NTNU
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Subsea Gas Boosting Laboratory: Design and Construction

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Task Description

For subsea oil and gas fields to produce hydrocarbons, there must be enough pressure to force the fluids to the surface. In some cases, it may be necessary to artificially increase the pressure. Reasons include deep water, ageing field (pressure drops as a field ages) and long tieback distances.

For predominantly liquid hydrocarbons (i.e, oil), pump-based boosting has been used for several years in a large number of fields worldwide. Gas boosting, by using compressors, is in its infancy, used only on two fields on the Norwegian continental shelf. There are significant technical issues to overcome before gas boosting becomes commonplace.

To investigate issues connected to gas boosting, the Department of Production and Quality Engineering at NTNU wishes to construct a lab, at a cost of approximately 150.000 NOK. In this project, master students will design and construct this lab.

This master project is a continuation of work done during the autumn project "Subsea Gas Boosting: Laboratory Design" undertaken during the autumn semester of 2015. As part of that project, the design of the lab was largely completed. The tasks for the master project is completing the remaining parts of the design (mostly connected to the sensor system and the electrical system) and constructing the lab. Designing the software to operate the lab is not part of the project.

Key aspects of this project are:

- Literature review of existing and future subsea gas boosting systems.
- Designing laboratory facilities, selecting equipment, choosing vendors and solving other practical issues as may arise.
- Budgeting and ordering of parts from selected vendors.
- Finalizing the physical construction of the lab, including the electrical system.
- Write the documentation necessary to use and maintain the lab.

Acknowledgements

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Abstract

Enhanced oil recovery has been a major focus area for the oil and gas industry over the past years. The need for more and better recovery methods has increased as many of the major oil and gas fields are entering the last phases of their lifetime. Subsea boosting technology was introduced as a result of this. The most common boosting methods are subsea multiphase pumping for transport over longer distances and water injection for increased reservoir pressure.

The latest development in subsea boosting is subsea gas compression. In this project the different existing subsea gas compression solutions are presented.

To investigate issues connected to gas boosting, the Department of Production and Quality Engineering at NTNU wanted to construct a laboratory. The goal of this master project was to design and construct this laboratory, at a cost of approximately 150.000 NOK.

The lab objectives include control of the flow in the system, mapping of the compressor characteristics, using the lab as a pre-testing facility before full-scale testing at the Department of Energy and Process Engineering, and using it for educational purposes.

The main components of the lab are a turbocharger, a piston compressor, a separator, a cooler and flow control valves.

It is possible to run three different scenarios to emulate the different existing wet gas compression solutions. The first is wet gas compression with separation where the gas and liquid are boosted separately before being rejoined in a multiphase pipeline. The second scenario is wet gas compression without separation. The separator is bypassed and the two-phase flow is compressed in the wet gas compressor. The last scenario is dry gas compression.

The final design of the lab was highly influenced by HSE. Risk analysis were conducted to find the most critical components in view of both personnel and system safety. In order to lower the risk for damage to personnel, safety measures were made that changed the physical layout of the lab.

Many of the system components had to be handmade by the student group. The main reason for this was to stay within the given budget of the lab. One example is the construction of the separator where the total cost ended at approximately 70 % less than the offer made by a potential supplier.

The lab is not yet completed. Before experiments can be conducted, software for control and monitoring of the flow has to be implemented. In addition, the lab location has to be decided to complete the final physical layout.

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List of Abbreviations

AC	Alternating Current
ASV	Anti-Surge Valve
BV	Ball Valve
DC	Direct Current
EOR	Enhanced Oil Recovery
EPT	Department of Energy and Process Engineering
ESP	Electric Submersible Pump
GOR	Gas Oil Ratio
GVF	Gas Volume Fraction
HSE	Health, Safety and Environment
HSP	Hydraulic Submersible Pump
IPK	Department of Production and Quality Engineering
NC	Normally Closed
NO	Normally Open
OWV	One Way Valve
PC	Polycarbonat
PMMA	polymethylmethacrylate
PT	Pressure Transmitter
PVC	Polyvinyl Chloride
PWM	Pulse Width Modulation
RPM	Revolutions Per Minute
TT	Temperature Transmitter

Chapter 1

Introduction

This master thesis is a continuation of the specialization project "Subsea gas boosting-Laboratory design" from the autumn of 2015. Excerpts taken from the specialization project will be explained and referred to in the thesis.

1.1 Objective

The objective of this master project is to perform a literature study of existing solutions, plan, design and build a subsea gas boosting laboratory. All aspects concerning the laboratory is part of the project. This means budgeting, design, component selection, laboratory placement, construction and procurement. In the report, the laboratory will be referred to as the lab. To limit the scope of the thesis, only wet gas compression was studied as a subsea boosting method.

1.2 Method

The design of the lab was based on existing subsea gas compression solutions. This is to be able to use the lab as a test facility when investigating gas boosting as the task description states. Another source of inspiration was the wet gas compression lab at the Department of Energy and Process Engineering (EPT) at NTNU.

1.3 Report structure

Chapter 1 presents subsea boosting and existing solutions. Chapter 2 presents an overview of the lab objectives and purpose. Chapter 3 presents a thorough description and explanation of the chosen design of the lab. Chapter 4 presents the HSE aspects of the lab, with respect to personnel safety and component reliability. The results of the project, as well as a detailed description of future work and how to implement the remaining components into the system, is presented in Chapter 5.

