UNIVERSIDAD DE VALLADOLID

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Diseño y desarrollo de una instalación experimental para investigar el efecto de la degradación de los componentes a nivel de sistema.

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TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Design and development of experimental facilities to investigate the effect of component degradation at the system level

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ACRONYMS

API Application Programming Interface

BIT Built In Test

CBM Conditioned Based maintenance

COTS commercial off the shelf

DPV Direct Proportional Valve

FMEA failure modes effects analysis

FMECA failure modes effects critically analysis

HMI Human Machine Interface

ISHM Integrated System Health Management

IVHM Integrated Vehicle Health Management

LCC Life cycle costs

OSA Open system architecture

PHM Prognostics Health Management

RCM Reliability Centred Maintenance

UAV Unmanned Aerial Vehicle

ABSTRACT

The present project constitutes the Final Proyect for the Universidad de Valladolid in the Mechanical Engineering Degree. The aim of the project is to research the effects of component degradation in a UAV fuel system. With this objective, we built a laboratory test rig to investigate its capacity to detect and isolate faults in a representative system. The framework of this study is the IVHM technologies, a combination of techniques from different fields used to assess the current and future state of the system health.

This works includes a review of the available IVHM literature, a basic description of the software that was used in this project and a detailed explanation of the process to install the components in the test rig as well as the programming code that I created to control and acquire data from them.

Keywords: *Integrated Vehicle Health Management, Unmanned Aerial Vehicle, Condition Based Maintenance, Component Degradation, Fuel System.*

RESUMEN

El presente proyecto constituye el Trabajo Fin de Grado de la Universidad de Valladolid en el Grado de Ingeniería Mecánica. El objetivo de este trabajo es estudiar el efecto de la degradación de los componentes del sistema de alimentación de un UAV (Vehículo Aéreo No Tripulado). Con este fin, construimos un banco de ensayos para estudiar su capacidad para detectar y aislar diferentes modos de fallo en un sistema representativo. El ámbito del proyecto está incluido en el marco de las tecnologías IVHM (Gestión Integrada del Estado del Vehículo), una combinación de técnicas de diferentes campos usada para evaluar el estado presente y futuro de un sistema.

Este trabajo incluye un repaso de la literatura disponible en el campo de IVHM, una descripción básica del software utilizado y una explicación detallada del proceso de instalación de los componentes y del código de programación creado para controlarlos y obtener datos de ellos.

Palabras Clave: *Gestión Integrada del Estado del Vehículo, Vehículo Aéreo No Tripulado, Mantenimiento Condicional, Degradación de los Componentes, Sistema de Alimentación.*

Integrated Vehicle Health Management

1.1 Introduction and definition:

This chapter corresponds to the task 1 in the Gantt Diagram in Appendix 1.The scope of this chapter is to summarize and interpret the currently available literature on IVHM. It will be defined what an IVHM systems is, how it differs from conventional vehicle design and which are the main enabler and inhibitors of technical and economic success of IVHM.

IVHM is one of the techniques which are referred to as Conditioned Based Maintenance (CBM) technologies. In these technologies maintenance is carried out when the indicators show that equipment is going to fail or its performance is deteriorating. Prompting users with alerts, updates and granting schematic representation of the vehicle status can benefit them to making conscious and aware decisions.

There is no unanimously definition of IVHM, yet many authors have proposed their own definition. An IVHM system can be generalized as a system which possess the ability to check, test and monitor systems for anomalies against designed parameters throughout the operational cycle. IVHM also has the ability to conduct diagnostic and prognostic analysis of the product whilst in use. This information is further processed to formulate appropriate operation and support actions and presented to the people who should decide and execute the actions. Furthermore, some authors include its ability to mitigate failing systems by reconfiguring the mentioned system as one of its main aspects as well.

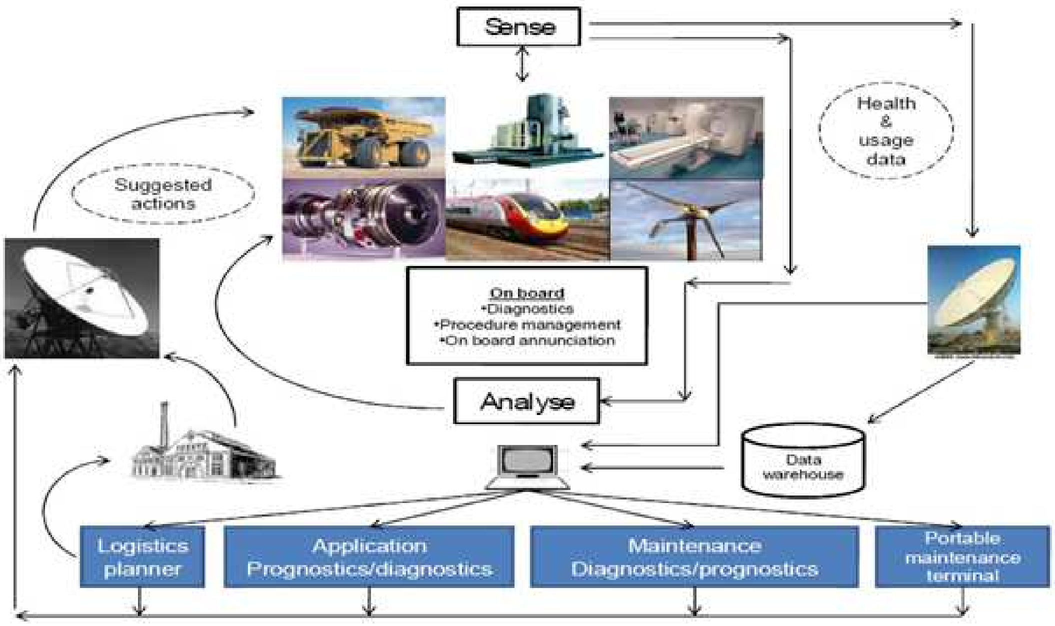

Figure 1.1 – Operation and Structure of an IVHM system

From this definition, we can extract the conclusion that significant differences exist between IVHM and conventional system. Information regarding vehicle condition is used to generate reactive plans and actions instead of merely processing health data for later manipulation. Another critical issue is the notion of integration. The health management system considers the vehicle has a whole; all the vehicle functions are merged rather than be implemented separately.

IVHM was first conceptualized by NASA. The first publication found was a report in 1992. This report stated IVHM as the highest technology for present and future NASA space transportation systems. However, several authors have suggested that the same functions can be found in other vehicles like helicopters, military ground vehicles or maritime systems as ships and submarines.

Maintenance operations benefit from reduced occurrences of unexpected faults as the health management system will provide early identification of failure precursors, while simultaneously condition based maintenance (CBM) is enabled, which can enhance availability, reliability and systems life. Besides, an improved awareness of vehicle condition and capabilities increase safety and the chance of mission success.

Much attention is being given to the operational and support activities that contribute a very large proportion of the lifecycle total ownership costs. New generations of vehicle platforms will undergo substantial changes and will integrate distinctive technological progress to improve in-service operations.

1.2 IVHM Strategy

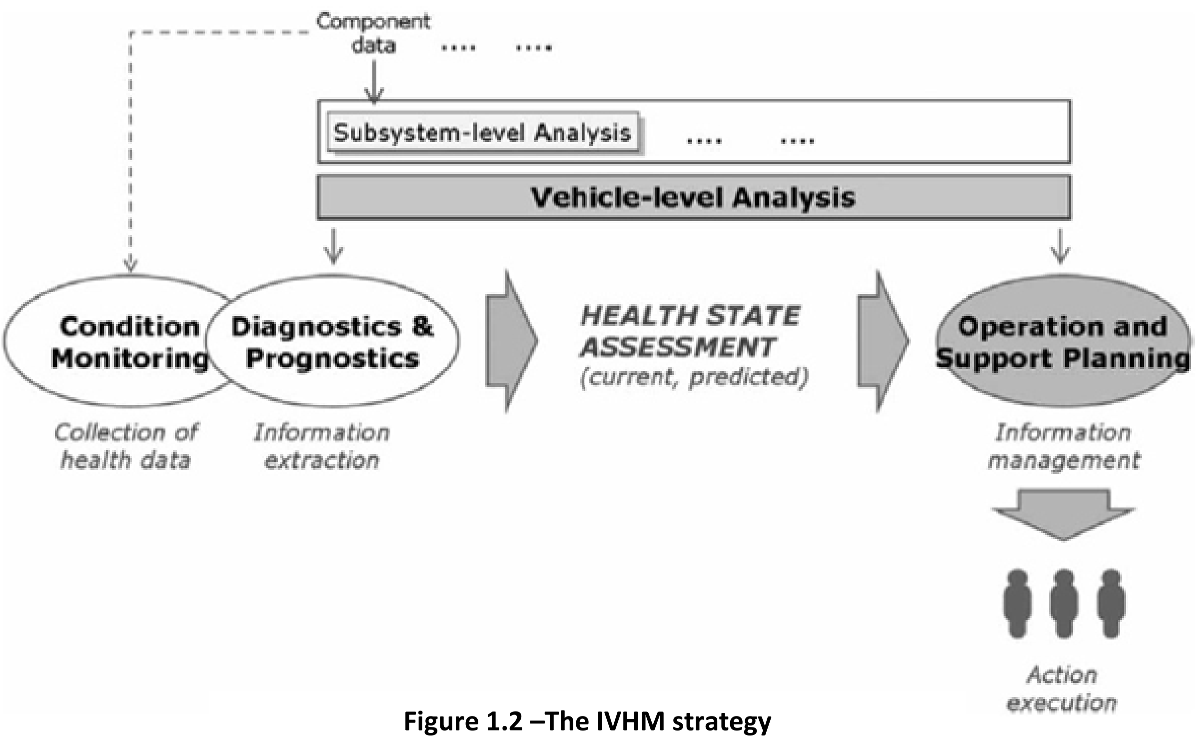

Figure 1.2 –The IVHM strategy

- **Monitoring**: Collection of health data from components and systems.
- **Processing:** Sensor data are preliminary processed to remove artefact and noises and then manipulated to extract fault features. These techniques include low-pass filtering or time synchronous averaging.
- **Assessment:** Detection, identification and isolation of incipient failure conditions. Diagnostic information is combined with historical data to generate a stimulation of the time to failure of components and subsytems assessing both current and predicted health state.
- **Operation and Support Planning**: After the analysis, corrective actions and planning must be taken in case of being necessary.

1.3 Configuration of IVHM systems:

Effective IVHM requires embedded sensors in key components and systems coupled with advanced reasoning linking on-board and ground based systems. The system should be focused on establishing decision support to provide autonomous, timely, and accurate assessments of a vehicle's health and functional availability for operations maintenance personnel.

Whilst in use, a combination of diagnostic and prognostic data is obtained from various sensors and systems monitoring the components. Risk limitation and mitigation are also initiated by algorithm driven procedure management routines. This data can be either stored on-board for download to the off-board operations or be sent by satellite communications to the organisation's control room where additional data analysis capabilities are deployed. Non critical data is usually stored on the vehicle during the mission and downloaded later at the ground station. These organizations usually work with open loop assessment and decision support is undertaken by the ground based reasoner. Wireless networks are used to send the data to the remote support centre so that analysis can still be performed in flight.

The autonomy of the vehicle can be increased incorporating health management solutions on board. This implies a reduced dependence on communications, a faster response and lower operation costs. On the other hand, when the data is processed at the support centre, the amount of instrumentation and computer resources on board is reduced. Besides, it provides enhanced fault forwarding, troubleshooting and historical information support. The election between the two options will depend on many factors. Weight and system complexity become major considerations as we cannot place all IVHM technology within the vehicle. Therefore only those technology applications that contribute to critical operations and revenue protection are fitted on board with all other functions being located off board.

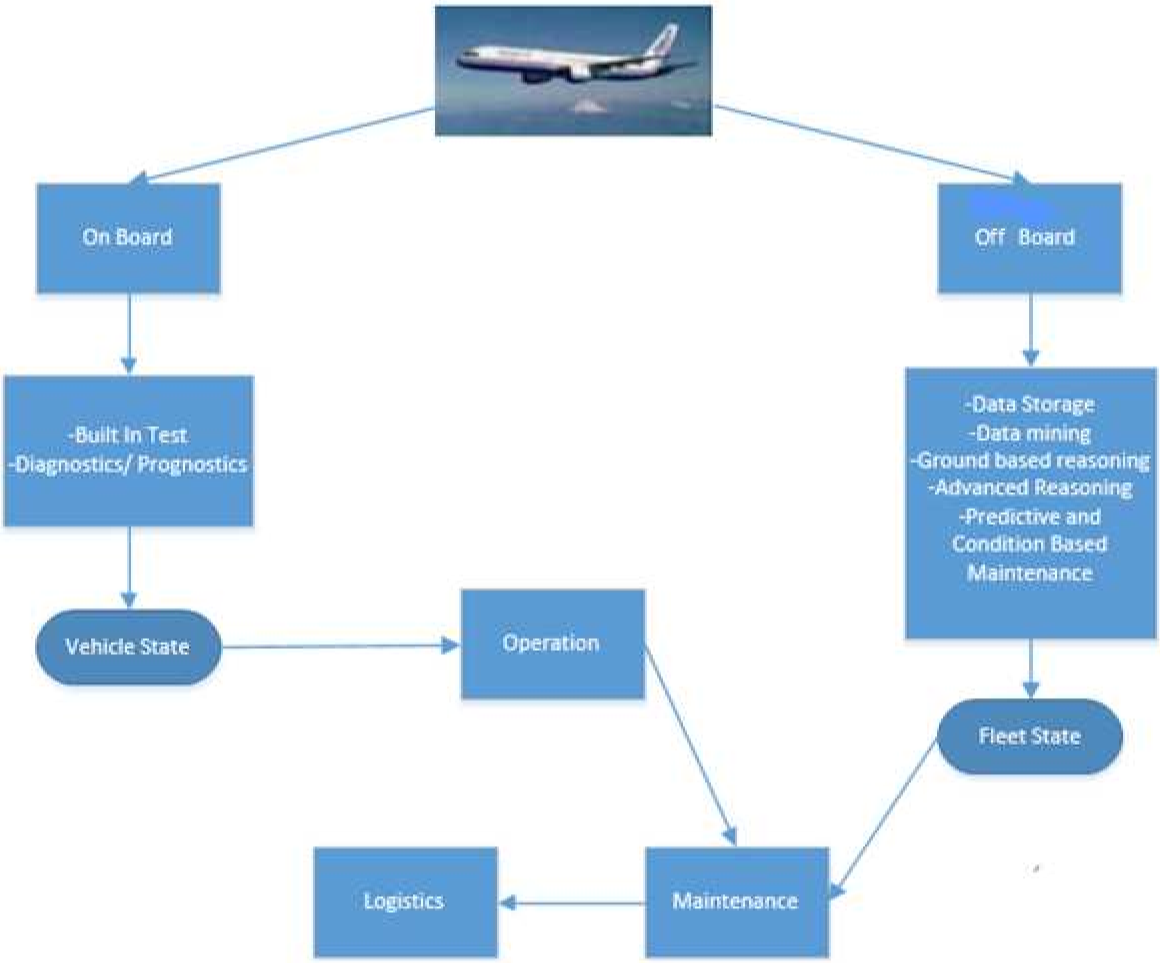

Figure 1.3 – On Board/Off Board Configuration

Therefore, it is very clear that the adoption of an IVHM philosophy requires a deep knowledge of interdisciplinary trends from the engineering sciences, computer sciences and communication technologies to achieve the cheapest possible and most effective asset utilization.

1.4 Architecture

The design of an IVHM system needs to be approached as a system engineering process. The IVHM system must be constructed into the host vehicle and in connection with other instrumentation systems and must be integrated according to open system architecture (OSA). This architecture allows the engineers to integrate and interface all the components of the IVHM system

Levels:

- **Subsystem Lowest level**: key parameters as pressure or temperature are monitored for each component within the system. If these parameters exceed a predetermined limit, warnings are issued and the system performs the required corrective actions.

- **Product Wide Monitoring Level**: This level monitors and reports the interactions of performance and degradation across the vehicle. A deep understanding of the relationship between causes and fault is required in order to foresee how a failure will propagate.

- **Decision Level**: In this level, using the information obtained from the lower levels, is where the decisions as to 'use', 'mitigate' or 'terminate' operations is made.

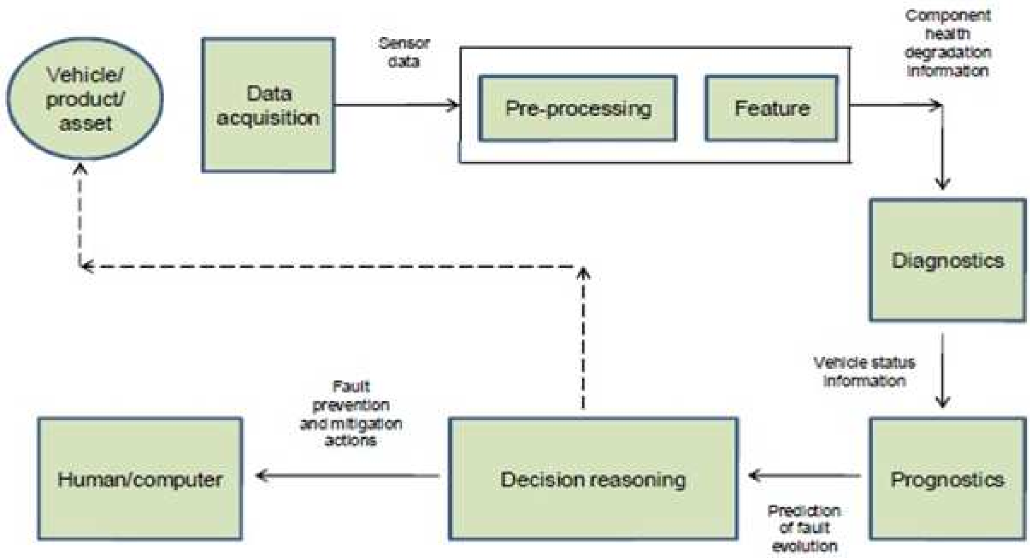

Figure 1.4 – IVHM architecture

1.5 Benefits of IVHM

- **Reliability and maintainability**: IVHM technologies have been developed to address safety, replace time based maintenance with CBM since the accurate and detailed assessment of health data, both current and future, supports early identification of failure onset and thus makes it possible to replace the damaged components before the cause an accident. Automation of monitoring and analysis minimizes the need for human input. This enhances a greater reliability and maintainability.

  IVHM allows the organisation to increase the mission duration and complexity as IVHM mitigates the risks involved. The application of such technology allows for the effective management of the whole aircraft, its systems and components. It's been demonstrated that benefits of IVHM extend well into the area of fleet management as vehicles can be assigned with alternative and coordinated missions.

- **Logistics:** The availability of continuously updated and detailed health information can be used automatically to trigger logistic actions. The Central service centre can pre-emptively prepare the appropriate actions and replacement components, as information is received before fault occurrence.

- **Autonomy**: In some applications, especially in military or aerospace sectors, missions take place in very remote places where unscheduled maintenance or repair can't be performed. The increased mission duration, distance and therefore the cost and delay of communication are leading these industries to aim for the highest level of vehicle autonomy. IVHM provides the assets with this required level of autonomy that allows the assets to operate autonomously even in hostile environments. The mass penalty of carrying spare parts inventories must be consider also as a driving factor.

- **Reduction of lifecycle costs (LCC):** It's been proved that 95% of aircraft lifecycle costs are attributable to maintenance activities. There are deep financial uncertainties in both military and commercial vehicle markets and therefore intense pressure to reduce costs. The application of IVHM solutions reduces need for inspections, fault ambiguity and wasteful removal of serviceable components and increases detection coverage. Component life can be extended when on-condition overhauls are performed.

- **Servitization**: This concept offers a radical shift in the operations strategy and associated business models. IVHM enables manufacturing firms to obtain revenue throughout the complete life cycle by offering maintenance services instead of just offering manufactured products. This kind of change in the business model is called servitization. To do so, the firm must reconfigure key elements of its business model. Manufacturers must design, adjust and align their different business model elements to successfully develop, sell and deliver services. A cultural change and a more holistic approach are absolutely necessary to adapt a company to this new business model.

- **Design support**: Finally, the application of IVHM technologies also supports the design of vehicle products as more detailed field data is available to use for further modifications and upgrades that will lead to a reduction of the costs and an improved availability.

As these technologies are becoming more popular, new tools are developed in different fields that make it easier to implant IVHM solutions to new systems. Generally, these tools are split in two groups with two different purposes.

-To assess the technical design and performance of IVHM enabled applications. In this group are included tools as Failure modes and effects critical analysis (FMECA) or event tree analysis (ETA). These tools will be discussed further.

-To assess the impact and benefits of the application for organisational performance using cost benefit analysis. This is a key insight into the larger issues surrounding the decision making process when considering the adoption of IVHM solutions.

1.6 Inhibitors to the adoption of IVHM

- Higher initial costs: The adoption of IVHM requires incremental and radical change to the organisational, technological financial, economic and commercial systems of the organisation. The legal framework of these organisations must be considered too. IVHM technologies should be applied to systems to maximise the operational benefit and what value the customer will apply to this benefit. There must be a balance between the greater installations costs weighed against the whole life revenue streams. The majority of authors see the main barrier to its adoption as the initial cost of the hardware and software that's required. This cost includes the development and implementation of this technology as well as other penalty cost such as weight, power, computing or communication resources.

- Application of new technologies: The lack of engineering abilities to implement and adopt IVHM systems is also one of the main problems. A cultural change is necessary to accept the shortcoming of potential false alarms or sensor failures. Sometimes during an operational service, a Built-In Test (BIT) fails or the possibility of a fail is reported. This event implies what is usually called a "diagnostic failure". When this happens, independent functionally tests are performed in order to verify and diagnose the fault. Ideally a Shop Replaceable Unit will be called out and sent back for a functional test. If the SRU passes at this stage a diagnostic failure will be recorded. There are then two possibilities. Either the SRU is healthy and it has been falsely replaced or it's faulty and the diagnostic testing is inadequate. These scenarios have a negative impact on system requirements that can include safety, dependability, availability and a negative impact in Life Cycle Costs (LCC).

- Phase of design: the cost and potential of IVHM are directly related to how early in the design it is considered. Organisations and firms have to be convinced of the benefits of this technology and IVHM should be designed 'in' from product conception. By doing this, the number of sensors is reduced as more sophisticated algorithms and models are incorporated.

The conclusion is that for the successful application of IVHM, benefits must be greater than the development cost. Understanding this trade-off between design, development, installation, maintenance and operational costs against whole life revenue streams is the major inhibition to adopt IVHM for most organisations.

1.7 Conclusions

IVHM involves a large number of sub-disciplines such as sensor technology, signal processing or control techniques and it can be apply to completely different systems. For this reason, it is very difficult to summarize all the elements of this emerging technology.

IVHM enabled improvements are found in operational and process innovation rather than in any individual innovative technology. The transition to health maintenance from health monitoring and the new system-level integration approach have demonstrated their capacity to increase the value of a certain asset.

In spite of these positive aspects, IVHM is still a relative emerging field and research initiatives are need to coordinate knowledge development and improve methods and tools in order to accomplish a more widespread adoption of IVHM and a deeper understanding of tis applications.

2. LabVIEW

2.1 Introduction

After studying the whole IVHM concept and all its different aspects, the objective was to create a system which could support this technology in order to test its scope. The system chosen was a UAV (Unmanned Aerial Vechicle) fuel system. The first step was to create a test rig that represented a physical model of the UAV system. Our intention was to control the different variables involved in the proper functioning of the system and simulate different faults in it. To control and acquire data from all the different components, we had to recourse to a software-program called LabVIEW that allows the user to interface with the system. My second task consisted on learning how to use this software and understanding its programming language with the help of two manuals: "LabVIEW: Course Manual and Exercises" (Core 1 and 2).

LabVIEW is a system-design platform and development environment for a visual programming language from National Instruments. It's used by engineers and scientist to de developed sophisticated measurement, test, control systems and industrial automation.

2.2 Data Acquisition

The purpose of data acquisition is to measure an electrical or physical phenomenon such as voltage, current, temperature or pressure. Every data acquisition system has its own application requirements, but we can define globally data acquisition as the process of acquiring signals from real world phenomena, digitizing the signals and analyzing, presenting and saving the data. The DAQ system has the following parts involved:

-Physical I/O signals.

-DAQ device/hardware

-Driver software.

-Application software.

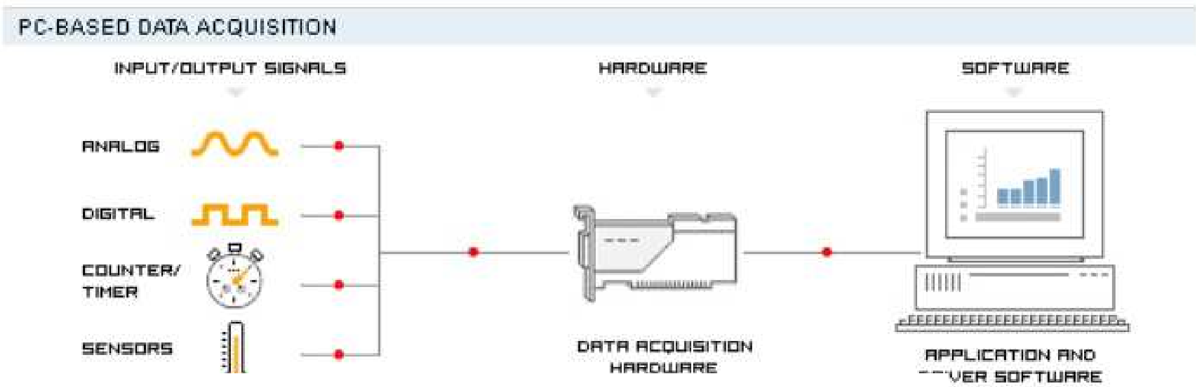

Figure 2.1 – Data Acquisition

2.2.1 DAQ Device:

The DAQ device digitizes incoming signals so that the computer can interpret them. Most DAQ devices have four standard elements – analog input, analog output, digital I/O and counters.

-**Analog input**: The process of measuring an analog signal and transferring it t o a computer for analysis, display or storage. An analog signal is a signal that varies continuously. In this process, it's required an analog-to-digital conversion so that a computer can process the data. Analog-to-digital converters transform a voltage level into a series of ones and zeros using a sample clock that controls the rate at which samples of the input signal are taken.

-**Analog Output**: The process of generating electrical signals from the computer. In this case, analog output is generated by digital-to-analog converters that using the data that the computer generates vary the voltage on an output pin over time. Digital-to-analog converters generate a new value at each cycle of the update clock.

-**Digital signals**: Electrical signals that transfer digital data. Digital signals only have two states, on and off or one and zero. When the voltage is applied, the receiver determines the value being sent depending on the value of the voltage level. Each state corresponds to a range of voltage values. Digital signals are usually applied to control devices such as switches, LEDS or to communicate between different devices.

-**Counters**: Digital timing devices. They're typically used to count events or to measure frequencies, periods or pulses.

2.2.2 Driver Software:

Driver software forms the middle layer between the application software and the hardware. There are two different drivers to choose from: NI-DAQmx and Traditional NI-DAQ. We used NI-DAQmx for our application because of the following reasons:

-More functions and development tools.

-It includes the DAQ Assistant for configuring channels and measurements tasks for a device.

-Increased performance.

-Simpler API (Application Programme Interface)

LabVIEW also includes a tool named MAX that can be used to configure the data acquisition devices.

The DAQ Assistant, included with NI-DAQmx is a graphical, interactive guide for configuring, testing and acquiring measurement data. It reduces the number of programming errors and reduces the time from setting up the DAQ system.

2.2.3 Application Software

Application software adds analysis and presentation capabilities to the driver. You can do the following tasks using this software.

-Real time monitoring

-Data analysis and logging.

-Control algorithms.

-Human machine interface (HMI)

2.3 Implementing a VI

2.3.1 Components

LabVIEW uses a dataflow programming language named “G” where execution is determined by the structure of a graphical block diagram on which the programmer connects different function-modes by drawing wires. These wires propagate variables and any node can execute as soon as all its input data is available. This programming language is capable of parallel execution, since different nodes can obtain the input data at the same time.

LabVIEW programs are called virtual instruments, or VI’s because their appearance and operation imitate physical instruments. LabVIEW contains a set of tools for acquiring, analyzing, displaying and storing data. LabVIEW VI’s contain three main components:

-Front Panel Window: This window represents the user interface. Controls and indicators are created here. They are the interactive input and output terminals of the VI. Controls can be knobs, push buttons, dials or other input devices. Indicators are graphs, LEDs and other displays.

-Block Diagram Window: After creating the user interface, code must be added here using graphical representations of functions to control the front panel objects which appear as terminals on the block diagram. Here we build the nodes, i.e., objects that have inputs and/or outputs and perform operations when VI ruins. Nodes can be functions, subVIs, or structures. Structures are process control elements, such as Case structures, Event structures, For Loops or While Loops. Functions are the fundamental operating elements of LabVIEW. For example the Add or Subtract functions are function nodes.

The data is transferred among block diagram objects through wires. Each wire has a single data source, but they can be connected to as many nodes as the user wants. Wires have different colors and styles depending on their data types.

