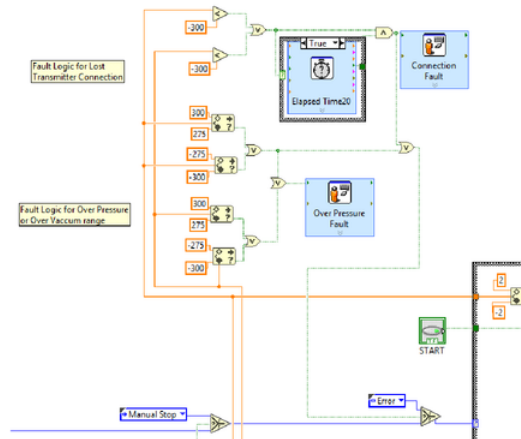


Figure 20 - Fault Monitoring

Figure 20 shows the logic that is used to fault monitor the system. The top group of logic monitors for a connection fault from both transmitters. The AX-ABC cards output 2-10VDC for 4-20mA off of the two transmitters. During testing, it was found that if the signal to the AX-ABC card was lost the card outputted near 0.5VDC. Using the equation from the voltage to mBAR formula node, a 0.5VDC signal would convert to:

$$mBAR = (0.5 - 6) \left(\frac{250}{4} \right) = -343.75 \text{ mBAR} \quad \text{Excellent}$$

Both signals are then compared to see if either are less than -300 mBAR. If either condition is true the connected OR gate activates a case structure that begins a 10 second timer. After 10 seconds; if the original condition remains true, the program is stopped and moved to the error state and the user is alerted to a faulty connection issue. The user is reminded every 10 seconds whilst a connection is lost and the program remains operational.

The bottom group of logic from Figure 20 monitors for over pressure and over vacuum conditions. Both transmitters are compared to a range of -300 mBAR to -275 mBAR to ensure the system doesn't go over the vacuum range. Both transmitters are then compared to a pressure range of 275 mBAR to 300 mBAR to ensure the system doesn't go over pressure. The 'In Range?' block is used to prevent the 'Over Pressure/Vacuum' error message displaying when 'Lost Connection' should be displayed. The conditions for over pressure/vacuum are fed into OR gates that connect to the 'Over Pressure/Vacuum' error message. Should any of the over-range conditions become true then the logic sequence will stop, move to the error state, drain the system and alert the user to the fault.

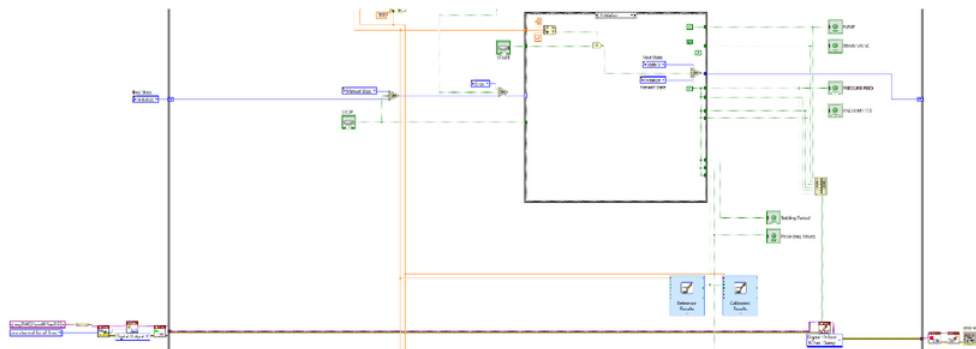


Figure 21 - State Machine

Figure 21 shows the state-machine used to control the main sequence of the system. The state-machine is a case structure loop that has multiple cases; i.e. multiple states. The initial state 'initialise' is loaded in through a set of 'true/false' cases. If the user presses the stop key then the first 'true/false' case sends the 'Manual Stop' case over-ride to the state-machine, over-riding the initialise. If the system detects an error the second 'true/false' case sends the 'Error' case over-ride to the state-machine, over-riding both 'Manual Stop' and 'Initialise' cases. The state-machine outputs several Boolean logic signals, these signals are used to control indicators on the front panel of the program and are outputted as digital outputs on the myDAQ, the Boolean signals are fed into an array that condenses 6 Boolean signals into a single digital output task, these signals are then outputted on digital channels 0 to 5.

The last three Boolean output signals from the state-machine control indicators that tell the user when the system is waiting for the pressure to settle after pump operation and when the system is recording readings. The 'record readings' Boolean signal activates four 'Write-to-File' nodes that record the upper tolerance reading, lower tolerance reading, reference

transmitter pressure and calibrated transmitter pressure. These four signal values are then sent to an Excel document. This document is responsible for displaying achieved results.

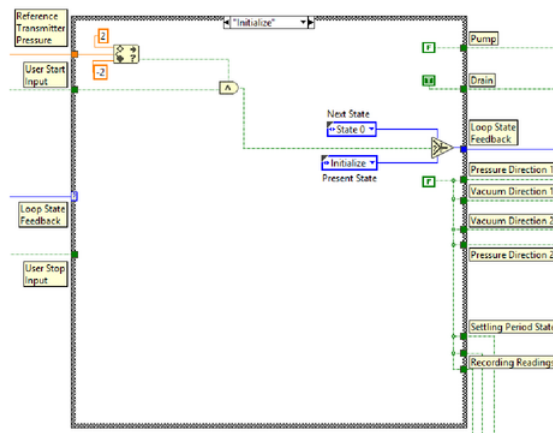


Figure 22 - Initialise State

Figure 22 shows the initialise state. In this state the system waits for the user to press the start key. During this period, all directional valves are closed and the pump remains off. The only output active is the drain valve. The system waits for the reference transmitter to be at atmosphere, then begins the sequence after the user presses 'start'. Whilst waiting for the start signal, a 'true/false' gate is used to feedback the 'initialise' state, when an initialise condition is met the true false gate is used to feedback 'State 0' into the case structure, moving the program on to the next step.

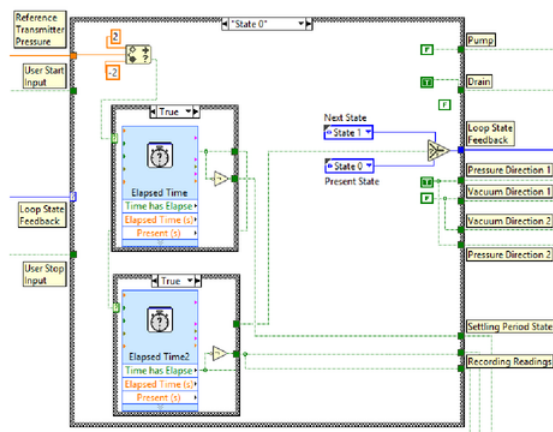


Figure 23 - State 0

Figure 23 shows the state-machine in 'State 0'. The logic first ensures the system is still at atmosphere. When the atmosphere condition is met the 'In Range?' node outputs a signal to a case structure, inside this case structure is an 'Elapsed Time' node that is set for 10 seconds; this timer is used to allow the pressure inside the tank to settle before any readings are recorded. During the 10 second window, a NOT gate outputs a high signal that controls an indicator on the front panel, alerting the user that the system is waiting for the pressure in the tank to settle. When the 10 seconds have passed, the first 'Elapsed Time' node outputs a signal to a second case structure.

Inside the second case structure is another 'Elapsed Time' node set at 1 second. A NOT gate is used to output a high signal during the elapsed time, this high signal is then sent to the four 'Write to File' nodes, enabling them to record the four desired signals. After the elapsed time has passed the 'True/False' node that was looping the case structure on 'State 0' switches and passes 'State 1' into the case-structure.

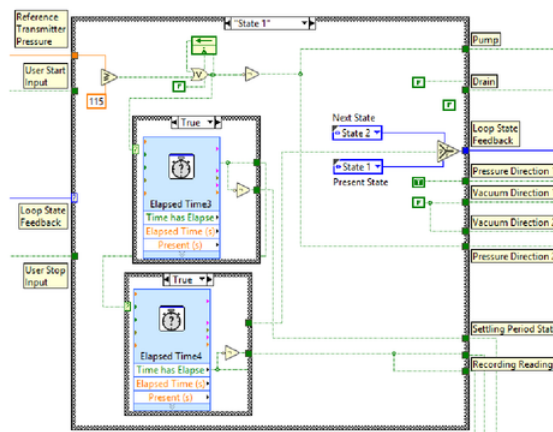


Figure 24 - State 1

Figure 24 shows the state-machine in state 1. In state 1, the drain valve is closed, the pressure directional valves are opened and the pump is activated. The state-machine compares the reference transmitter signal against a 115 mBAR set point and outputs a high signal when the desired pressure is achieved; after multiple runs it was found that stopping the pump at 115 mBAR allowed the pressure to peak and settle at 125 mBAR; i.e. the 16 mA point. After pumping up to 115 mBAR pressure, an OR gate is used that feeds back the output signal into the input. During testing, it was found that the indicators and controls would flicker as the pressure passed the 115 mBAR point, the locking OR gate prevents this.

After the OR gate, a NOT gate is used to control the pump and one of the valves. Before 115 mBAR pressure is achieved, the NOT gate outputs a high signal, which turns on the pump and opens the pressure directional valve that is connected to atmosphere. When 115 mBAR pressure is achieved, the NOT gate outputs a low signal which turns off the pump and closes the pressure directional valve connected to atmosphere. Closing this valve acts as a double isolator, should the one-way valve connected to the air tank fail, this closing valve will hold the pressure in the system.

The same system of recording from state 0 in Figure 23 is used for state 1. The system waits 10 seconds with the first 'Elapsed Time' node, records the pressure readings for 1 second with the second 'Elapsed Time' node. The sequence then moves onto state 2 by switching the 'True/False' node.

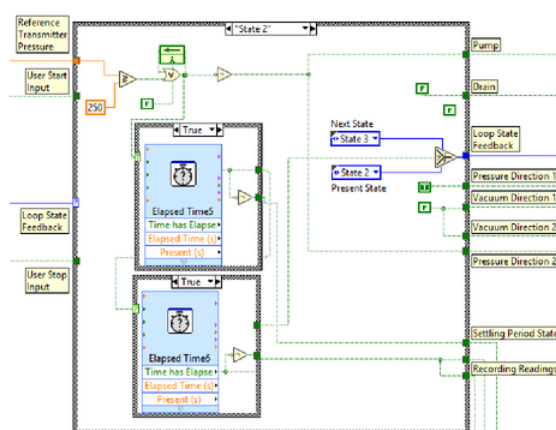


Figure 25 - State 2

Figure 25 shows the sequence in state 2. The principle for state 2 is the same as the principle of state 1 in Figure 24; the only difference is the pressure target. The system pumps up to 250 mBAR, turns off the pump and isolates the directional atmosphere valve, allows the pressure to settle for 10 seconds, then records the pressure reading for 1 second. The 'False' constant entered into the feedback node attached to the OR gate sets the initial condition of the output of the feedback node when the program is first initialised. The pressure target for state 2 is 250 mBAR, this is because the pressure rate of rise is reduced compared to state 1. The reduced pressure gain prevents a significant overshoot over 250 mBAR. The target is 250 mBAR as this is the 20 mA point on the range. After completing this step the second 'Elapsed Time' node outputs a high signal and moves the sequence onto state 3.

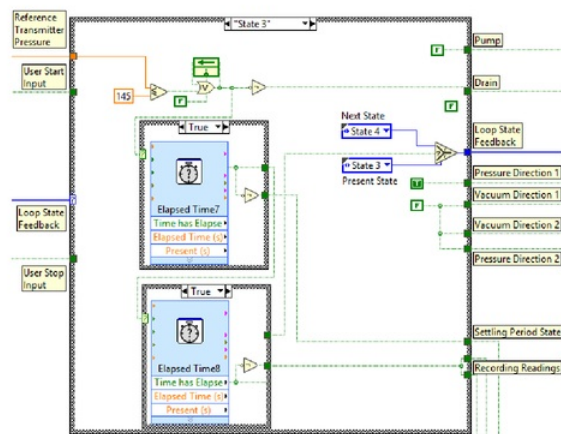


Figure 26 - State 3

Figure 26 shows the sequence in state 3. The principle for state 3 is the same as state 2. The difference now is that this state is controlling the state of the drain valve; the pump remains off constantly. The system is trying to achieve a result close to 125 mBAR. The sequence starts by draining the pressure to 145 mBAR then closing the drain valve, the system waits for 10 seconds using the first 'Elapsed Time' node, then records the results for 1 second using the second 'Elapsed Time' node. From testing, it was found that closing the drain valve at 145 mBAR gave a reading close to the 125 mBAR target with negligible difference.

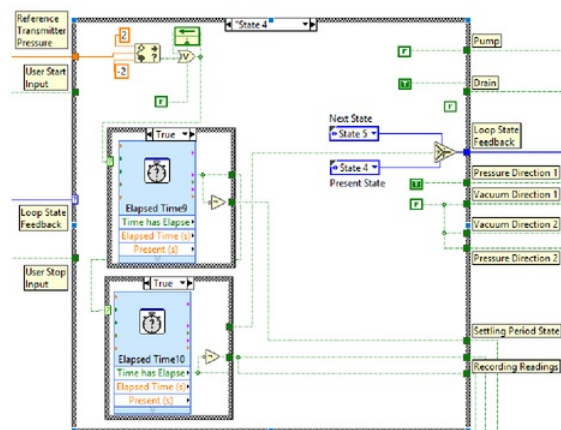


Figure 27 - State 4

Figure 27 shows the sequence in state 4. The sequence uses the same principle as state 3, the only difference is the target pressure being atmospheric pressure and the drain valve is constantly open. The system opens the drain valve and allows the system to vent to atmosphere. The first 'Elapsed Time' node then operates, allowing for a 10 seconds settling

period. The second 'Elapsed Time' node then operates, recording the pressure reading for 1 second. The system then moves onto state 5 when the recording has completed.

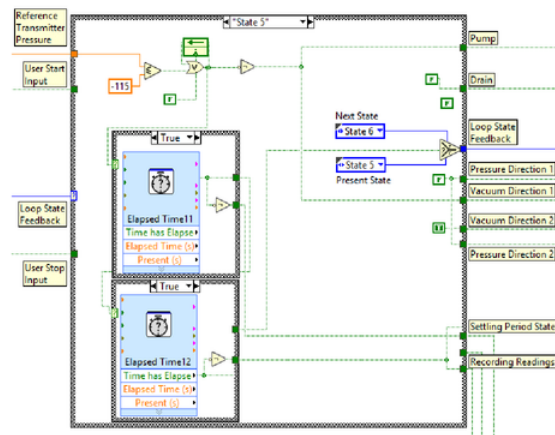


Figure 28 - State 5

Figure 28 shows the state-machine in state 5. The orientation of the air flow has changed now and the pressure direction valves have gone off. The vacuum direction valves have been opened and the pump is active, drawing air from the tank. The sequence will wait for the reference pressure to be less than -115 mBAR, then stop the pump and close the vacuum direction valve connected to atmosphere; similar to earlier with the pressure setup, this closed valve will act as a double isolation, preventing vacuum loss should the non-return valve connected to the tank fail. After -115 mBAR vacuum has been achieved, the first 'Elapsed Time' activates and the system waits for 10 seconds, at which time the system vacuum peaks and settles at -125 mBAR. After 10 seconds, the second 'Elapsed Time' activates and records the system vacuum reading. The sequence then moves onto state 6.

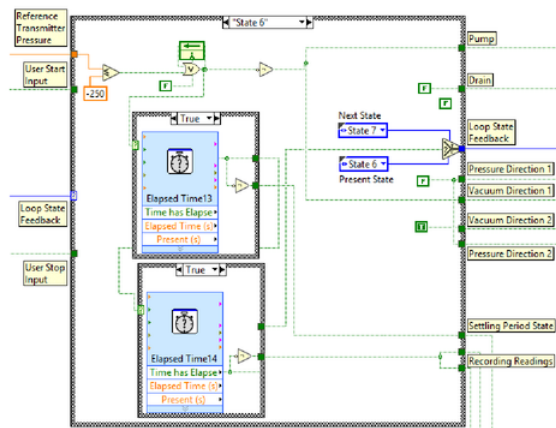


Figure 29 - State 6

Figure 29 shows the state-machine in state 6. The target vacuum for this step is -250 mBAR. The directional valves are set for vacuum and the pump is set to operate until the target vacuum. When the vacuum is achieved, the vacuum directional valve connected to atmosphere is closed; acting as a double isolation for the vacuum, and the pump is switched off. The first 'Elapsed Time' node activates for 10 seconds, allowing the vacuum to peak and settle close to -250 mBAR. After 10 seconds, the second 'Elapsed Time' node activates and allows the four 'Write-To-File' nodes to record the desired readings. The sequence then moves onto state 7.

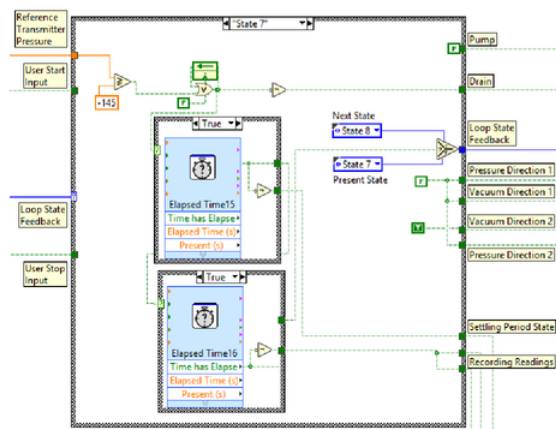


Figure 30 - State 7

Figure 30 shows the state-machine in state 7. The sequence is now venting the vacuum to reach -125 mBAR, the pump remains off and the sequence is now controlling the drain valve. The sequence drains the vacuum until it reaches -145 mBAR, the first 'Elapsed Time' node is

then activated; this allows the vacuum to drop and settle close to -125 mBAR. The second 'Elapsed Time' node is then activated and the desired results are recorded. The sequence then moves on to state 8.

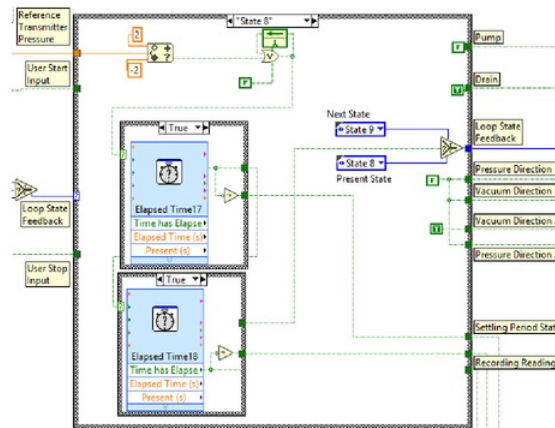


Figure 31 - State 8

Figure 31 shows the state-machine in state 8. The sequence is now venting down to atmosphere, the drain valve is left open constantly. When the system reaches atmospheric pressure. The first 'Elapsed Time' node activates, allowing the system pressure to settle. The second 'Elapsed Time' node then activates, allowing the system to record the desired pressure readings.