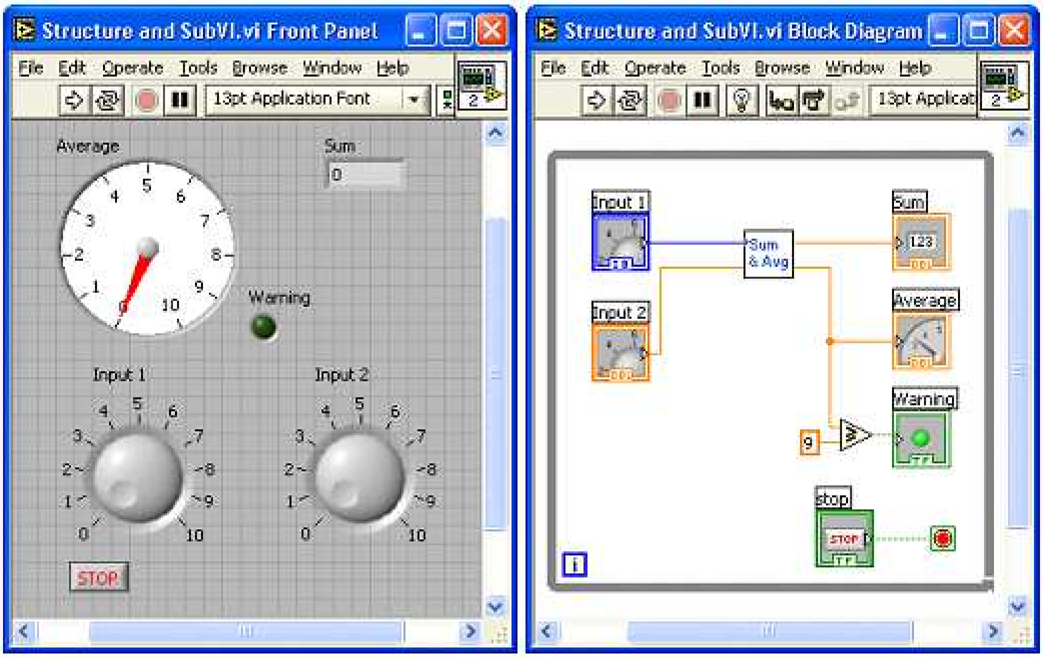

Figure 2.2 – Front Panel and Block Diagram

-Icon and Connector Pane: LabVIEW allows the users to use and view a VI in another VI. A VI that is used in another VI is called a subVI. To use a subVI it must have an icon and a connector plane. The icon is just the graphical representation of a VI, it identifies the subVI on the block diagram of the subVI. The connector pane is a set of terminals on the icon that corresponds to the controls and indicator of that VI.

2.3.2 Data types:

- **Numeric**: Numeric data type represents number of various types. It includes the following subcategories of representation: floating-point numbers, signed and unsigned integers and complex numbers. They are all represented with orange except integers which are represented with the color blue,

- **Boolean**: Boolean data is stored as 8-bit values. If the 8-bit value is zero, the Boolean Value is False, Any nonzero value represents True. Boolean data are represented with color green.

- **String:** A string is a sequence of ASCII characters. They can be used to create text messages, prompt the user with dialog boxes or store numeric data to disk. Text commands can be used to control instruments.

- **Dynamic**: Dynamic data stores the information generated or acquired by an Express VI. DAQ-Assistants are an example of an Express VI, they are used to acquire data for measurements tasks or to generate data for output tasks.

Different data types can be combined using enums.

2.4 Structures

While Loop:

Similar to a Do Loop in text-based programming languages, a While Loop executes a subdiagram until the conditional terminal, an input terminal, receives a specific Boolean value. The While Loop infinitely if the condition never occurs. A While Loops has an iteration terminal that contains the number of completed iterations. The iteration count always starts at zero.

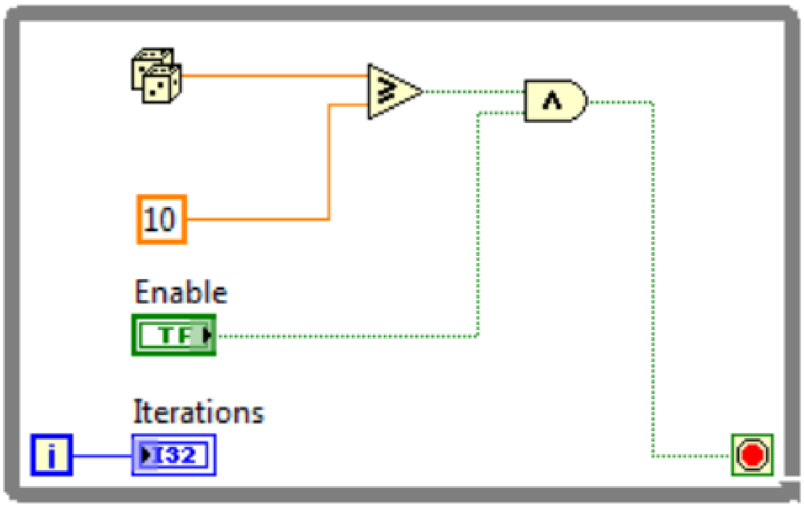

Figure 2.3 – While Loop

If a conditional terminal is "Stop if True", the Boolean control is placed outside the While Loop and the control is FALSE when the loop starts, you cause an infinite loop. Similarly, you also cause an infinite loop if the conditional terminal is "Continue if True" and the control outside is TRUE. The values that are outside the loop are only read once, so changing the value of the control does not stop the infinite loop.

For Loop:

A For Loop executes a subdiagram a number of times. It has a iteration terminal that contains the number of completed iterations. The count terminal is an input terminal whose value indicates how many times to repeat the subdiagram.

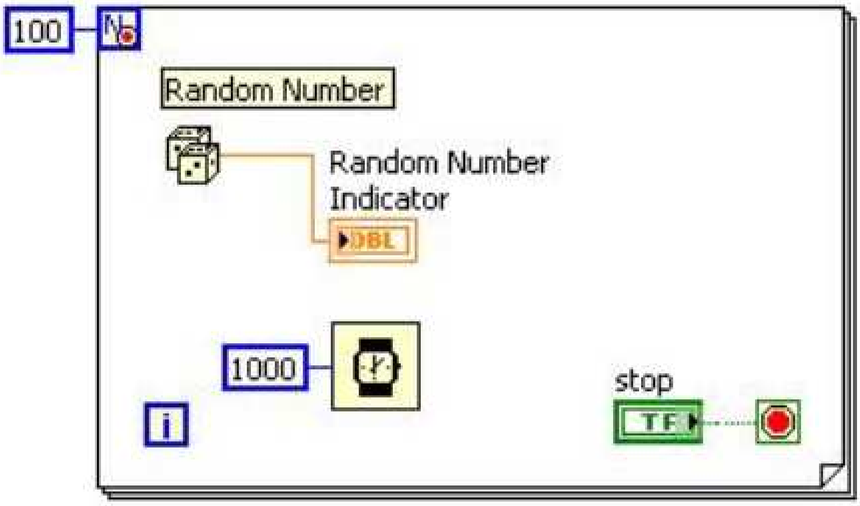

Figure 2.4 – For Loop

The For Loop differs from the While Loop in that the For Loop executes a set number of times. A conditional terminal can be added to the For Loop too. A For Loop with a conditional terminal executes until the condition occurs or until all iterations are complete.

Structure Tunnels:

Tunnels feed data into and out of structures. The loop executes only after arrive data arrive at the tunnel. When the loop starts executing it reads the values of the input tunnels just once. Only after the loop execution ends the data is sent to the output tunnels.

Shift Register:

When we are programming with loops, we usually need access data from previous iterations. Shifts registers are the elements that allow us to access to this information. A shift register passes values from previous iterations through the loop to the next iteration. Shift registers appear as a pair of terminals directly opposite each other on the border of the loop. Shift registers must be initialized with an input value.

Case Structure:

A Case Structure is a structure that has two or more subdiagrams. Only one is visible at a time and only one case can be executed at a time. An input value connected to the case selector determines which subdiagram execute. The user must select one case as the default case to handle out of range values.

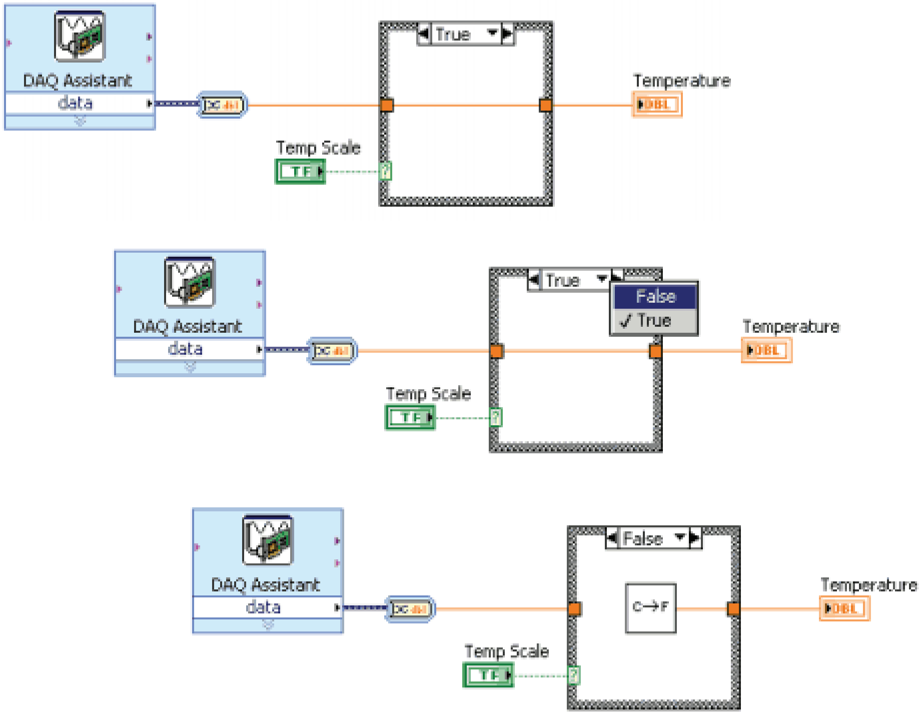

Figure 2.5 – Case Structure

Event Structure:

The Event Structure works like a Case Structure with a built-in Wait on Notification function. Each case handles one or more events. When the Event structure executes, it waits until one of the configured events occur and then executes the corresponding case for that event. It does not implicitly loop to handle multiple events.

State Machine:

A state machine is a design pattern. It consists of a While Loop, a Case structure and a shift register. Each state of the machine is a separate case in the case structure. The case structure is placed inside a While Loop, so the code executes until the condition occurs. The shift register stores the state that should execute upon the next iteration of the loop.

3. TEST RIG

3.1 Introduction and System Description

After all the previous research we could start building the test rig. This third task included the installation of every component of the UAV fuel system and the development of the code to control them. An unmanned air vehicle can be considered as a sub-system of a UAS (Unmanned Aircraft System). UAS usually have the same elements as system based upon manned aircraft; however a UAS is being designed from its conception to be operated without an aircrew aboard. Instead of it, it has a sub-system that controls the aircraft and its habitation with an electronic intelligence and control sub-system. Unlike drones which don't have any intelligence and can only be launched into pre-programmed missions, UAVs have 'automatic intelligence' at some degree and are able to communicate with its controller and to return payload. It will also transmit information as to its condition, covering aspects as the amount of fuel it has or the temperature of the engine.

It a fault occurs in any of the system's components, the UAV may be designed automatically to take corrective action and alert its operator to the event. Decisions can be made on-board using artificial intelligence, thus achieving a greater autonomy. This feature that UAVs possess is what makes them interesting for our purpose. The goal was then to create a model of a UAV fuel system to assess the IVHM technologies discussed before and see how effective these technologies are for detecting and isolating faults in the system.

The real system is shown in figure 3.1 and is composed of the main and sump tanks, the pump, a filter and a nozzle.

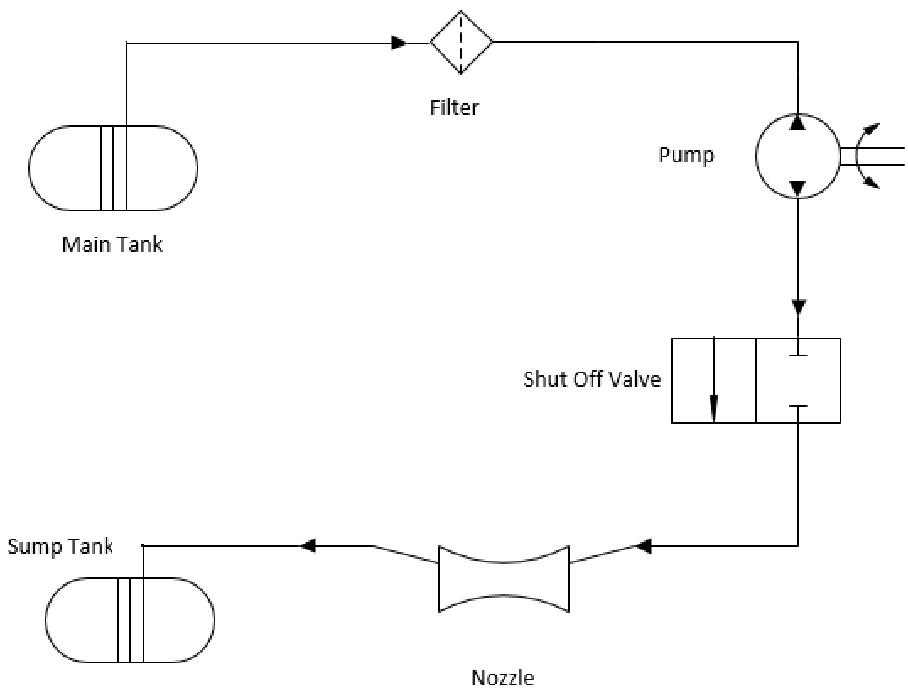

Figure 3.1 – Diagram of the fuel system

Fault Emulation

We have to keep in mind that degradation modes are very difficult to test. It is not only the cost and the time that are required to capture a significant degradation but the reproduction constrains that are involved in the system. One approach is to increase the duty of the components to accelerate their degradation. However, the approach we took was to simulate degradation modes by direct proportional valves (DPV) that we can gradually control.

DPV	***Fault Description***
DPV1	Clogged filter
DPV2	Degradation of the gear pump
DPV3	Shut-off valve stuck mide range
DPV4	Leaking pipe
DPV5	Clogged nozzle

A clugged filter would be emulated by replacing the filter with the DPV1. Flow and pressure reduce through a filter when it is clogged. This process can be emulated by the valve. When the valve is fully opened it is equivalent to a healthy filter. As we gradually close it, it emulates the clogging effect. The severity of the fault can be controlled by varying the valve position.

When a gear pump suffers degradation, it provides a lower flow rate with the same pump speed. This effect can be emulated creating a leak after the pump. The flow of this secondary pipe would be controlled by DPV2.

A malfunction of the shut-off valve can be obtained with DPV3, simulating the position of the stuck valve with the proportional valve.

Installing another secondary pipe, we can simulate a leak in the main pipe. The flow of this new pipe would be controlled by DPV4. When the valve is closed, it simulates a healthy pipe. Opening this valve we can control the severity of the leak.

Likewise, the clogged nozzle situation could be implemented by replacing the nozzle with DPV5.

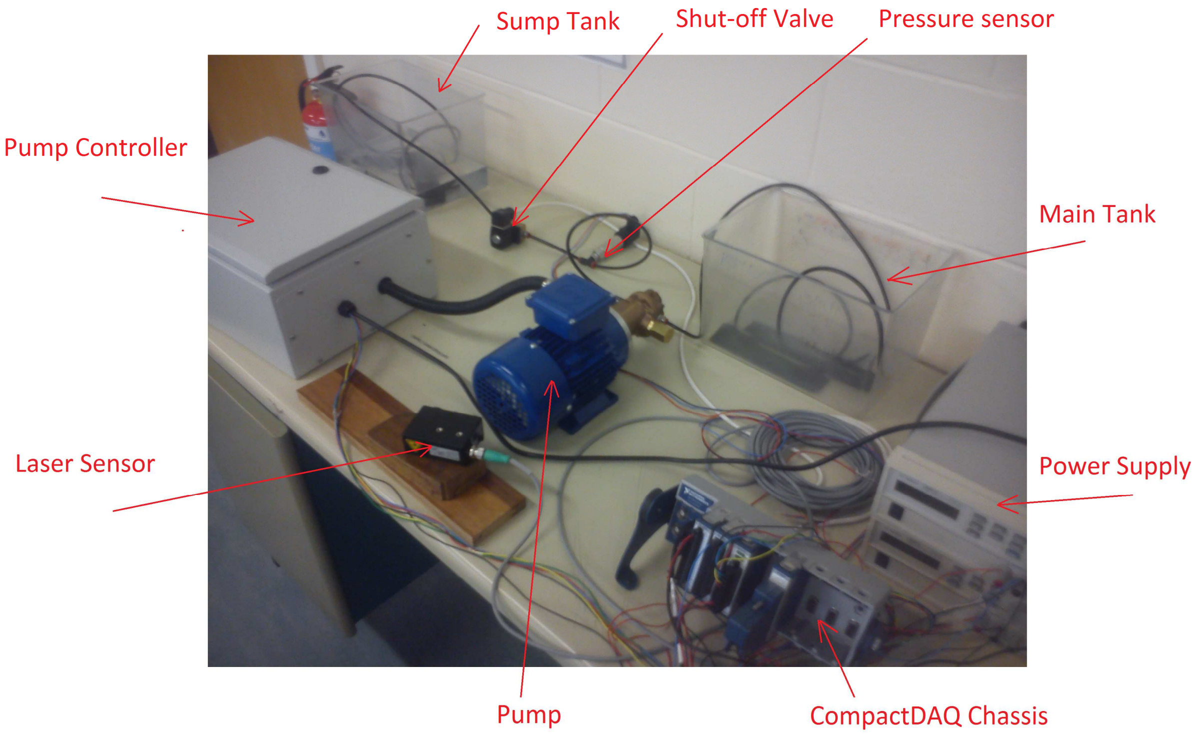

Figure 3.2 – Photograph of the fuel system

The final model we aimed to create is shown in the next diagram.

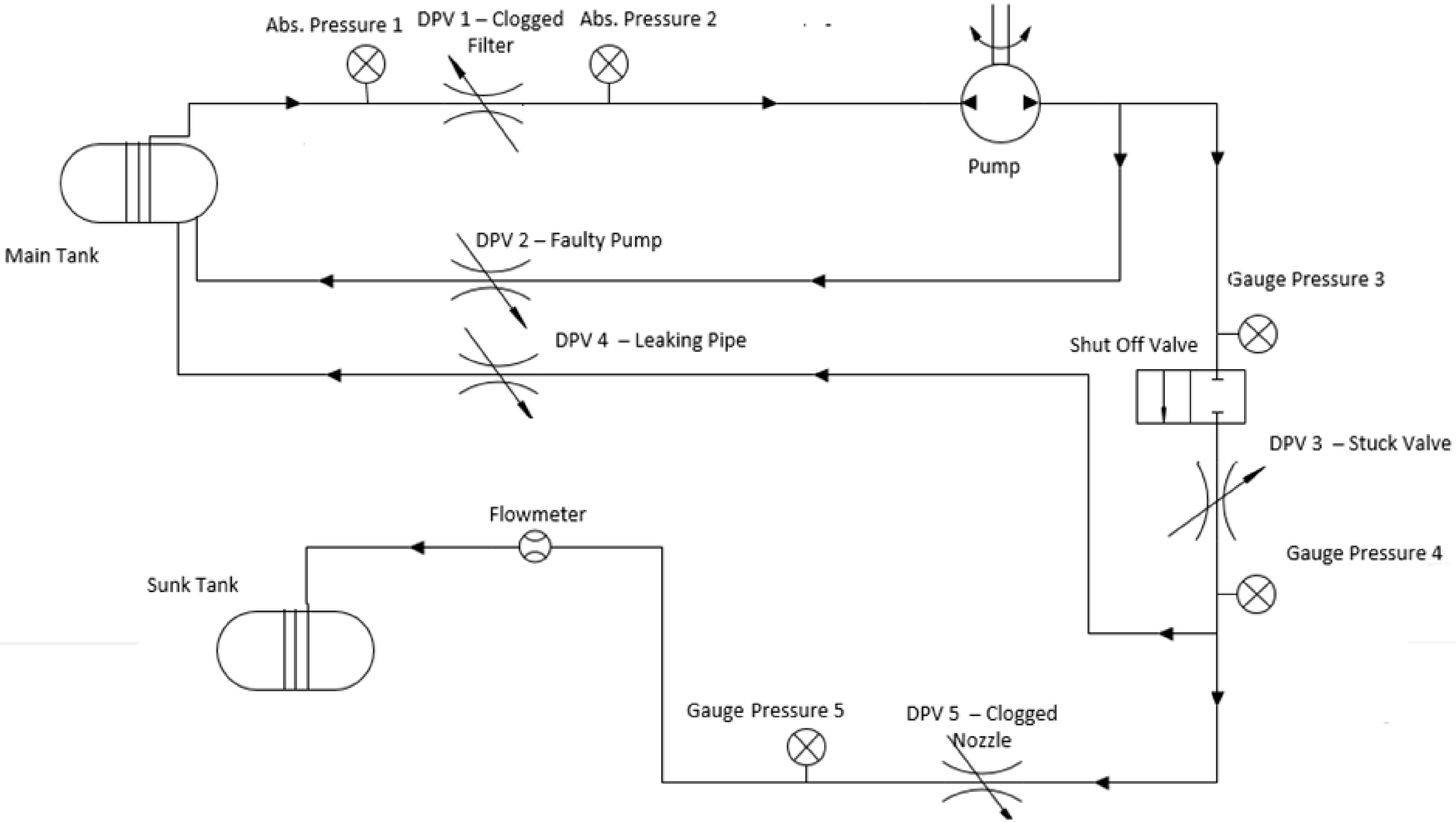

Figure 3.3 – Fuel system schematic

3.2 Commissioning:

3.2.1 Shut-off Valve:

This valve has an electric circuit. When the circuit is closed, the valve is open and the fluid flows. If the circuit is opened, the valve closes and the flow is quickly stopped. Therefore, unlike control valves which have intermediate positions and are used to regulate the pressure or the flow rate, a shutoff valve has only two states: completely open and completely closed.

Shutoff valves are usually fail-safe devices. This means that if any failure is detected, the valve should close and stop the flow in order to prevent any harm in the rest of components of the system.

When a valve suddenly closes and a flow is stopped at the end of a pipe, the fluid transforms its kinetic energy into potential energy. This potential energy provokes a pressure wave that propagates into the pipe. This pressure wave is usually called fluid hammer. This phenomenal provokes noise and vibration but it can also damage the pipe. The main solution to alleviate this problem is to connect a relief valve.

The valve we used for our system is a Bürkert 6013 2/2-way direct acting solenoid valve. The valve is controlled by an electric current through a solenoid. When the solenoid is activated, its armature is withdrawn by the magnetic force and the water can then flow.

Figure 3.4 – Bürkert 6013 2/2-way direct

The valve is controlled by the NI 9485 module. It has 16 terminals that provide connection for 8 channel solid-state-rely sourcing or sinking digital output module. The DAQ Assitant was configured to Digital Line Output. The generation mode is one sample on demand. Below, the wiring diagram of the shutoff valve is shown.

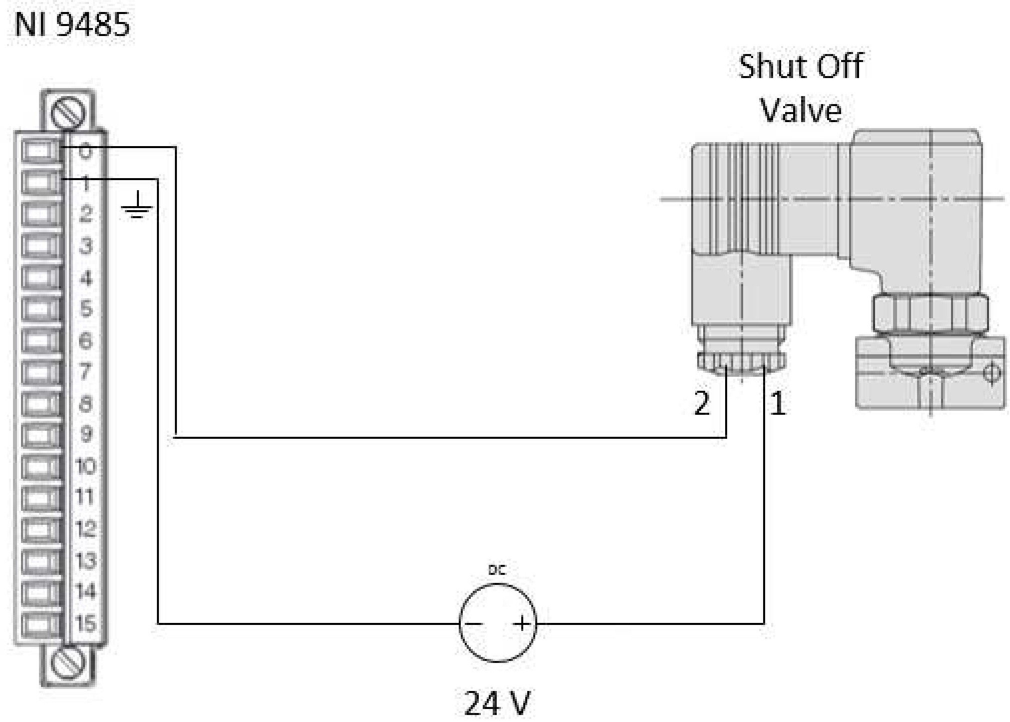

Figure 3.5 – Shut-off Valve Wiring Diagram

3.2.2 Pump Controller

A pump is a device that moves a fluid by mechanical action. There are many different types of pumps but all of them consume energy to perform mechanical work by moving the fluid. In our system, the energy source is an induction motor controlled by the ACS150 driver. The pump controller can be set in manual or remote control. For our purpose, we set it into remote control using the NI 9472 module. This module provides connection for 8 digital output channels. The pump controller requires 5 channels that transmit the data for the following actions:

-Stop / Start.

-Forward / Reverse: Changes the direction the pump spins.

-Frequency reference up.

-Frequency reference down.

-Constant Speed: Changes the speed of the pump to a predetermined value.

We used the DAQ Assistant to configure a digital line output for five channels. The generation mode was 1 sample on demand.

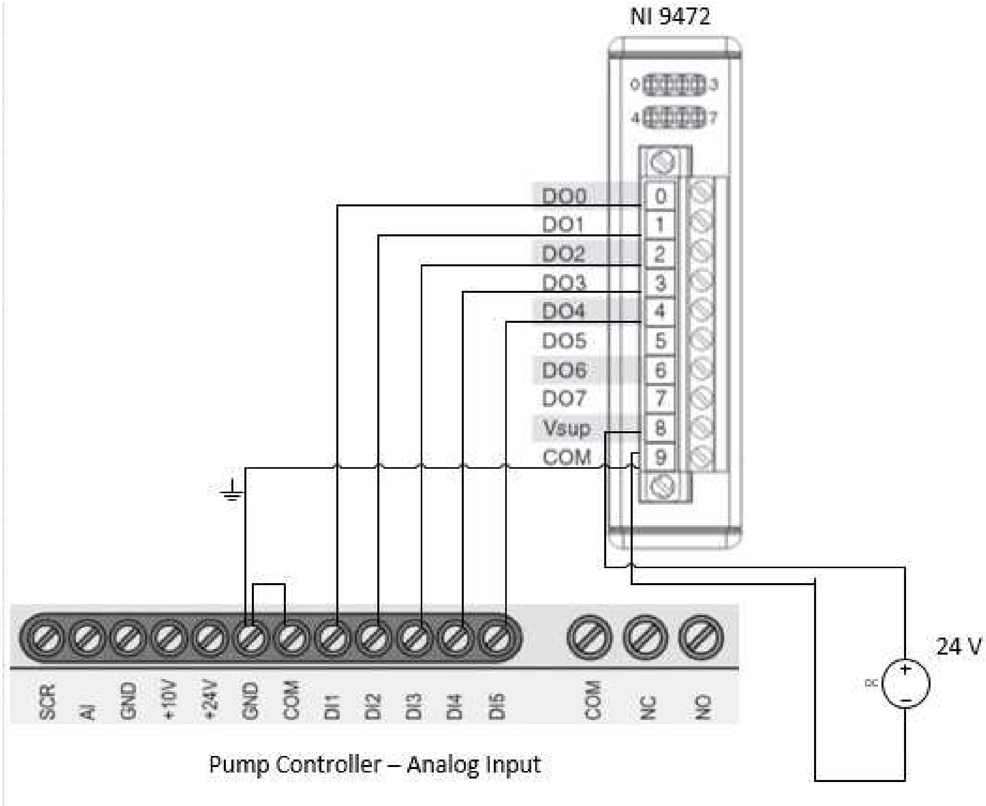

Figure 3.6 – Pump Controller Wiring Diagram

3.2.3 Laser Sensor:

It was necessary for us to know the real speed of the pump so as to have a better control of the system. We concretely wanted to know the frequency of the pump. Frequency is the rate of recurrence of a cyclic or periodic event.

We used a contrast laser sensor that emits a beam that's reflected on a surface and sent back to the sensor. The sensor is capable to recognize if the surface absorbs the light (dark surface) or reflects it (white surface).