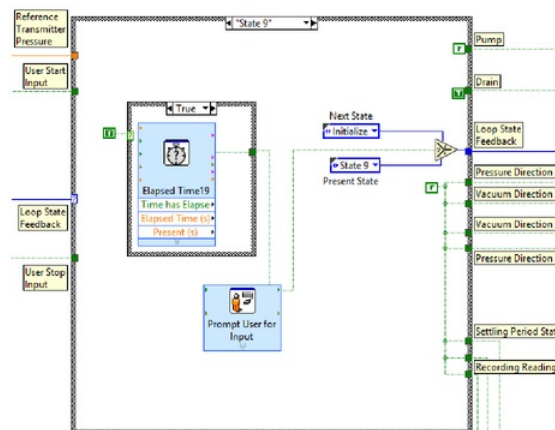


Figure 32 - State 9

Figure 32 shows the state-machine in state 9. The calibration process has completed, therefore all the directional valves have been closed and the pump has been switched off. An 'Elapsed Time' activates when state 9 begins, this then triggers a 'Prompt User' node that

alerts the user that the calibration process has finished and the results can be found in the Excel document. The sequence then moves to the 'Initialise' state, waiting for the next calibration process to begin.

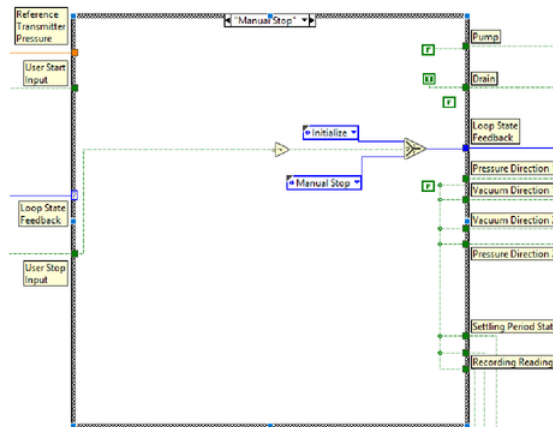


Figure 33 - Manual Stop

Figure 33 shows the 'Manual Stop' state in the state-machine. This state activates when the user presses the manual stop button on the front panel. When the sequence is in this state, the drain valve is opened, the directional valves are closed and the pump is switched off. The NOT gate connected to the 'True/False' node prevents the system from returning to the 'Initialise' until the user releases the latched stop button.

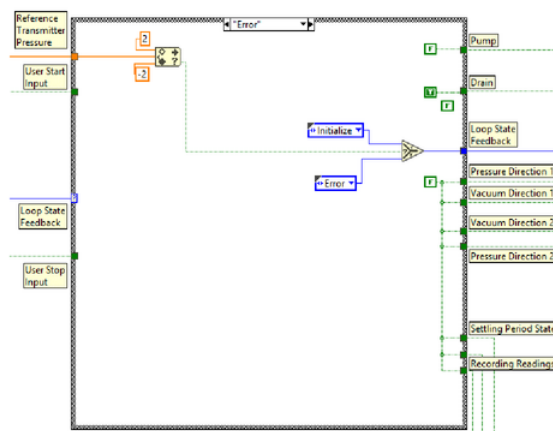


Figure 34 - Error

Figure 34 shows the state-machine in the 'Error' state. The sequence goes to this state when an error is detected. All directional valves are closed, the pump is switched off and the drain valve is opened. The sequence remains in this state until atmospheric pressure is achieved.

Excellent detail on the states used within the state diagram and how they control the testing process

When the pressure is between -2 mBAR and +2 mBAR, the 'In Range?' node outputs a high signal, operating the 'True/False' node, moving the sequence back to the initialise state.

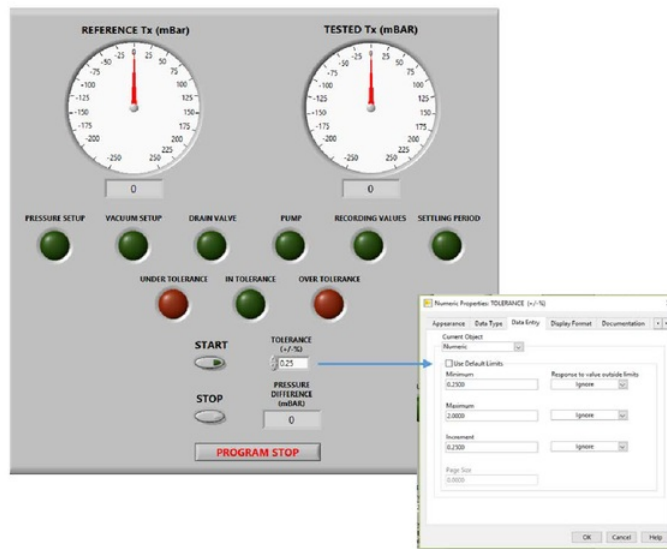


Figure 35 - LabVIEW Front Panel

Figure 35 shows the LabVIEW front panel that the user will use to control the prototype. The front panel displays the pressure for both transmitters on a dial and numerically in the box below the respective dial. The top row of indicators displays the condition of the directional valves, the drain valve, the pump, the recording and settling period. The second row of indicators shows the condition of the calibration, the two red indicators will illuminate during the recording period if the results are over or under tolerance, the green indicator will illuminate when the system is in tolerance. The start and stop keys control the state-machine, beginning and stopping the sequence when the user presses the respective key. The tolerance tab is an adjustable range that can be set from 0.25% to 2% accuracy. The pressure difference node displays the pressure difference between the transmitters in mBAR.

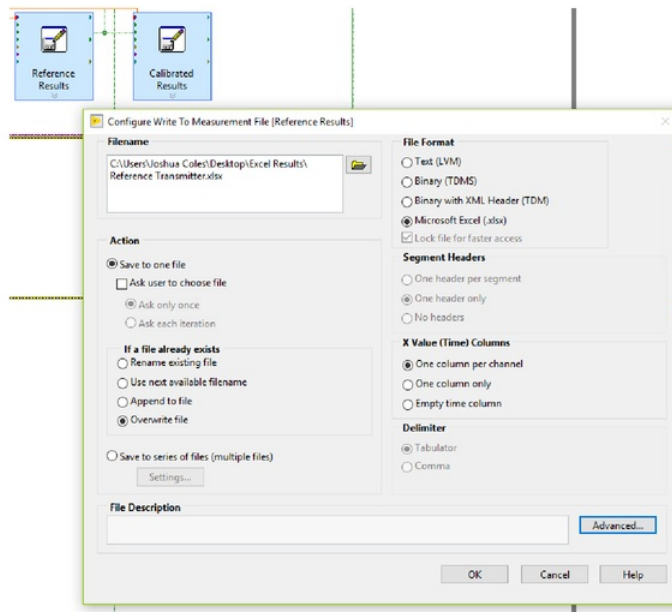


Figure 36 - Write to File Setup

Figure 36 shows how the write-to-file nodes were setup. A file path is given for an Excel document. The excel document file format was selected and each node records a single channel.

[Very good detail on how the LabVIEW 'data logs' the pressures allowing for CSV outputs to be generated](#)

6.1.2 Microsoft Excel Results Page

Time	Untitled
20:33:46	0.06978
20:33:46	-0.256082
20:33:46	0.06978
20:33:47	0.049414
20:33:47	0.029047
20:33:47	0.110513
20:33:47	0.049414
20:33:47	-0.052418
20:34:15	123.978783
20:34:15	123.917684
20:34:15	123.734386
20:34:15	123.652921
20:34:15	123.612188
20:34:15	123.632554
20:34:16	123.591822
20:34:51	253.610736
20:34:52	253.590369

Figure 37 - Reference Result Sample

Figure 37 shows a sample of the results exported from LabVIEW to the Excel document for the reference transmitter pressure readings; A complete copy of the Excel results sheet can be found in Appendix 10.4: Excel Results Sheet. Each 'Write-to-File' node in the LabVIEW program sends its readings to an individual Excel document, this is because every operation of the prototype overwrites the individual file; setting up a graph in these overwritten files would be useless as the graph would get deleted every operation.

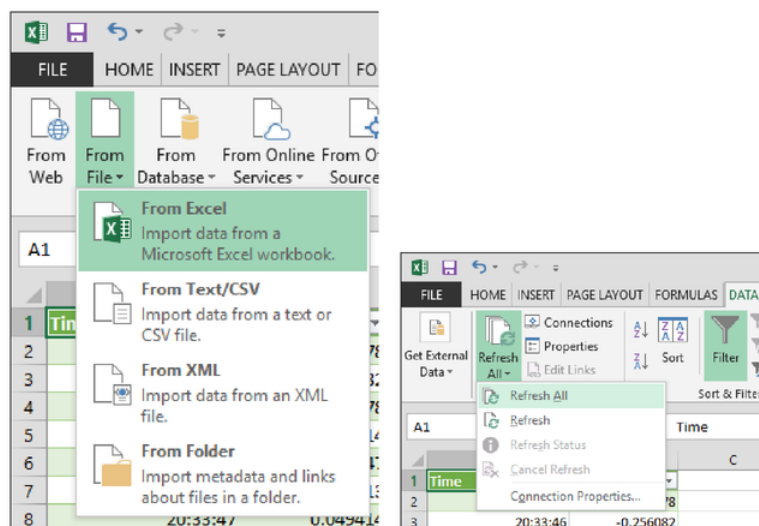


Figure 38 - Import Results & Refresh Results Method

Figure 38 shows how several documents are condensed into one master document; the master document can be edited to house graphs and comparison logic without being overwritten. The Power Query tab in Microsoft Excel has the import function that can read values from other Excel documents. After completing a calibration process the 'Refresh All' tab under the Data tab updates the readings for each variable for the most recent calibration.

Time	Reference Transmitter (psf@40)	Calibrated Transmitter (psf@40)	Pressure Difference (psf@40)	Upper Tolerance (psf@40)	Lower Tolerance (psf@40)	Lower Tolerance (psf@40)	Upper Tolerance (psf@40)	Below Tolerance?	Above Tolerance?
9:32:46 PM	0.09278	0.314177	-0.241397	1.25	-1.25	-1.9022	1.27978	0	0
9:32:46 PM	-0.256022	0.253077	-0.509153	1.25	-1.25	-1.900862	0.992298	0	0
9:32:46 PM	0.09278	0.314543	-0.225763	1.25	-1.25	-1.9022	1.27978	0	0
9:32:47 PM	0.045414	0.354303	-0.305495	1.25	-1.25	-1.200505	1.250414	0	0
9:32:47 PM	0.029047	0.314543	-0.305495	1.25	-1.25	-1.200505	1.27047	0	0
9:32:47 PM	0.102519	0.314543	-0.212023	1.25	-1.25	-1.120487	1.365513	0	0
9:32:47 PM	0.045414	0.09278	-0.620366	1.25	-1.25	-1.200505	1.250414	0	0
9:32:47 PM	-0.052436	0.253077	-0.305495	1.25	-1.25	-1.302418	1.197582	0	0
9:34:05 PM	123.593703	24.293312	-1.305123	1.25	-1.25	123.720703	123.593703	0	0

Calibration Results:	PASS
Calibration Date:	10/4/14
Calibrating Technician:	J. Colton

Figure 39 - Master Document Sample

Figure 39 shows a sample of the master document. The 'Below Tolerance?' and 'Above Tolerance?' columns are usually hidden during normal operation. Figure 40 shows how the calibrated transmitter reading is compared to each tolerance point to see whether the reading

is above or below tolerance. An IF command is used, if the result is in tolerance then the result for the command will be 0, if the reading is out of tolerance then the result will be 1.

The left screenshot shows the formula bar with $=IF(D2<E2,1,0)$ and the spreadsheet with columns D (Calibrated Transmitter (mBAR)), E (Lower Tolerance (mBAR)), F (Upper Tolerance (mBAR)), G (Below Tolerance?), and H (Above Tolerance?). Row 2 shows values 0.314177, -1.18022, 1.31978, and 0.

The right screenshot shows the formula bar with $=IF(D2>F2,1,0)$ and the spreadsheet with the same columns. Row 2 shows values 0.314177, -1.18022, 1.31978, and 0.

Figure 40 - Out of Tolerance Formula

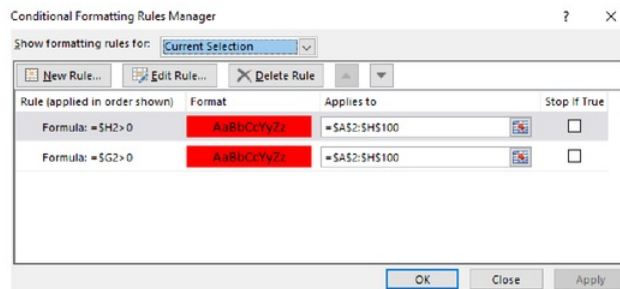


Figure 41 - Tolerance Conditional Formatting

Figure 41 shows the conditional formatting used on the tolerance columns. Should any of the columns have a result greater than zero; i.e. results out of tolerance, then the respective row will illuminate red to identify the defective reading.

The screenshot shows a spreadsheet with columns H (Above Tolerance?), I, J, K, L, M, N, and O. Row 2 shows values 0, 0, 0, and 0. To the right, a box labeled 'Calibration Results:' contains a green button labeled 'PASS'.

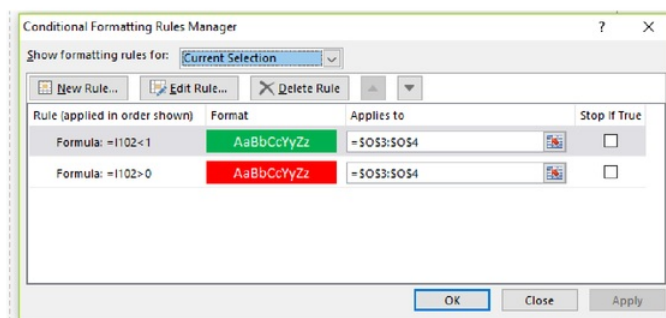


Figure 42 - Result Conditional Formatting

Figure 42 shows the formula used to determine if the calibration has passed or failed, and the conditional formatting used to highlight the pass/fail. The 'Above Tolerance?' and 'Below Tolerance?' tab are totalled into a single value, if this value is greater than zero then the reading for the calibrated transmitter went out of tolerance. If the totalled value is zero then the calibration has passed and the calibration result is displayed is 'Passed' in a green background. If the result is greater than zero then the displayed result is 'Failed' with a red background.

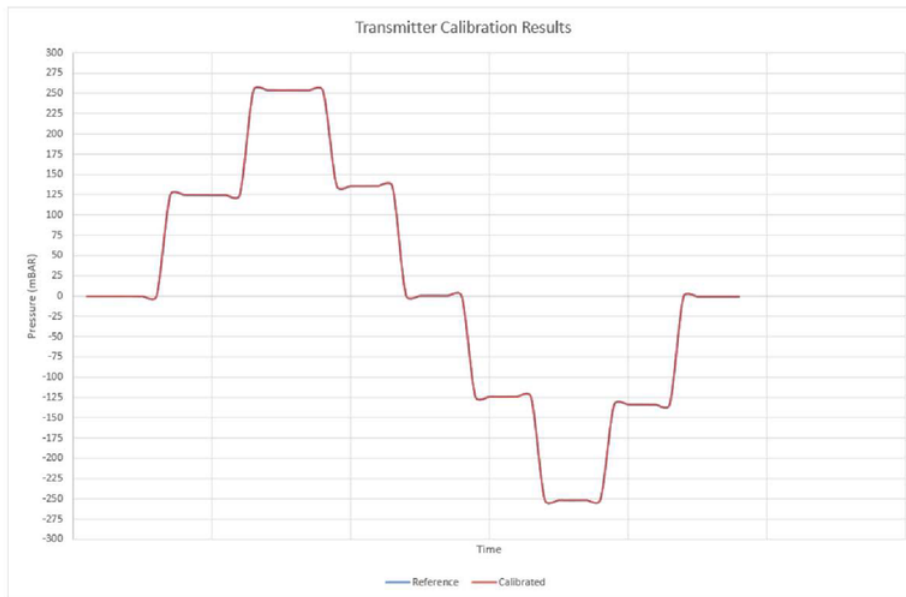


Figure 43 - Calibration Graph

Figure 43 shows the graph setup to show the recorded results for the reference transmitter and the calibrated transmitter readings. The graph shows how the sequence records multiple results at 20% increments across the scale of the instrument. The difference between the two transmitter signals is very small. The small difference makes it difficult to distinguish between the two signals. Therefore the graph in Figure 44 was produced to show the pressure difference between the two signals inside of the tolerance limits.

Excellent set of test results in Figs 43 & 44 showing the system is being tested right through the positive and negative pressure ranges and does not go out of tolerance

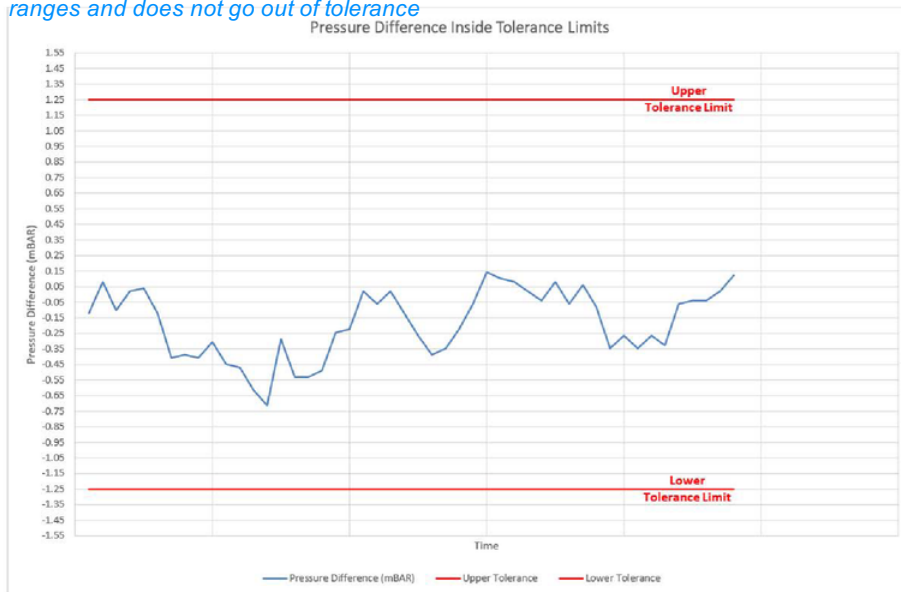


Figure 44 - Pressure Difference Graph

Figure 44 shows the pressure difference graph. The blue graph line indicates the pressure difference in mBAR, the two red lines indicate the upper and lower tolerance limits. The tolerance is $\pm 0.25\%$, converting that to mBAR is done by calculating the full scale range of 500 mBAR into a percentage, then multiplying by 0.25. A tolerance of $\pm 0.25\%$ converts to ± 1.25 mBAR.

=IFERROR(C60-D60,"")	
D	E
1.296815	-0.142564
1.480112	-0.22403

Figure 45 - IF ERROR Command

Figure 45 shows the 'IFERROR()' command used. The LabVIEW program records a result every 100mS, therefore the amount of results achieved can vary depending on system timing. The master Excel document will import from the other Excel documents, if a cell imports an empty field then the '#ERROR

VALUE' alarm will be display in the cell. To prevent the error from interrupting the graph the 'IFERROR()' command is used to display an empty cell when an error is detected. Setting up the graphs in this manner allows the graph to update with varying number of samples with the system automatically adjusting the graph size.