Our initial idea was to stick a reflecting sticker on the fan of the pump motor. This solution didn't work because the sensor was not able to difference between the reflective sticker and the white fan. However we managed to make it work the other way around, instead of using a reflective sticker we used a black one. This worked because the sensor can be set to detect either black or white. What the sensor does it's to send a pulse every time it detects the black sticker, that's one pulse per lap. For an analog or digital waveform, you can invert the signal period to obtain the frequency.

The laser sensor we used was a Print mark contrast sensor DK10-LAS-54/76/110/124.

Figure 3.6 – DK10-LAS-54/76/110/124

This signal was received by the NI 9401 module, a 25-dsub connector that provides connections or eight digital input/output channels. This module has to be used together with the NI 9924 Terminal Block that contains the screw terminals to connect the laser sensor. The block has two thumbscrews for secure connection to the module. The DAQ Assistant was configured to do frequency measurements. The signal input range is 10m-100Hz. The Starting edge is Falling, the measurement method is one counter (Low frequency) and the acquisition mode is one sample on demand.

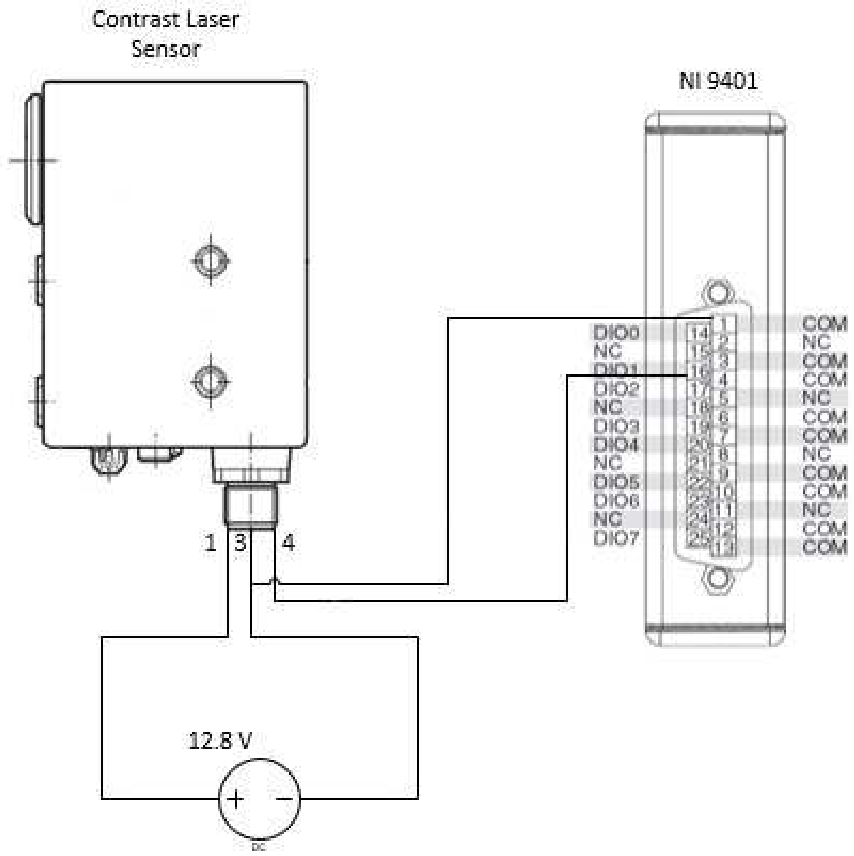

Figure 3.7 – Laser Sensor Wiring Diagram

3.2.4 Pressure Sensors:

All the faults that we have been studying and have been included in this project lead in first term to a decrease of the flow. The main consequence is therefore that the sump tank receives an insufficient flow of fuel or at least, the flow rate is lower than the one we could expect under normal consequences. Either way, our system is not being efficient in its main purpose.

However, the decrease of the flow rate is not the only symptom of a faulty system. In our system, it is also accompanied by a change of the pressure in the tubing. As it was said at the abstract, the scope of this project is to detect and isolate faults. Hence, it is not important for us to know how severe the fault is but to detect it. This means that we didn't pay attention to the specific value of the decrease of the flow for every component. Because of this, instead of using flowmeters between the components, we used pressure sensors. The reason for this decision is that it's been proved that pressure sensors can detect small changes better than flowmeters do.

When the pump starts running, it provokes a decrease of the pressure in the inlet. This effect is what makes the fluid flow from the tank to the pump. It's been proved in previous experiments that the pressure before the gear pump is below atmospheric, so the need for absolute pressure sensors was mandatory. The pressure after the pump is above atmospheric on the other hand, so we could use gauge sensors that measure relative pressure.

Sadly, neither the flowmeter nor the absolute pressure sensors arrived in time when we were building the test rig, so we could only use the gauge pressure. That's the reason why the wiring diagram only shows the relative pressure transducers. The pressure sensors we used were UNIK 5000 PMP 5074-TB-A1-CA-H1-PA.

In order to acquire data from the different sensors, we used the NI 9205 module. This module receives the analogue voltage output from the pressure transducers and the flowmeter. Using the pre-defined calibration curves into digitized information it converts the input data into digitized information readable on our VI. The range input is 0-5 bars. The acquisition mode is Continuous Samples, the samples to read are 500 and the rate is 1 kHz.

The pressure transducers actually measure a voltage and only after applying the predefined calibration curves in the DAQ Assistant Setup, we can get the pressure measurement. To understand how to measure voltages, it is essential to understand that the voltage is the electrical potential difference between two points in an electrical circuit. A common point of confusion is how the measurement reference point is determined. There are essentially two methods to measure voltages: ground reference and differential.

Ground Reference:

This method consists on measuring voltage with respect to a common or "ground" point. These points are stable and most commonly around 0 V. The ground reference is provided by either the device taking the measurement or by the external signal being measured. When the ground is provided by the device, this setup is called ground referenced single-ended mode (RSE), and when the ground is provided by the signal, the setup is called non-referenced single-ended mode (NRSE).

The following images how to do these two types of measurements using a CompactDAQ Chassis and a NI 9205 analog input module.

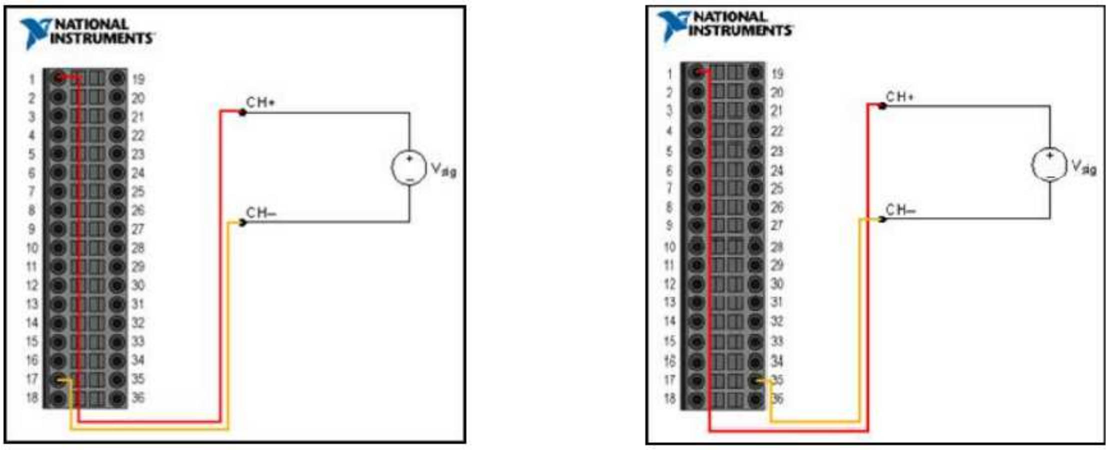

Figure 3.8 – Ground reference: RSE (left) and NRSE (right)

Differential Reference:

The other way to measure a voltage is to determine the differential voltage between two points of the circuit. Usually, differential voltage measurements are useful in determining the voltage that exists across individual elements of a circuit or it the signal source is noisy. In differential mode, the negative signal is wired to the analog pin directly facing the analog channel that is connected to the positive signal as the following image shows:

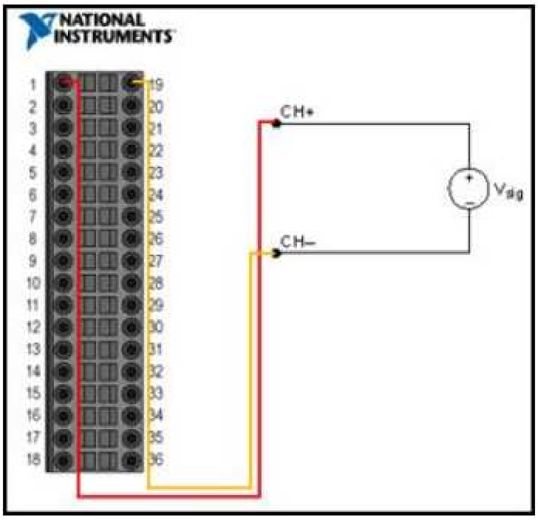

Figure 3.9 – Differential Reference

The disadvantage of differential mode is that it effectively reduces the number of analog input measurement channels by half.

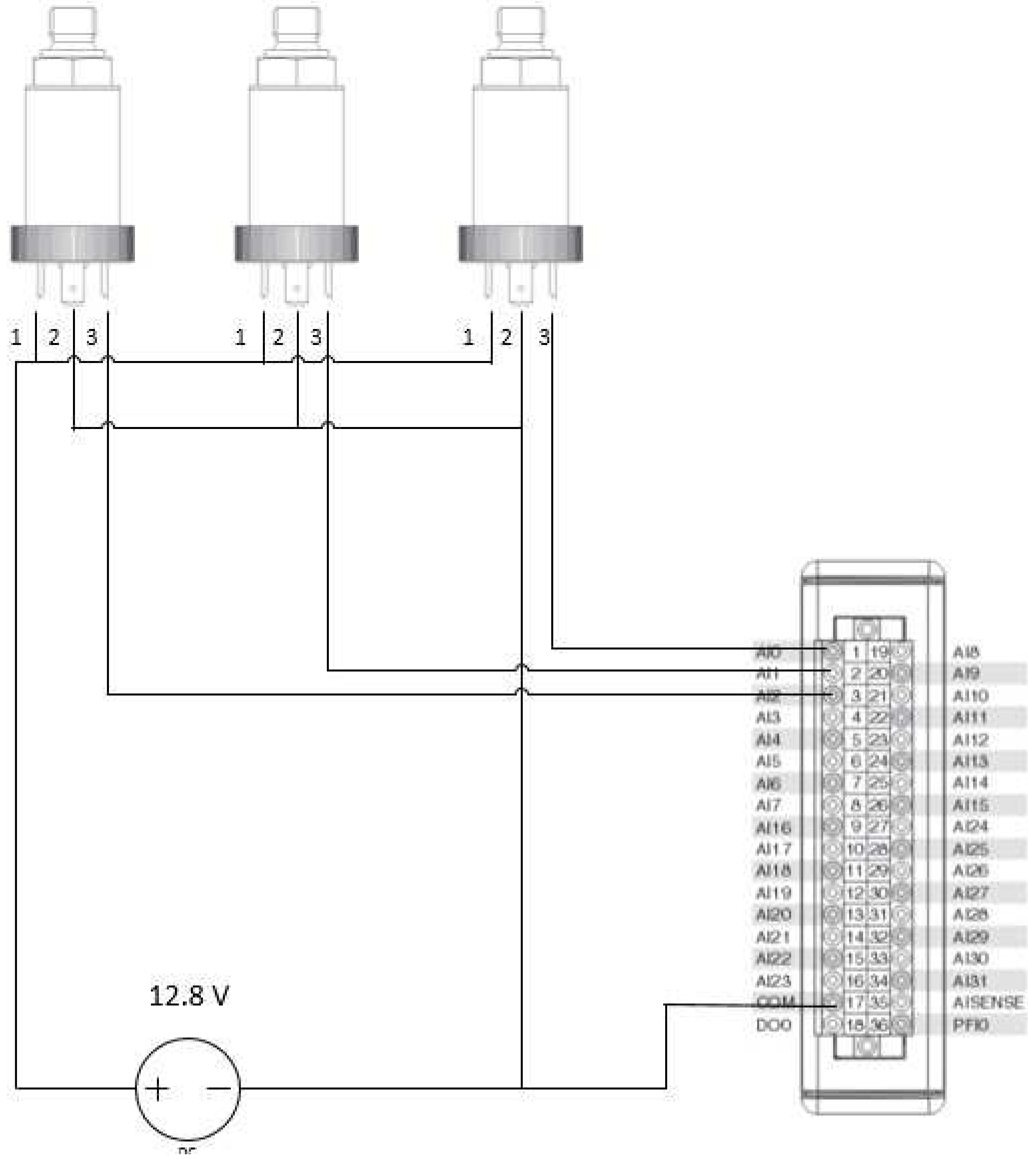

Figure 3.10 – Pressure Sensors Wiring Diagram

3.2.5 Direct Proportional Valves:

The description of these components will be very brief and will only focus on their main mission as we didn't receive them by the time this report was done.

As it was explained in the introduction of this chapter, in order to simulate component degradation, some of the elements of the system had to be replaced by direct proportional valves that have opening positions between 0-100% that represent how severe the fault is. These valves can be used as flow control valves and are characterized by low loss, low hysteresis, high repeatability and high sensitivity.

We wanted to simulate five different faults, each one correspond to one of the direct proportional valves:

-Clogged filter: DPV1

-Malfunction of the gear pump: DPV2

-Shut-off valve stuck in an interim position: DPV3

-Leaking Pipe: DPV4

-Clogged Nozzle: DPV5

You can see where every DPV should be placed in the system looking at the system scheme on the page 21.

3.3 LabVIEW Code:

In this last part it will be shown and explained in detail all the subdiagrams that we created to control the components.

3.3.1 Shut-off Valve

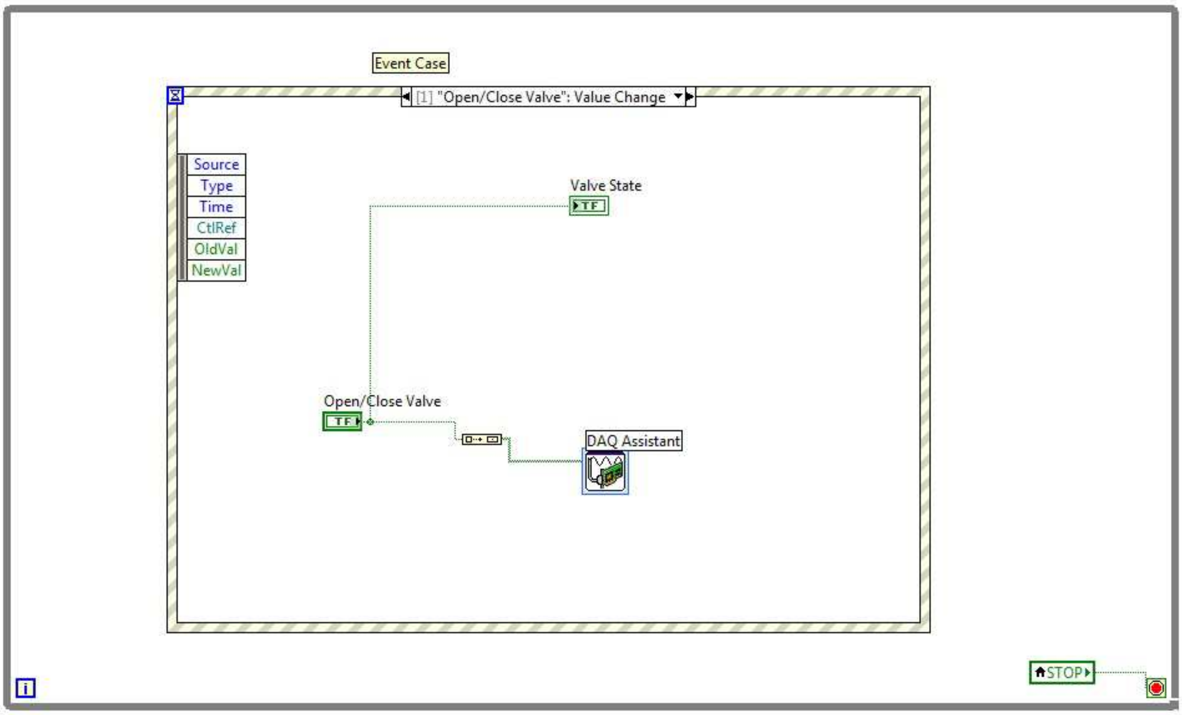

Figure 3.11 – Shut-off Valve Code

The code is all included in a while loop structure. This structure executes the code that is inside the loop until the conditional terminal receives a TRUE value from the STOP control.

Inside the While Loop, there is an event structure. When the Event Structure executes, It waits until one of the configured events occur, then executes the corresponding case for that event. The control button has two states: true and false. When the control sends the False value, the valve stays closed. When we press the button, the control sends a True Value instead to the DAQ Assistant, which sends the signal to the module that opens the valve. We also included an indicator that informs the user whether the valve is open or closed at that moment.

Figure 3.12 – Shut-off Valve Front Panel

3.3.2 Gear Pump Controls - Initial Version

This was the initial code we created to control the pump:

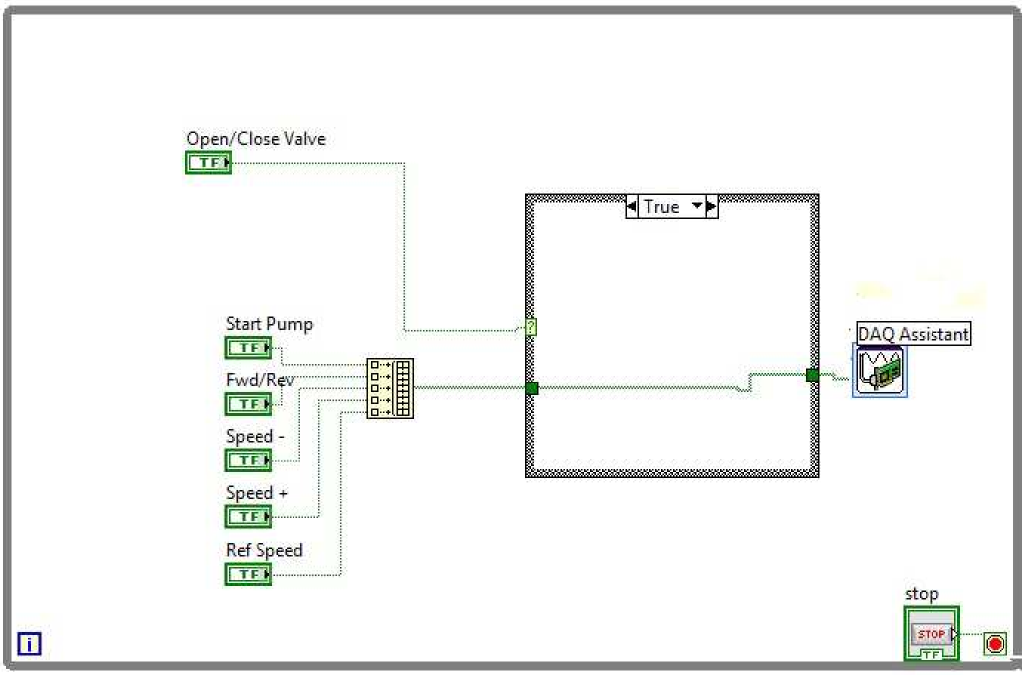

Figure 3.13 – Gear Pump Control: True Case

There is a Case Structure. It has two values depending on whether the valve is open or close. When it's open (TRUE case) the DAQ Assistant receives the data the user send through the controls. When the valve is closed (FALSE case), all the values that are sent to the DAQ Assistant are changed to zero. The aim of this case is to avoid the situation where the fluid is pumped against a closed valve.

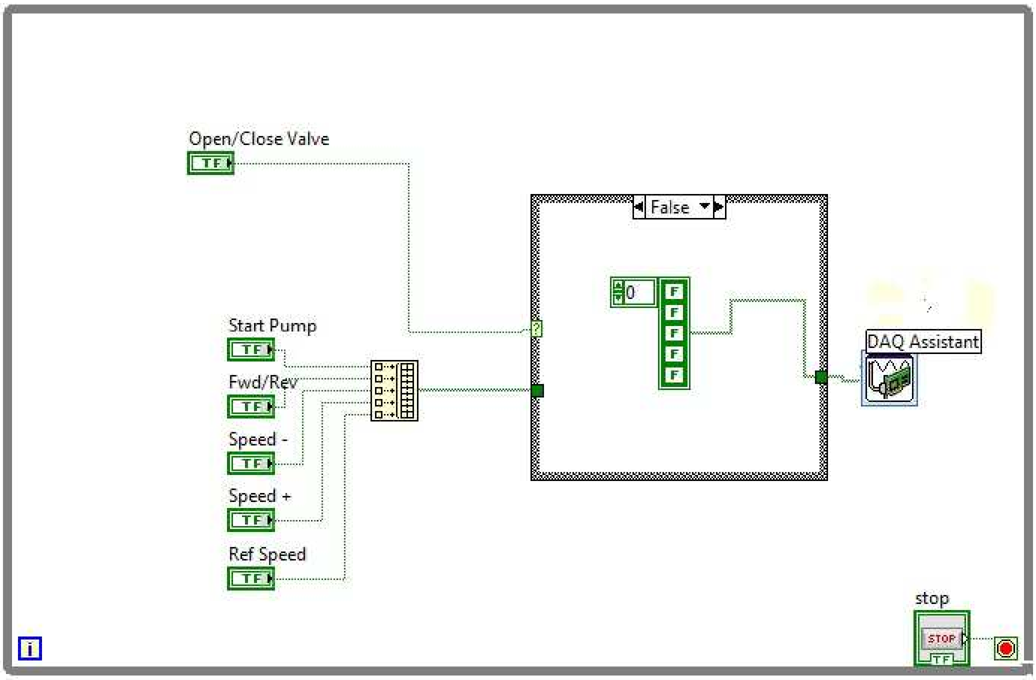

Figure 3.14 – Gear Pump Control: False Case

After installing the laser sensor, we were able to measure the speed of the pump, so we introduced many changes to this code that will be explained in the next section.

3.3.3 Laser Sensor

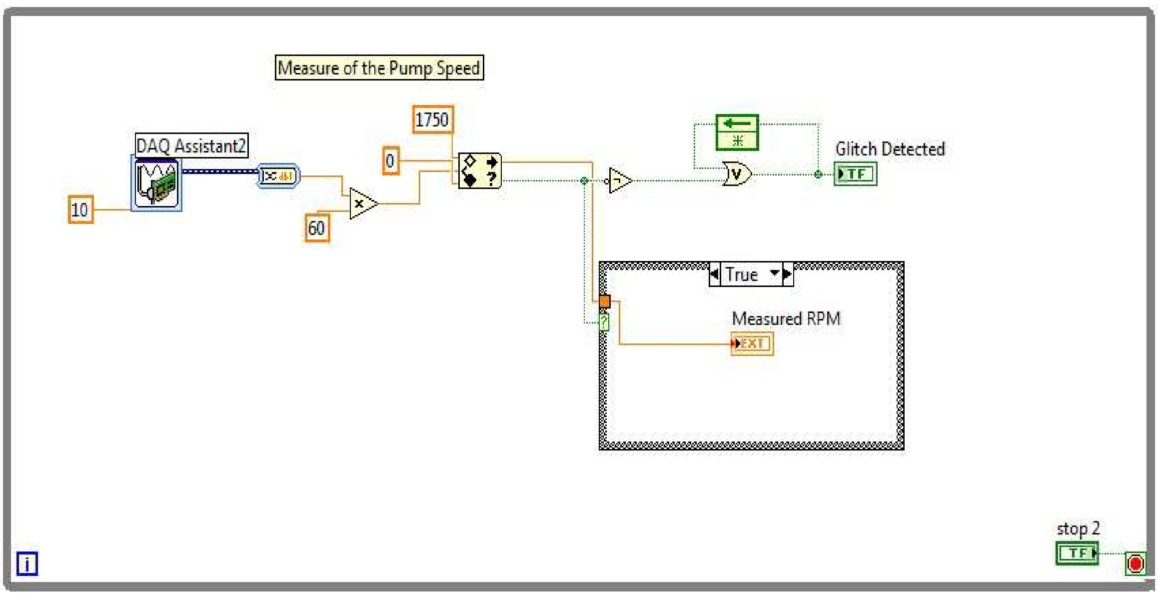

Figure 3.15 – Laser Sensor Code

The DAQ Assistant data receives the data and after converting it into Numeric Data is displayed in the "Measured RPM" Indicator. The original measurement units are Hz. To transform into Revolution Per Minute (RPM) we have to multiply the original value by 60. The code also includes the "In Range and Coerce Function". It determines whether the input value falls within a range specified by the upper and lower limits (0 and 1750) and coerces the value to fall within the range in case it didn't before. If the measured value is no between the upper and lower limits, the Boolean output value is FALSE and after the "Not" function, it activates the "Glitch Detected" Indicator. The "Measured RPM" indicator stops displaying the value as the false case is executed in the case structure.

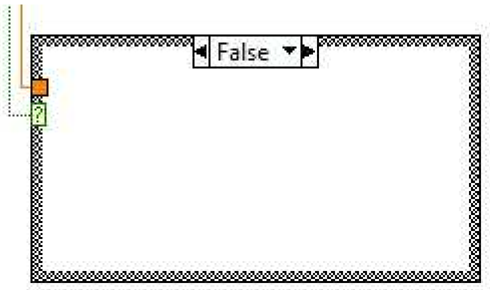

Figure 3.16 – Laser Sensor Code: False Case

3.3.4 Gear Pump Controls – Final Version

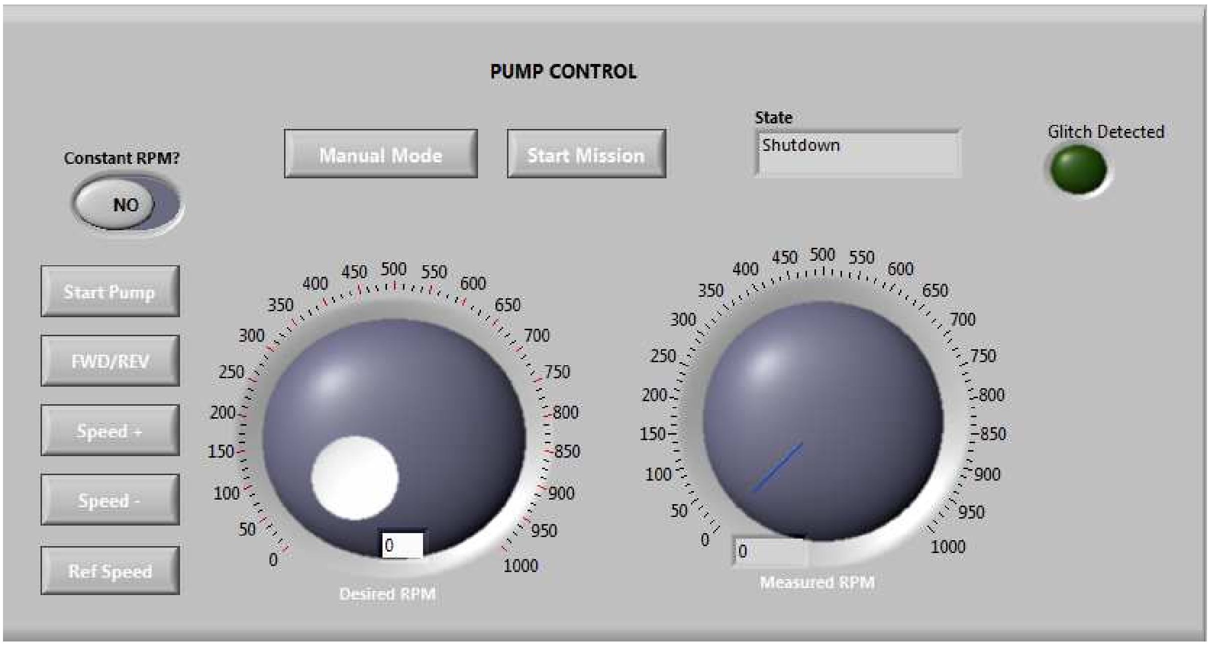

Figure 3.17 – Pump Controls Front Panel

Now that we know the speed of the pump, we can use this information to have a better control of the pump. To simplify the code, a SubVI named "Motor Control" was created to send the data to the pump controller.

Motor Control SubVI:

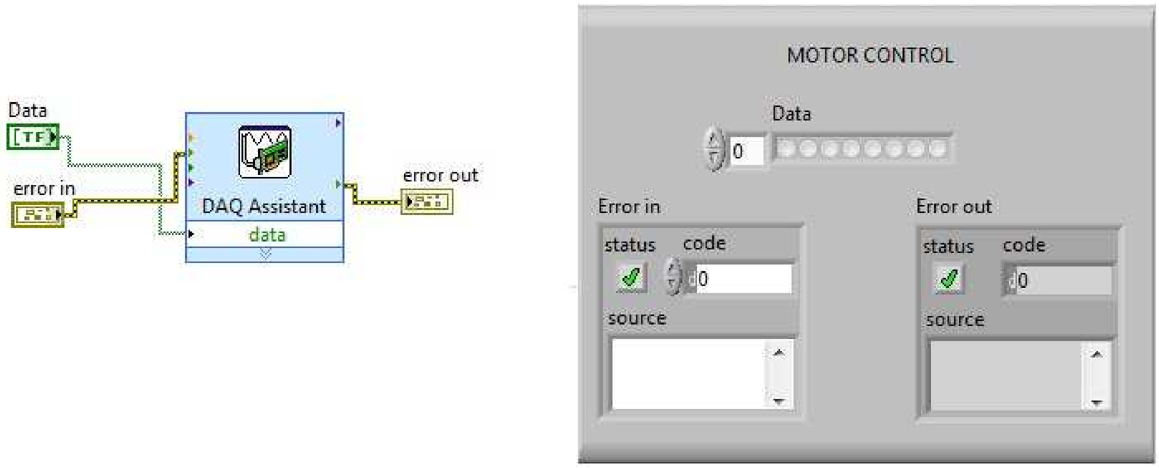

Figure 3.18 – Motor Control: Block Diagram and Front Panel

This SubVI simply sends the Boolean data to the Pump Controller for its five possible actions:

-Start / Shutdown Pump

-Forward / Reverse: Changes the direction the pump spins.

-Frequency reference up.

-Frequency reference down.

-Constant Speed: Changes the speed of the pump to a predetermined value.

We decided to implement two different pump control modes. The user can run the pump manually adjusting the pump speed or set some parameters in order to run the pump through a mission profile. This profile consists of UAV flight sectos. To change from one state to another we use an Enum that contains the following states:

- Shut-down
- Manual Control
- Mission Profile: Accelerate To Taxi 1, Taxi 1, Take-off, Cruise, Landing, Taxi 2, and Decelerate to Shut-down.

There is an Enum Indicator after the Case Structure that displays the name of the state that is being executed at that moment.

-SHUTDOWN:

This is the default state. It’s executed in first place when we run the VI.

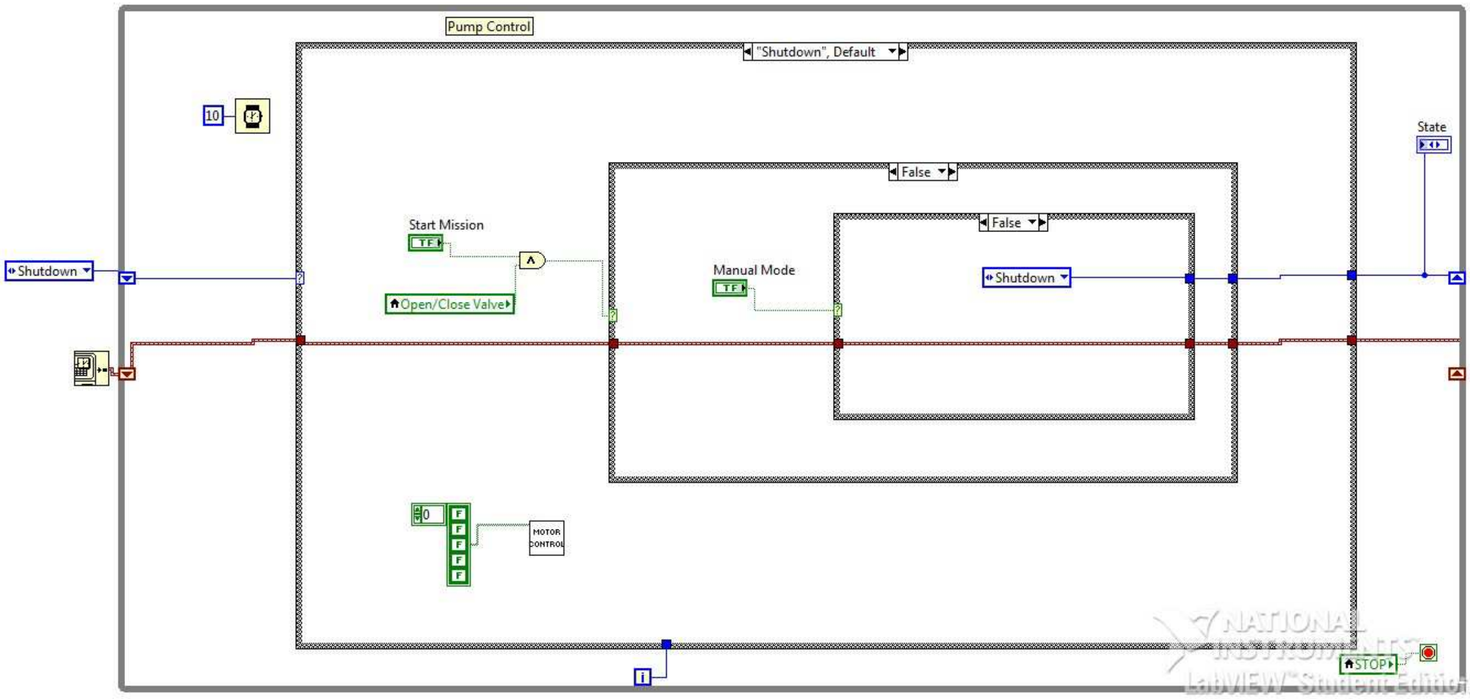

Figure 3.19 – Shut-down Case

The main function of this case is to stop the pump. It sends an array of five false Boolean values to the Motor Control that stop the pump.

Then, we have two Case Structures that lead to three scenarios:

- **Start Mission or Open/Close Valve = False and Manual Mode = False**:

  This is the case illustrated in the image above. The manual mode is not activated and either the valve is closed or the Start Mission button has not been pressed. This is the case that is executed when we run the VI for the first time. The program continues executing this state until one of the controls is activated.

- **Start Mission or Open/Close Valve = False and Manual Mode = True:**

  If we activate the Manual Mode, this code sends the order to move to that case through the shift register.

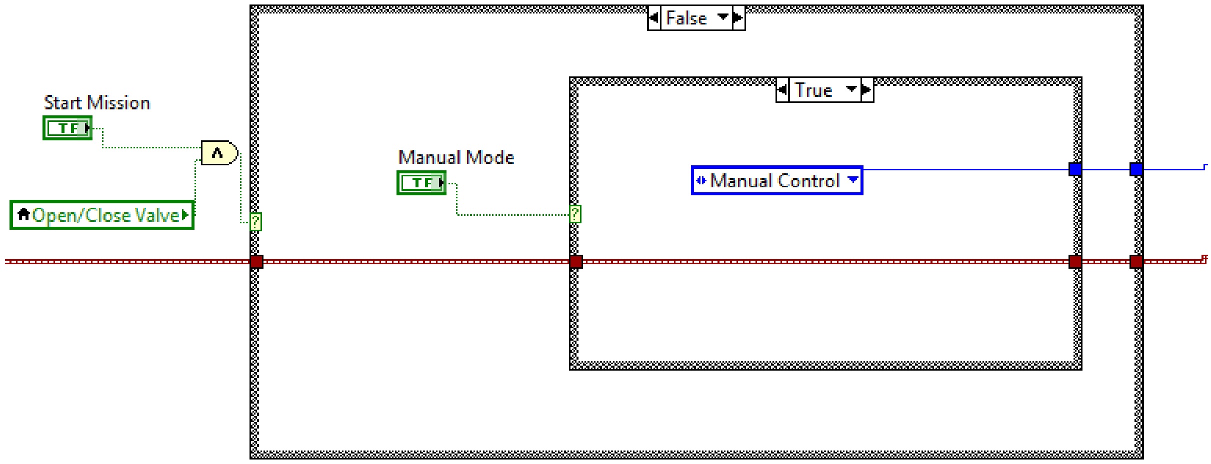

Figure 3-20 – Shut-down Case: Second Scenario

- **Start Mission AND Open/Close Valve = True**

When we pressed the “Start Mission” button and the valve is open, the Automatic Mode starts. Notice that if both the Manual and Start Mission Modes are activated, the code will only execute the Start Mission Mode. The first state of the mission is “Acc To Taxi”. The “Get Data/Time in Seconds” returns the current time. This data will be required later.

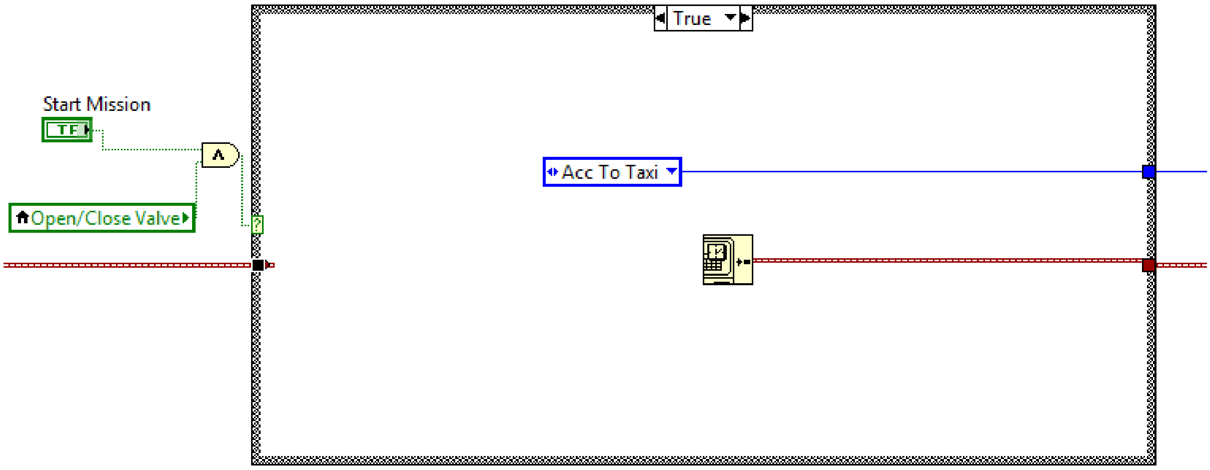

Figure 3-21 – Shut-down Case: Third Scenario

-MANUAL CONTROL:

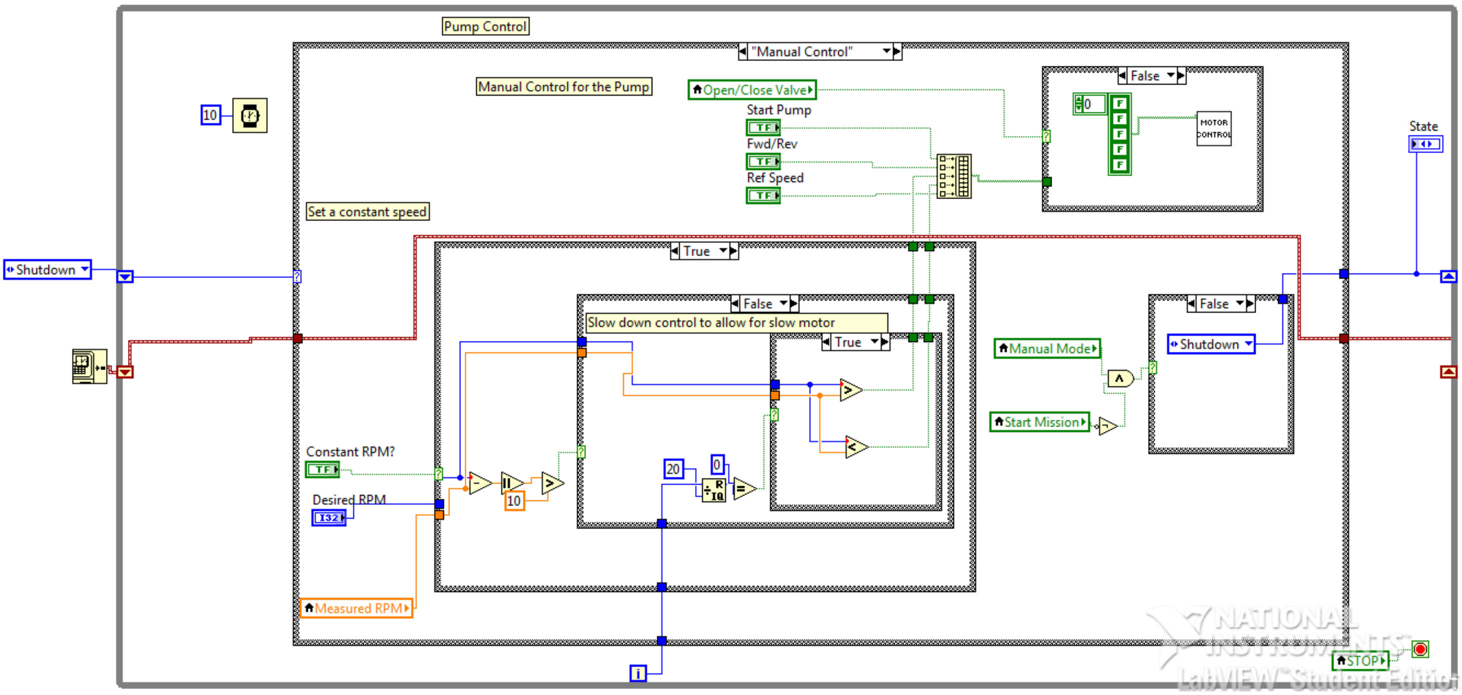

Figure 3-22 – Manual Control

This subroutine has three cases structures with different sub-diagrams:

- The one in the right down corner controls the state that has to be executed in the next iteration.

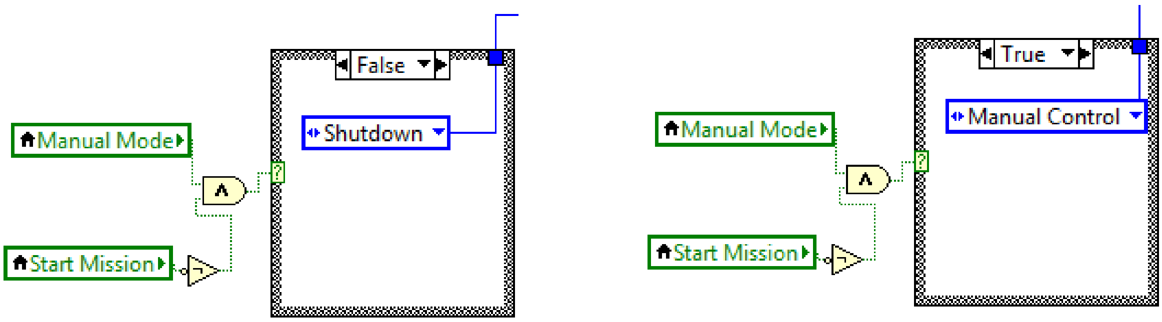

Figure 3-23 – Manual Control Subdiagram 1

If the Manual Mode is still activated and the Start Mission is not, the program will stay in the Manual Mode. In any other case, it will go back to Shut-down.

- The case structure in the left down corner controls the Speed Up and Slow Down controls of the pump. It has two other case structures inside with four different situations:

  - Constant RPM? = FALSE. We use the Constant RPM option when we want to set the speed of the pump to a determined value. In this scenario the pump will speed up or down when we press the corresponding controllers.

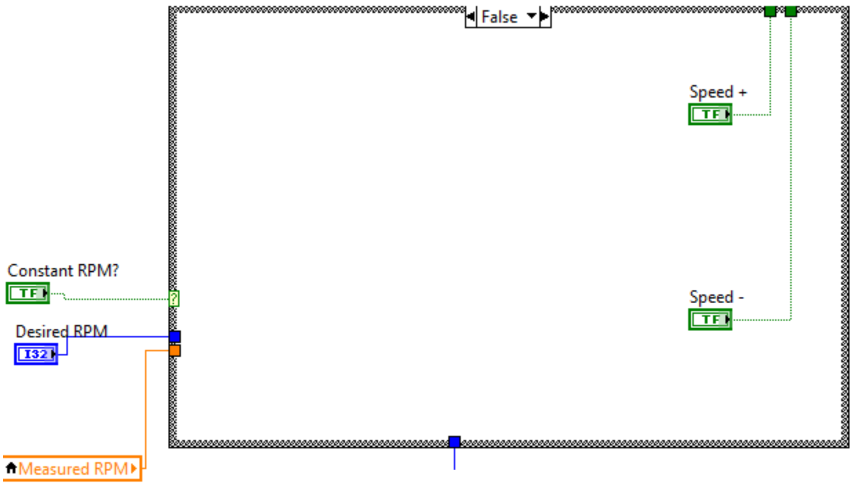

Figure 3-24 – Manual Control Subdiagram 2

  -Constant RPM? = TRUE and the difference between the measured and the desired RPM is higher than ten:

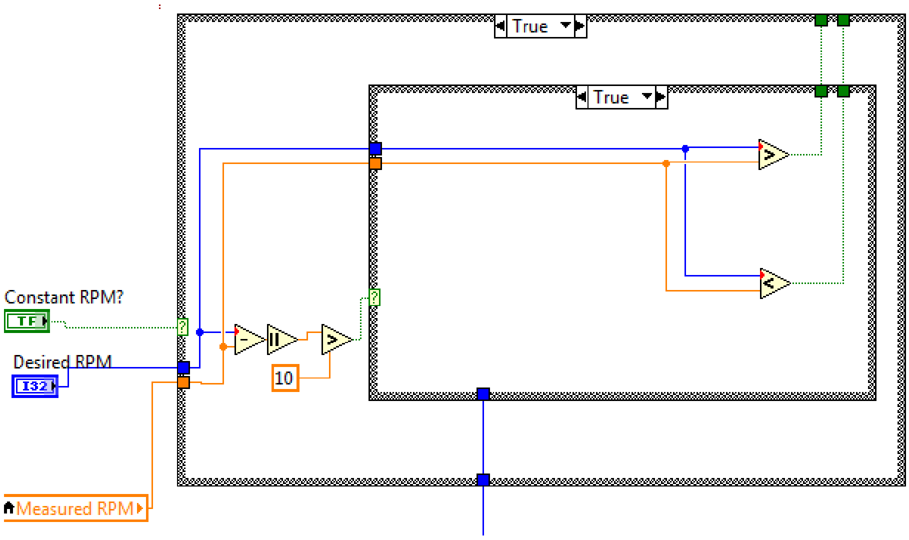

Figure 3-25 Manual Control Subdiagram 3

If we want to set the pump to a determined value we have to press the Constant RPM? Option and then set the value we want in the Desired RPM control. The program will compare the measured and the desired speeds. If the desired RPM is higher than the measured RPM, the controller will speed up the pump. If it's the other way around, the pump will be slowed down.

-Constant RPM? = TRUE and the difference between the measured and the desired RPM is lower than ten:

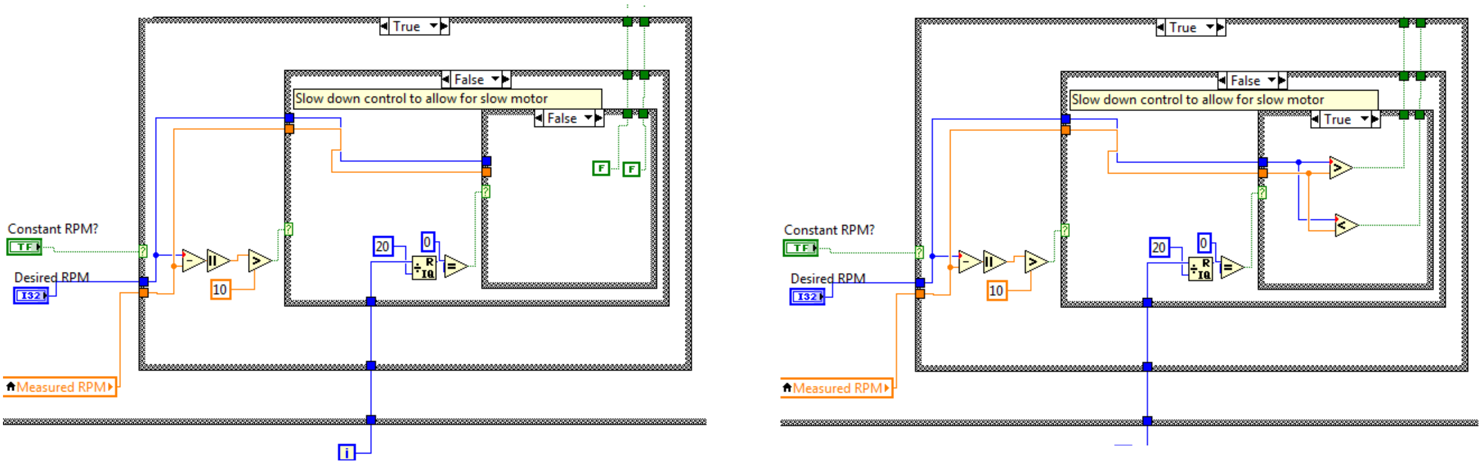

Figure 3-25 Manual Control Subdiagram 4

This scenario is very similar to the previous one but it has an important variation. When the measured and the desired speed are similar (the difference is lower than 10), it's a good idea to slow down the control to allow the motor for a smoother response. To achieve this, the total number of iterations is divided by twenty. If the remainder is different from zero, the pump neither speeds up or down. When the remainder is zero, it compares both measure and desired speeds and return the proper action (speed up or down) just as it did in the previous situation. The conclusion is that only once every twenty iterations, the motor will receive an order and thus it will have a slower response.

- The third and last structure, in the top right corner, sends the data to the Motor Control SubVI. It receives the "Speed Up" and "Slow Down" data from the previous structure. The rest of the data is sent by the other three controls.However, if the valve is closed, all the values are set to FALSE and the pump stops.

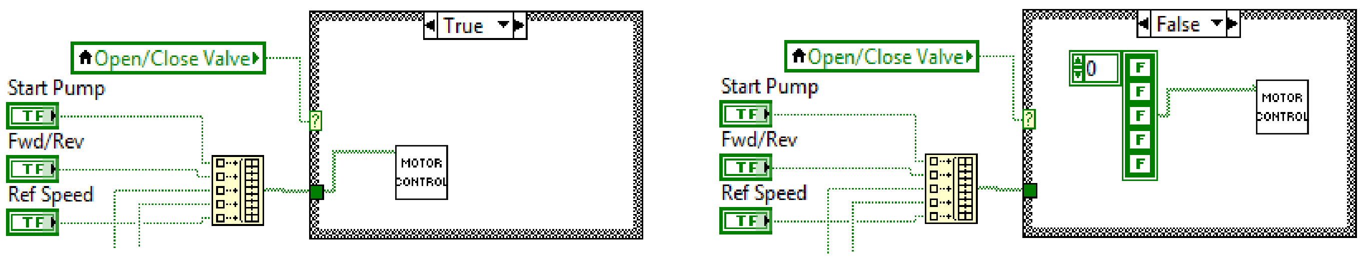

Figure 3-25 Manual Control Subdiagram 5

-MISSION CONTROL:

Whenever the user presses the Start Mission button, the pump will follow a profile that we can previously define. The profile has three stages: Taxi, Cruise and Taxi 2. Each one has an RPM value and a duration that the user determines in the second page of the Tab Control.

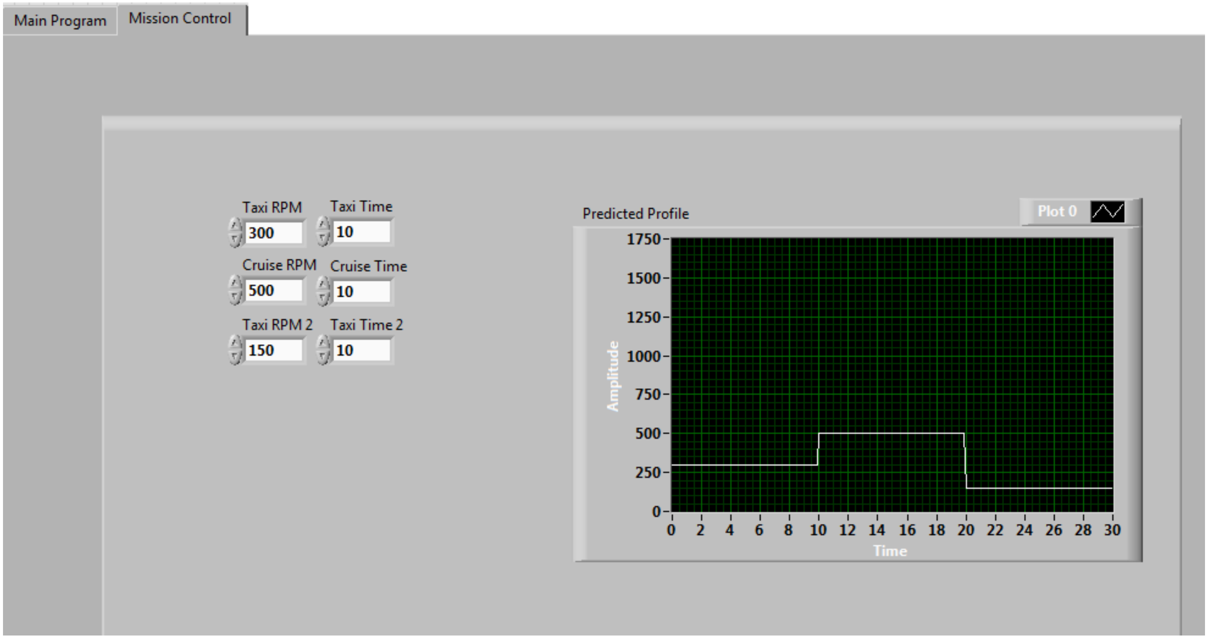

Figure 3-26 Mission Control: Front Panel

The predicted profile is generated by this piece of code:

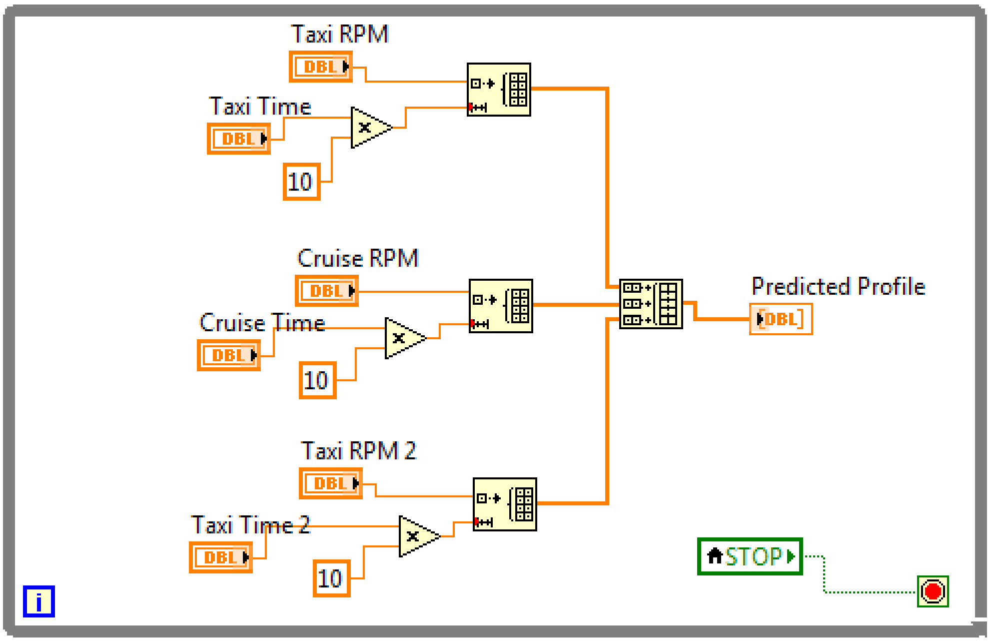

Figure 3-27 Predicted Profile: Block Diagram

The time that it takes to the motor to reach the predetermined values is not included in the predicted profile so there might be important differences from the actual profile.

Those transient states are:

-Acc To Taxi: Until the pump reaches the Taxi RPM value.

-Takeoff: Between Taxi and Cruise states.

-Landing: Between Cruise and Taxi 2.

-Deacc To Shutdown: After Taxi 2, the pump progressively slows down until it stops.

When we press the Start Mission program, LabVIEW will execute these states following the profile what we created. In order to simplify the code, we included a SubVI called “Ramp Motor” that sends the order that the motor has to follow to reach the desired speed in every state. It works exactly the same way as the second structure that we saw in the Manual Mode.

Ramp Motor SubVI:

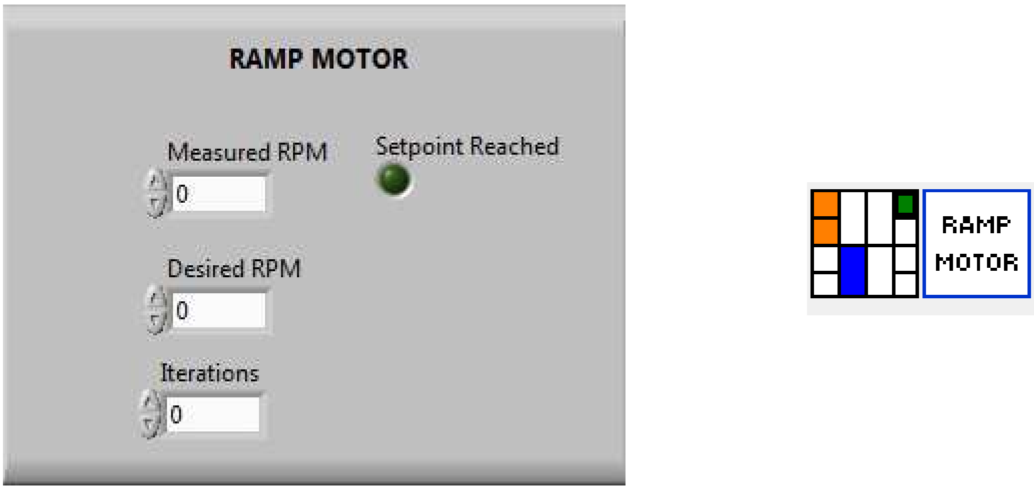

Figure 3-28 Ramp Motor: Front Panel and Connector Pane

This SubVI has three inputs: Measured RPM, Desired RPM and number of Iterations. It has one output: Setpoint Reached. The structure on the left determines if the motor has to speed up or down. The structure on right sends the data to the Motor Control SubVI.