6.2 Hardware Implementation

Wiring diagrams were created based off the hardware design in Figure 9. Power wiring diagrams and an analogue signal wiring diagram can be seen in Appendix 10.1: Hardware Wiring Diagrams.

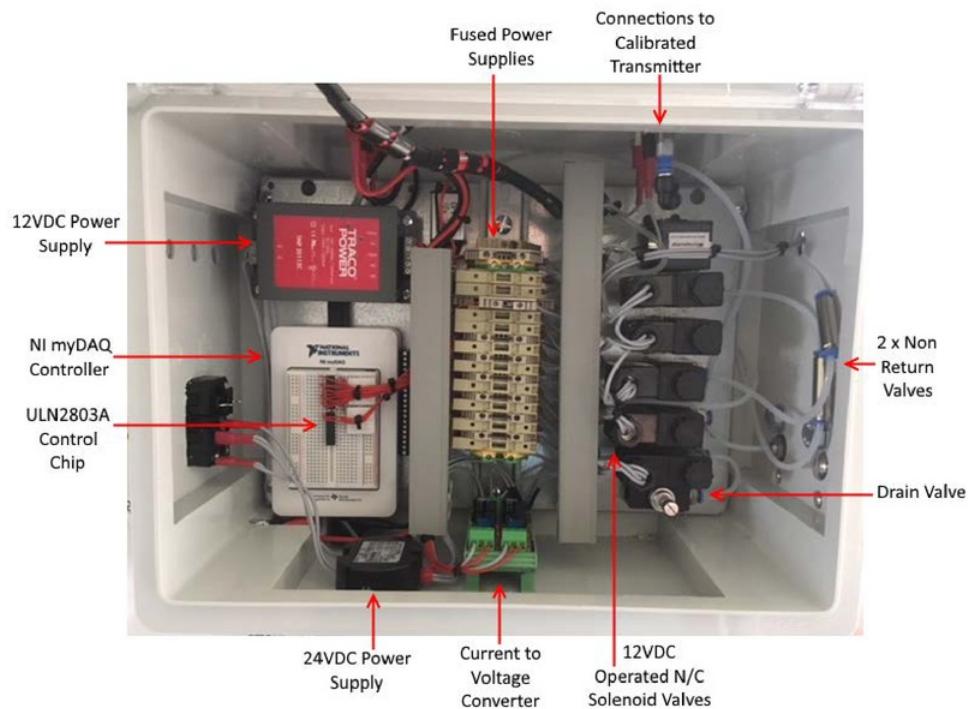


Figure 46 - Internal Components

Figure 46 shows the internal components of the prototype. The electronic components have been kept to the left of the panel, whilst the pneumatic components have been kept to the right. There are two ULN2803A chips used in the prototype; one operates at 12VDC and controls the directional and drain valves. The second chip operates at 6VDC and operates the pump. The wiring schematic from Figure 12 in the design segment was used to connect to the chip to the myDAQ and relevant components.

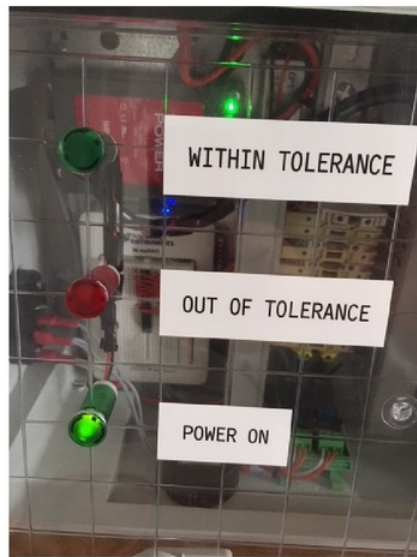


Figure 47 - Indicator Lamps

Figure 47 shows the indicator lamps on the front of the prototype. The ULN2803A chip that operates at 12VDC is also responsible for operating the 'Within Tolerance' and 'Out of Tolerance' indicators on the front of the prototype.



Figure 48 - External Connections & Tank

Figure 48 shows the external connections available for the prototype. The myDAQ connections on the left are made up of three 4mm test port connectors that connect to the multi-meter feature of the myDAQ. The black lead is a USB cable that connects to the

myDAQ, this lead is used to connect to the operating PC. The connections on the right hand side of the panel are for the calibrated transmitter. The red and black leads connect to the power terminals of the transmitter. The prototype is capable of powering the transmitter and reading the mA signal on the same connection point. The 4mm push-fit connection supplies the generated pressure to the transmitter. The grey 3 inch pipe attached to the back of the panel is used as the pressure/vacuum tank. The tank has had several 4mm push-fit connections fixed into the wall to connect to the other pneumatic components.



Figure 49 - Transmitters

Figure 49 shows the two transmitters used in the project. The reference transmitter has been mounted to the side of the prototype and has internal connections in the panel. The calibrated transmitter has been mounted on a small stand as an example transmitter. This example transmitter is used to simulate the operation of taking the prototype into industry and calibrating a transmitter on plant.

Hardware implementation clearly noted and informative

7.0 Project Testing & Evaluation

7.1 Project Testing

7.1.1 Testing Against Test Tables

Test	Pass Requirement	Pass / Fail	Comment
Use the Druck DPI pressure hand pump to pressurise the system to test for air leaks.	Pressure loss is negligible after system pressure settles.	PASS	Pressure hand pumped up to 300 mBAR, pressure loss negligible.
Use the Druck DPI pressure hand pump to draw vacuum from the system to test for air leaks.	Vacuum loss is negligible after system pressure settles.	PASS	Vacuum drawn down to -300 mBAR, vacuum loss negligible.
Inject 4-20 mA into the AX-ABC card to test for voltage output.	The voltage output is 2-10 VDC for 4-20 mA linearly.	PASS	Injected target mA into system. Desired voltage outputs were read.
Inject appropriate signals into each component using the calibrated Fluke 724 process meter and the Fluke 789 multi-meter.	Each component operates as expected from manufacturers specification; i.e. Solenoid Valves open, The pump operates etc.	PASS	Solenoid Valves, pump and indicator lamps operated successfully.
Measure voltage off each power supply using the calibrated Fluke 789 multi-meter.	Correct Voltage level outputted from each power supply.	PASS	6 VDC, 12 VDC and 24 VDC power supplies output desired voltages.
Use the inbuilt multi-meter to measure varying voltage values.	The multi-meter is capable of use from the panel connections and varying voltage readings are reading expected values.	PASS	In built multi-meter used to measure internal power supplies.

Table 5 - Preliminary Test Table

Table 5 shows the preliminary test table used to carry out initial tests on the prototype before the final operation was tested. These tests were designed to ensure the individual components in the prototype operate as required.

The capability of the custom tank was tested first. The tank was pressurised and had vacuum drawn from it to test for any leaks; after completing both tests the pressure/vacuum loss found was negligible. The next test proved the operation of the AX-ABC conversion card. A known mA value was injected into the input of the card using the Fluke 789 multi-meter; the multi-meter was setup to accept loop power as the AX-ABC card supplies the loop power. The AX-ABC card outputted the desired 2-10VDC linearly from the 4-20 mA input, it was also found that having the loop open circuit made the AX-ABC card output a signal close to 0.5 VDC. The next test was designed to test the operation of the solenoid valves, the pump

and the indicator lamps. The Fluke 724 and Fluke 789 meters were used to inject the required voltage input into the separate components, the results of this test can be seen in Table 6.

Component	Injected Voltage	Pass / Fail	Test Equipment	Comment
Pressure Solenoid Valve 1	12 VDC	PASS	FLUKE 724	N/C VALVE OPENED
Pressure Solenoid Valve 2	12 VDC	PASS	FLUKE 724	N/C VALVE OPENED
Vacuum Solenoid Valve 1	12 VDC	PASS	FLUKE 724	N/C VALVE OPENED
Vacuum Solenoid Valve 2	12 VDC	PASS	FLUKE 724	N/C VALVE OPENED
Drain Valve	12 VDC	PASS	FLUKE 724	N/C VALVE OPENED
Pump	6 VDC	PASS	FLUKE 724	PUMP OPERATED
Indictor Lamp 1	12 VDC	PASS	FLUKE 724	LAMP ILLUMINATED
Indictor Lamp 2	12 VDC	PASS	FLUKE 724	LAMP ILLUMINATED
Indictor Lamp 3	12 VDC	PASS	FLUKE 724	LAMP ILLUMINATED
AX-ABC Channel 1	24 VDC	PASS	FLUKE 789	REFERENCE TX TURNED ON
AX-ABC Channel 2	24 VDC	PASS	FLUKE 789	CALIBRATED TX TURNED ON

Table 6 - Component Test Table

The next set of tests were done to test the operation of the power supplies in the prototype. The capability of the myDAQ multi-meter was also tested, the results from these tests can be seen in Table 7; the myDAQ is only capable of reading up to 20 VAC, therefore the 230 VAC test was not done on the myDAQ multi-meter. Figure 50 shows the myDAQ multi-meter display as the meter is connected to the 24VDC power supply.

Power Supply	myDAQ multi-meter	Fluke 789 Multi-Meter
6VDC	6.1 VDC	6.03 VDC
12VDC	12.1 VDC	12.04 VDC
24 VDC	24.3 VDC	24.24 VDC
230 VAC	/	236.06 VAC

Table 7 - Power Supply Test

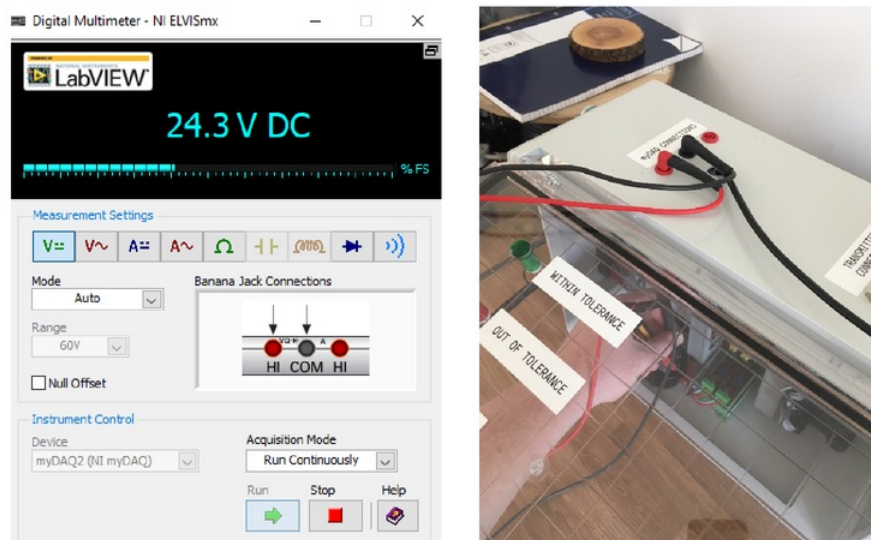


Figure 50 - Example myDAQ multi-meter

Test	Pass Requirement	Pass / Fail	Comment
Run the program in normal condition multiple times.	The results must be inside of tolerance for each program operation, this proves the operation, repeatability and reliability of the prototype.	PASS	The program was operated 4 times. See the graph results in Figure 51 and Figure 52
Whilst the program is running, observe the reference transmitter display	Both the dial and numerical display show the same reading of pressure / vacuum	PASS	Both displays operated, showing the pressure / vacuum in the dial and numerically.
Whilst the program is running, observe the calibrated transmitter display	Both the dial and numerical display show the same reading of pressure / vacuum	PASS	Both displays operated, showing the pressure / vacuum in the dial and numerically.
Whilst the program is running, observe the operation of the indicators.	Relevant indicators for valve direction, pressure condition and results recording illuminate when required.	PASS	All indicators illuminated on LabVIEW display and prototype when required.
Operating the start button.	The program sequence moves from the 'initialise' state to 'state 0' and the prototype begins to operate.	PASS	Start button moved the program into state 0, beginning the sequence.
Operate the stop button.	The program sequence moves from its current state to the 'manual stop' state, stopping the operation of the system.	PASS	Pressing the stop button moved the sequence into 'Manual Stop' state, the system drained and then returned to the 'initialise' state.
Operate the program with the adjustable tolerance set at 0.25% and 2%.	The program detects the adjustment of the tolerance and adjusts the tolerance logic as required.	PASS	The program was operated when the system tolerance was 0.25 % and 2%. See results in Figure 53 and Figure 54
Whilst the program is running, observe the pressure difference display.	The display shows a pressure reading throughout the operation.	PASS	Display operated correctly, showing the pressure difference between the two transmitters.

Table 8 - System & LabVIEW Test Table

Table 8 shows the system and LabVIEW test table. These set of test were designed to test the performance of the prototype and the LabVIEW program.

All tests carried out according to the test tables produced in specification with good detail on test results obtained



Figure 51 - 4 Tests of Pressure Difference against Tolerance Limits

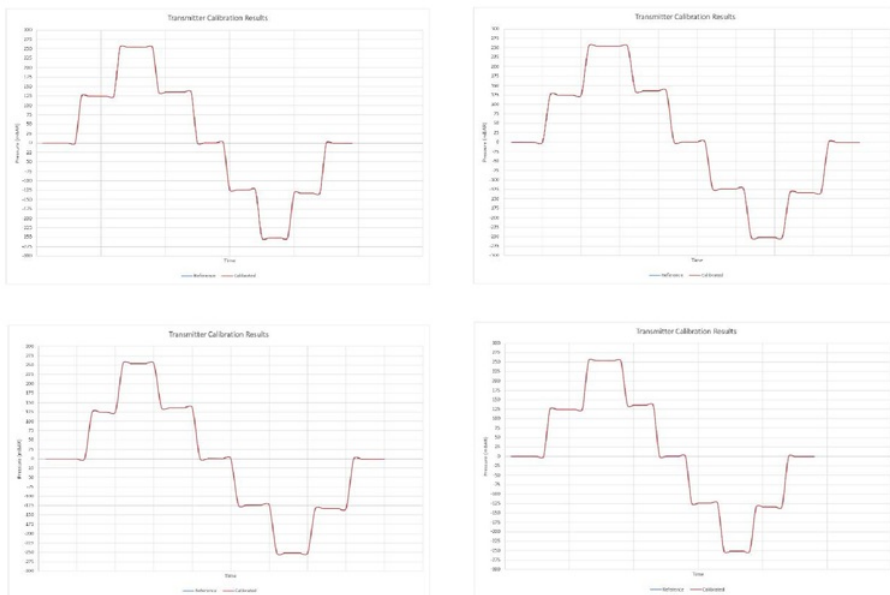


Figure 52 - 4 Tests of Calibrated against Reference Transmitter Pressure

Figure 51 and Figure 52 are the results achieved from running the prototype on the calibrated transmitter 4 times. The graphs in Figure 51 show the pressure difference between the two transmitters against the tolerance limits. The results from operating the prototype show that

Good set of graphical test results noted and explained clearly

the pressure difference between the tests is similar and the pressure readings remain in tolerance throughout all tests. Figure 52 shows the calibrated transmitter pressure against the reference transmitter pressure. The results from the graph show that multiple readings are taken at 20% intervals across the pressure transmitters range. Similar results were achieved from multiple operations of the prototype, therefore it can be concluded that this test was a success, proving the performance and reliability of the prototype.

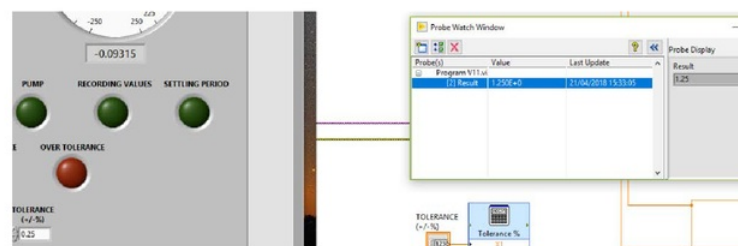


Figure 53 - Tolerance Set at 0.25%

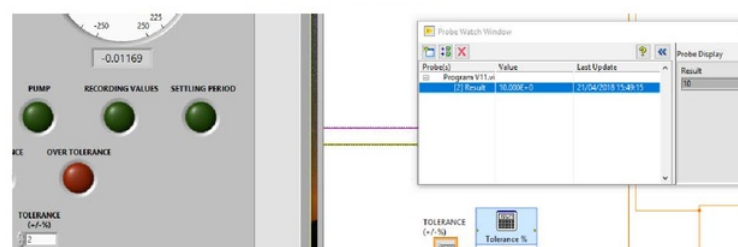


Figure 54 - Tolerance Set at 2%

Figure 53 and Figure 54 shows the adjustable tolerance being tested. Figure 53 shows the tolerance set by the user at 0.25%, from this the program has calculated that the tolerance is ± 1.25 mBAR, the program will use this value in the comparison logic shown in Figure 19. Figure 54 shows the tolerance set at 2% by the user, from this the program has calculated that the tolerance is ± 10 mBAR.

7.1.2 Testing LabVIEW Sequence

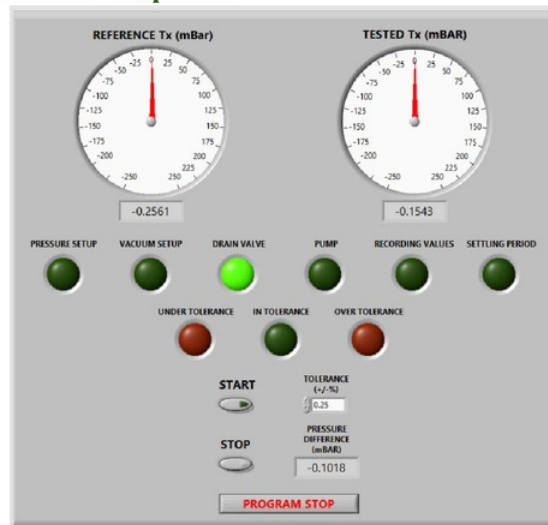


Figure 55 - Initialise State

Figure 55 shows the sequence in the initialise state. The system is draining pressure from the tank and waiting for the user to press 'Start'.

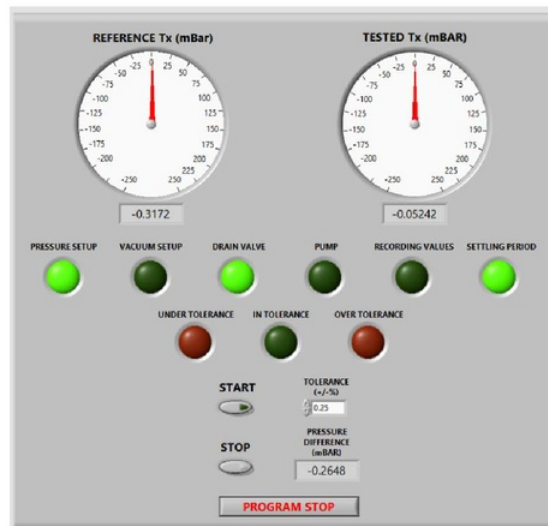


Figure 56 - State 0

Figure 56 shows the sequence in state 0. The system has set the directional valves to the pressure orientation. After the sequence has waited 10 seconds for the pressure to settle, the pressure readings from both transmitters will be recorded.