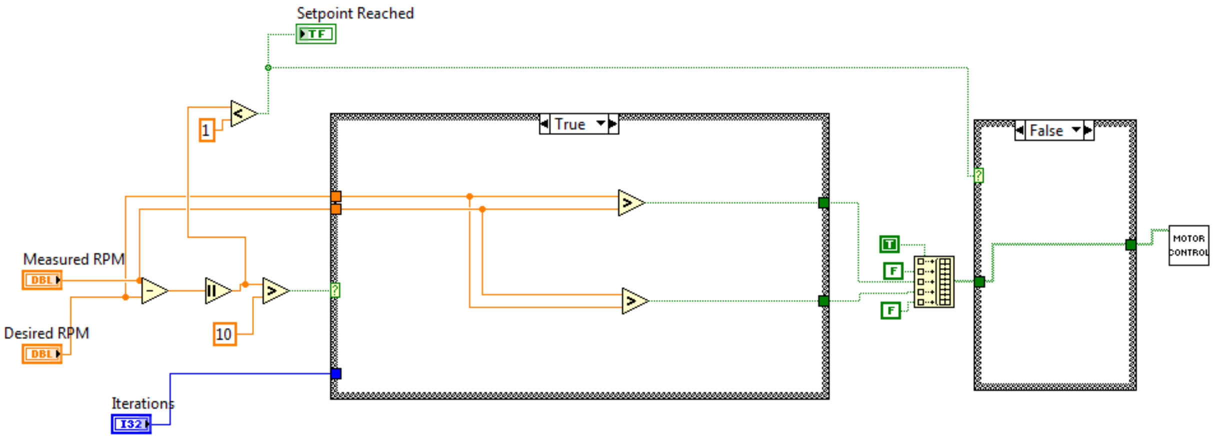

Figure 3-29 Ramp Motor: Block Diagram

When the difference between the Measured RPM and the Desired RPM is lower than one, the “Less?” function returns TRUE. Otherwise, it returns FALSE. This Boolean data is also connected to the case selector of the structure on the right. While the setpoint hasn’t been reached, this structure simply connects the data from the other structure with the Motor Control SubVI. Once the setpoint is reached, the speed up and down controls are set to FALSE.

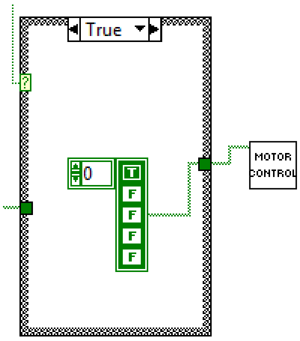

Figure 3-30 Ramp Motor: Block Diagram – Setpoint reached

The other structure performs the same actions as the one that was explained for the Manual Mode case. (Page 38). It compares the Measured and Desired speeds and sends the data to the pump control in order to execute the corrective action.

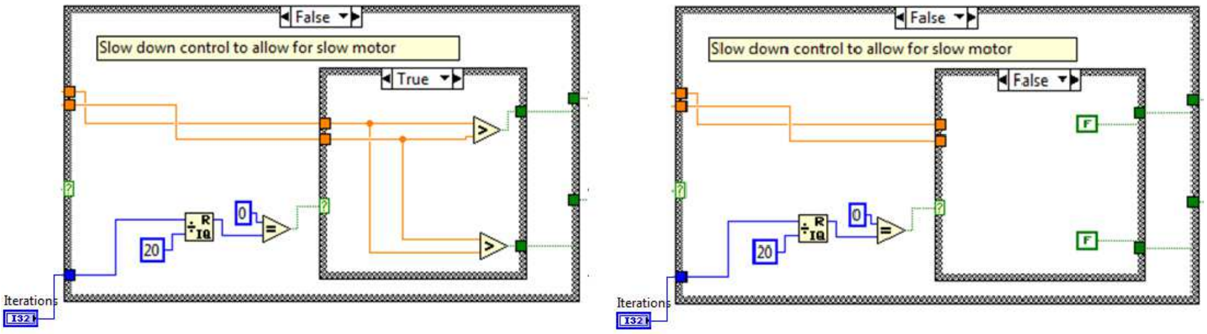

Figure 3-31 Ramp Motor: Block Diagram – Slow response

Mission Control Cases:

-Accelerate To Taxi: In this state, the goal is to reach the Taxi RPM value. For this purpose we used the Ramp Motor SubVI that we previously discussed and sent the required input to it. The "Select Function" connected just after the SubVI works in the following way: if the Boolean Input is TRUE (Setpoint Reached), the function returns the upper value (Taxi) and the codes move to the next state. If the setpoint has not been reached, the function returns "Acc To taxi", so the same code is executed again.

The Manual Mode Control is set to FALSE in case it wasn't before. The "Get Data/Time In Second Function" returns the current time in seconds. This data will be necessary in the next state.

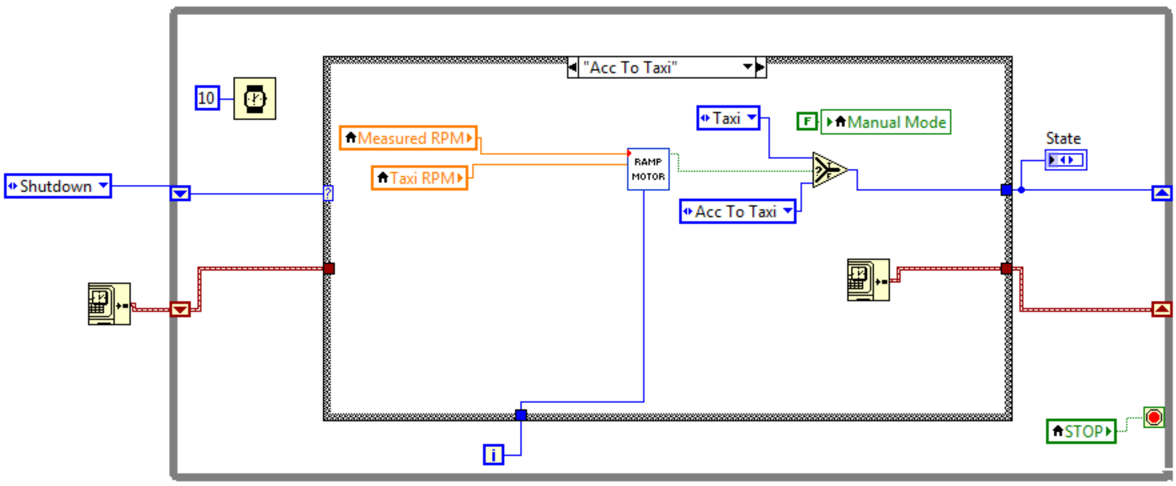

Figure 3-32 Mission Control: Acc To Taxi

-Taxi 1: For every iteration, it compares the current time with the time of the last iteration on the previous state. When the difference between these two times is higher than the Taxi Time, the "Select Function" moves to the following state: Takeoff. Until that moment, it stays in Taxi. Input data is still sent to the Ramp Motor SubVI to make sure that the pump remains at the desired speed. The rest of the states are repetitions of this state and the previous one, so their codes won't be shown.

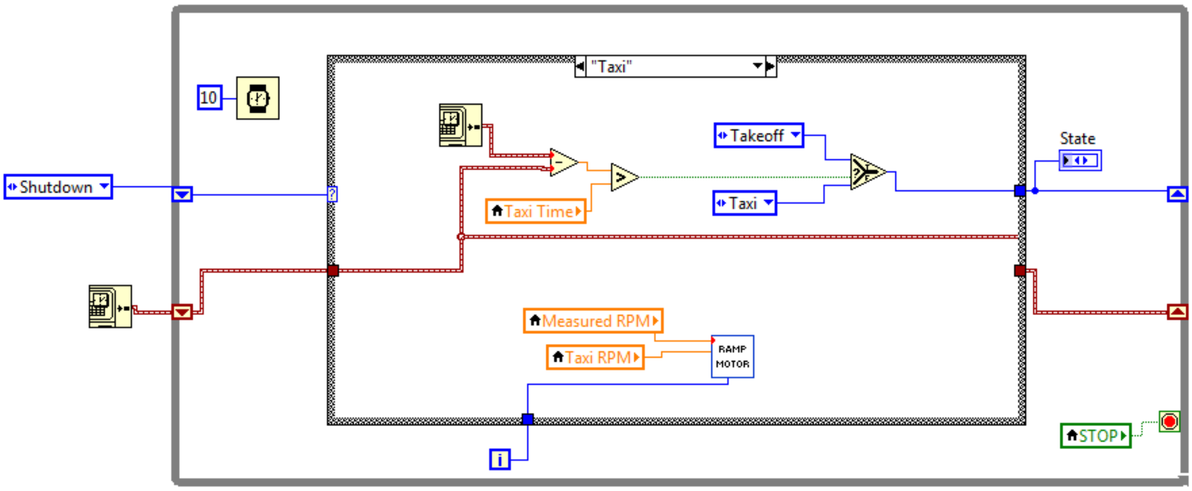

Figure 3-33 Mission Control: Taxi 1

-Takeoff: The program stays in this state until the pump reaches the “Cruise RPM” Speed.

-Cruise: The pump keeps the “Cruise RPM” as long as the “Cruise Time” indicates.

-Landing: The program stays in this state until the pump reaches the “Taxi 2” Speed.

-Taxi 2: The pump keeps the “Taxi 2 RPM” as long as the “Taxi 2 Time” indicates.

-Decelerate To Shut-down: The pump is slowed down until it stops. The “Start Mission” control is set back to FALSE

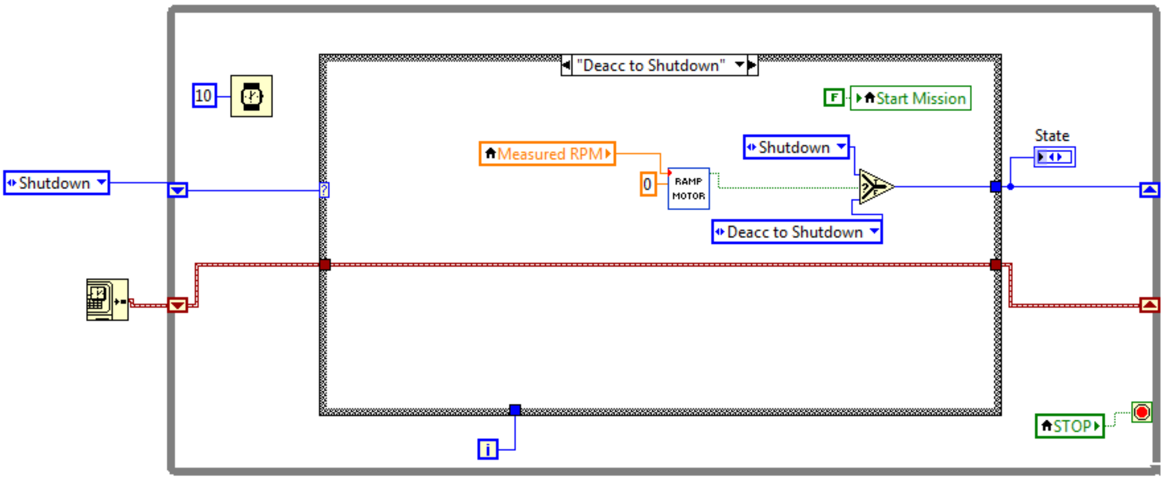

Figure 3-34 Mission Control: Decelerate to Shut-down

3.3.5 Pressure Sensors

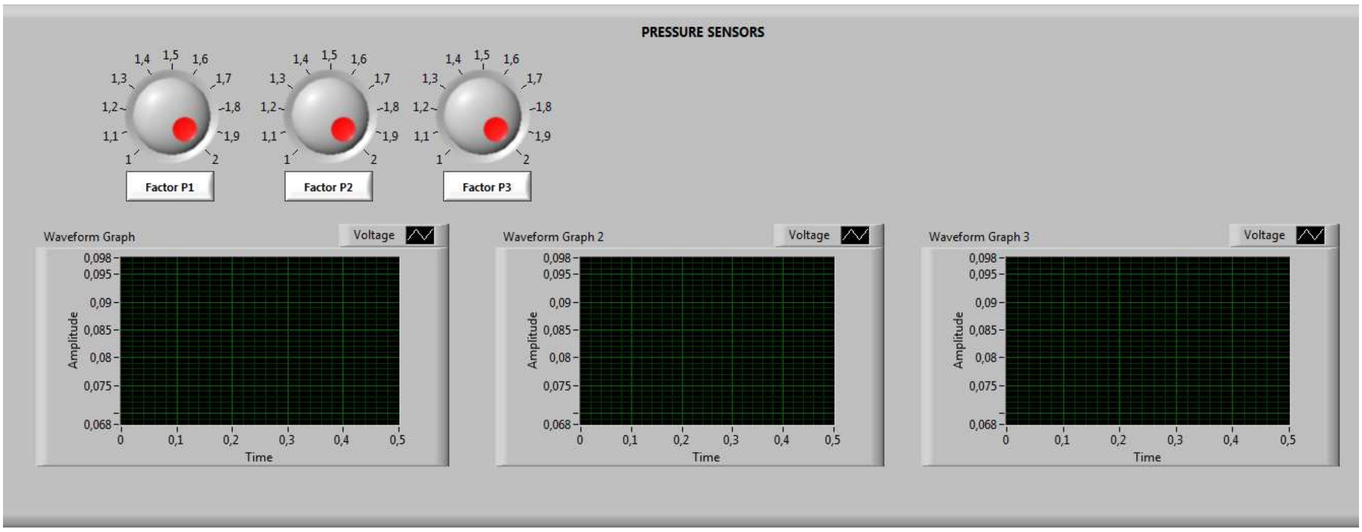

Figure 3-35 Pressure Sensors: Front Panel

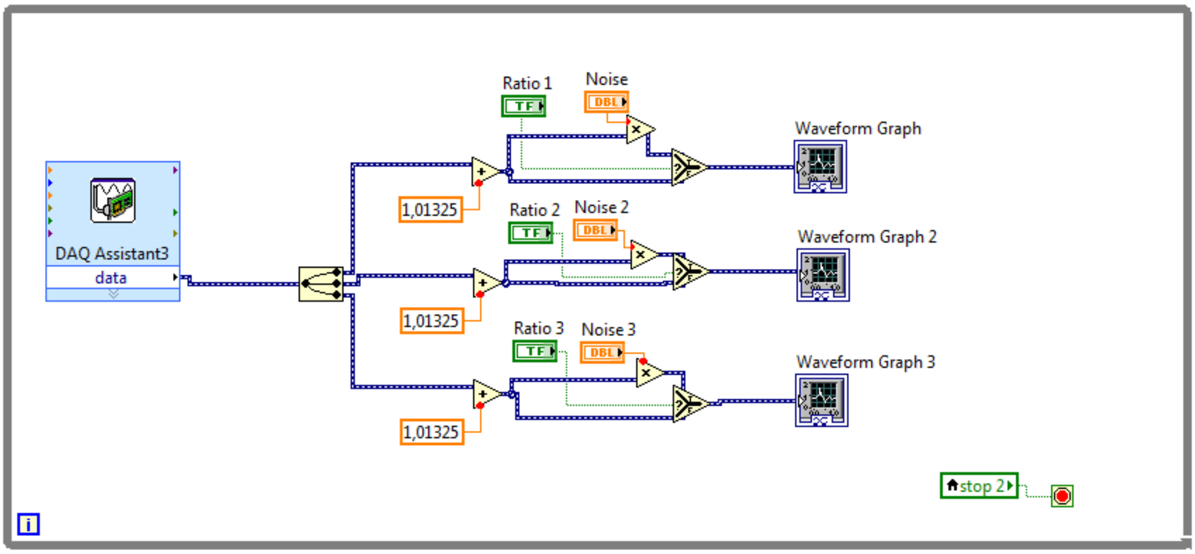

Figure 3-36 Pressure Sensors: Block Diagram

After acquiring the voltage measurements and converting them into pressure sensors we use the "Split Signals" Function to get the component signals of the three pressure transducers. These sensors measure relative pressure so we have to add 1.01325 bars to these measures in order to get the absolute pressure.

We included the option of multiplying the obtained values by a ratio that the user can select. These factors will only be applied if the correspondent control (Ratio 1, Ratio 2 or Ratio 3) is activated. The final values are displayed in waveform graphs.

There was another idea that we couldn't develop due to lack of time, however it will be exposed here. We saw that we could have a better control of the flow if instead of controlling the speed of the pump; we controlled the pressure in the pipe after the pump. It only requires some little modifications.

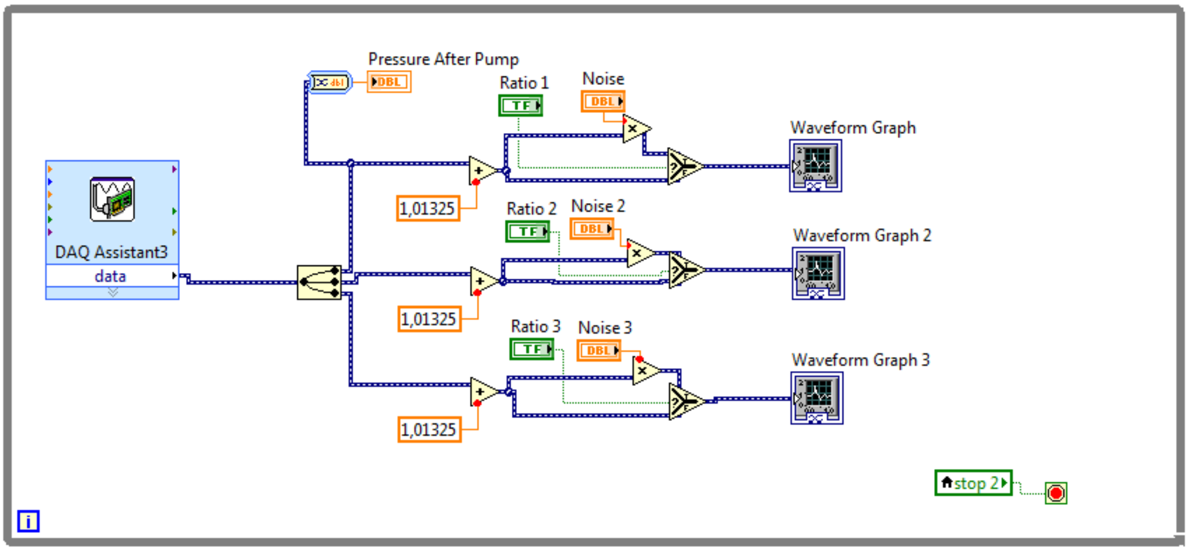

Figure 3-37 Pressure Sensors: Block Diagram 2

We just need to add an additional control to stablish the desired pressure and an indicator that displayed the measured pressure. All that remains is to substitute the Desired RPM control by the Desired Pressure one and the Measured RPM by the Pressure After Pump indicator in the pump code.

4. Maintenance Aware Design Environment (MADe)

4.1 Introduction

This last chapter corresponds with Task 4 and presents MADe, a new tool in IVHM design. This section will be divided in two parts; the first one will explain the general concept of this tool with the help of the manual: “MADe Quickstart Guide 1”and the last one will show how we created the model of our system using this software.

MADe and other PHM technologies present a new approach to the development of health management solutions that can be applied during the conceptual design phase of a vehicle. This approach involves the qualitative functional modelling of a system design, the placement of sensor and the diagnostic rules.

We aimed to create a functional system model using MADe (Maintenance Aware Design environment), a COTS software developed by PHM Techonology used for health management design. The model we created includes five failure modes of the different components of an UAV system. The objective was to create an inherent health management solution for the system and find an optimum set of sensors.

The initial approach that most companies used was to focus on fault identification during operations and maintenance. Later, a second approach was developed that used IVHM solutions to support design analysis. In this second framework is where MADe and other software tools are created. As a result of this, the community started employing safety and reliability anaylisis in the Preliminary Design phase.

-System safety analyses include Fault Tree Analysis (FTA), Event Tree Analysis and Probabilistic Risk Assessments. With these analyses, the developers can know which features of the design might be problematic and adapt the design to mitigate or eradicate their potential failures.

-The most frequent type of reliability analysis is the Failure Modes and Effects Critically Analysis (FMECA) that determines the fundamental failure modes that have an effect on a specific component or function.

MADe software tool was selected for being the only COTS software that employs functional analysis as a method to design IVHM solution during the Conceptual Design phase of a new asset. In the next section it will be shown the main parts of the program and how it works.

MADe is an engineering decision support solution that is used to consistently identify and mitigate engineering risks based on their potential technical, capability and economic consequences. Creating a model that represents the system and defining how it functions we can get information about how, why and when it can fail and identify the dependency between the different components or sub-systems of the system. The MADe analysis capabilities are used to determine appropriate mitigation for the potential impacts of failures on availability and support costs.

4.2 Functional Modelling

First thing we have to do to create our system is to define its components and the component functions. Component functions in Made act to show a relationship between the various outputs and inputs of different parts and components, the relationship defined in the components affects the response propagation in a system. To define these functions the flows need to be created, linked with causality and then connected through the system. In MADe, functions are defined in terms of the operation of the element with a verb. Once we have selected the function, we have to define the output and input flows. MADe distinguish three types of flow:

- Energy: Electrical, Thermal, Hydraulic, Mechanical, etc.
- Material: Gas, Liquid, Solid or Mixtures.
- Signal: Continuous, Discrete or Generic.

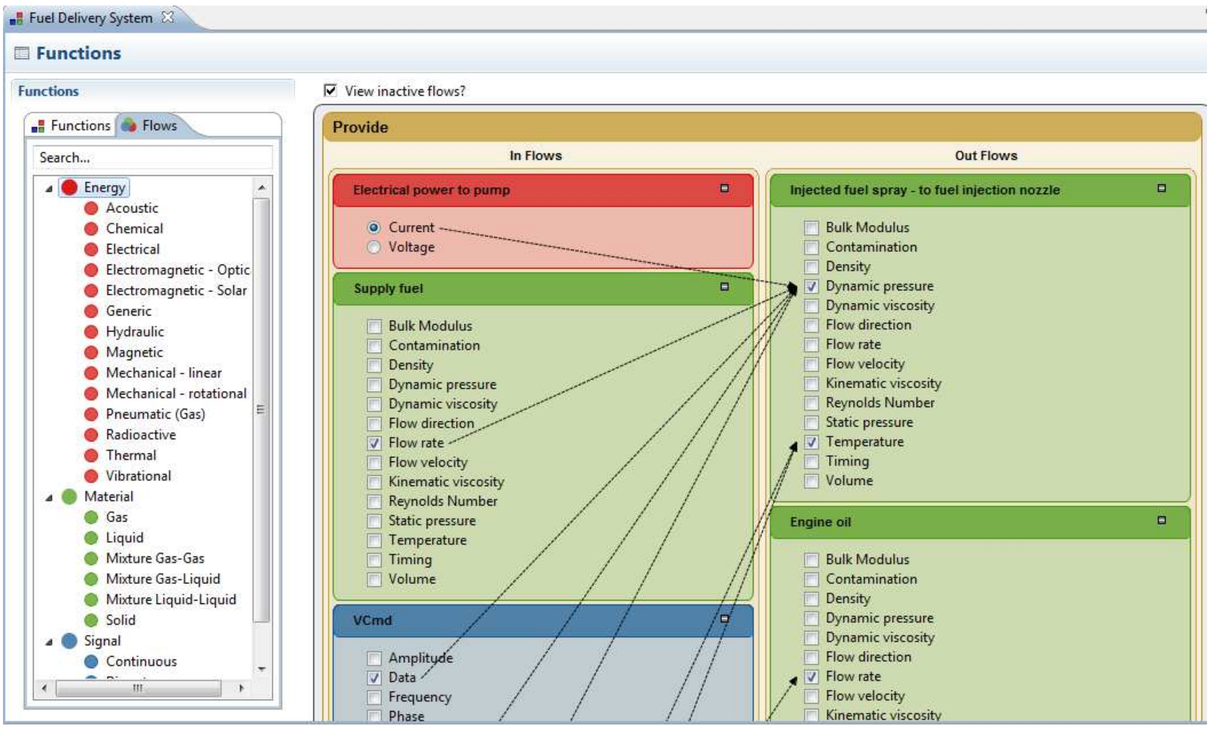

Figure 4-1 Functions in MADe

When the flows are defined, you have to select the properties of that specific flow. These represent the functional requirements of the component and are used to define its function and its functional failure modes. Internal causal connections must be defined between the inflows and outflows properties of the component. To fully describe the causal relationships we have to define its polarity and causal strength. An increase of an inflow property can cause an increase (positive polarity) or a decrease (negative polarity) in the outflow property. Causal strength is defined as the degree to which the target functional output flow will be perturbed up or down by the input flow. The value of the causal strength is determined by the user.

After the functions of the different components are defined, then we have to stablish to relationships between the components. They represent the functional interdependeces.

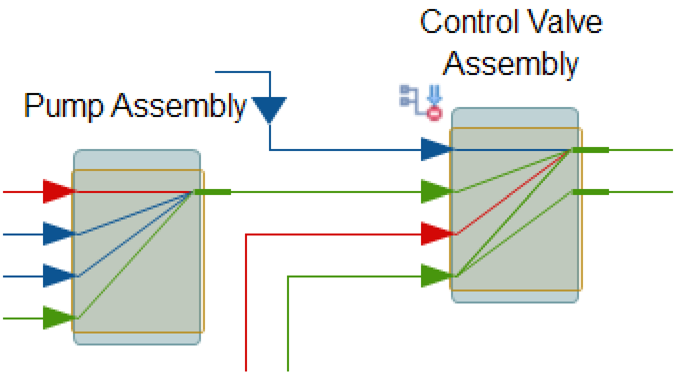

Figure 4-2 Components Connections

Changes to flows and properties may only occur within components or subsystems. The connections between them do not operate on the flows.

Components can be divided too into individual parts that have to be connected later forming a pair. Parts do no fulfill a function by themselves; however they may work together with one or more parts to fulfill a function. The pair editing window looks similar to the component and subsystem function window except there is no input flow. Only output flows are required to define the impact of the pair.

Once all the sub-models of a system have been populated with functions, we have to define the system function. This will identify the input and output flows that the system require to perform its overall function. If the components are already connected, the only thing that is left is to relate the components connections with the inputs and outputs of the system. These are represented by grey shaded bars called MUX bars.

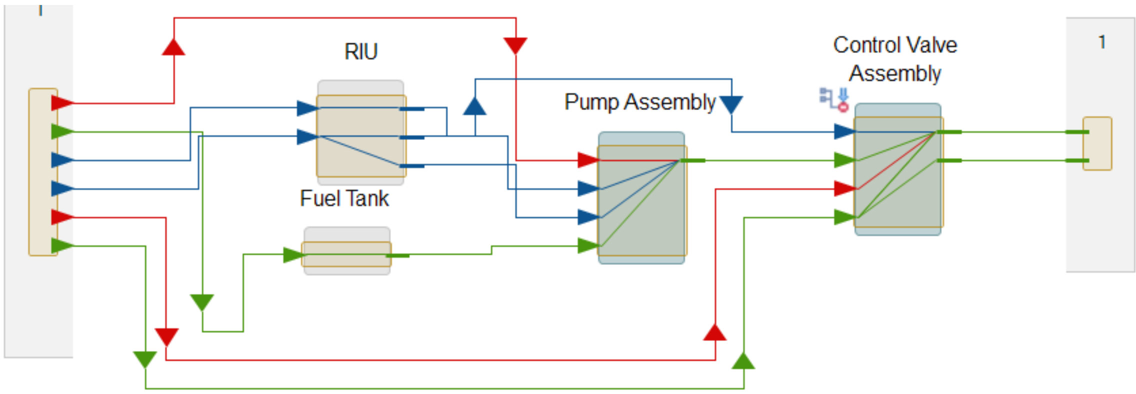

Figure 4-3 Component To System Connections

4.3 Failure Diagrams.

We can assign hypothetical failures that are based solely on the erroneous properties of its functional outputs. A failure diagram shows the sequence of event that to component failure. To create the diagram, MADe distinguish between causes, mechanisms, faults, failures and symptoms.

-Cause: The fundamental reason for a failure mode, which may see the physical degradation or process leading to a failure mode. A cause can relate to design, manufacture, environmental, operational or maintenance actions or an input flow that exceeds specified limits.

-Mechanism: The chemical, electrical or mechanical process which causes physical degradation of a system element and results in a fault.

-Fault: Commonly used as a synonym for failure mode, however in MADe the term fault refers specifically to the physically degraded state of a system element (static) or a change in its behavior (dynamic) that which will result in a failure mode.

-Failure: The variance of a property of the output flow of a function. It occurs when the value of that property is different from the nominal value, because it is either too high or low.

-Symptom: The response of a failed system element that can be used to detect a failure mode, or a loss generated by a failure process that can be used to detect a failure mode.

We can create failure paths that define the relationships between the concepts to generate a functional fault tree for a component or part. We have to create causal connections to the failure terms in the following order: Causes – Mechanisms – Fault – Failures and Symptoms.

After following all these steps, the model will be created and we will be able to get information from it such as FMEA reports that summarize the effects of each potential failure mode with respect to its local, next and end-effect. The end-effect item is usually an item that is chosen by the user and whose output flows decide whether or not the system is functioning properly.

4.4 UAV Fuel System Model

As it was explained before, the system that we wanted to create is a UAV fuel system which contains the following components:

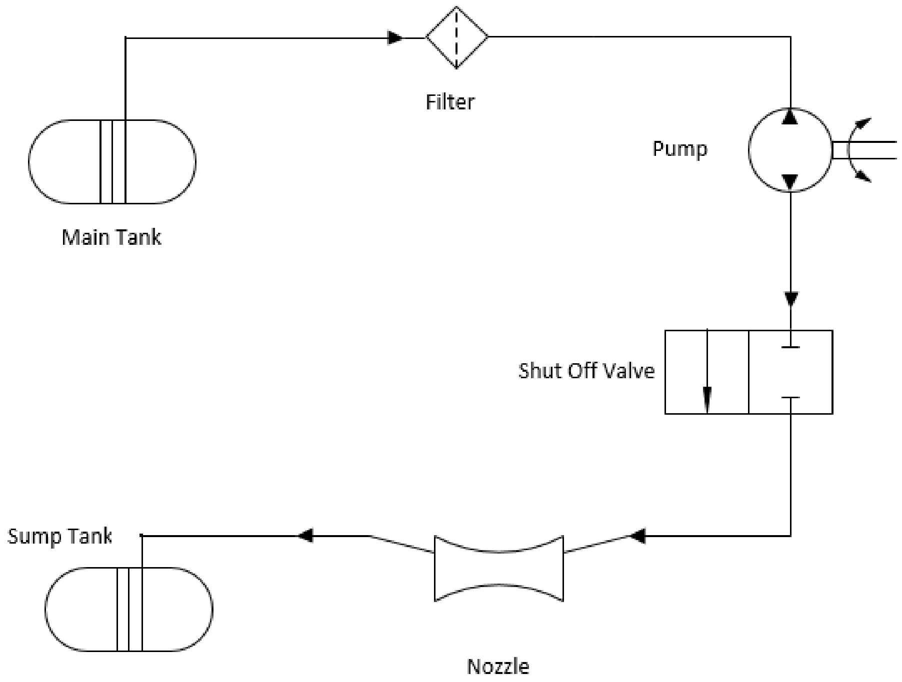

Figure 4-4 Fuel system diagram

We created this model in MADe but we added some modifications to create a more realistic system

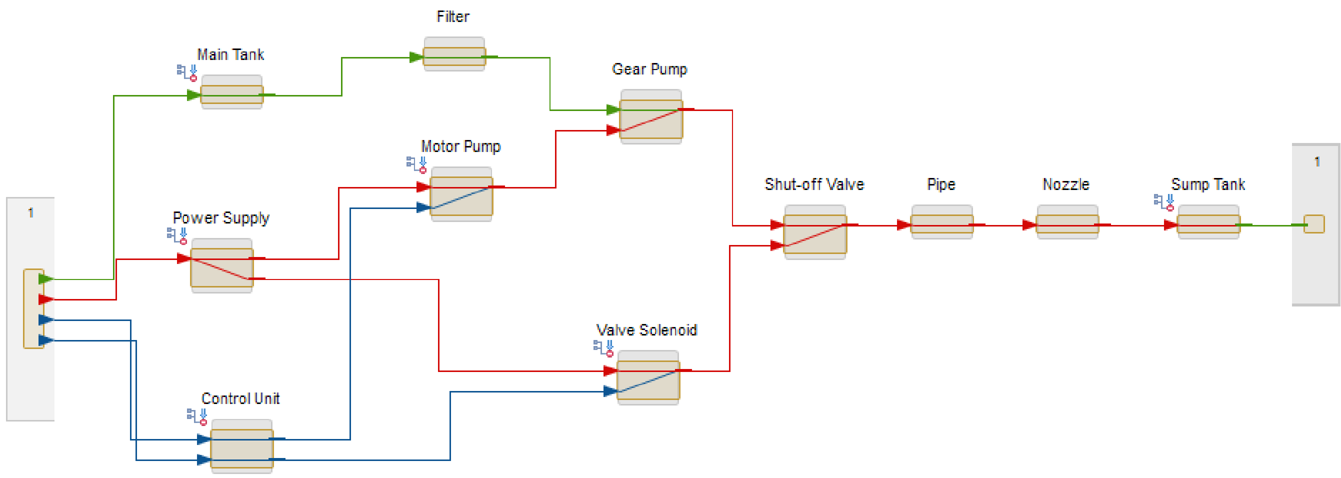

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Figure 4-5 MADe Fuel system model

Two of the components have been split in two, in order to have better understanding of how the system works:

-Pump: Gear Pump + Motor Pump

-Shut-Off Valve: Valve Solenoid

We also added a power supply and a Control Unit that in our case is the LabVIEW program that controls the system.

Component	*Function*	*Input Flow*	*Input Properties*	*Output Flow*	*Output Properties*
Main Tank	Store	Liquid (Material)	Volume	Liquid (Material)	Flow rate
Power Supply	Supply	Electrical (Energy)	Voltage	Electrical(Energy)	Current
				Electrical(Energy)	Current
Control Unit	Convert	Continuous (Signal)	Data	Continuous (Signal)	Amplitude
		Continuous (Signal)	Data	Continuous (Signal)	Amplitude
Filter	Separate	Liquid (Material)	Flow rate	Liquid (Material)	Flow rate
Motor Pump	Convert	Electrical (Energy)	Current	Mechanical-rotation (Energy)	Angular Velocity
		Continuous (Signal)	Amplitude		
Gear Pump	Supply	Liquid (Material)	Flow rate	Hydraulic (Energy)	Flow rate
		Mechanical-rotation (Energy)	Angular velocity		
Valve Solenoid	Convert	Electrical (Energy)	Current	Mechanical-linear (Energy)	Linear velocity
		Continuous (Signal)	Amplitude		
Shut-off Valve	Regulate	Hydraulic (Energy)	Flow rate	Hydraulic (Energy)	Flow rate
		Mechanical-linear (Energy)	Linear velocity		
Pipe	Transport	Hydraulic (Energy)	Flow rate	Hydraulic (Energy)	Pressure
Nozzle	Regulate	Hydraulic (Energy)	Pressure	Hydraulic (Energy)	Flow rate
Sump Tank	Store	Hydraulic (Energy)	Flow rate	Liquid (Material)	Volume

System	Provide	Liquid (Material)	Volume	Liquid (Material)	Volume
		Electrical (Energy)	Voltage		
		Continuous (Signal)	Data		
		Continuous (Signal)	Data		

Table 4.1 – Functions, flows and properties

4.5 UAV Fuel System Failure Diagrams:

4.5.1 Clogged Filter:

Filters usually get clogged for one of the following reasons:

- Waxing of gelling: It occurs when fuel reaches its cloud point and the paraffin in the fuel crystalize. This happens in low temperatures.
- Water-freezing: The same cold temperatures con form ice that clog the filter.
- Asphaltenes: Particles that appear when fuel decomposes.
- Presence of bacteria and fungus.

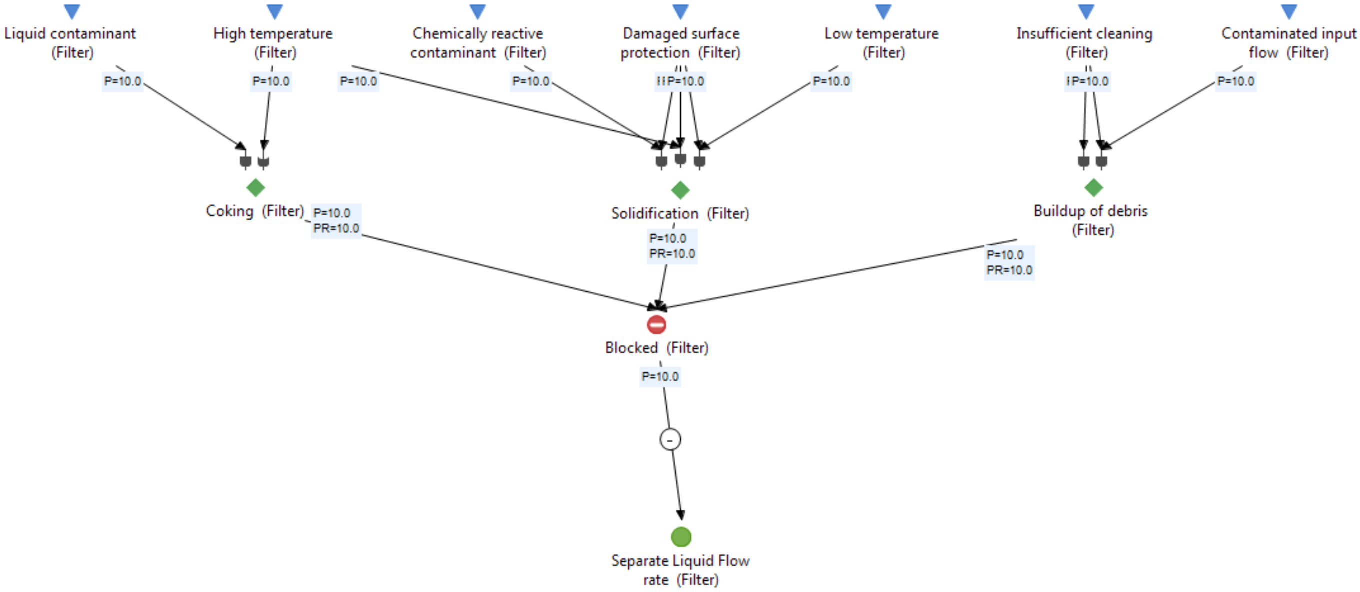


Figure 4-6 Clogged Filter Failure Diagram

4.5.2 Faulty gear pump:

The main reason why a gear pump can't provide enough pressure or flow is because it has an excessive wear. This can be caused by:

- High mechanical loads and impacts.
- Presence of solid particles.
- Cavitation: Formation and collapse of bubbles in a flowing liquid which generates high, localized loading on the surface.

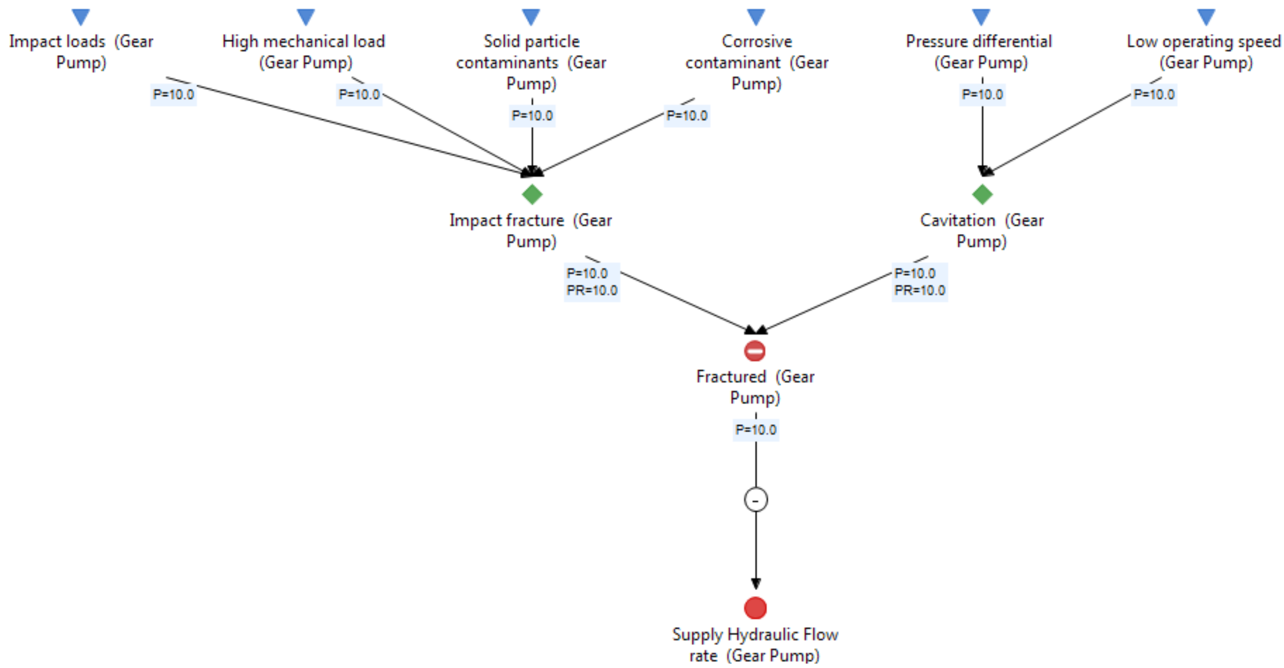


Figure 4-7 Faulty Gear Pump Failure Diagram

4.5.3 Stuck shut-off valve:

Stuck valves are usually caused by:

- A build-up of deposits, especially when heavily leaded fuels are used
- Corrosion on the valve stem. Because the fit of the stem in the guide is so snug, it doesn't take much build-up on the valve stem to interfere with free movement of the valve within the guide.

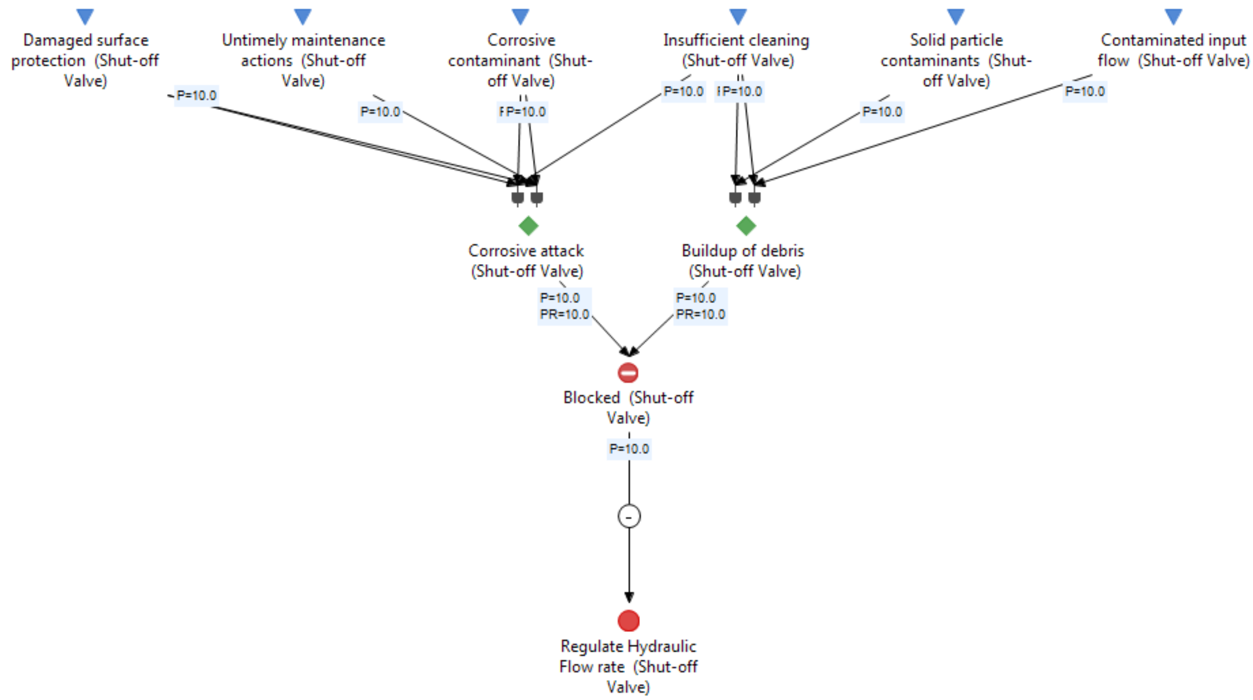


Figure 4-8 Stuck Shut-off Valve Failure Diagram

4.5.4 Leaking Pipe:

The reason why a pipe leaks is because a fracture has been produced somewhere. The main factors that can lead to a fracture are:

- High mechanical load
- Creep: the tendency of a solid material to move slowly or deform permanently under the influence of mechanical stresses, especially at high temperatures.

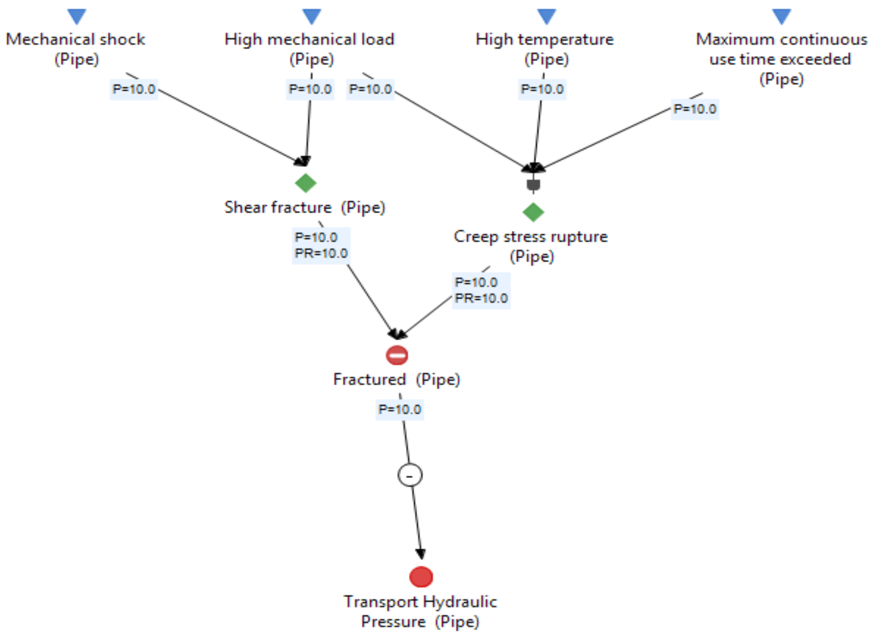


Figure 4-9 Leaking Pipe Failure Diagram

4.5.5 Clogged Nozzle:

Nozzles inject the fuel and required a special attention in its maintenance. The main reasons why nozzles get clogged are:

- Corrosion
- Dirt due to presence of solid particles in the fluid.

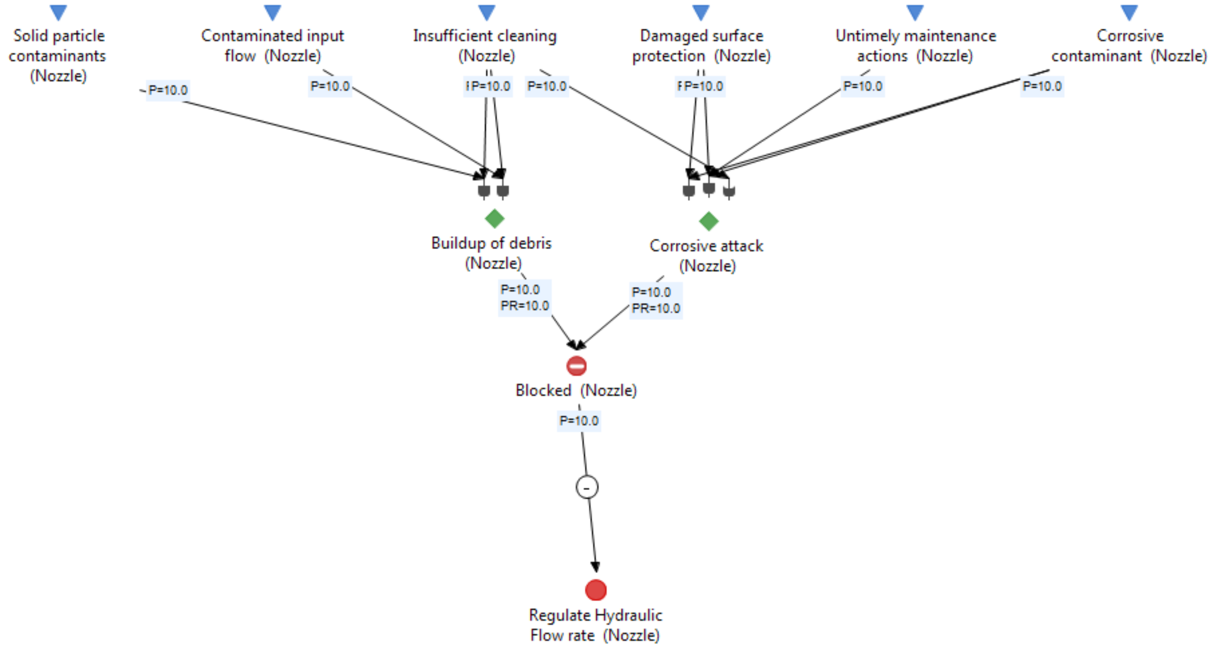


Figure 4-10 Clogged Nozzle Failure Diagram

5. Conclusions and Future Work

The work I have been doing during these months in GCU is part of more long-term project. This report is therefore also a guide for the future work. In this section it will be exposed some of the ideas that we could not carry out during this time due to different reasons and some proposals for future developments.

IVHM

IVHM is a means of establishing current and predicted vehicle condition and using this information to enhance operational decisions. It has been proved that this new approach has a positive effect in the reliability and maintainability of the asset. IVHM reduces the life cycle costs and provide the vehicle with a higher autonomy. Descriptions of successful IVHM applications demonstrate that the technology is mature, but the literature emphasizes the expectations from future developments and claims that the main inhibitor is the difficulty of assessing the trade-off between the associated costs and risks and the future revenue. One of the goals of this project is contribute to the consolidation of tools and methodologies for the design of IVHM systems.

LabVIEW

LabVIEW is a system-design platform and development developed by National Instruments. Its graphical systems design and programming language offer the performance and flexibility of a programming language, as well as high level functionality and configuration utilities designed specifically for measurements and automatic applications. LabVIEW provides with data acquisition tools to gather or generate information and data analysis and visualization tools to process and present all this information. It has proved its value to acquire data from the different sensors we used and to control all the different components with a very intuitive interface.

TEST RIG

Due to equipment issues, we could not finish the construction of the test rig for the UAV fuel system. Specifically, we did not get in time the absolute pressure sensor and the direct proportional valve that simulate the failures. After the installation of these components, the future work should focus on verification and validation of the fuel rig. All the sensor and components must be tested in order to find possible measurements errors or inadequate performances. Once all this work is done, the system capacity of simulate both normal and fault scenarios as well as detect and isolate fault should be tested. The work would finish with the creation of physical model of the system with a thermo-fluid system simulation software.

MADe

We created a MADe model of the fuel system including the failure diagrams of the five failure modes which purpose was to develop a qualitative functional modelling of the system to perform analysis and assessment of the failures. The model automatically generates a sensor set that contains a diagnostic rule set that should be validated on the fuel rig. The goal is to design an IVHM solution capable of discriminating between normal and faulty scenarios and isolate all five faults. The qualitative diagnostic layer produced by MADe will have to be complemented by a quantitative layer obtained by physical simulation of the system flows.

6. References

1. *Mary S. Reveley, Tolga Kurtoglu, Karen M. Leone & Jeffrey L. Briggs and Colleen A. Withrow:* Assessment of the State of the Art of Integrated Vehicle Health Management Technologies as Applicable to Damage Conditions. NASA/TM—2010-216911 (2010)

2. *T.S. Baines, O. Benedettini, R.M. Greenough & H.W. Lightfoot:* State-of-the-art in Integrated Vehicle Health Management (2009)

3. *L. E. Redding:* A strategy formulation methodology for companies seeking to compete through IVHM enabled service delivery systems (2009)

4. *Ian K. Jennions:* Integrated Vehicle Health Management: Perspectives of an Emerging Field – SAE International (2011)

5. *Ian K. Jennions*: Integrated Vehicle Health Management: The Technology– SAE International (2013)

6. *Ian K Jennions:* The Developing Field of Integrated Vehicle Health Management – Journal of Aerospace Sciences and Technologies (2013)

7. *Samir Khan, Paul Phillips, Chris Hockley & Ian Jennions:* No Fault Found, Retest OK, Cannot Duplicate or Fault No Found? Towards a standarised taxonomy. (2012)

8. *LabVIEW Core 1:* Course Manual and Exercises- National Instruments (2010)

9. *LabVIEW Core 2:* Course Manual and Exercises- National Instruments (2010)

10. *Reg Austin: Unmanned Aircraft Designs. UAV Design, Development and Deployment – Wiley (2010)*

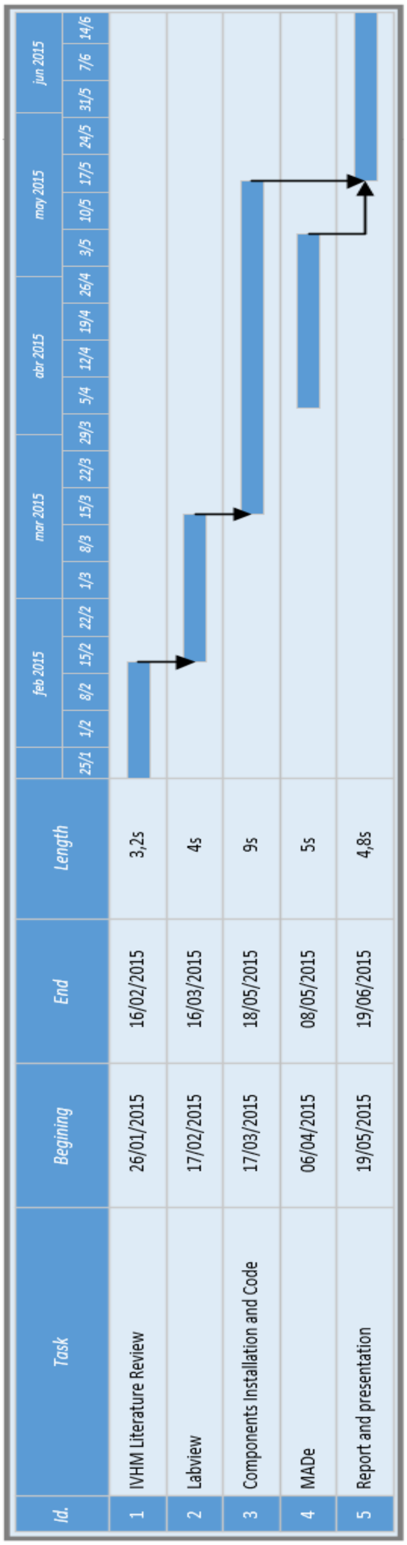
11. *Seth S. Kessler, Christopher T. Dunn, Michael Borgen, Ajay Raghavan, Jeffrey Duce and David L. Banks:* A Cable-Free Digital Sensor-Bus for Structural Health Monitoring of Large Area Composite Structures (2009)

12. *Octavian Niculita, Phil Irving, and Ian K Jennions:* Use of COTS Functional Analysis Software as an IVHM Design Tool for Detection and Isolation of UAV Fuel System Faults. Integrated Vehicle Health Management Centre, Cranfield University,(2012)

13. *PHM Technology:* MADe Quickstart Guide 1 (2013)

14. *Alan Asmus and Barry Wellington:* Diesel Engines and Fuel Systems – Pitman (1988)

APPENDIX 1: GANTT DIAGRAM



APPENDIX 2: DATA SHEET

bürkert
FLUID CONTROL SYSTEMS

2/2-way direct acting solenoid valve

- High quality seal material
- Special versions up to +180°C
- Impulse version optional
- Threaded port and sub-base connections
- Explosion proofed version optional

Type 6013 can be combined with…

Type 2508
Cable plug

Type 1078
Timer unit

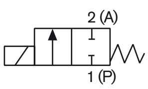
Type 2511
ASI Cable plug

This direct-acting 2/2-way miniature solenoid valve is available in two versions.

Standard version:
Type 6013 is a small direct acting solenoid valve for general purpose used for shut-off and dosing. It is of modular design and may be mounted individually or as a block on a multiple manifold.

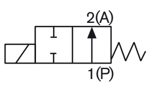
Analysis and vacuum technology:
Type 6013 A is a high-quality small solenoid valve for analysis and vacuum technology.
It is manufactured under clean-room conditions. This includes thorough cleaning of all parts in contact with media from organic and inorganic substances. The limit for residual hydrocarbons is below 0.2 mg/dm².
The valve will undergo an external 100 % non-standard leakage test with respect to seat tightness and impermeability. The permissible leakage rate is 10^{-4} mbar l/s. The valve is used for shut-off, dosing, filling, ventilating and particularly for analysis technology.