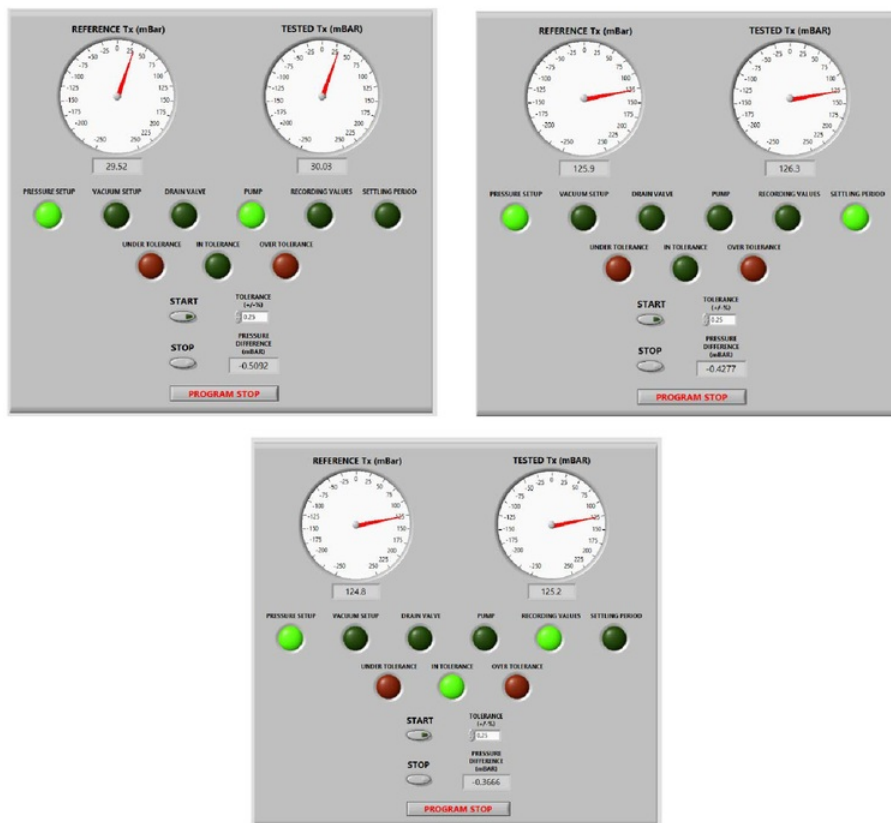


Figure 57 - State 1

Figure 57 shows the multiple operations of state 1. The sequence first closes the drain valve and pumps until the pressure reaches 125 mBAR. The sequence waits for the pressure to settle, then records the pressure readings for 1 second. The sequence then moves onto the next step.

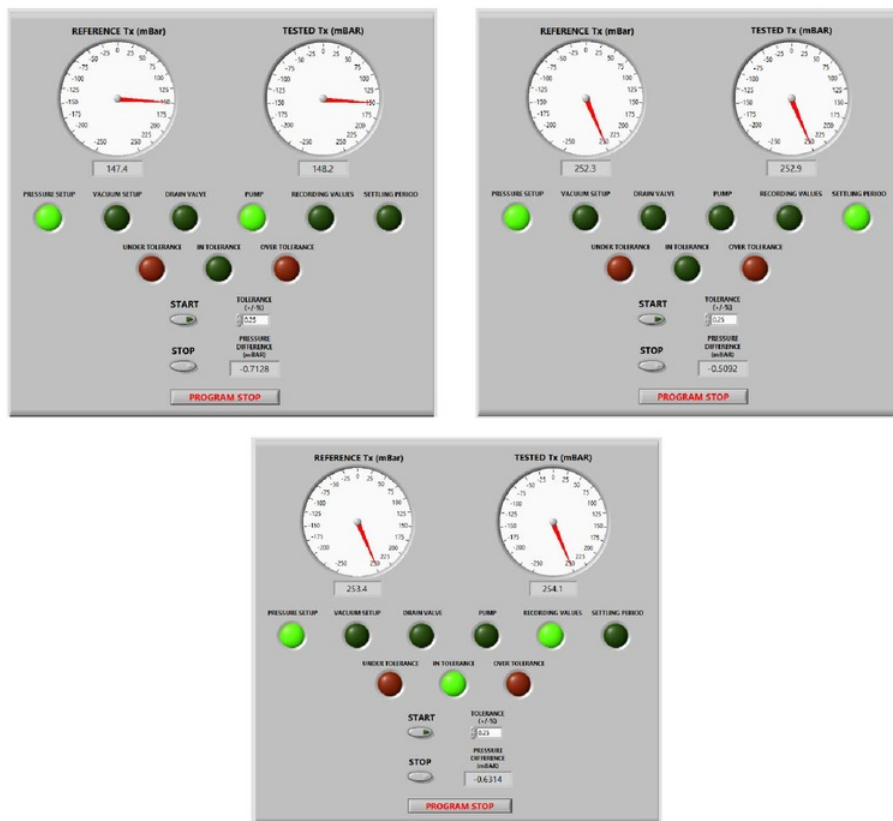


Figure 58 - State 2

Figure 58 shows the multiple operations of state 2. The sequence operates the pump until the pressure reaches 250 mBAR. The sequence waits for the pressure to settle, then records the pressure readings for 1 second. The sequence then moves onto the next step.

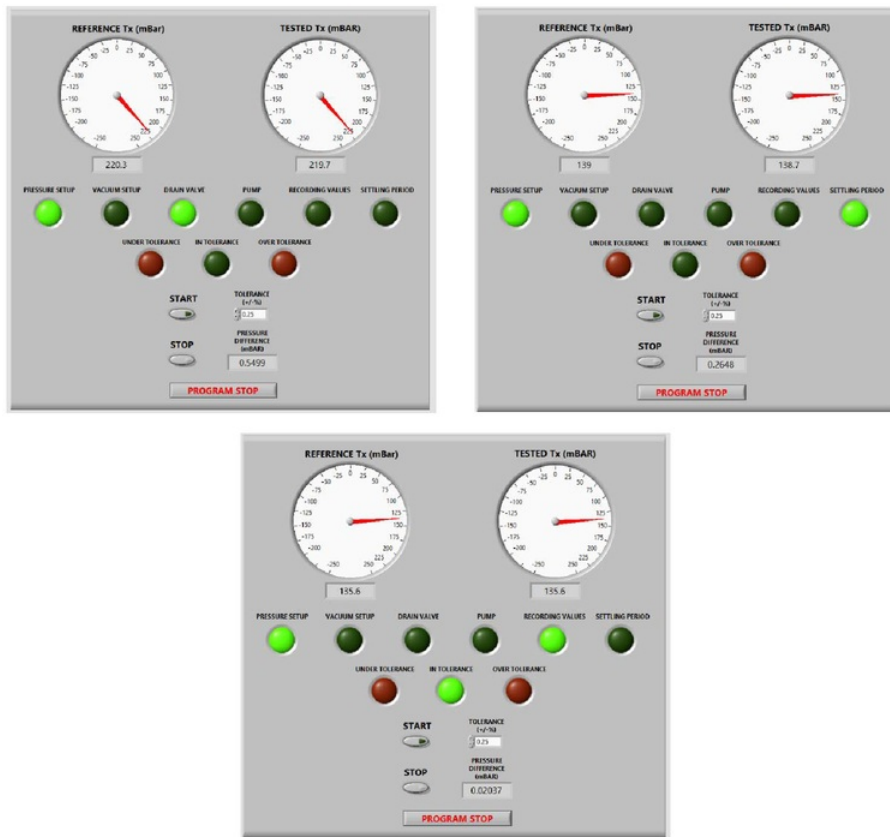


Figure 59 - State 3

Figure 59 shows the multiple operations of state 3. The sequence operates the drain valve until the pressure drops back to 125 mBAR. The sequence waits for the pressure to settle, then records the pressure readings for 1 second. The sequence then moves onto the next step.

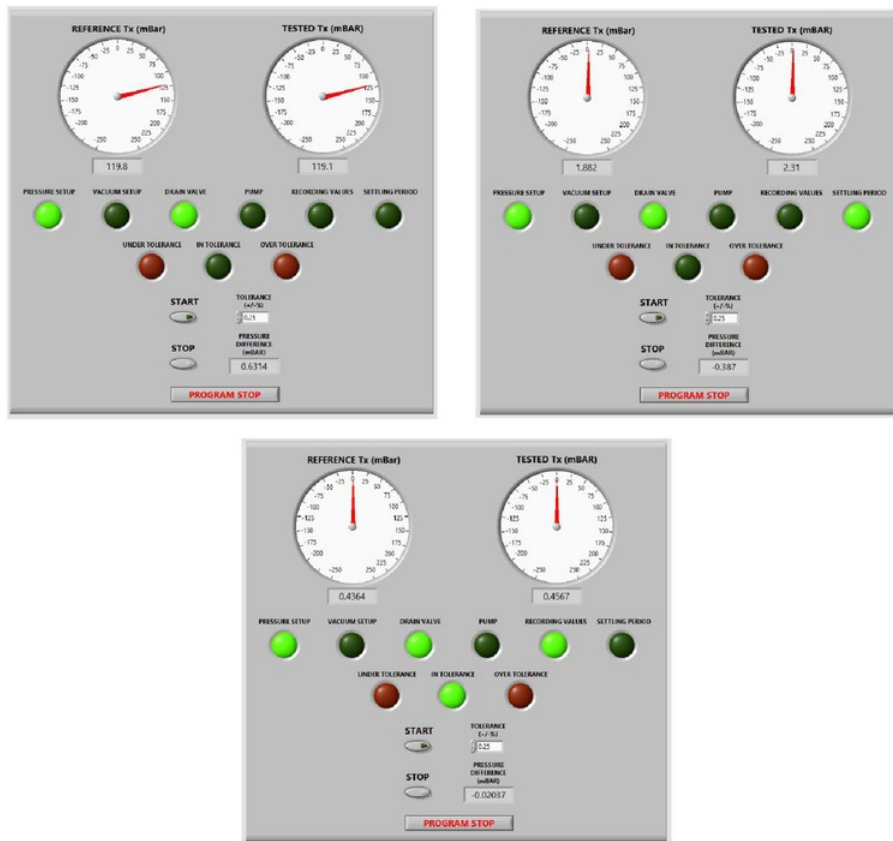


Figure 60 - State 4

Figure 60 shows the multiple operations of state 4. The sequence operates the drain valve until the pressure drops back to atmospheric pressure. The sequence waits for the pressure to settle, then records the pressure readings for 1 second. The sequence then moves onto the next step.

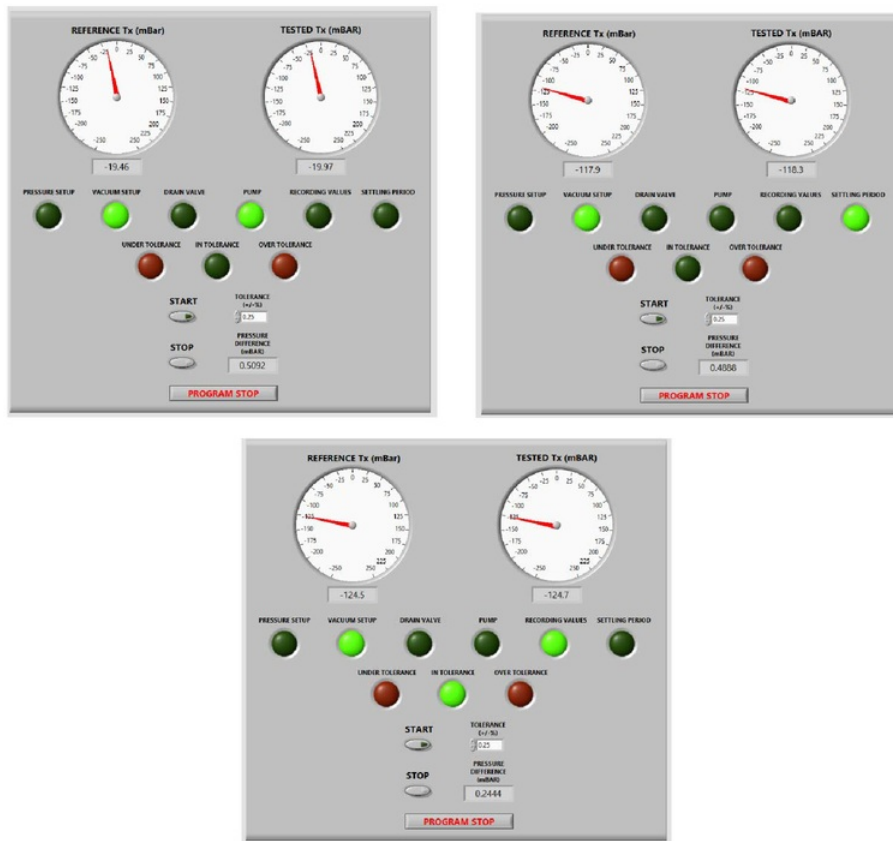


Figure 61 - State 5

Figure 61 shows the multiple operations of state 5. The pressure orientation valves switch to the vacuum direction. The drain valve closes and the pump operates, drawing vacuum from the system. Vacuum is drawn until the system reaches -125 mBAR. The sequence waits for the vacuum to settle, then records the vacuum readings for 1 second. The sequence then moves onto the next step.

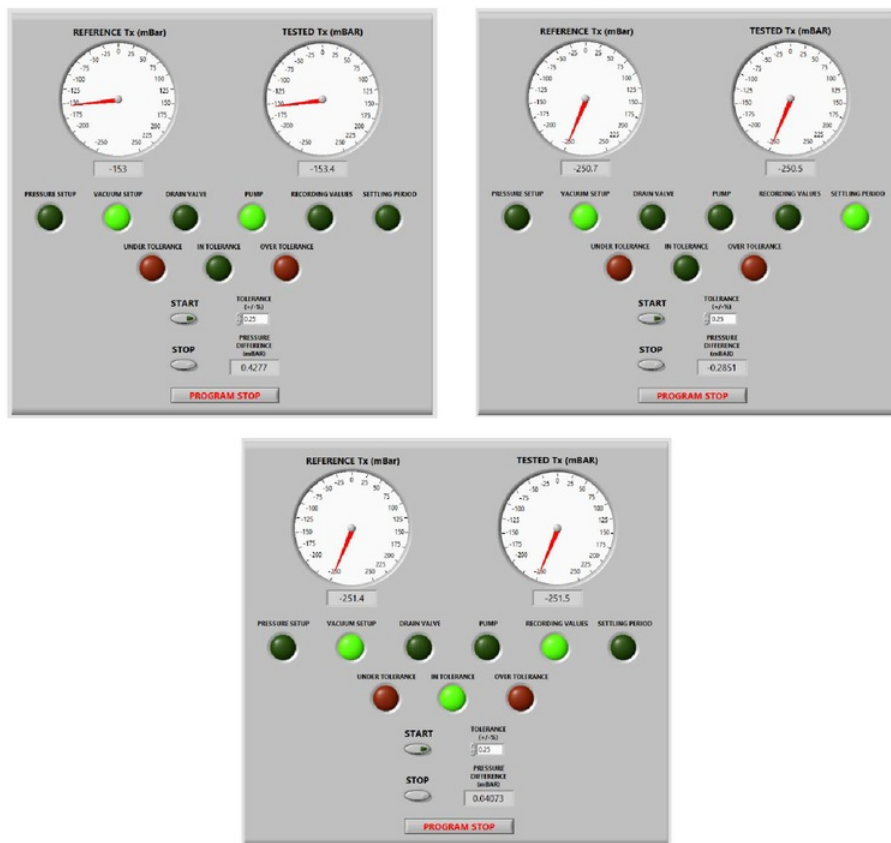


Figure 62 - State 6

Figure 62 shows the multiple operations of state 6. The pump operates until a vacuum of -250 mBAR is achieved. The sequence waits for the vacuum to settle, then records the vacuum readings for 1 second. The sequence then moves onto the next step.

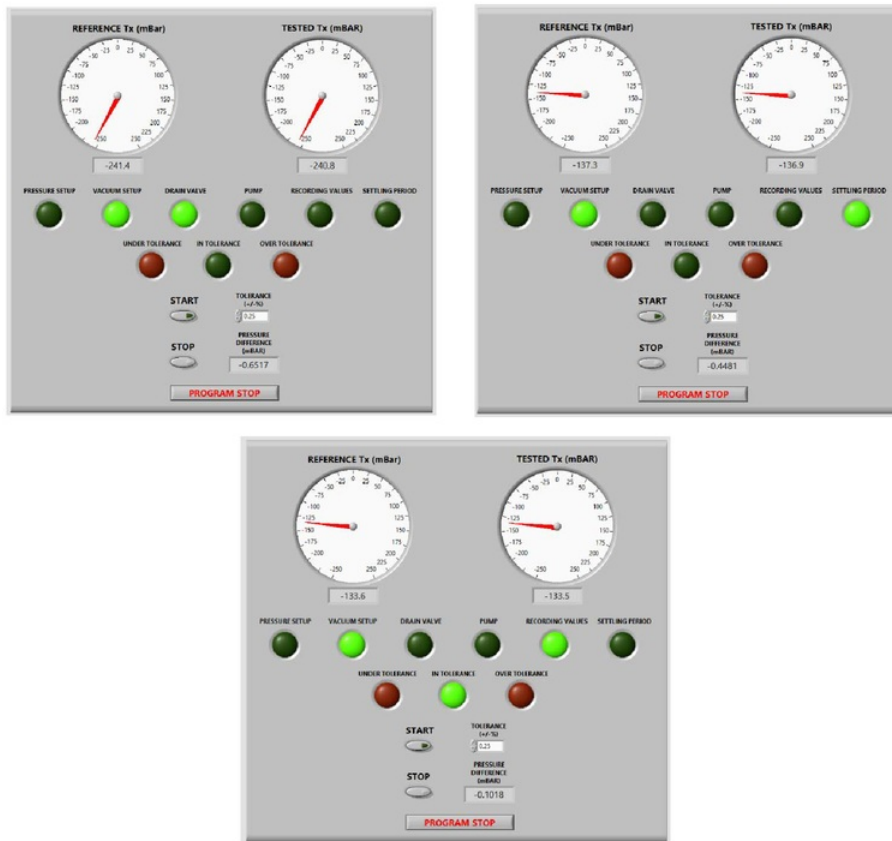


Figure 63 - State 7

Figure 63 shows the multiple operations of state 7. The drain valve operates until the vacuum drops to the target of -125 mBAR. The sequence waits for the vacuum to settle, then records the vacuum readings for 1 second. The sequence then moves onto the next step.

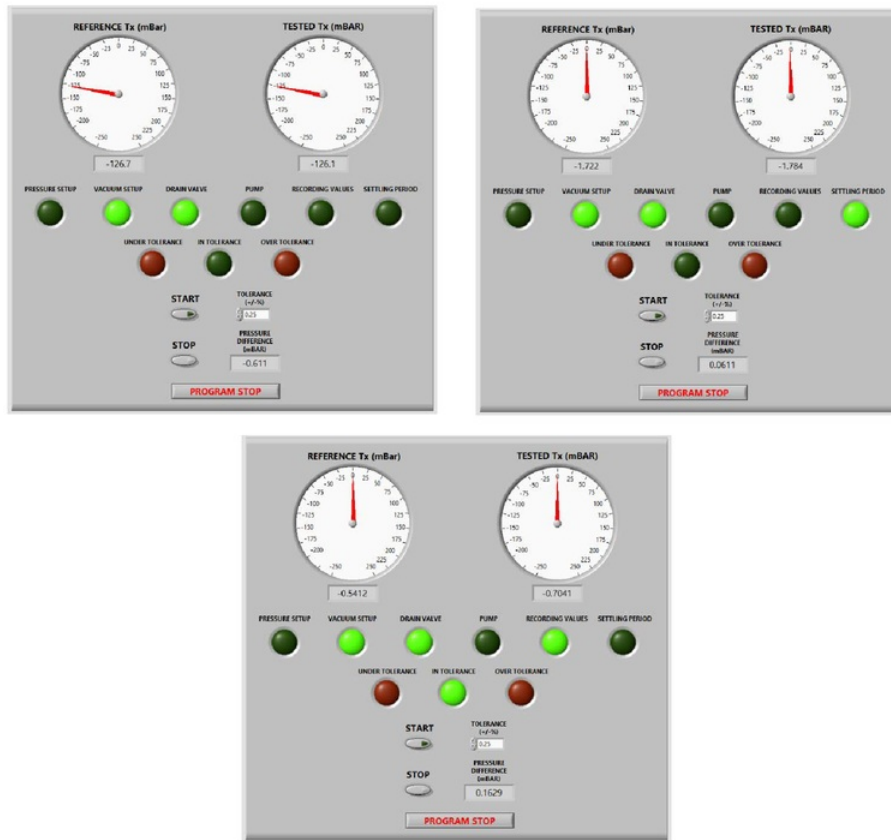


Figure 64 - State 8

Figure 64 shows the multiple operations of state 8. The drain valve operates until atmospheric pressure is achieved. The sequence waits for the pressure to settle, then records the pressure readings for 1 second. The sequence then moves onto the next step.

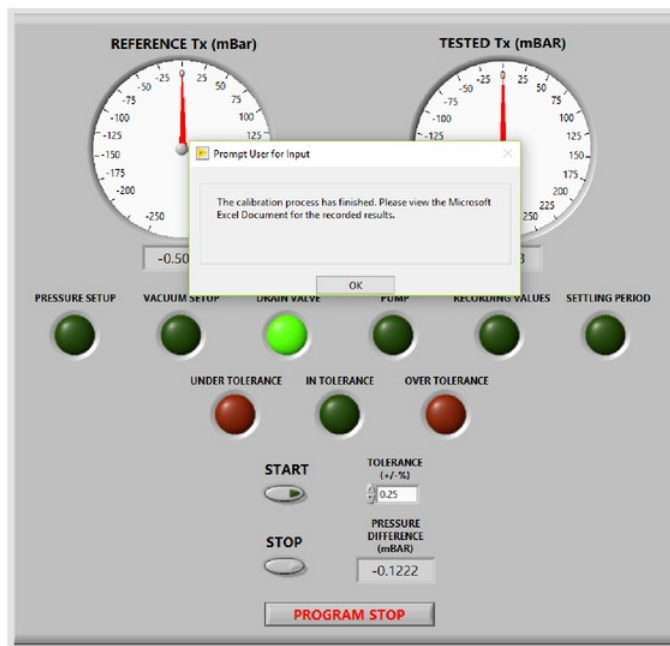


Figure 65 - State 9

Figure 65 shows the sequence in state 9. The system has opened a prompt, telling the user the calibration process has completed and that the results can be located in the calibration Excel document. Once the user presses the OK button on the prompt, the sequence will return to the 'initialise' state, waiting for the next calibration.

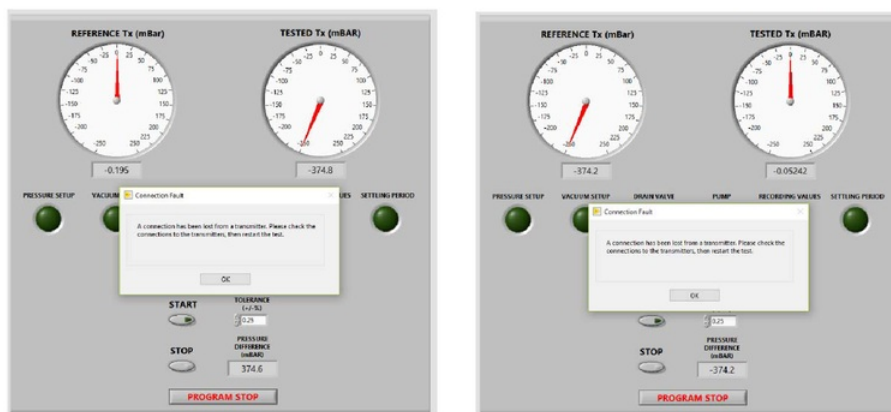


Figure 66 - Lost Connection Error

Figure 66 shows the lost connection prompt, alerting the user that a connection has been lost from both transmitters.

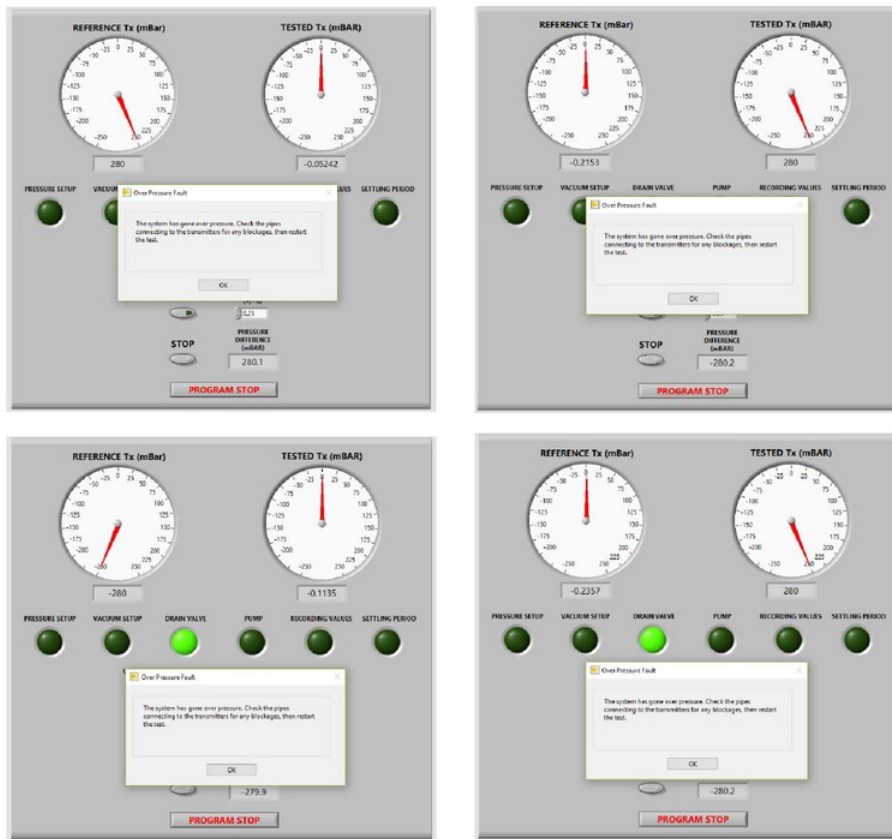


Figure 67 - Over Pressure Error

Figure 67 shows the over pressure / over vacuum error operating. A pressure and vacuum signal was injected into the system to simulate the fault on both transmitters for both pressure and vacuum.

The sequence has been tested and the desired operation has been achieved. The over pressure / over vacuum fault operates, preventing the system from damaging internal components. The lost connection fault operates, preventing false readings in a calibration.

[LabVIEW Front panel full test sequence noted and explained in great detail](#)

7.1.3 Testing Excel Document

Time	Reference Transmitter (mbar)	Calibrated Transmitter (mbar)	Upper Tolerance Limit	Lower Tolerance Limit	Pressure Difference (mbar)	Lower Tolerance (mbar)	Upper Tolerance (mbar)
4:10:41 PM	-0.250515	-0.110517	1.25	-1.25	-0.139998	-1.548815	0.955185
4:10:42 PM	-0.327281	-0.174616	1.25	-1.25	-0.142565	-1.567281	0.932219
4:10:43 PM	-0.194983	-0.111517	1.25	-1.25	-0.083466	-1.444983	1.055017
4:10:44 PM	-0.133684	-0.071776	1.25	-1.25	-0.061909	-1.383684	1.116116
4:10:45 PM	-0.119425	-0.052418	1.25	-1.25	-0.101832	-1.40425	1.09575
4:10:46 PM	-0.114245	-0.052418	1.25	-1.25	-0.101832	-1.40425	1.09575
4:11:00 PM	124.472209	124.782705	1.25	-1.25	-0.309496	123.162705	124.497209
4:11:10 PM	124.58611	124.773071	1.25	-1.25	-0.386961	123.19811	125.63611
4:11:10 PM	124.304645	124.508308	1.25	-1.25	-0.203663	123.054645	125.554645
4:11:10 PM	124.080515	124.613014	1.25	-1.25	-0.532505	122.830515	125.130515
4:11:10 PM	124.141714	124.447209	1.25	-1.25	-0.305495	122.891714	125.391714
4:11:10 PM	124.023513	124.267344	1.25	-1.25	-0.243831	122.769513	124.289513
4:11:46 PM	254.567953	255.117867	1.25	-1.25	-0.549914	253.117953	255.817953
4:11:46 PM	254.620868	254.875451	1.25	-1.25	-0.254583	253.356868	255.856868
4:11:46 PM	254.208236	255.016435	1.25	-1.25	-0.713199	253.493236	255.516435
4:11:46 PM	254.26246	254.93455	1.25	-1.25	-0.67209	253.53246	255.51246
4:11:46 PM	254.282826	254.751252	1.25	-1.25	-0.468426	253.612826	255.512826
4:11:47 PM	254.049796	254.802153	1.25	-1.25	-0.752357	253.287796	255.902153
4:12:12 PM	134.733227	135.050889	1.25	-1.25	-0.317662	133.482227	135.982227
4:12:12 PM	134.772939	135.098823	1.25	-1.25	-0.325884	133.522939	136.022939
4:12:13 PM	134.831534	135.139564	1.25	-1.25	-0.30803	133.440534	136.140534
4:12:13 PM	134.891538	135.050889	1.25	-1.25	-0.162931	133.645538	136.145538
4:12:13 PM	135.047356	135.242386	1.25	-1.25	-0.22403	133.767356	136.267356
4:12:13 PM	134.960257	135.139188	1.25	-1.25	-0.182911	133.786257	136.286257
4:13:08 PM	0.395642	0.456741	1.25	-1.25	-0.061099	-0.854358	1.645642
4:13:08 PM	0.373444	0.477787	1.25	-1.25	-0.104343	-0.976556	1.523444
4:13:08 PM	0.373444	0.375276	1.25	-1.25	-0.101832	-0.976556	1.523444
4:13:08 PM	0.375276	0.456741	1.25	-1.25	-0.081465	-0.876724	1.625276
4:13:09 PM	0.130879	0.456741	1.25	-1.25	-0.346862	-1.118121	1.388879
4:13:34 PM	-124.592778	-124.613145	1.25	-1.25	-0.020367	-125.842778	-123.342778
4:13:34 PM	-124.450214	-124.389113	1.25	-1.25	-0.061099	-125.700214	-123.280214
4:13:35 PM	-124.518479	-124.429447	1.25	-1.25	-0.101832	-125.761479	-123.361479
4:13:35 PM	-124.459647	-124.34055	1.25	-1.25	-0.119097	-125.679647	-123.179647
4:13:35 PM	-124.287288	-124.208117	1.25	-1.25	-0.089171	-125.537288	-123.187288
4:14:14 PM	-252.402807	-252.130659	1.25	-1.25	-0.272148	-253.750807	-250.209807
4:14:14 PM	-252.228827	-252.130659	1.25	-1.25	-0.101832	-253.478827	-250.978827
4:14:15 PM	-252.971932	-252.086262	1.25	-1.25	-0.88567	-254.851932	-251.221932
4:14:15 PM	-252.199956	-252.086262	1.25	-1.25	-0.113694	-253.513956	-251.013956
4:14:15 PM	-252.065896	-252.126995	1.25	-1.25	-0.061099	-253.315896	-250.815896
4:14:41 PM	-133.411783	-133.147021	1.25	-1.25	-0.264762	-134.681783	-132.141783
4:14:41 PM	-133.472516	-133.329952	1.25	-1.25	-0.142564	-134.722516	-132.222516
4:14:41 PM	-133.414147	-133.240852	1.25	-1.25	-0.142564	-134.664147	-132.164147
4:14:41 PM	-133.414147	-133.305985	1.25	-1.25	-0.108162	-134.464147	-132.164147
4:14:41 PM	-133.515249	-133.305985	1.25	-1.25	-0.209264	-134.703249	-132.203249
4:15:41 PM	-0.765245	-0.581944	1.25	-1.25	-0.183297	-1.015245	0.484755
4:15:41 PM	-0.620277	-0.581944	1.25	-1.25	-0.038333	-0.878277	0.627223
4:15:41 PM	-0.581944	-0.520845	1.25	-1.25	-0.061099	-1.831944	0.688056
4:15:41 PM	-0.660409	-0.581944	1.25	-1.25	-0.101832	-1.912409	0.588591
17:08:08/07/2005	-0.60231	-0.581944	1.25	-1.25	-0.020366	-1.85231	0.64769

Calibration Results:	Pass
Calibration Date:	21/4/18
Calibrating Technician:	J. Gales

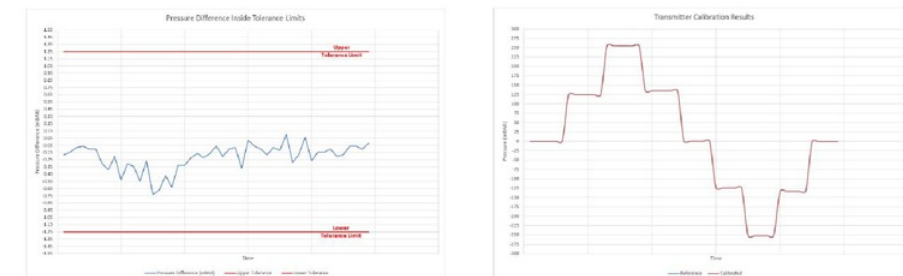


Table 9 - Excel Calibration Passed Results

Table 9 shows the results achieved from the 'Passed Calibration'. The master document has illuminated the results in green and created graphs, showing the results being compared against each other and the tolerance limits.

Time	Reference Transmitter (mBAR)	Calibrated Transmitter (mBAR)	Upper Tolerance Limit	Lower Tolerance Limit	Pressure Difference (mBAR)	Lower Tolerance	Upper Tolerance
5:33:28 PM	-0.133349	-0.093151	1.25	-1.25	0.122198	-1.480349	1.038651
5:33:29 PM	-0.093151	-0.174614	1.25	-1.25	0.081461	-1.363151	1.156849
5:33:29 PM	-0.144983	-0.093151	1.25	-1.25	0.101832	-1.444983	1.055017
5:33:29 PM	-0.093151	-0.113917	1.25	-1.25	0.010366	-1.343151	1.156849
5:33:29 PM	-0.113349	-0.256882	1.25	-1.25	0.040733	-1.480349	1.038651
5:33:29 PM	-0.117121	-0.144983	1.25	-1.25	0.122198	-1.567121	0.932879
5:33:29 PM	124.450873	125.0582	1.25	-1.25	0.407329	123.440873	125.908873
5:33:57 PM	124.408476	124.813804	1.25	-1.25	0.407329	123.158476	125.656476
5:33:57 PM	124.345377	124.450873	1.25	-1.25	0.304495	123.095377	125.595377
5:33:58 PM	124.262812	124.712372	1.25	-1.25	-0.449561	123.512812	125.515212
5:33:58 PM	124.182446	124.450873	1.25	-1.25	0.468427	122.812446	125.412446
5:34:34 PM	254.7533	254.364202	1.25	-1.25	0.122198	253.5313	255.9753
5:34:34 PM	255.448537	254.10114	1.25	-1.25	0.712625	252.128537	254.778537
5:34:34 PM	255.570003	251.855132	1.25	-1.25	0.285129	252.100003	254.820003
5:34:34 PM	255.468271	251.907697	1.25	-1.25	0.529626	252.128271	254.719271
5:34:34 PM	255.407072	255.596598	1.25	-1.25	0.529626	252.157072	254.657072
5:34:35 PM	255.162676	251.851468	1.25	-1.25	0.488792	251.912676	254.412676
5:35:01 PM	135.587614	135.852311	1.25	-1.25	-0.344697	134.175614	136.837614
5:35:02 PM	135.628247	135.852377	1.25	-1.25	-0.22403	134.178247	136.878247
5:35:02 PM	135.730179	135.708613	1.25	-1.25	0.021566	134.482179	136.862179
5:35:02 PM	135.791278	135.852377	1.25	-1.25	0.061599	134.541278	137.541278
5:35:02 PM	135.813444	135.791278	1.25	-1.25	0.022166	134.561444	137.561444
5:35:59 PM	0.477267	0.595506	1.25	-1.25	0.122199	-0.777267	1.727507
5:35:59 PM	0.273444	0.538207	1.25	-1.25	0.264763	-0.976556	1.523444
5:35:59 PM	0.232711	0.619672	1.25	-1.25	0.386961	-1.017289	1.482711
5:35:59 PM	0.193578	0.538207	1.25	-1.25	0.346229	-1.048022	1.448378
5:36:00 PM	0.232711	0.456741	1.25	-1.25	-0.22403	-1.017289	1.482711
5:36:25 PM	124.168516	124.263817	1.25	-1.25	0.041099	-125.518516	123.018516
5:36:26 PM	-123.981787	-124.124752	1.25	-1.25	0.141545	-125.151787	122.751787
5:36:26 PM	124.085119	124.185451	1.25	-1.25	0.101832	-125.335619	122.835619
5:36:26 PM	123.914564	-124.02252	1.25	-1.25	0.061446	-125.191964	122.838564
5:36:26 PM	-123.951421	-123.981787	1.25	-1.25	0.033566	-125.211421	122.711421
5:37:06 PM	-251.780767	-251.740034	1.25	-1.25	0.040733	-253.008767	250.530767
5:37:06 PM	-251.638462	-251.718668	1.25	-1.25	0.081466	-252.888462	250.888462
5:37:06 PM	-251.841864	-251.780767	1.25	-1.25	0.061099	-253.081864	250.581864
5:37:07 PM	-251.577363	-251.638462	1.25	-1.25	0.061099	-252.877363	250.527363
5:37:07 PM	-251.536837	-251.454505	1.25	-1.25	0.081465	-252.756837	250.556837
5:37:33 PM	134.042775	133.696546	1.25	-1.25	0.346229	133.292775	132.792775
5:37:33 PM	133.520576	133.055814	1.25	-1.25	0.264762	133.170576	132.875076
5:37:33 PM	134.042775	133.696546	1.25	-1.25	0.346229	133.292775	132.792775
5:37:34 PM	134.083767	133.818745	1.25	-1.25	0.264762	133.303767	132.813507
5:37:34 PM	134.033874	133.778812	1.25	-1.25	0.255862	133.353874	132.853874
5:38:36 PM	-0.704142	-0.643043	1.25	-1.25	-0.061099	-1.3954142	0.545838
5:38:36 PM	-0.663469	-0.622677	1.25	-1.25	0.040732	-1.312469	0.586591
5:38:36 PM	-0.643043	-0.602331	1.25	-1.25	0.040733	-1.803043	0.608957
5:38:37 PM	-0.581944	-0.602331	1.25	-1.25	0.025566	-1.831944	0.668056
5:38:37 PM	-0.541211	-0.663469	1.25	-1.25	0.122198	-1.791211	0.708769

Calibration Results:	Fail
Calibration Date:	22/01/18
Calibrating Technician:	J.Coles

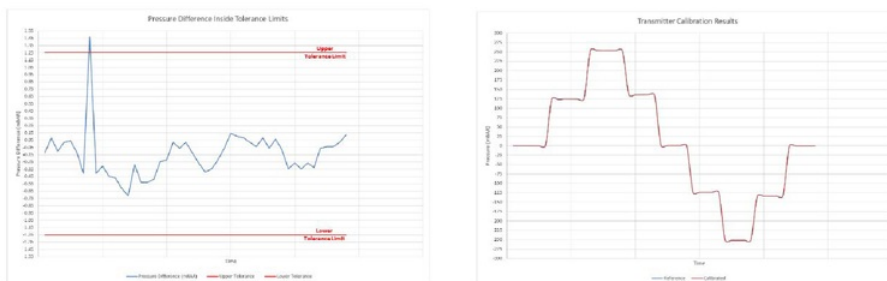


Table 10 - Excel Calibration Failed Results

Table 10 shows the results achieved from a 'Failed Calibration'. A 123 mBAR signal was simulated when the lower tolerance limit was 123.21. The low reading has been highlighted, showing the user where the defect has occurred, causing the calibration to fail. The graph showing the pressure difference against tolerance limits shows the pressure spike going over tolerance.