Circuit Function A



2/2-way valve, normally closed by spring fornce

Circuit Function B



2/2-way valve, normally open by spring fornce

Technical data	
Body material	
Type 6013	Brass, stainless steel 1.4305
Type 6013 A	Brass, stainless steel 1.4305
Seal material	FKM, PTFE/Graphite (EPDM on request)
Analysis version	Silicon, oil and fat free version
Type 6013 A	Tightness $<10^{-4}$ mbar l/s
Limit value for risidual carbon	
Type 6013 A	<0.2 mg/dm²
Medium	▪ Technical vacuum
Type 6013	▪ Neutral gases and liquids (e.g. compressed air, water, hydraulic oil)
Type 6013 A	▪ Neutral medium, which does not attack the body and seal materials (see chemical resistance chart)
Media temperature	
FKM	-10 to +100 °C (PA coil) till 120°C (Epoxy coil)
PTFE/Graphite	Up to +180 °C (see chemical resistance chart)
FKM, Circuit function B	-10 to 100°C (AC) -10 to 120°C (DC)
Ambient temperature	Max. +55 °C
Viscosity	Max. 21 mm²/s
Port connection	
Type 6013	G1/8, G1/4, G3/8, sub-base
Type 6013 A	G1/8, G1/4
Operating voltage	
Type 6013	24 V DC, 24 V/50 Hz, 230 V / 50 Hz
Type 6013 A	24 V DC, 230 V / 50 Hz (other voltages on request)
Voltage tolerance	± 10%
Duty cycle/single valve	100% continuous rating
With block assembly on manifold	Intermittent operation 60% (30 min) or with 5 W coil on request
Electrical connection	Tag connector acc. to DIN EN 175301-803 Form A (previously DIN 43650) for cable plug Type 2508 (see accessories)
Installation	As required, preferably with actuator upright
Assembly	No oils, fats or silicone to be used during installation
Protection class	IP65 with Cable Plug
Coil insulation class	Polyamide class B Epoxy class H

Technical data, continued

Circuit function A

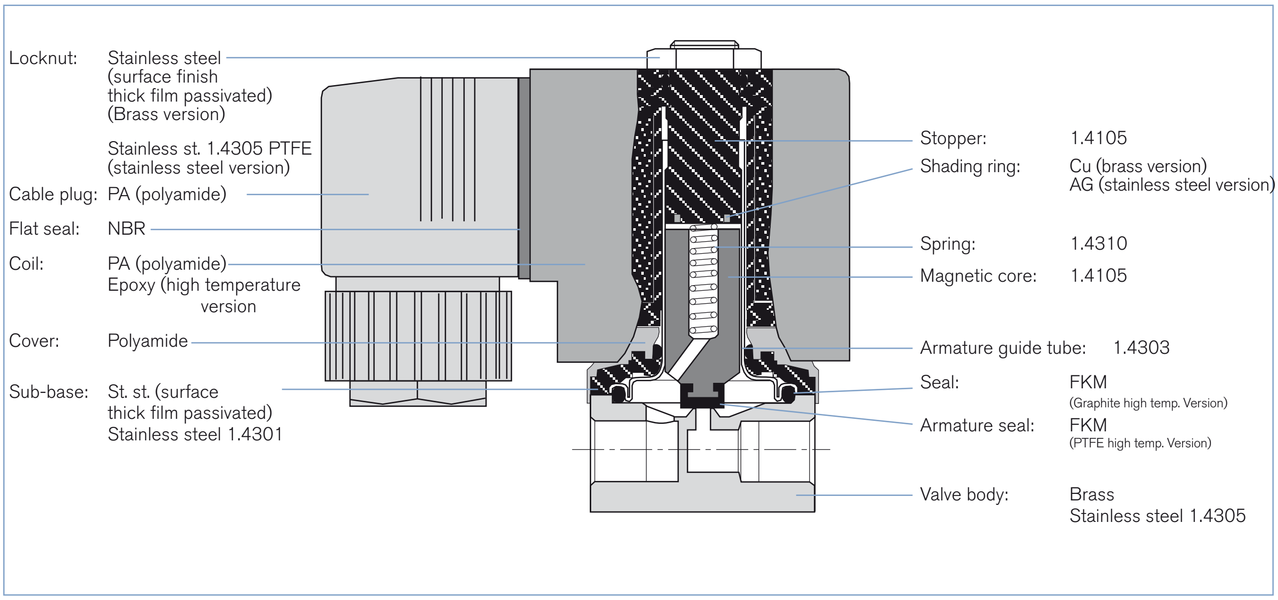
Orifice [mm]	Port connection	Kv-value water [m3/h]	Weight [g]	Power consumption [1] [W]	Electr. power Inrush (AC)	Hold (AC)	Coil size	Response times opening [ms]	closed [ms]
2.0	G1/8	0.12	325	8W AC or 8W DC (9)	24 VA	17 VA	5 (32mm)	20	30
2.0	G1/4	0.12	465	8W AC or 8W DC (9)	24 VA	17 VA	5 (32mm)	20	30
2.0	sub-base	0.12	290	8W AC or 8W DC (9)	24 VA	17 VA	5 (32mm)	20	30
2.5	G1/8	0.16	325	8W AC or 8W DC (9)	24 VA	17 VA	5 (32mm)	20	30
2.5	G1/4	0.16	465	8W AC or 8W DC (9)	24 VA	17 VA	5 (32mm)	20	30
3.0	G1/8	0.23	325	8W AC or 8W DC (9)	24 VA	17 VA	5 (32mm)	20	30
3.0	G1/4	0.23	465	8W AC or 8W DC (9)	24 VA	17 VA	5 (32mm)	20	30
3.0	G3/8	0.23	550	10W AC or 10WDC (11)	30 VA	22 VA	6 (40mm)	20	30
4.0	G1/4	0.30	465	8W AC or 8W DC (9)	24 VA	17 VA	5 (32mm)	20	30
4.0	G3/8	0.30	550	10W AC or 10WDC (11)	30 VA	22 VA	6 (40mm)	20	30
6.0	G1/4	0.55	465	8W AC or 8W DC (9)	24 VA	17 VA	5 (32mm)	20	30
6.0	G3/8	0.55	550	10W AC or 10WDC (11)	30 VA	22 VA	6 (40mm)	20	30

Circuit function B

Orifice [mm]	Port connection	Kv-value water [m3/h]	Weight [g]	Power consumption [1] [W]	Electr. power Inrush (AC)	Hold (AC)	Coil size	Response times opening [ms]	closed [ms]
2.00	G 1/8	0.12	325	7 W(AC) or 8 W DC (9)	24VA	17VA	5 (32mm)	20	30
2.00	G 1/4	0.12	465	7 W(AC) or 8 W DC (9)	24VA	17VA	5 (32mm)	20	30
2.00	sub-base	0.12	290	7 W(AC) or 8 W DC (9)	24VA	17VA	5 (32mm)	20	30
3.00	G 1/8	0.23	325	7 W(AC) or 8 W DC (9)	24VA	17VA	5 (32mm)	20	30
3.00	G 1/4	0.23	465	7 W(AC) or 8 W DC (9)	24VA	17VA	5 (32mm)	20	30
3.00	sub-base	0.23	290	7 W(AC) or 8 W DC (9)	24VA	17VA	5 (32mm)	20	30
4.00	G 1/4	0.3	465	7 W(AC) or 8 W DC (9)	24VA	17VA	5 (32mm)	20	30
6.00	G 1/4	0.55	465	7 W(AC) or 8 W DC (9)	24VA	17VA	5 (32mm)	20	30

[1] Values in brackets at coil temperature 20°C

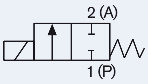
Materials



Ordering chart for valves (other versions on request)

6013 Universal valve with FKM seal, brass and stainless steel body (Polyamide coil)

Delivered without cable plug (see accessories)

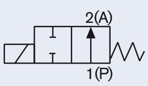
Circuit function	Orifice [mm]	Port connection	Kv value water [m³/h] [1)]	Coil power [W]	Pressure range [bar] [2)]	Voltage/ Frequency [V/Hz]	Item no. brass body FKM Seal	Item no. Stainless steel body, FKM seal
A 2/2-way valve NC	2.0	G 1/8	0.12	8	0 - 12	024/DC	134 237	134 233
					0 - 25	024/50	132 865	134 234
					0 - 25	230/50	134 239	134 236
		G 1/4	0.12	8	0 - 12	024/DC	137 537	137 533
					0 - 25	024/50	137 538	137 534
					0 - 25	230/50	137 540	137 536
		sub-base	0.12	8	0 - 12	024/DC	134 244	–
					0 - 25	024/50	134 245	–
					0 - 25	230/50	134 247	–
	2.5	G 1/8	0.16	8	0 - 10	024/DC	134 240	–
					0 - 16	024/50	134 241	–
					0 - 16	230/50	134 243	–
	3.0	G 1/8	0.23	8	0 - 6	024/DC	126 091	126 078
					0 - 10	024/50	126 092	126 079
					0 - 10	230/50	126 094	126 081
		G 1/4	0.23	8	0 - 6	024/DC	125 301	125 317
					0 - 10	024/50	125 302	126 082
					0 - 10	230/50	125 304	126 084
	4.0	G 1/4	0.30	8	0 - 1.5	024/DC	125 306	125 318
					0 - 4	024/50	125 307	125 319
					0 - 4	230/50	125 309	125 320
	6.0	G 1/4	0.55	8	0 - 0.5	024/DC	125 311	126 086
					0 - 1.5	024/50	125 312	126 087
					0 - 1.5	230/50	125 314	126 089

[1)] Measured at +20 °C, 1 bar[2)] pressure at valve inlet and free outlet..
[2)] Measured as overpressure to the atmospheric pressure

Ordering chart for valves

6013 Universal valve with FKM seal, brass body (Epoxy coil)

Delivered without cable plug (see accessories)

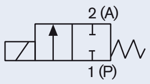
Circuit function	Orifice [mm]	Port connection	Kv value water [m³/h] [1)]	Pressure range [bar] [2)]	Coil power [W]	Voltage/ Frequency [V/Hz]	Item no..
B 2/2-way valve NO	2.0	G1/8	0.12	0 - 16	8	24/DC	213 543
					7	230/50	213 550
	3.0	G1/8	0.23	0 - 8	8	24/DC	213 545
					7	230/50	213 551
		G1/4	0.23	0 - 8	8	24/DC	213 546
					7	230/50	213 552
	4.0	G1/4	0.3	0 - 4	8	024/DC	213 548
					7	230/50	213 553
	6.0	G1/4	0.55	0 - 2	8	024/DC	213 549
					7	230/50	213 554

[1)] Measured at +20 °C, 1 bar[2)] pressure at valve inlet and free outlet..
[2)] Measured as overpressure to the atmospheric pressure

Ordering chart for valves

6013 Universal valve with FKM seal, G 3/8, brass body (polyamide coil)

Delivered without cable plug (see accessories)

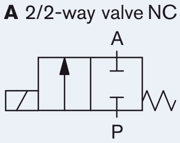
Circuit function	Orifice [mm]	Port connection	Kv value water [m³/h] [1]	Coil power [W]	Pressure range [bar] [2]	Voltage/ Frequency [V/Hz]	Item no. brass seat, FKM Seal	Item no. Stainless steel seat, FKM Seal
A 2/2-way valve NC 	3.0	G 3/8	0.23	10	0 – 8	024/DC	134 248	135 430
					0 – 14	024/50	134 249	135 431
					0 – 14	230/50	134 251	135 433
	4.0	G 3/8	0.30	10	0 – 2.5	024/DC	134 252	135 434
					0 – 6	024/50	134 253	135 435
					0 – 6	230/50	134 255	135 437
	6.0	G 3/8	0.55	10	0 – 0.75	024/DC	134 256	135 438
					0 – 2.5	024/50	134 257	135 439
					0 – 2.5	230/50	134 259	135 441

[1] Measured at +20 °C, 1 bar[2] pressure at valve inlet and free outlet..
[2] Measured as overpressure to the atmospheric pressure

Ordering chart for valves

6013 Valves for high temperature applications (to ±180°C), PTFE seat seal, brass body

Delivered without cable plug (see accessories)
Brass body with Stainless steel seat
(Epoxy coil)

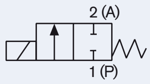
Circuit function	Orifice [mm]	Port connection	Kv value water [m³/h] [1]	Coil power [W]	Pressure range [bar] [2]	Voltage/ Frequency [V/Hz]	Item no.
A 2/2-way valve NC 	2.0	G 1/4	0.12	8	0 – 12	024/DC	136 015
					0 – 25	024/50	136 016
					0 – 25	230/50	136 018
	3.0	G 1/4	0.23	10	0 – 6	024/DC	136 019
					0 – 10	024/50	136 020
					0 – 10	230/50	136 022
		G 3/8	0.23	10	0 – 8	024/DC	136 023
					0 – 14	024/50	136 024
					0 – 14	230/50	136 026

[1] Measured at +20 °C, 1 bar[2] pressure at valve inlet and free outlet.
[2] Measured as overpressure to the atmospheric pressure.

DTS 1000011032 EN Version: O Status: RL (released | freigegeben | validé) printed: 29.08.2013

Ordering chart for valves, Standard temperature version for DC power supply, impulse version

All valves with 32mm coil(AC10), Impulse version, seal material FKM,thermal Insulation class H (epoxy coil), medium temperature -10°C to 120°C, without manual override and cable plug

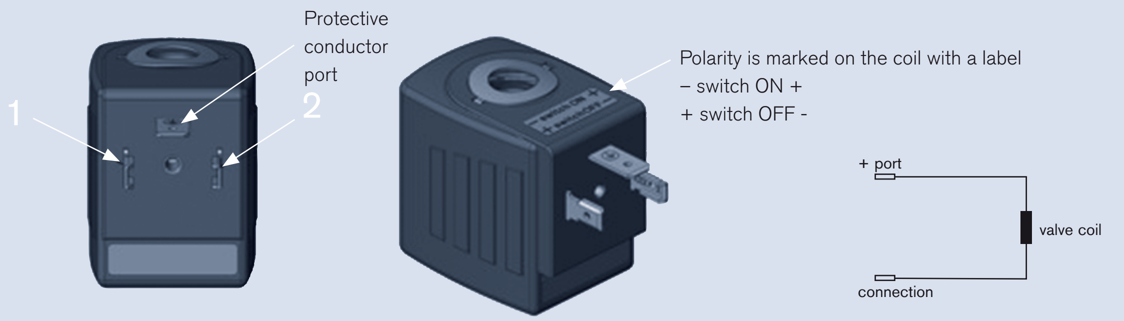
Circuit function	Port connection	Orifice [mm]	Kv-value water [m3/h] [1]	Pressure range [bar] [2]	Power consumption DC (hot/cold coil) [W]	Item no. per voltage/ frequency [V/Hz] 012/DC	024/DC
A 2/2-way valve 	**Brass body**						
	Sub-base	2.0	0.12	0-16	7	209 266	209 272
		2.5	0.16	0-10	7	209 267	209 273
		3.0	0.23	0-6	7	209 268	209 274
	G 1/8	2.0	0.12	0-16	7	209 269	209 275
		2.5	0.16	0-10	7	209 270	209 276
		3.0	0.23	0-6	7	209 271	209 277

[1] Measured at +20 °C, 1 bar[2] pressure at valve inlet and free outlet..
[2] Measured as overpressure to the atmospheric pressure

Please note that the cable plug must be ordered separately, see accessories on page 8 and separate datasheet, Type 2508.

Control for impulse version with polarity reversal control

Polarity is marked on the coil with a label	Features	Terminal connections
- switch ON +	valve (P-seat) open	(+) on terminal 2 and (-) on terminal 1 (see below)
+ switch OFF -	valve (P-seat) closed	(+) on terminal 1 and (-) on terminal 2 (see below)



Pulse duration at least 50 ms.

Note: Please use only the cable plug without electrical circuitry for the impulse version

Technical data - analytical version

Analysis version	Media flowing through are not contaminated
Limit for risidual carbon	<0.2 mg/dm^2
Permissible leakage rate for medium	10-4 mbar l/sec ▪ Neutral medium, which does not attack the body and seal materials ▪ Technical vacuum
Electr. connection	Tag connector acc. to DIN EN 175301-803 Form A (previously DIN43650) for cable plug Type 2508 (see accessories)
Mounting instructions	No oils, fats or silicone used during the assembly

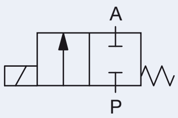
Solenoid valves for higher Requirements
This version is particularly suitable for switching from extremely pure gaseous medium. All media-affected parts are submitted to additional purification processes, so that the media is not contaminated under any circumstances. The assembly takes place under clean-room conditions.

The tightness test takes place at the Helium leak detector from a min. of 10^{-4} mbar l/sec.

Ordering chart for valves (other versions on request)

6013A Analytical valve with brass body and FKM seal, (Polyamide coil)

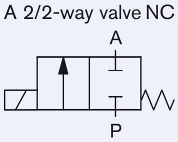
Delivered without cable plug (see accessories)

Circuit function	Orifice [mm]	Port connection	Kv value water [m³/h] 1)	Pressure range [bar] 2)	Coil power [W]	Voltage/ Frequency [V/Hz]	Item no.
A 2/2-way valve NC	2.0	G 1/8	0.12	0-12	8	24/DC	137 826
				0-25		230/50	137 827
	2.5	G1/8	0.16	0-10	8	24/DC	137 828
				0-16		230/50	137 829
	3.0	G 1/4	0.23	0-6	8	24/DC	137 830
				0-10		230/50	137 831
	4.0	G 1/4	0.30	0-1.5	8	24/DC	137 832
				0-4		230/50	137 833

[1] Measured at +20 °C, 1 bar[2] pressure at valve inlet and free outlet..
[2] Measured as overpressure to the atmospheric pressure

6013A Analytical valve with stainless steel body and FKM seal, (Polyamide coil)

Delivered without cable plug (see accessories)

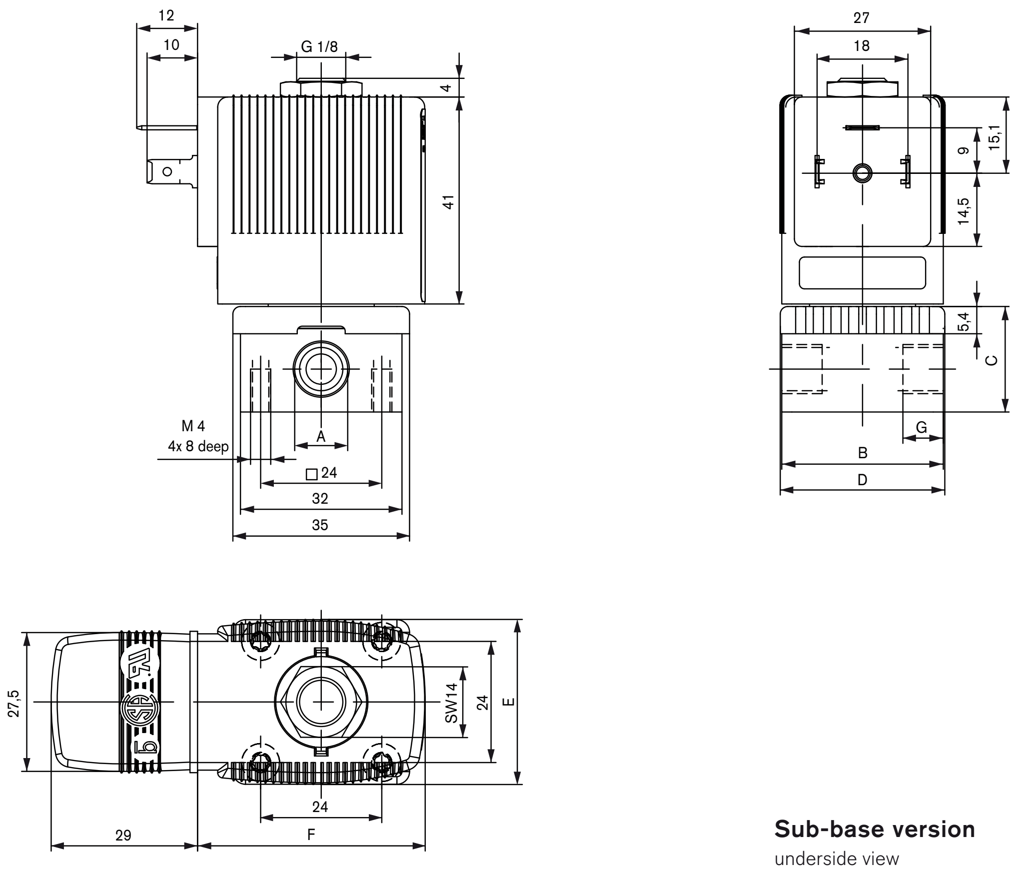
Circuit function	Orifice [mm]	Port connection	Kv value water [m³/h] 1)	Pressure range [bar] 2)	Coil power [W]	Voltage/ Frequency [V/Hz]	Item no.
A 2/2-way valve NC	2.0	G 1/8	0.12	0-12	8	24/DC	137 818
				0-25		230/50	137 819
	2.0	G1/4	0.12	0-12	8	24/DC	137 820
				0-25		230/50	137 821
	3.0	G 1/4	0.23	0-6	8	24/DC	137 822
				0-10		230/50	137 823
	4.0	G 1/4	0.30	0-1.5	8	24/DC	137 824
				0-4		230/50	137 825

[1] Measured at +20 °C, 1 bar[2] pressure at valve inlet and free outlet..
[2] Measured as overpressure to the atmospheric pressure

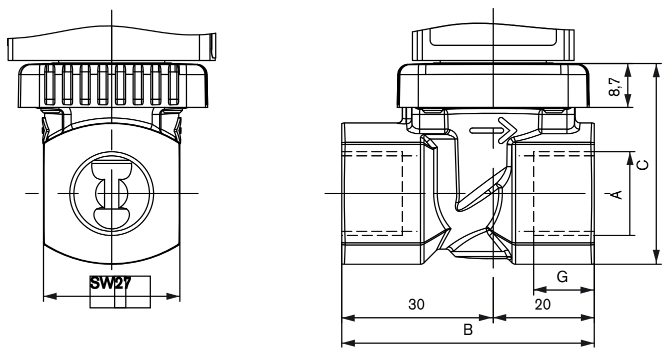
Please note that the cable plug must be ordered separately, see accessories on page 8 and separate datasheet, Type 2508.

Dimensions [mm]

View without cable plug

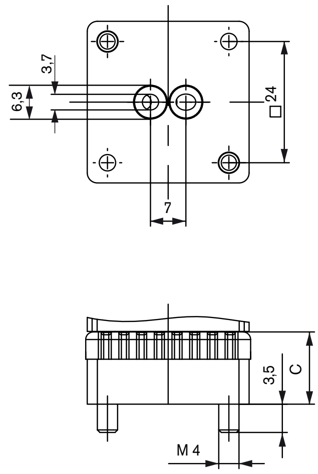


G3/8 connection



Sub-base version

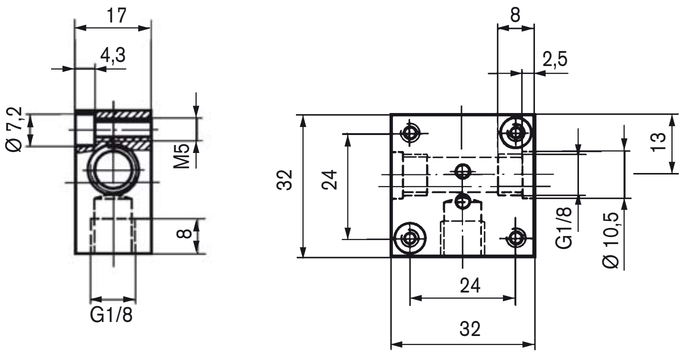
underside view



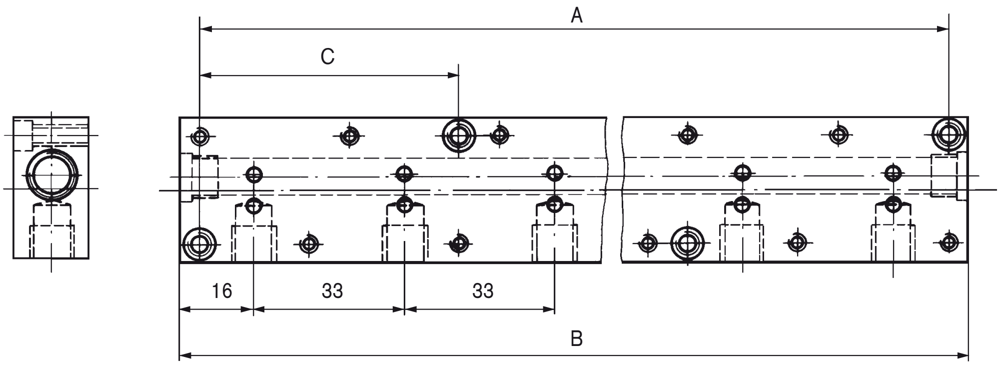
Port connection	Body dimensions [mm]					Coil width	Coil depth
	A	B	C	D	G	E [mm]	F [mm]
G1/8	G1/8	32	20.8	32.6	8	32 (8W)	45 (8W)
G1/4	G1/4	46	26.8	49	12	32 (8W)	45 (8W)
G3/8	G3/8	50	39.8	49	12	40 (10W)	51 (10W)
Sub-base	–	32	14.3	32.6	–	32 (8W)	45 (8W)

Manifold mounting

Single manifold



Multiple manifold



Ordering chart for Manifolds

Accessory part	Quantity of valve places				Item no.
Single manifold	in aluminium				005 020
Multiple manifold	in aluminium	Hole spacing A [mm]	Total length B [mm]	Hole spacing C [mm]	
	2	57	65	–	005 023
	3	90	98	–	005 286
	4	123	131	–	005 287
	5	156	164	57	005 035
	6	189	197	57	005 038
	8	255	263	90	005 386
	10	321	329	90	005 764
Connector nipple	with O-Ring, to connect from manifold				005 040
Covering plate	with screws and O-ring for locking unoccupied valve positions				005 630

With manifold mounting, please comply with the permissible duty cycle (5W models with 100% continuous rating or 8W model with 60% duty cycle). The pressure port for the manifold is designated with P (R), and the outlet port with A (B). Only connect together ports with the same designation.

2/2-way valves of Type 6013 can be operated together on a manifold with 3/2-way valves of Type 6014, circuit function C (not D or T!) if the operating pressures agree according to the rating plates. The manifolds can also be expanded if the valve functions are taken into consideration. Connector nipples with O-rings are used to connect the P (R) ports.

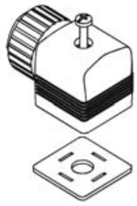
Attention!
Unused, open valve ports must be closed off with covering plates (see accessories). Manifold should be fixed on to a rail.

Ordering chart for accessories

Included in delivery is a cable plug with flat seal and fixing screw.
Other versions with cable plug acc. to DIN EN 175301-803
(previously DIN43650), see Datasheet: Type 2508.

Circuit	Voltage	Item no.
without circuitry	0 -250 V	008 376
with LED	12 -24 V	008 360
with LED and varistor	12 -24 V	008 367
with LED and varistor	200 -240 V	008 369
with inverter [1]	24V DC	on request
further versions	see datasheet Type 2508	

[1] The inverter plug contains an electronic, which especially enables the electric 3 wire control
Input for 3 wire technology, common "-" polarity, two split "+" polarity.
Output suitable for implulse version for Type 6013/6014



Type 2508 Cable plug
acc. to DIN EN 175301-803
(previously DIN 43650)

Further versions on request

Approval
Ex version
UL / UR / CSA
ATEX
FM / CSA-EX Div 1/2
European gas approval Class A, Group 2

Port connection
Threaded port NPT, Rc

Voltage
Further voltages

Materials
Seal material EPDM

Pressure
Variants with increased coil power for higher medium pressure

CE

cULus

Model Number

DK10-LAS/76a/110/124

Print mark contrast sensor

with 5-pin, M12 x 1 connector

Features

- Laser print mark contrast sensor for recording very small print marks
- Large focus depth range from 3 mm ... 300 mm
- Laser class 2, eyesafe
- Adjustable sensitivity
- 30 µs response time, suitable for extremely rapid scanning processes

Product information

The contrast sensor series DK10, DK2X, DKE2X and DK3X have an extreme robust and IP67 tight industrial standard housing with eight M5 metal reinforced inserts for sensor mounting. The lenses are made of high grade glass. All sensors offer different light spot shapes and orientations and have powerful push-pull outputs (NPN/PNP/push-pull).

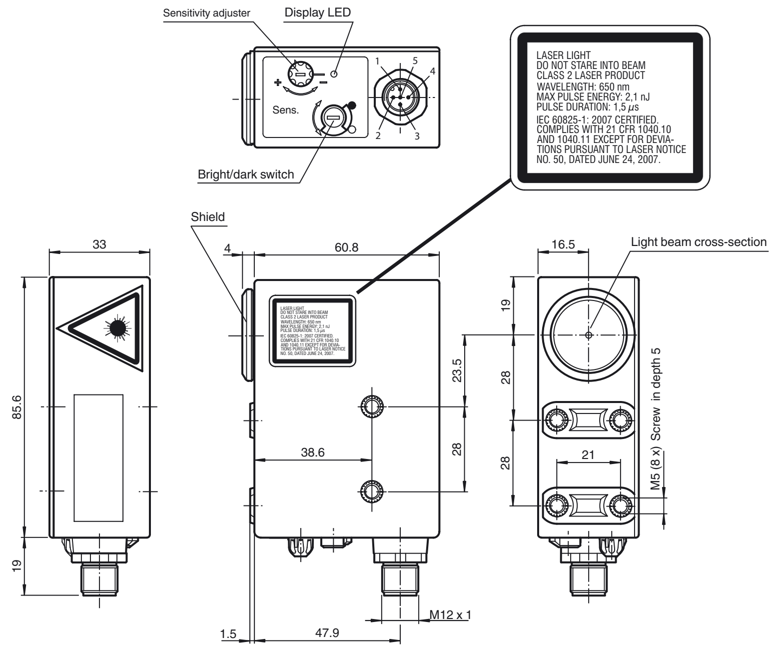
The DK10 sensor series offers laser and LED light sources, a manual sensitivity adjustment and high sensing ranges up to 800 mm.

The DK20/DK21/DKE2X standard contrast sensor series offers a very good contrast recognition and are available in extreme robust stainless-steel housings (DKE).