Excellent detail on how a failed test would indicate within the test sequence

7.2 Project Evaluation

7.2.1 Evaluation against Specification

This section will evaluate the project against the specification, and detail how each specification was achieved.

Hardware

- *The prototype must automatically calibrate a pressure transmitter.*
 - The prototype has been tested and is capable of calibrated the -250 mBAR to +250 mBAR transmitter to a tolerance of +/- 0.25%. The system operates in a sequence and completes the calibration unless the fault monitoring logic or user stops the system.
- *The prototype must generate pressure up to 250 mBAR and draw vacuum down to -250 mBAR.*
 - The system has been tested and is capable of pumping enough pressure and drawing enough vacuum to achieve this.
- *The prototype must be able to read a 4-20mA signals from two pressure transmitter simultaneously.*
 - The myDAQ cannot directly read the 4-20mA signal, however the AX-ABC conversion card converts the signal into a voltage reading, allowing the myDAQ to indirectly read the 4-20mA signal.
- *A transmitter must be installed for control and to record and reference pressure.*
 - The reference transmitter is used as the pressure reference for the system. This pressure reference is used to control the main sequence and fault monitoring logic in the system.
- *The prototype must be able to pump in increments of 20% along the pressure range and hold the pressure/vacuum inside of a small tank.*
 - The system is operated to control the pressure in the tank and read a stabilised pressure at 20% increments on the instruments scale.
- *Any transmitters used in this prototype must be calibrated externally before installing onto the prototype.*
 - Both the reference and calibrated transmitters were calibrated against the Druck DPI pressure calibrator before being installed onto the project. The Druck DPI pressure calibrator is sent away annually for external calibration

against national standards. Calibration results for the instruments can be found in Appendix 10.3: Calibration Results.

- ***The supply to each component must be fused.***
 - The hardware wiring diagram in Appendix 10.1 shows how the power supply to each component is fused.
- ***The prototype must be portable.***
 - A strap has been attached to the prototype allowing the user to carry it around.
- ***The main controller for this prototype must be the NI myDAQ.***
 - The main controller is the NI myDAQ. The myDAQ controls the operation of each components through the use of the ULN2803A Darlington array chip.

Software

- ***The program controlling the prototype must have a form of HMI.***
 - The myDAQ cannot operate with the use of a computer. Therefore, the laptop the user has to operate the myDAQ will act as the HMI to control the prototype.
- ***The program must have interlocks that prevents the prototype from damaging itself.***
 - The program has the capability to detect when the system goes over pressure or over vacuum. The system is also capable of detecting when a connection is lost from either transmitter.
- ***The prototype must be capable of storing the results achieved and determining if the pressure transmitter has passed or failed the calibration depending on a tolerance.***
 - The results are exported to the Excel Calibration document, this document compares the results against the tolerance limits and indicates whether the calibration has passed or failed. The results are also plotted on a graph.
- ***The program controlling the prototype must have a structured sequence.***
 - The prototype utilises the case structures in LabVIEW to create a state machine that operates in a sequence.
- ***The prototype must be able to test a pressure transmitter within a tolerance of 0.25%***
 - The prototype has been tested with the tolerance set at 0.25% and 2%. The results showed that for both tests, the pressure readings remained in tolerance throughout the whole range of the instruments.

- *The software must alert the user if the instrument goes out of tolerance.*
 - The Excel document is capable of comparing the pressure readings against the tolerance and alerting the user if the calibration has failed.
- *The software must produce results in a table and graph format.*
 - The excel document imports the results from LabVIEW and automatically converts the results into two graphs when the user updates the data.

[Very detailed evaluation of project hardware / software outcomes](#)

7.2.2 Cost Evaluation

System Components	Quantity	Total
NI myDAQ	1	£400.00
ULN2803A Chip	2	£1.50
4mm Test Lead Panel Connectors	5	£10.00
12VDC power supply	1	£40.00
24VDC power supply	1	£12.00
6VDC power supply	1	£10.00
Fused Terminals	20	£7.00
Terminal	20	£4.00
Panel	1	£120.00
1mm Grey Cable, 0.5mm Red Cable & Cable Accessories	1 SET	£20.00
Solenoid Valve 2/2 Way	5	£40.00
Needle Valve	1	£36.00
4mm Nylon Hose	1 ROLL	£12.50
4mm SMC Non-Return Valve	2	£9.00
4mm SMC Elbow	10	£10.20
4mm SMC to 1/4" BSP Fitting	10	£8.30
4mm SMC Tee	10	£9.60
4mm SMC Straight	10	£9.60
1mm SY Cable	4m	£8.00
Micro-Pump	1	£130.20
3" Tank Components	1 SET	£20.00
Total		£917.90

Table 11 - Final Cost

Table 11 shows the final cost of the prototype. The project was successfully completed under the £1,000 budget set in the specification. The most expensive components in this project were the NI myDAQ controller, the TCS Micro-pump and the panel housing the prototype.

7.2.3 Return on Investment (ROI)

This section will cover the time to return on investment of the prototype. Table 9 from section 7.1.3 shows the successful operation of the prototype, the first recording was sampled at 4:20:41 PM whilst the last sample recording was taken at 4:25:41 PM. From these time stamps, it can be calculated that the total calibration time for the prototype is 5 minutes.



Table 12 - Druck DPI Pressure Calibrator

To calibrate a -250 mBAR to +250 mBAR transmitter, a technician from KCS would use the Druck DPI 2 BAR pressure calibrator. The 'Calibrated Transmitter' was calibrated multiple times using the Druck pressure calibrator and the time to calibrate was recorded; the time-to-calibrate can be seen in Table 13. There were two main delays; waiting for system pressure to settle and the coarse adjustment on the hand pump. Because the Druck is designed for up to 2 BAR pressure operation the thread adjuster was very coarse, making pressure adjustment difficult.

Test No.	Timed to Calibrate
1	00:23:33
2	00:21:18
3	00:20:58

Table 13 - Time to Calibrate

From Table 13, the average time to calibrate can be worked out at approximately 22 minutes; approximately 2.7 instruments and hour.

KCS would pay a technician £25 an hour for calibrating pressure instruments in industry.

From this it can be calculated that the cost of calibrating an instrument for KCS is:

$$\text{Cost per instrument} = \frac{£25}{2.7} = £9.26$$

Calibrating an instrument with the prototype takes 5 minutes, therefore a maximum of 12 instruments can be calibrated an hour. From this the cost of calibrating an instrument can be calculated at:

$$\text{New Cost Per Calibration} = \frac{£25}{12} = £2.08$$

The saving between the new cost and the old cost is £7.18. From this it can be calculated how many instruments it would take to regain the cost of constructing the prototype using £917.90 of the budget.

$$ROI = \frac{£917.90}{£2.08} = \text{Approx. 128 instruments.}$$

From this, the minimum time to return can be calculated:

$$\text{Minimum Time to ROI} = \frac{128 \text{ instruments}}{12 \text{ instruments an hour}} = \text{Approx. 11 working hours}$$

Well thought out criteria used to produce a minimum time for 'return on investment though it could have been left as 128 calibrated instruments.

8.0 Conclusion, Recommendations & Reflection

8.1 Conclusion

This project was undertaken to design and create a prototype automatic pressure calibrator that could calibrate a pressure transmitter from -250 mBAR to +250 mBAR. Research was done on the existing methods of calibration; manual, semi-automatic and automatic methods to help understand the process. Research was also carried out on what pressure and vacuum are as well as *gauge* and *absolute* pressures.

The literature review investigated three potential solutions that could be used to control the prototype. From solution analysis and comparison the NI myDAQ was chosen as the solution to control the prototype.

The project specification was created based on the chosen solution, from this the final solution was designed and implemented. The prototype was then tested against the test tables and evaluated against the specification.

To conclude on the project, the prototype designed is capable of calibrating the -250 mBAR to +250 mBAR transmitter to a tolerance of $\pm 0.25\%$. The NI myDAQ is capable of operating the prototype indirectly through the use of the ULN2803A Darlington array chip. The logic is setup in a sequence to pump pressure or draw vacuum in 20% increments and record the results obtained. The recorded results are then transferred to the Excel documents, the master Excel document then displays the achieved results in a table and in graphs, comparing both transmitters against each other and comparing the pressure difference against the tolerance limits.

The minimum time to return on investment was calculated at 11 working hours, calibrating 128 instruments. All specifications set out at the beginning of the project have been met, the prototype is capable of working portably and can be taken to an instrument set for -250 mBAR to +250 mBAR and calibrate it. (*within 5 mins*)

8.2 Recommendations

The first recommendation would be to alter the prototype to control the pressure and vacuum more accurately. When the pressure or vacuum target is achieved the signal tends to spike and settle slightly over or under the target set point. An adjustable drain valve could be installed that could slowly close the drain valve as the system pressure approaches the target pressure. Similarly, a pump with a better analogue control could be installed so as the pressure or vacuum rises to meet the target, the speed of the pump slows down. To further

control the pressure more accurately, the state machine could be adjusted to only vary the pressure or vacuum target, this value could be fed into a logic circuit that is constantly monitoring system pressure against the target pressure, from this difference the system would decide whether the pump or drain valve needed operating.

The second recommendation would be to add a method of detecting an air leak or loose pipe connection in the software. A logic circuit could be implemented to measure the system pressure whilst the pump is running and compare the reading to another sample taken 10 seconds later. If there is a leak or connection issue then the pressure difference between the two samples would be near zero.

The third recommendation would be to have a custom air tank designed using the Autodesk 3D CAD software and have it 3D printed to fit the size of the prototype panel. The tank currently used reduces the aesthetics of the prototype.

The fourth recommendation would be to have an adjustable pressure and vacuum range. The user would enter the pressure / vacuum range into the front panel, similar to the adjustable tolerance implemented already. This would allow the prototype to work on a much wider range of pressure transmitters.

*Excellent detail on future
recommendations*

8.3 Reflection

This project has helped me develop my designing skills for both hardware and software. For the software, I initially intended to implement the program using combinational logic. However after recommendations from my academic supervisors, I began to design the logic using the sequence structures in LabVIEW. Designing and implementing the logic sequentially was far simpler and controlled the prototype in a much better fashion. Had I began the process designing the LabVIEW program sequentially the software implementation would have been completed much sooner.

For the hardware I initially intended to use the myDAQ to control a set of reed-relays to drive the solenoids and pumps. After further investigation I could not find reed-relays to match the 3.3VDC at 4 mA digital output of the myDAQ. My academic supervisors recommended the use of a Darlington pair transistor because of the high current gain, after further investigation I found the ULN2803A Darlington array chip that was capable of acting as a buffer for the myDAQ to control the prototype. Had I taken the limitations of the hardware into account sooner, the implementation of the hardware would have been finished much sooner.

*Reflection given shows understanding through
knowledge gained*

9.0 Citation List

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Good, varied list of research carried out

10.0 Appendix & Project Planning

Appendix Contents:

10.1: Prototype Hardware Wiring Diagrams

10.2: Project Planning

10.3: Instrument Calibration Results

10.4: Excel Results Sheet

10.5: Component PDFs

10.1 Appendix: Prototype Hardware Wiring Diagrams

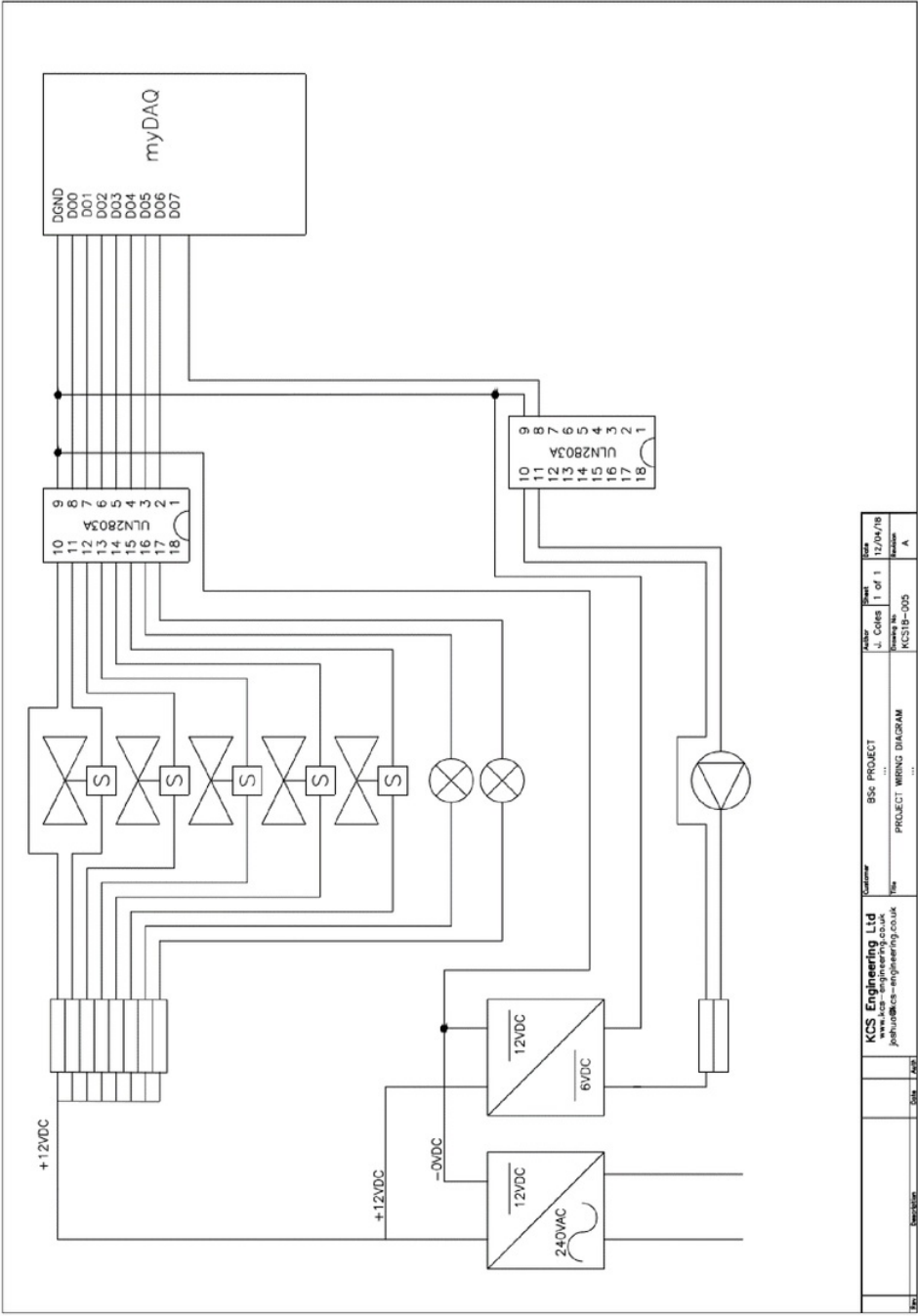


Figure 68 - Power Wiring Diagram

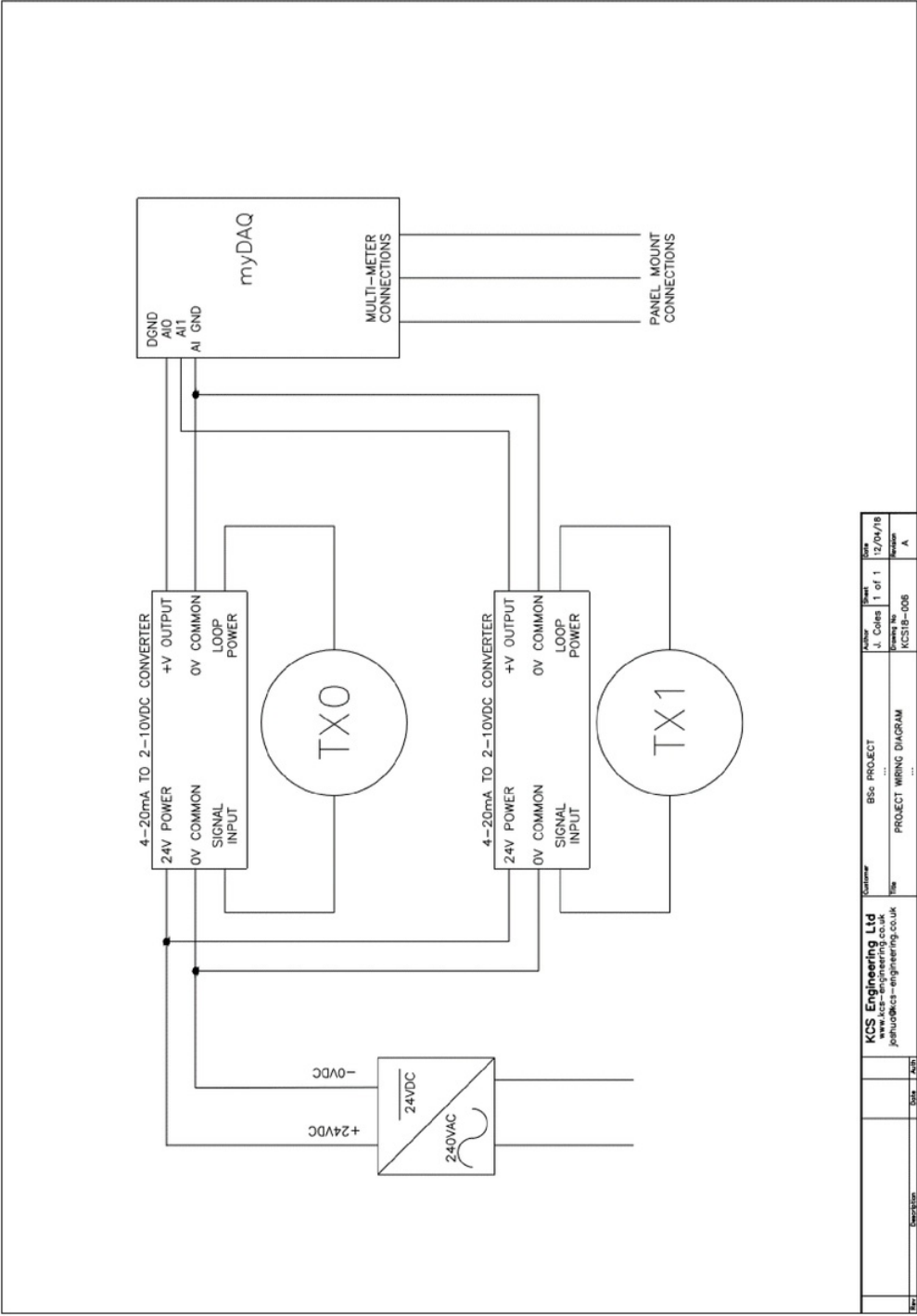


Figure 69 - Analogue Signal Wiring Diagram

10.2 Project Planning

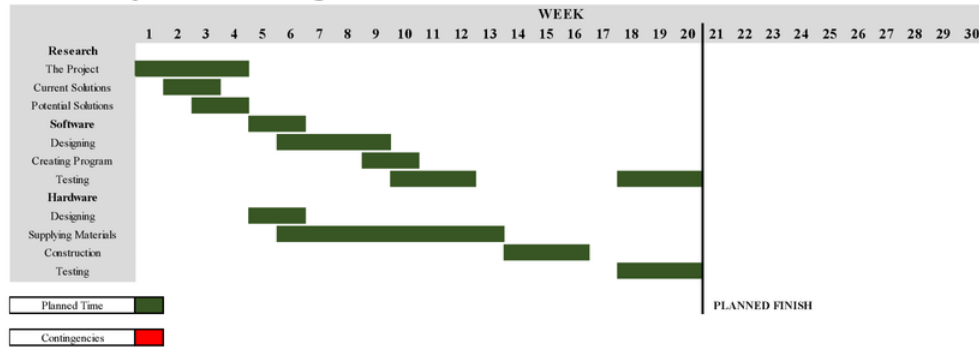


Figure 70 - Planned Gantt chart

Figure 70 shows the planned Gantt chart for the project. The project completion date was set for the end of March 2018, however time was allocated until the end of April 2018 should an unplanned delay happen.

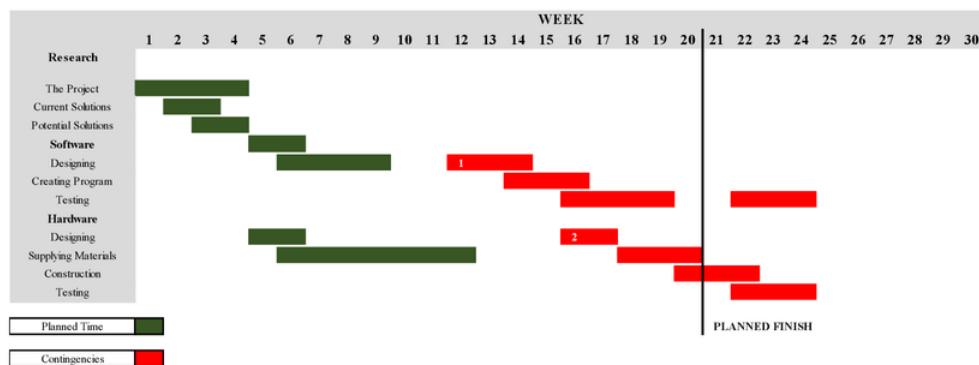


Figure 71 - Actual Gantt chart

Figure 71 shows the actual Gantt chart for the project. The delayed tasks are highlighted in red. The software design task highlighted in red and reference 1 occurred because the logic design switched from combinational logic to sequential logic. Therefore the follow up sections of implementing and testing the logic were also delayed.

The second delay, highlighted as 2, was the designing and implementing of the hardware. The initial intention was to use reed relays as a buffer to control the logic. After discovering that reed relays wouldn't be able to work with my design an alternative method of controlling the circuit needed to be researched. Therefore the following section of designing, implementing and final testing were also delayed.

Good comparison made of the proposed and actual Gantt chart clearly showing where problems occurred and how they were overcome

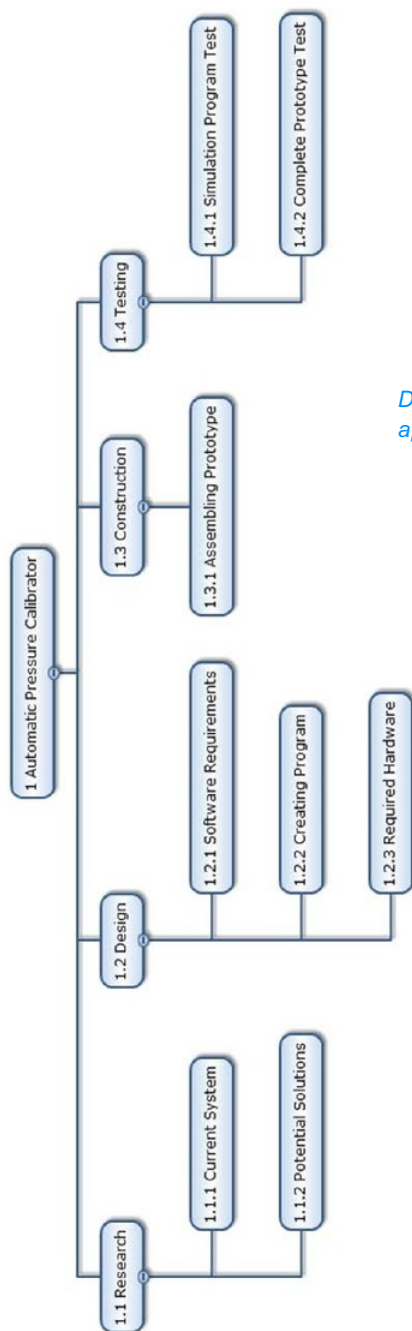


Figure 72 - Work Breakdown Structure

Detailed WBS shown in appendix

Figure 72 shows the work break down structure used to summarise the tasks to complete the project. The tasks have been broken up four main sections; research, design, construction & testing.

10.3 Instrument Calibration Results

KCS ENGINEERING LTD			
PRESSURE TRANSMITTER			
CUSTOMER: JOSHUA KCS		CONTRACT NUMBER: KCS	
UNIT: /		DATE: 10/11/2017	
TITLE: REFERENCE TRANSMITTER		SERIAL No: TX0	
LOCATION: /		MANUFACTURE: SIEMENS	
LOCAL ID No: /		RANGE: -250mBAR TO +250mBAR	

APPLIED VALUE	
Units	mBAR
UP	DOWN
-250	-250
-125	-125
0	0
125	125
250	

AS FOUND	
Units	mA
UP	DOWN
4.00	4.00
8.00	8.00
12.01	12.00
16.01	16.01
20.02	

AS LEFT	
Units	mA
UP	DOWN
4.00	4.00
8.00	8.00
12.01	12.00
16.01	16.01
20.02	

TEST EQUIPMENT:	DRUCK DPI 20 BAR
SERIAL NUMBER:	4970/00-03

1. Check for correct and adequate identification.
 2. Check the calibration of the Transmitter at 20% intervals using approved test equipment.

COMMENTS

TECHNICIAN: SAUL COLES	DATE: 10/11/2017
------------------------	------------------

KCS ENGINEERING LTD**PRESSURE TRANSMITTER**

CUSTOMER: JOSHUA KCS	CONTRACT NUMBER: KCS
UNIT: /	DATE: 10/11/2017

TITLE: CALIBRATED TRANSMITTER	SERIAL No: TX1
LOCATION: /	MANUFACTURE: SIEMENS
LOCAL ID No: /	RANGE: -250mBAR TO +250mBAR

APPLIED VALUE	
Units	mBAR
UP	DOWN
-250	-250
-125	-125
0	0
125	125
250	

AS FOUND	
Units	mA
UP	DOWN
3.99	3.98
7.99	7.98
12.00	11.99
16.01	16.01
20.01	

AS LEFT	
Units	mA
UP	DOWN
3.99	3.98
7.99	7.98
12.00	11.99
16.01	16.01
20.01	

TEST EQUIPMENT:	DRUCK DPI 20 BAR
SERIAL NUMBER:	4970/00-03

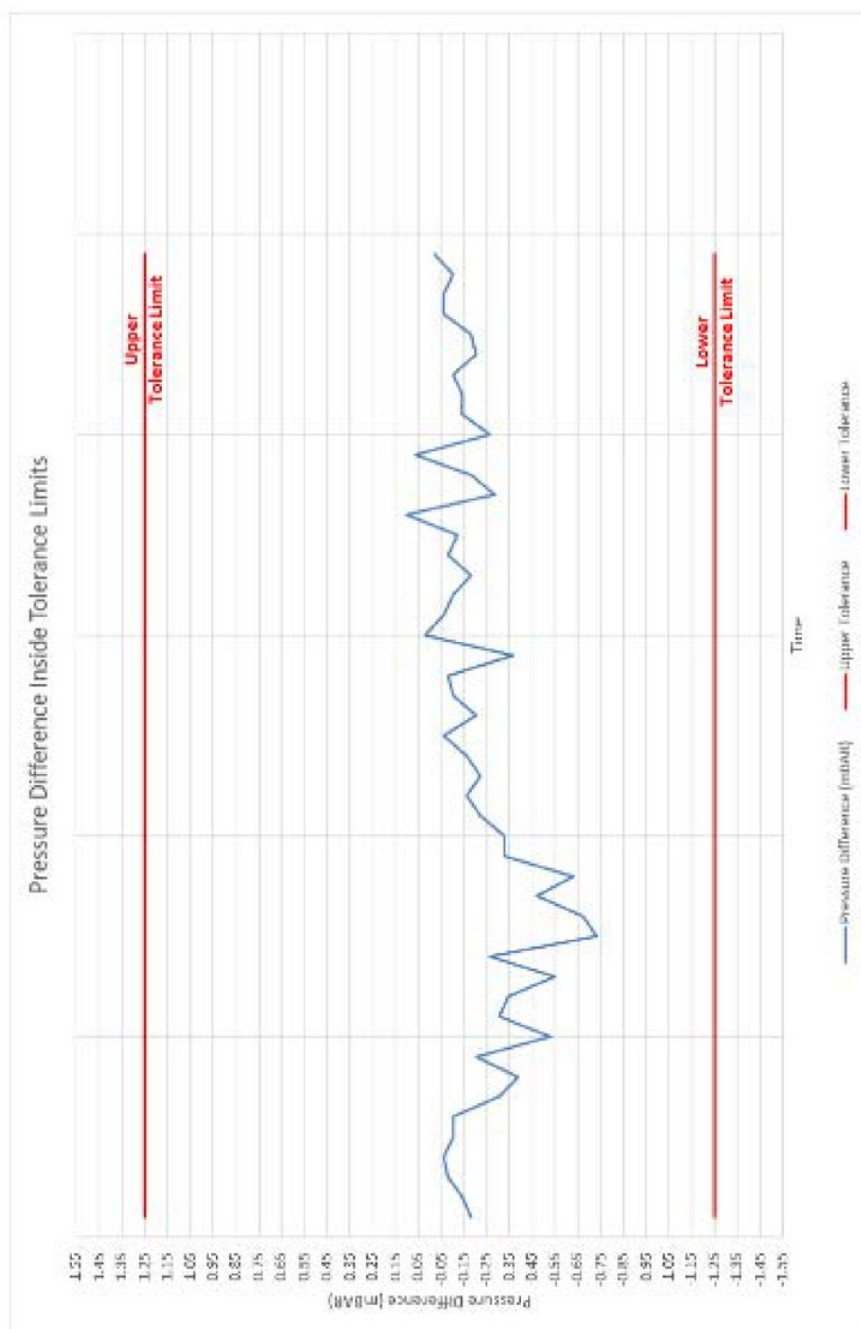
1. Check for correct and adequate identification.
2. Check the calibration of the Transmitter at 20% intervals using approved test equipment.