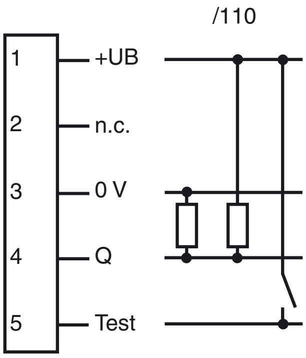
The DK31/DK34/DK35 sensor series is designed for cutting edge contrast recognition at highest sensitivity level.

The series DK20/DK34 offer a static Teach-In, the DK21/DKE21/DK31/DK35 series offer a dynamic Teach-In.

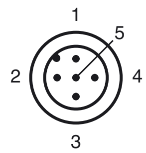
Dimensions



Electrical connection



Pinout



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Technical data

General specifications		
Sensor range		300 mm
Detection range		3 ... 300 mm
Light source		laser diode
Light type		modulated visible red light
Laser nominal ratings		
Note		LASER LIGHT , DO NOT STARE INTO BEAM
Laser class		2
Wave length		650 nm
Beam divergence		< 1.5 mrad
Pulse length		1.5 µs
Repetition rate		108.7 kHz
max. pulse energy		2.1 nJ
Light spot representation		approx. 0.8 mm at a distance of 300 mm
Ambient light limit		
Continuous light		40000 Lux
Functional safety related parameters		
$MTTF_d$		550 a
Mission Time (T_M)		20 a
Diagnostic Coverage (DC)		60 %
Indicators/operating means		
Function indicator		LED yellow: lights up if receiver is lit (light on), lights up if receiver is not lit (dark on)
Control elements		Light/Dark switch, sensitivity adjuster
Electrical specifications		
Operating voltage	U_B	10 ... 30 V DC
Ripple		10 %
No-load supply current	I_0	≤ 55 mA
Input		
Test input		emitter deactivation with +Ub
Output		
Switching type		light/dark on switchable
Signal output		Push-pull output, short-circuit protected, reverse polarity protected
Switching voltage		PNP: U_B - 2.5 V / NPN: U_{Rest} 1.5 V
Switching current		max. 200 mA
Switching frequency	f	16.5 kHz
Response time		30 µs
Ambient conditions		
Ambient temperature		-10 ... 50 °C (14 ... 122 °F)
Storage temperature		-20 ... 75 °C (-4 ... 167 °F)
Mechanical specifications		
Protection degree		IP67
Connection		M12 x 1 connector, 5-pin
Material		
Housing		PC (glass-fiber-reinforced Makrolon)
Optical face		glass
Mass		200 g
Compliance with standards and directives		
Directive conformity		EMC Directive 2004/108/EC
Standard conformity		
Product standard		EN 60947-5-2:2007 IEC 60947-5-2:2007
Shock and impact resistance		IEC / EN 60068. half-sine, 40 g in each X, Y and Z directions
Vibration resistance		IEC / EN 60068-2-6. Sinus. 10 -150 Hz, 5 g in each X, Y and Z directions
Laser class		IEC 60825-1:2007 Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated June 24, 2007

Approvals and certificates	
UL approval	cULus Listed , Class 2 power source
CCC approval	CCC approval / marking not required for products rated ≤36 V

Accessories

V15-G-5M-PVC
Female cordset, M12, 5-pin, PVC cable

V15-W-5M-PVC
Female cordset, M12, 5-pin, PVC cable

OMH-DK
Right-Angled Mounting Bracket

OMH-DK-1
Flat Mounting Bracket

Other suitable accessories can be found at www.pepperl-fuchs.com

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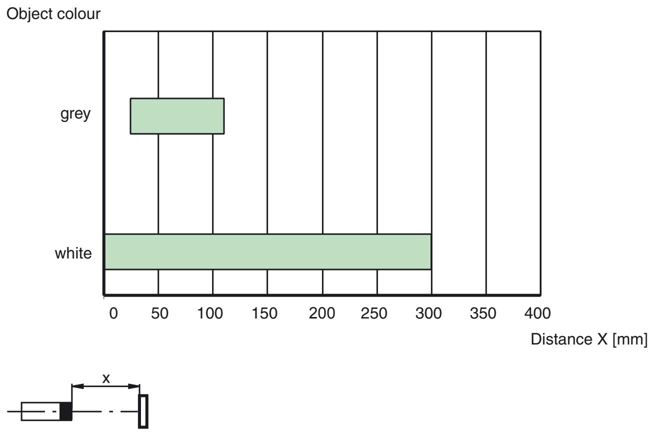
Detection ranges

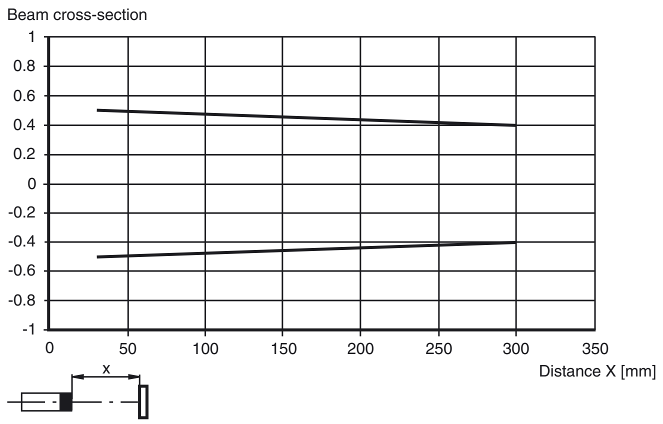
DK10-LAS



Curves/Diagrams

Emission divergence

DK10-LAS



Adjustment instructions

Switching threshold adjustment

The required switching threshold is adjusted with the sensitivity control. Please proceed as follows:

1. Switch the light/dark change-over switch to the light setting.
2. Point the light spot at the light part of the surface being scanned.
3. If the yellow indicator LED lights up, turn the sensitivity control to the left until the indicator LED goes off again. If the yellow indicator LED does not light up, miss out this step.
4. Turn the sensitivity control to the right until the indicator LED just lights up.
5. Point the light spot at the dark part of the surface being scanned.
6. The indicator LED must have gone off.
7. Turn the sensitivity control to the right again until the indicator LED lights up again. Counting the number of turns.
8. Turn the sensitivity control back to the left by half the number of counted turns.

Once the DK10 colour mark scanner has been adjusted in this way, the switching thres-hold is exactly in the middle of the measured light and dark values. The greater the number the number of times the sensitivity control is turned between the light and the dark marks, the greater the contrast.
Recommendation: The number of turns should be to > 0.5.

Switching mode adjustment:

Setting of light/dark switch	Receiver	Output PNP	Output NPN
H	exposed	inactive	active
	unexposed	active	inactive
D	exposed	active	inactive
	unexposed	inactive	active

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Laser notice laser class 2

- The irradiation can lead to irritation especially in a dark environment. Do not point at people!
- Caution: Do not look into the beam!
- Maintenance and repairs should only be carried out by authorized service personnel!
- Attach the device so that the warning is clearly visible and readable.
- Caution – Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure.

Release date: 2013-09-18 11:09 Date of issue: 2013-10-07 418066_eng.xml

GE
Measurement & Control Solutions

UNIK 5000

Pressure Sensing Platform

The UNIK 5000 is a high performance configurable solution to pressure measurement. The use of Druck silicon technology and analogue circuitry enables best in class performance for stability, low power and frequency response. The use of modular design and lean manufacturing techniques allow users to design the product required to their unique application requirements and for them to be delivered inside standard product lead times.

Features

- Ranges from 70 mbar (1 psi) to 700 bar (10,000 psi)
- Accuracy to ±0.04% Full Scale (FS) Best Straight Line (BSL)
- Stainless Steel construction
- Hazardous Area certifications (Pending)
- mV, mA, voltage and configurable voltage outputs
- Multiple electrical connector options
- Multiple pressure connector options
- Operating temperature ranges to –55 to 125°C (-67 to 257°F)
- Frequency response to 5 kHz
- High reliability
- High stability
- High over pressure capability

GE imagination at work

5000 Specifications

Measurement

Operating Pressure Ranges

Gauge ranges

Any zero based range between 70 mbar and 70 bar (1 to 1,000 psi) (values in psi are approximate)

Sealed Gauge Ranges

Any zero based range between 10 and 700 bar (145 to 10,000 psi)

Absolute Ranges

Any zero based range between 350 mbar and 700 bar (5 to 10,000 psi)

Differential Ranges

Wet/Dry

Uni-directional or bi-directional 70 mbar to 35 bar (1 to 500 psi)

Wet/Wet

Uni-directional or bi-directional 350 mbar to 35 bar (5 to 500 psi)

Line pressure: 70 bar max (1000 psi)

Barometric Ranges

Barometric ranges are available with a minimum span of 350 mbar (5.1 psi)

Non Zero Based Ranges

Non zero based ranges are available. Please contact GE Sensing to discuss your requirements

Over Pressure

- 10 × FS for ranges up to 150 mbar (2 psi)
- 6 × FS for ranges up to 700 mbar (10 psi)
- 2 × FS for barometric ranges
- 4 × FS for all other ranges (up to 200 bar for ranges ≤70 bar and up to 1200 bar for ranges >70 bar)

For differential versions the negative side must not exceed the positive side by more than:

- 6 × FS for ranges up to 150 mbar (2 psi)
- 4 × FS for ranges up to 700 mbar (10 psi)
- 2 × FS for all other ranges up to a maximum of 15 bar (200 psi)

Containment Pressure

Ranges up to 150 mbar (2 psi) gauge 10 × FS
Ranges up to 70 bar (1000 psi) gauge 6 × FS (200 bar (3000 psi) max)
Ranges up to 70 bar (1000 psi) absolute 200 bar (3000 psi)
Ranges above 70 bar (1000 psi) 1200 bar (17500 psi)

Differential (-ve port) must not exceed positive port by more than 6 × FS (15 bar (200 psi) maximum)

Supply and Outputs

Electronics Option	Description	Supply voltage (V)	Output	Current Consumption (mA)
0	mV Passive	2.5 to 12	10 mV/V^	<2 at 10 V
1	mV Linearised	7 to 12	10 mV/V^	<3
2	mA	7 to 32	4-20 mA	4-20
3	0 to 5 V 4-wire	7 to 32	0 to 5 V	<3
4	0 to 5 V 3-wire	7 to 32	0 to 5 V*	<3
5	1 to 6 V 3-wire	7 to 32	1 to 6 V	<3
6	0 to 10 V 4-wire	12 to 32	0 to 10 V	<3
7	0.5 to 4.5 V Ratiometric	5.0 ± 0.5	0.5 to 4.5 V	<3
8	Isolated/Configurable	7 to 36	See below	See below

^ with a 10 volt supply mV output sensors give 100 mV over the full scale pressure.
- Output is ratiometric to the supply voltage
- Output reduces pro-rata below 350 mbar (5 psi)

*0 to 5 V 3-wire output is non true zero. At pressures below 1% of span the output will be fixed at approximately 50 mV

Isolated/Configurable (Option 8)

Any pressure signal output configurations will be available, subject to the following limitations:

- Minimum span: 2 V
- Maximum span: 20 V
- Output limits: ±10 V
- Maximum zero offset: ≤ span

Reverse output response to pressure is available.
The output will continue to respond to 110% FS. i.e. if a 0 to 10 V output is specified, the output will continue to increase proportionally to applied pressure until at least 11 V.
Current consumption is <20 mA @ 7 Vdc supply, reducing to <5 mA @ 32 Vdc supply. On startup <100 mA drawn for 10 ms typically.

Examples

Allowed	Not Allowed
-10 to 0 V	0 to 12 V (outside ±10 V limits)
0 to 5 V	6 to 10 V (offset too big)
-5 to +5 V	0 to 0.5 V (span too small)
-2 to 10 V	
1 to 6 V	
10 to 0 V	

Power-Up Time

- mV, Voltage and current versions: 10 ms
- Isolated/configurable version: 500 ms

Shunt Calibration

Shunt Calibration provides a customer accessible connection which, when connected to -ve supply (mV) or -ve signal (isolated configurable), cause a shift in output of 80% FS in order to simulate applied pressure.
It is fitted to the mV and Isolated/Configurable versions as standard. It is not available with DIN or M12x1 electrical connectors (options 7 and G).

Performance Specifications

There are three grades of performance specification: Industrial, Improved and Premium

Accuracy

Voltage, Current and mV Linearised

Combined effects of non-linearity, hysteresis and repeatability:

Industrial:	±0.2% FS BSL
Improved:	±0.1% FS BSL
Premium:	±0.04% FS BSL

mV Passive

≤ 70 bar

Industrial:	±0.2% FS BSL
Improved:	±0.2% FS BSL

> 70 bar

Industrial:	±0.5% FS BSL
Improved:	±0.5% FS BSL

Zero Offset and Span Setting

Voltage and Current Outputs

Adjustable electrical connector options allow access to potentiometers that give at least ±5% FS adjustment (see Electrical Connector section)

Factory set to:

Industrial:	±0.5% FS
Improved:	±0.2% FS
Premium:	±0.2% FS

mV Outputs

All specifications ±3 mV

Long Term Stability

±0.05% FS typical (±0.1% FS maximum) per year increasing pro-rata for pressure ranges below 350 mbar

Temperature Effects

Four compensated temperature ranges can be chosen

Industrial Accuracy performance:

-10 to +50 °C (-14 to +122 °F):	±0.75% FS Temperature error band (TEB)
-20 to +80 °C (-4 to 176 °F):	±1.5% FS TEB
-40 to +80 °C (-40 to 176 °F):	±2.25% FS TEB
-40 to +125 °C (-40 to 257 °F):	±2.25% FS TEB

Improved and Premium Accuracy performance:

-10 to +50 °C (-14 to +122 °F):	±0.5% FS TEB
-20 to +80 °C (-4 to 176 °F):	±1.0% FS TEB
-40 to +80 °C (-40 to 176 °F):	±1.5% FS TEB
-40 to +125 °C (-40 to 257 °F):	±1.5% FS TEB

Temperature effects increase pro-rata for pressure ranges below 350 mbar (5 psi) and are doubled for barometric ranges.

Physical Specifications

Environmental Protection

- See Electrical Connector section
- Hyperbaric Pressure: 20 bar (300 psi) maximum

Operating Temperature Range

See Electrical Connector section

Pressure Media

Fluids compatible with Stainless Steel 316L and Hastelloy C276.

For the wet/dry differential version, negative pressure port: fluid compatible with stainless steel 316L, pyrex, silicone and structural adhesive.

Pressure Connector

Available options are

- G1/4 female*
- G1/4 male flat
- G1/4 male 60° internal cone
- G1/8 male 60° internal cone
- 1/4 NPT female*
- 1/4 NPT male
- 1/8 NPT male
- M20 x 1.5 male
- M14 x 1.5 60° internal cone
- M12 x 1 60° internal cone
- 7/16-20 UNF male
- G1/2 Male via Adaptor*
- 1/2 NPT Male via Adaptor*
- Depth Cone (G1/4 female)

Choose connectors marked * for pressure ranges over 70 bar.

Other pressure connectors may be available.

Contact GE Sensing to discuss your requirement

Electrical Connector

Various electrical connector options are available offering different features

Code Number	Description	Max Operating temp range °C	°F	IP rating	Zero span Adjust
0	No Connector	-55 to +125	-67 to +257	-	Y
1	Cable Gland	-40 to +80	-40 to +176	65	N
2	Raychem Cable	-55 to +125	-67 to +257	65	N
3	Polyurethane Depth	-40 to +80	-40 to +176	68	N
4	Hytrel Depth	-40 to +80	-40 to +176	68	N
6	Bayonet MIL-C-26482	-55 to +125	-67 to +257	67	N
7	DIN 43650 Demountable	-40 to +80	-40 to +176	65	Y
A	Bayonet MIL-C-26482 Demountable	-55 to +125	-67 to +257	65	Y
C	1/2 NPT Conduit	-40 to +80	-40 to +176	67	N
G	M12x1 4pin	-55 to +125	-67 to +257	67	N

Electrical Connector

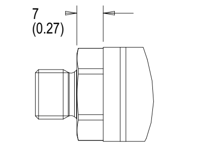
Connector Type	Option code		Electronics Option				
			4 to 20 mA	Voltage (3-wire)	Voltage (4-wire)	Isolated/Configurable	mV
Bayonet	6, A	A	+ve Supply	+ve Supply	+ve Supply	+ve Supply	+ve Supply
		B	-ve Supply	+ve Output	+ve Output	+ve Output	+ve Output
		C	-	-	-ve Output	-ve Output	-ve Output
		D		0V common	-ve Supply	-ve Supply	-ve Supply
		E	-	-	-	Shunt Cal	Shunt Cal
		F	-	-	-	-	-
DIN	7	1	+ve Supply	+ve Supply	+ve Supply	+ve Supply	+ve Supply
		2	-ve Supply	0V common	-ve Supply	-ve Supply	-ve Supply
		3	-	+ve Output	+ve Output	+ve Output	+ve Output
		E	Case	Case	-ve Output	-ve Output	-ve Output
Cable	1, 3, 4, C	Red	+ve Supply	+ve Supply	+ve Supply	+ve Supply	+ve Supply
		Yellow	-	+ve Output	+ve Output	+ve Output	+ve Output
		Blue	-	-	-ve Output	-ve Output	-ve Output
		White	-ve Supply	0V common	-ve Supply	-ve Supply	-ve Supply
		Orange	-	-	-	Shunt Cal	Shunt Cal
		Black	-	-	-	-	-
		Screen	-	-	-	-	-
Raychem Cable	2	Red	+ve Supply	+ve Supply	+ve Supply	+ve Supply	+ve Supply
		White	-	+ve Output	+ve Output	+ve Output	+ve Output
		Green	-	-	-ve Output	-ve Output	-ve Output
		Blue	-ve Supply	0V common	-ve Supply	-ve Supply	-ve Supply
		Black	-	-	-	Shunt Cal	Shunt Cal
		Screen	-	-	-	-	-
Molex	0	1 Red	+ve Supply	+ve Supply	+ve Supply	+ve Supply	+ve Supply
		2 Yellow	-	+ve Output	+ve Output	+ve Output	+ve Output
		3 Green	-	-	-ve Output	-ve Output	-ve Output
		4 Blue	-ve Supply	0V common	-ve Supply	-ve Supply	-ve Supply
		5 Orange	-	-	-	Shunt Cal	Shunt Cal
		6 Black	-	-	-	-	-
M12 X 1 4-Pin	G	1	+ve Supply	+ve Supply	+ve Supply	+ve Supply	+ve Supply
		2		+ve Output	+ve Output	+ve Output	+ve Output
		3	-ve Supply	0V common	-ve Supply	-ve Supply	-ve Supply
		4	Case	Case	-ve Output	-ve Output	-ve Output

Certification

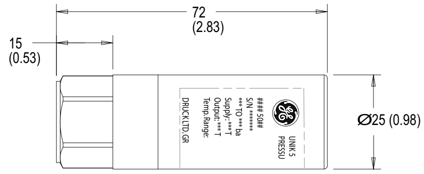
- CE Marked
- RoHS
- EMC Standards

BS EN 61000-6-1: 2007	Susceptibility - Light Industrial
BS EN 61000-6-2: 2005	Susceptibility - Heavy Industrial (except mV versions)
BS EN 61000-6-3: 2007	Emissions - Light Industrial
BS EN 61000-6-4: 2007	Emissions - Heavy Industrial
BS EN 61326-1: 2006	Electrical Equipment for Measurement, Control and Laboratory Use - EMC requirements

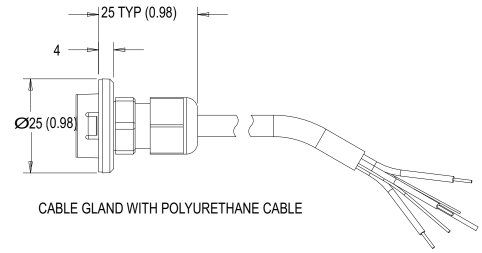
Mechanical Drawings



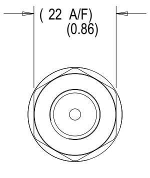
MALE PRESSURE CONNECTION

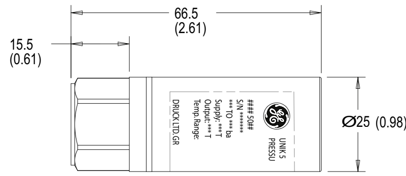


HIGH PRESSURE
CONSTRUCTION

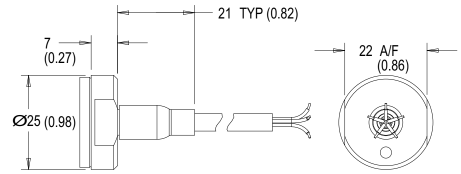


CABLE GLAND WITH POLYURETHANE CABLE

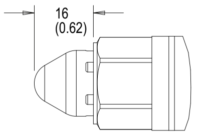




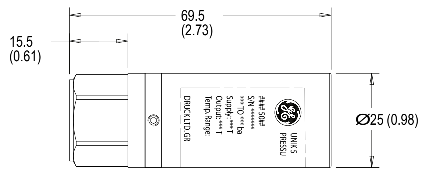
MEDIUM PRESSURE
CONSTRUCTION



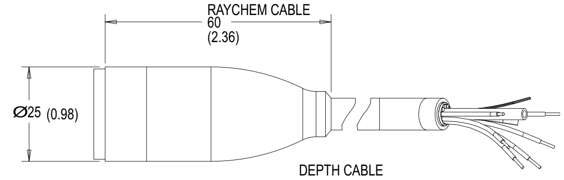
RAYCHEM CABLE



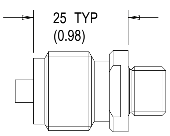
DEPTH CONE
PRESSURE ADAPTOR



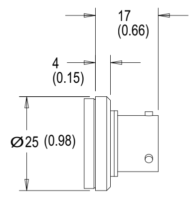
LOW PRESSURE
CONSTRUCTION



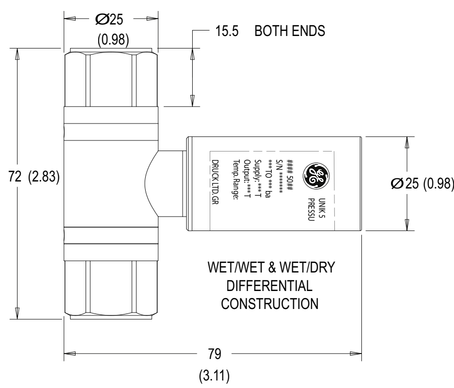
DEPTH CABLE



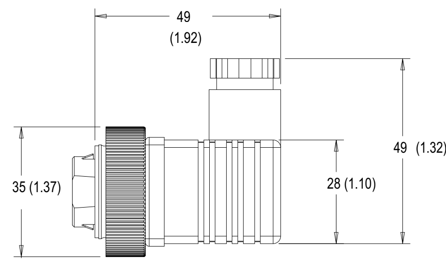
OPTIONAL WELDED
PRESSURE ADAPTOR



BAYONET MIL-C-26482
NON-DEMOUNTABLE



WET/WET & WET/DRY
DIFFERENTIAL
CONSTRUCTION



DIN 43650 DEMOUNTABLE

NOTES:

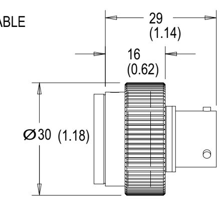
[1] DIMENSIONS SHOWN ARE FOR STANDARD LENGTH PRODUCTS WITH THE FOLLOWING ELECTRICAL OUTPUT OPTIONS:
mV LINEARISED (PDCR)
4 TO 20 mA (PTX)
STANDARD VOLTAGE OPTIONS (PMP)

FOR mV PASSIVE (PDCR) - SUBTRACT 10mm (0.39 in)
FOR ELECTRICALLY ISOLATED VOLTAGE (PMP) - ADD 15mm (0.59 in)

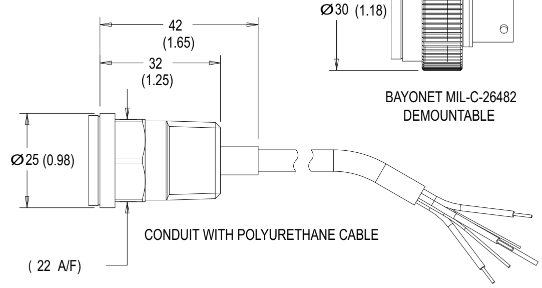
[2] REFER TO PAGE 3 FOR LIST OF PRESSURE CONNECTION OPTIONS (ORIENTATION NOT CRITICAL)

[3] ALL DIMENSIONS ARE IN MILLIMETERS (INCHES IN PARENTHESES)

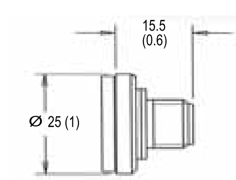
(4) HIGH PRESSURE IS >70 BAR (1000 PSI)
MEDIUM PRESSURE
INDUSTRIAL ACCURACY >1 BAR ≤ 70 BAR (1000 PSI)
IMPROVED/PREMIUM ACCURACY >2 BAR ≤ 70 BAR (1000 PSI)
LOW PRESSURE
INDUSTRIAL ACCURACY ≤ 1 BAR (15 PSI)
IMPROVED/PREMIUM ACCURACY ≤ 2 BAR (29 PSI)



BAYONET MIL-C-26482
DEMOUNTABLE



CONDUIT WITH POLYURETHANE CABLE



M12 x 1 4-PIN

Ordering Information

(1) Select model number

Main Product Variant

PMP Amplified Pressure Transducer
PDCR mV Pressure Transducer
PTX 4-20 mA Pressure Transmitter

Product Series

5 UNIK 5000

Diameter and Material

0 25mm Stainless Steel

Electrical Connector

0 No Electrical Connector
1 Cable Gland (Polyurethane Cable)
2 Raychem Cable
3 Polyurethane Cable (Depth)
4 Hytrel Cable (Depth)
6 MIL-C-26482 (6-pin Shell Size 10) (Mating connector not supplied)
7 DIN 43650 Demountable (Mating connector supplied)
A Demountable MIL-C-26482 (6-pin Shell Size 10) (Mating connector not supplied)
C 1/2" NPT Conduit (Polyurethane cable)
G M12 x 1 4-pin male (Mating connector not supplied)

Electronics Option

0 mV Passive 4-wire (PDCR) **Note 1**
1 mV Linearised 4-wire (PDCR)
2 4 to 20 mA 2-wire (PTX)
3 0 to 5 V 4-wire (PMP)
4 0 to 5 V 3-wire (PMP)
5 1 to 6 V 3-wire (PMP)
6 0 to 10 V 4-wire (PMP)
7 0.5 to 4.5 V Ratiometric 3-wire (PMP)
8 Isolated/Configurable V 4-wire (PMP)

Compensated Temperature Range

TA -10 to +50 °C (14 to 122 °F)
TB -20 to +80 °C (-4 to +176 °F
TC -40 to +80 °C (-40 to +176 °F)
TD -40 to +125 °C (-40 to 257 °F) **Note 2**

Accuracy

A1 Industrial
A2 Improved
A3 Premium

Calibration

CA Zero/Span Data
CB Room Temperature
CC Full Thermal

Hazardous Area Approval

H0 None

Pressure Connector

PA G1/4 Female **Note 3**
PB G1/4 Male Flat
PC G1/4 Male 60 degree Int Cone
PD G1/8 Male 60 degree Int Cone
PE 1/4 NPT Female **Note 3**
PF 1/4 NPT Male
PG 1/8 NPT Male
PH M20x1.5
PJ M14x1.5 60° Cone
PK M12x1 Internal Cone
PL 7/16 UNF Male
PN G1/2 Male via Adaptor **Note 3**
PR 1/2 NPT Male via adaptor **Note 3**
PS G 1/4 Swagelok Bulkhead
PT G1/4 Male Flat Long
PU 7/16-20 UNF Long 37 degree flare tip
PV 7/16 UNF Female
PW Depth Cone (G1/4 Female)

PTX 5 0 7 2 - TA - A2 - CB - H0 - PA **Typical Model Number**

Ordering Notes

Note 1 Premium Accuracy is not available on this version
Note 2 Please ensure that the electrical connector selected is option 0, 2, 6, or A.
Note 3 Select one of these pressure connectors for pressure ranges over 70 bar

2) State pressure range and units: e.g. 0 to 10 bar, -5 to + 5 psi

Unit options are:

Symbol	Description
bar	bar
mbar	millibar
psi	pounds/sq. inch
Pa	Pascal
hPa	hectoPascal
kPa	kiloPascal
MPa	MegaPascal
mmH_2O	mm water
cmH_2O	cm water
mH_2O	metres water
inH_2O	inches water
ftH_2O	feet water
mmHg	mm mercury
inHg	inches mercury
kgf/cm^2	kg force/sq. cm
atm	atmosphere
Torr	torr

3) State Pressure reference: e.g. gauge

Reference options are:

- gauge
- absolute
- barometric
- sealed gauge
- wet/dry differential
- wet/wet differential

4) State cable lengths and units: e.g. 1m cable, 8 ft cable (only required on certain electrical connectors)

5) Output option 8 only: State voltage output at minimum and maximum pressure: e.g. output –1 to 9 V

Typical order examples:

PTX5012-TB-A2-CA-H0-PA, 0 to 10 bar, gauge, 3 m cable
PMP5028-TD-A3-CC-H0-PE, -15 to 75 psi, gauge, 15ft cable, output voltage -1 to 5 volts
PDCR5071-TB-A1-CB-H0-PB, 0 to 100 bar, sealed gauge

Accessories

Mating connector for MIL-C-264821 (Electrical connector option 6 and A) under part number S-163-009 www.gesensinginspection.com

920-483E
(SDS0013)