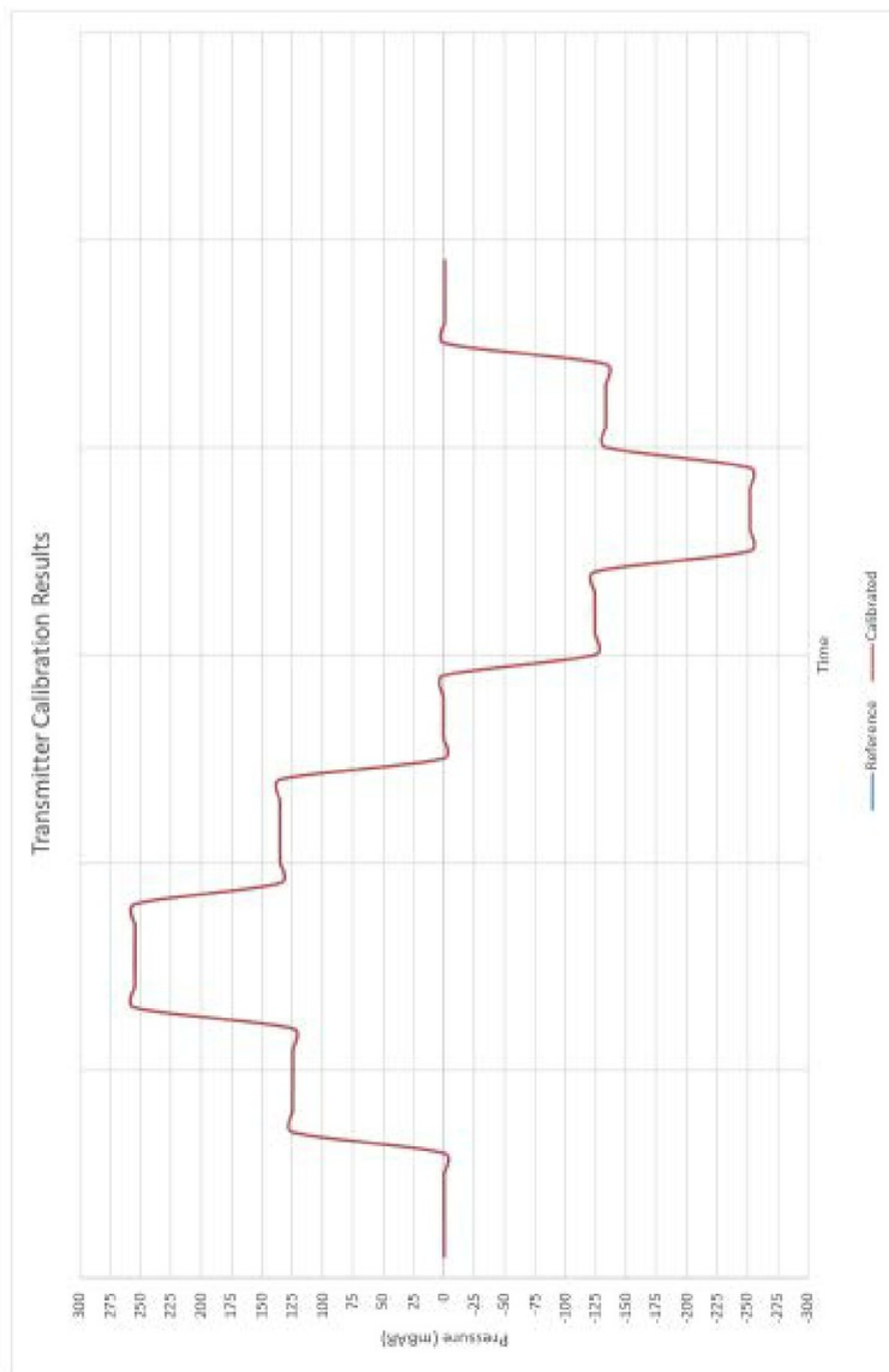
COMMENTS

TECHNICIAN: SAUL COLES	DATE: 10/11/2017
------------------------	------------------

10.4 Excel Results Sheet

Calibration Results: PASS									
Calibration Date: 21/4/18									
Calibrating Technician: J. Cole									
Time	Reference Transmitter (mBar)	Calibrated Transmitter (mBar)	Upper Tolerance Limit	Lower Tolerance Limit	Pressure Difference (mBar)	Lower Tolerance (mBar)	Upper Tolerance (mBar)		
4:20:41 PM	-0.296815	-0.113517	1.25	-1.25	-0.183298	-1.546815	0.933185		
4:20:42 PM	-0.317181	-0.174616	1.25	-1.25	-0.142565	-1.567181	0.932819		
4:20:42 PM	-0.194983	-0.113517	1.25	-1.25	-0.081466	-1.444983	1.055017		
4:20:42 PM	-0.133884	-0.072785	1.25	-1.25	-0.061099	-1.383884	1.116116		
4:20:42 PM	-0.15425	-0.052418	1.25	-1.25	-0.101832	-1.40425	1.09575		
4:20:42 PM	-0.15425	-0.052418	1.25	-1.25	-0.101832	-1.40425	1.09575		
4:21:09 PM	124.447209	124.752705	1.25	-1.25	-0.305496	123.197209	125.697209		
4:21:10 PM	124.38611	124.773071	1.25	-1.25	-0.386961	123.13611	125.63611		
4:21:10 PM	124.306645	124.508308	1.25	-1.25	-0.201663	122.054645	125.554645		
4:21:10 PM	124.080615	124.50004	1.25	-1.25	-0.529525	122.830615	125.330615		
4:21:10 PM	124.141714	124.447209	1.25	-1.25	-0.305495	122.891714	125.391714		
4:21:10 PM	124.019515	124.365744	1.25	-1.25	-0.346229	122.769515	125.269515		
4:21:46 PM	254.507955	255.117647	1.25	-1.25	-0.549692	253.317955	255.817955		
4:21:46 PM	254.606688	254.873451	1.25	-1.25	-0.264763	253.336688	255.836688		
4:21:46 PM	254.262826	255.016015	1.25	-1.25	-0.753189	253.012826	255.532826		
4:21:46 PM	254.26246	254.934535	1.25	-1.25	-0.67209	253.01246	255.31246		
4:21:46 PM	254.282826	254.731252	1.25	-1.25	-0.448426	253.032826	255.332826		
4:21:47 PM	134.058796	134.690133	1.25	-1.25	-0.631337	133.468796	135.888796		
4:21:47 PM	134.42527	134.658209	1.25	-1.25	-0.232937	133.42527	135.82927		
4:22:12 PM	134.77265	132.698821	1.25	-1.25	-0.353822	133.5265	136.02265		
4:22:12 PM	134.61632	135.198554	1.25	-1.25	-0.58223	133.645524	136.45524		
4:22:12 PM	134.895158	135.658089	1.25	-1.25	-0.762931	133.645158	136.45158		
4:22:12 PM	135.017355	135.941886	1.25	-1.25	-0.924531	133.767355	136.967355		
4:22:13 PM	134.986257	135.119188	1.25	-1.25	-0.132931	133.706257	136.206257		
4:23:08 PM	0.395442	0.456741	1.25	-1.25	-0.061299	-0.854358	1.645642		
4:23:08 PM	0.773444	0.477107	1.25	-1.25	-0.203663	-0.976556	1.523444		
4:23:08 PM	0.73444	0.375276	1.25	-1.25	-0.101832	-0.976556	1.523444		
4:23:08 PM	0.375276	0.456741	1.25	-1.25	-0.081465	-0.874724	1.652276		
4:23:09 PM	0.130679	0.497474	1.25	-1.25	-0.366595	-1.19121	1.360879		
4:23:34 PM	-124.592778	-124.613145	1.25	-1.25	0.020367	-125.842778	-123.342778		
4:23:34 PM	-124.450214	-124.389115	1.25	-1.25	-0.061099	-125.700214	-123.200214		
4:23:35 PM	-124.531679	-124.425847	1.25	-1.25	-0.101832	-125.781679	-123.281679		
4:23:35 PM	-124.429847	-124.246555	1.25	-1.25	-0.183297	-125.679847	-123.179847		
4:23:35 PM	-124.287283	-124.205817	1.25	-1.25	-0.081466	-125.537283	-123.037283		
4:24:14 PM	-352.452857	-252.330659	1.25	-1.25	-0.122198	-253.702857	-251.202857		
4:24:14 PM	-352.228827	-252.330659	1.25	-1.25	0.101832	-253.478827	-250.978827		
4:24:15 PM	-352.371392	-252.086262	1.25	-1.25	-0.28513	-253.621392	-251.121392		
4:24:15 PM	-352.26956	-252.086262	1.25	-1.25	-0.183298	-253.51956	-251.01956		
4:24:15 PM	-352.065896	-252.126995	1.25	-1.25	0.061099	-253.315896	-250.815896		
4:24:41 PM	-133.431783	-133.167021	1.25	-1.25	-0.264762	-134.681783	-132.181783		
4:24:41 PM	-133.472516	-133.329552	1.25	-1.25	-0.142564	-134.722516	-132.222516		
4:24:41 PM	-133.411417	-133.268852	1.25	-1.25	-0.142565	-134.461417	-132.161417		
4:24:41 PM	-133.411417	-133.305585	1.25	-1.25	-0.101832	-134.461417	-132.161417		
4:24:41 PM	-133.513249	-133.305585	1.25	-1.25	-0.203664	-134.763249	-132.263249		
4:25:41 PM	-0.765241	-0.581544	1.25	-1.25	-0.183297	-2.015241	0.484759		
4:25:41 PM	-0.62677	-0.561577	1.25	-1.25	-0.0611	-1.872677	0.627323		
4:25:41 PM	-0.381944	-0.530845	1.25	-1.25	-0.061099	-1.831944	0.668056		
4:25:41 PM	-0.653409	-0.561577	1.25	-1.25	-0.101832	-1.913409	0.586591		
17:48:04:007365	-0.60231	-0.581544	1.25	-1.25	-0.020566	-1.82331	0.64779		





10.5 Component PDFs

This section will have relevant PDF document sections that were used during the project' i.e. wiring diagrams and signal connections for individual components.

D3K Series - Data Sheet



Miniature Diaphragm Gas/Air Pump

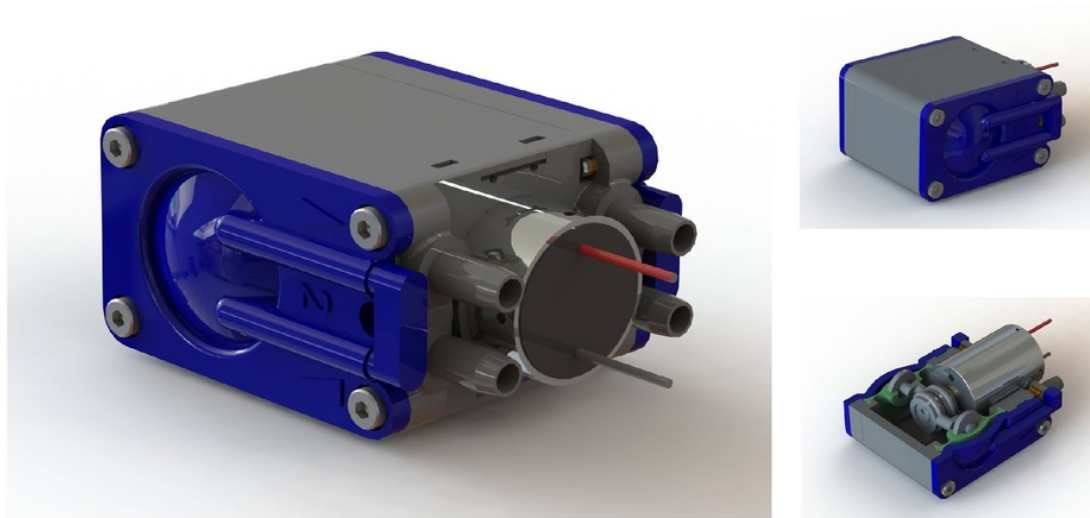
Overview : Gas Pump, Very Efficient, Good Pressure and Vacuum

The D3K pumps are miniature diaphragm pumps designed for maximum performance with minimum power consumption making them especially suitable for portable, battery powered devices.

They are constructed from a special blend of Polycarbonate and ABS for maximum strength and rigidity and have elastomeric components manufactured from Nitrile. They are powered by a small and highly efficient coreless DC motor for ultimate efficiency.

The dual inlet and outlet ports allow the two pump heads to be plumbed in series for maximum pressure and vacuum or in parallel for maximum flow.

Pump



Typical Applications

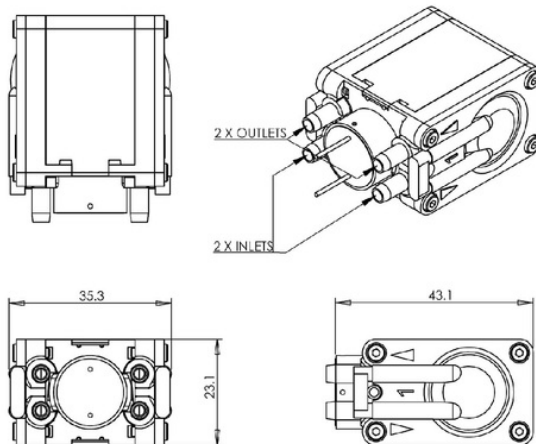
- Medical devices
- Analysis Systems
- Gas detection and monitoring
- Cooling Systems
- Precision Flow

Features

- High Efficiency
- High flow rate
- Good performance under suction
- Low power consumption
- Small size only 36 x 23 x 43 mm
- Light weight 45g
- Robust design
- Can be user optimised for either best flow or pressure

TCS Micropumps Ltd
www.micropumps.co.uk
Email sales@micropumps.co.uk Tel +44 (0) 1795 539 655

Document Ref No.
DS27 Page 1 Rev 1.



Materials

Wetted Parts

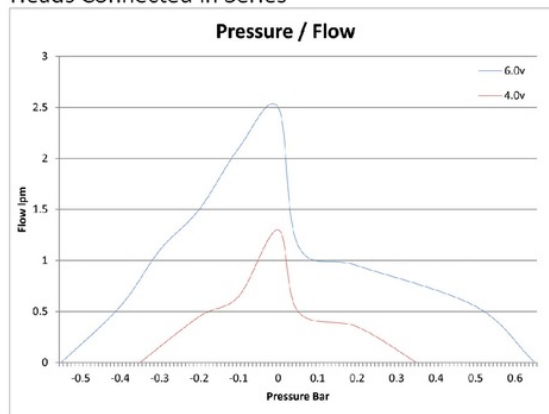
- PC / ABS Polymer
- Nylon 66
- Nitrile

Other Components

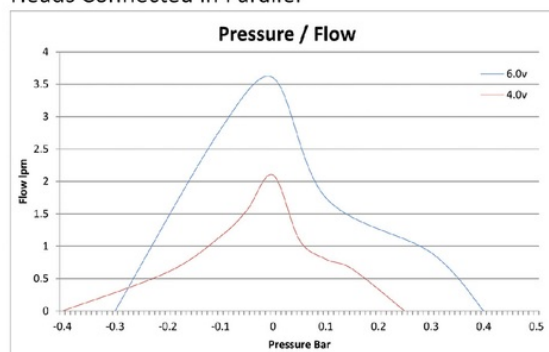
- DC Motor
- Acetal
- 316 Stainless Steel

Custom versions available for chemical compatibility

Heads Connected in Series



Heads Connected in Parallel



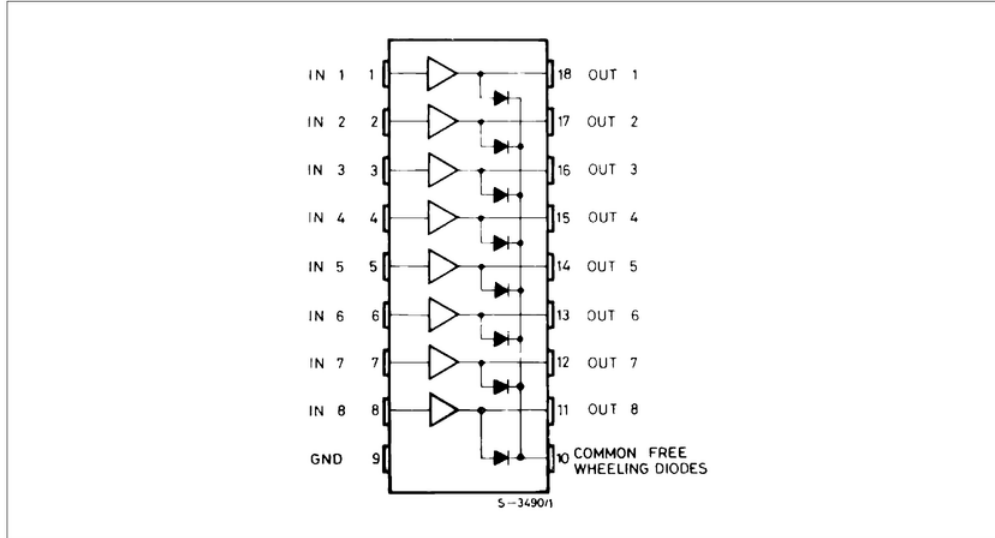
Performance Data

- Operating Voltage 3-6 volts DC
- Power Consumption 0.3 - 2.5 watts
- Small Size 36 x 23 x 43mm
- Weight 45g
- Operating Temp 0 to 60 deg C
- IP Rating IP41
- Noise Levels <25db
Measured at a distance of 1m with a 50dB ambient noise level and with the pumps inlet and outlet ports silenced
- MTBF 3,000hrs

Custom configurations available for upto 20,000 hrs

2 Pin configuration

Figure 2. Pin connections (top view)



3 Maximum ratings

Table 2. Absolute maximum ratings

Symbol	Parameter	Value	Unit
V_O	Output voltage	50	V
V_I	Input voltage (for ULN2802A - ULN2803A - ULN2804A)	30	V
I_C	Continuous collector current	500	mA
I_B	Continuous base current	25	mA
P_{TOT}	Power Dissipation (one Darlington pair)	1	W
	Power Dissipation (total package)	2.25	
T_A	Operating ambient temperature range	- 20 to 85	°C
T_{STG}	Storage temperature range	- 55 to 150	°C
T_J	Junction temperature	-20 to 150	°C

Table 3. Thermal data

Symbol	Parameter	Value	Unit
R_{thJA}	Thermal resistance junction-ambient	55	°C/W

Final Report

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

72/100

PAGE 1

PAGE 2

Text Comment. Concise abstract given which does fairly reflect the project undertaken

PAGE 3

Text Comment. Very brief set of acknowledgements

PAGE 4

Text Comment. Numbered incorrectly

PAGE 5

PAGE 6

PAGE 7

PAGE 8

Text Comment. Good, clear introduction to the project

PAGE 9

PAGE 10

PAGE 11

Text Comment. Good background research showing what equipment is available at present

PAGE 12

Text Comment. Why 2.3.3 and not 1.2.5?

PAGE 13

Text Comment. Good explanation of what the problem is that the project will attempt to alleviate

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

Text Comment. 3 potential solutions noted, a realistic comparison table produced and a good, reasoned choice made as to which solution to take forward

PAGE 19

Text Comment. General specification given which is detailed and realistic

PAGE 20

Text Comment. Good pre-test table noted to test the equipment before main test begins

PAGE 21

Text Comment. Very good set of tests to be carried out on the main sequence with a 'pass requirement' noted

PAGE 22

Text Comment. Where is the POWRA?

Text Comment. Very good detail noted on Safety, Sustainability, Environmental protection & Professionalism

PAGE 23

Text Comment. Maintenance & Reliability taken into consideration in relation to equipment used

PAGE 24

PAGE 25

PAGE 26

Text Comment. Excellent series of block diagrams and explanations which clearly shows how the project is to be designed

PAGE 27

PAGE 28

PAGE 29

Text Comment. All hardware components being used have been researched, referenced and clearly understood

PAGE 30

Text Comment. Very clear design flow chart noted which will help in developing main LabVIEW program

PAGE 31

Text Comment. The main LabVIEW program Block Diagram could have been clearer

PAGE 32

Text Comment. Very good detail on how the analogue inputs are converted in to pressure in mBAR

PAGE 33

PAGE 34

Text Comment. Excellent detail

Text Comment. Excellent

PAGE 35

PAGE 36

PAGE 37

PAGE 38

PAGE 39

PAGE 40

PAGE 41

PAGE 42

PAGE 43

Text Comment. Excellent detail on the states used within the state diagram and how they control the testing process

Text Comment. Very good detail on how the LabVIEW 'data logs' the pressures allowing EXCEL graphs to be produced

Text Comment. Excellent set of test results in Figs 43 & 44 showing the system is being tested right through the positive and negative pressure ranges and does not go out of tolerance

Text Comment. Hardware implementation clearly noted and informative

Text Comment. All tests carried out according to the test tables produced in specification with good detail on test results obtained

Text Comment. Good set of graphical test results noted and explained clearly

PAGE 63

PAGE 64

PAGE 65

PAGE 66

PAGE 67

PAGE 68

PAGE 69

Text Comment. LabVIEW Front panel full test sequence noted and explained in great detail

PAGE 70

PAGE 71

Text Comment. Excellent detail on how a failed test would indicate within the test sequence

PAGE 72

PAGE 73

PAGE 74

Text Comment. Very detailed evaluation of project hardware / software outcomes

PAGE 75

PAGE 76

Text Comment. Well thought out criteria used to produce a minimum time for 'return on investment though it could have been left as 128 calibrated instruments.

PAGE 77

Text Comment. (within 5 mins)

PAGE 78

Text Comment. Excellent detail on future recommendations

Text Comment. Reflection given shows understanding through knowledge gained

PAGE 79

Text Comment. Good, varied list of research carried out

PAGE 80

PAGE 81

PAGE 82

PAGE 83

Text Comment. Good comparison made of the proposed and actual Gantt chart clearly showing where problems occurred and how they were overcome

PAGE 84

Text Comment. Detailed WBS shown in appendix

PAGE 85

PAGE 86

PAGE 87

PAGE 88

PAGE 89

PAGE 90

PAGE 91

PAGE 92

PAGE 93

PAGE 94

GRADING FORM: MAJOR PROJECT 2017_18

JOSHUA COLES

71.60

RESEARCH (20%)

Research Informed Literature: 1. Abstract, acknowledgements, introduction and setting out of aims and objectives. (/20) 2.

Background research, setting the context of the project, statement of user or customer needs. (/30) 3. Literature review, solutions considered and choice made. (/40) 4. Use of Harvard Referencing for citing and listing sources. (/10)

14.2



1. Concise abstract given which fairly reflects the project undertaken. Very brief set of acknowledgements. Good clear introduction to the project. (13) 2. Good background research showing what equipment is available at present. Good explanation of what the problem is that the project will attempt to alleviate. (24) 3. Three potential solutions noted, a realistic comparison table produced and a good, reasoned choice made as to which solution to take forward. (27) 4. Correct use made of Harvard referencing and a good list of references cited. (7)

KNOWLEDGE (20%)

Knowledge & Understanding of Subject: 1. Specification, design requirements and project outcomes, time and financial constraints. (/30) 2. Test planning and procedures. (/20) 3. Formal project planning and identification of milestones. (/25) 4. Consideration of maintenance and reliability. (/25)

13.8



1. General specification given which is detailed and realistic. Excellent series of block diagrams and explanations which clearly shows how the project is to be designed. Very clear design flow chart noted which will help in developing the main LabVIEW program. No time constraints. (22) 2. Good pre-test table noted to test the equipment before main test begins. Very good set of tests to be carried out on the main sequence with a 'pass requirement' noted. (15) 3. Detailed WBS shown in appendix. Good comparison made of the proposed and actual Gantt chart clearly showing where problems occurred and

how they were overcome. (18) 4. Maintenance & Reliability taken into consideration in relation to equipment used. (14)

ANALYSIS (20%)

Analysis: 1. Evaluation of Implementation stage, monitoring of progress and milestone activities. (/20) 2. Testing & test results. (/30) 3. Comparison of project outcomes to specification. (/20) 4. Conclusions, recommendations and reflections. (/30)



1. Very good detail on how the analogue inputs are converted into pressure in mBAR. Excellent detail on the states used within the state diagram and how they control the testing process. Hardware implementation clearly noted and informative. (17)
2. Good set of graphical test results noted and explained clearly. LabVIEW Front panel test sequence noted and explained in great detail. (25)
3. All tests carried out according to the test tables produced in the specification with good detail on test results obtained. (19) 4. Very detailed evaluation of the project hardware / software outcomes. Excellent detail on future recommendations. Reflection given shows understanding through knowledge gained. (24)

17

PRACTICAL APPLICATION (20%)

Practical Application & Deployment: 1. Quality, innovation and creativity of design solution. (/20) 2. Implementation stage, working independently with limited supervision. (/30) 3. Meeting customer or user needs, fitness of solution to purpose, working within time and financial constraints. (/20) 4. Log book. (/30)



1. Design solution explained in great detail, clearly showing understanding of the use of LabVIEW

15.8

software and chosen hardware which was both innovative and creative. (17) 2. Hardware implementation clearly noted through pictorial evidence and clearly working with limited supervision. (25) 3. The project evaluation shown clearly indicates the project is fit for purpose. Actual Gantt chart shows timing met and Costing exercise shows the project was completed within budget. (17) 4. Log book shows clearly how the project was developed over the time allocation given. (20)

PROFESSIONAL PRACTICE (20%)

Skills for Professional Practice: 1. Professionalism and ethical conduct. (/25) 2. Health and safety, assessment of risk. (/25) 3. Sustainability and environmental protection.. (/25) 4. Presentation and organisational quality of report. (/25)



1. Very good detail noted on Professionalism. (11) 2. Safety mentioned in Section 4 and comment on POWRA being carried out. No evidence of this in report. (7) 3. Very good detail noted on Sustainability and Environmental protection. (14) 4. Very good report structure and use of pictorial evidence, EXCEL graphical results and varied screen dumps to prove project functions as specified. (22)

10.8