1.4 Background

Enhanced oil recovery (EOR) has received more and more focus from oil companies worldwide over the past years. The need for better recovery methods has increased as the production rate in ageing oil and gas fields naturally decreases. In addition, the focus on cost reduction and effectiveness has increased over the past two years as the oil price has dropped dramatically forcing companies to be more careful with investments. It is often more economical to find solutions to increase the lifetime of an existing field, rather than finding and developing a new and perhaps more challenging field.

Boosting technology was developed to increase the recovery rate from old, existing fields, as well as using this infrastructure for development of new fields. As the oil and gas field ages, the reservoir pressure decreases. The pressure reduction decreases the production rate of the well, which in the end will stop the total production if no actions are taken.

Figure 1.1 shows the potential increase in plateau, maturation and tail production of an oilfield with EOR methods.

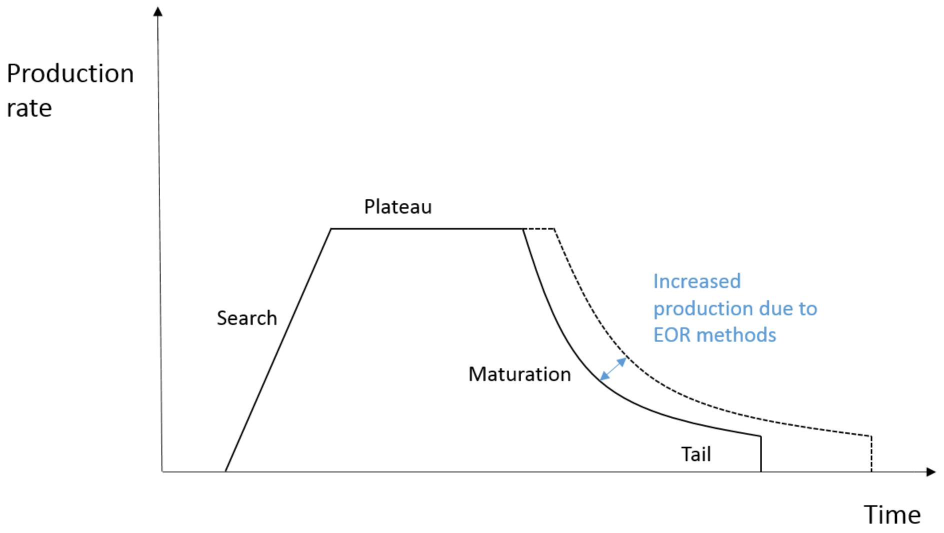


Figure 1.1: Production rate with and without enhanced oil recovery [39].

In the beginning, water injection was the only EOR method. After a while, the technology evolved and was moved subsea for other purposes such as transport over long distances and tie-back of new wells and fields into existing infrastructures. Subsea boosting is a major part of the finalization of the ”subsea factory” where the production, processing and storage equipment is moved from topside to the seabed. The oil and gas industry has worked for this since the beginning of subsea technology in the 1980’s [65].

By installing a subsea boosting method, the pressure over the wellhead is decreased as the hydrostatic pressure in the riser is removed. This allows the reservoir fluid to flow more freely.

Subsea boosting has increased the lifetime of many offshore fields around the world and the technology allows a much higher recovery rate from oil and gas reservoirs than what was possible just a few years ago. In addition, it allows production from new and more challenging fields. New fields may be in ultra deep waters or in remote areas such as the arctic where ice is a major obstacle to overcome. Subsea boosting enables production from these reservoirs which was unthinkable in the past. An overview of past, existing and future subsea boosting solutions is given in the following sections.

1.4.1 Water injection

Water injection was the first boosting method developed. Water is injected into the reservoir to increase the pressure and thereby the production. This technology was developed in the US in the 1920's, and by the 1970's most onshore oilfields in the US and China where using water injection as a boosting method [49].

The water used in injection may be external brine water or water produced with the hydrocarbons. It is then re-injected into the formation. It is sometimes necessary to filter and process the water before injection. This is to ensure that no material or bacteria growth clogs the formation pores. In addition, oxygen is often removed from the water to reduce corrosion in production pipes and equipment.

There are different techniques for determining where the injection wells should be drilled. The five-spot pattern is one technique. Four injection wells are drilled in a square around one production well. This is repeated around all the production wells resulting in four injection wells surrounding one production well and vice versa. There are also techniques where the wells are drilled in line patterns. The effectiveness of water injection can vary from 5-50 % increased recovery, depending on the formation characteristics. Figure 1.2 gives a schematic overview of water injection. [53]

One of the greatest contributors to increased production on the Ekofisk field in the North Sea was the introduction of water injection in 1981. The Ekofisk field was discovered in 1969 and was the first commercial oil discovery on the Norwegian Continental Shelf. The pilot water injection well was the first ever to be drilled in a chalk reservoir, and at the time many believed that it was impossible to produce from such a reservoir at all. After positive results from the pilot well, a new water injection platform was installed and injection began in 1987. Today, the operators are still injecting water into the field to maintain the production rate. [22]

Water from the production flow can also be used for re-injection into the reservoir. The water must be separated from the well stream. To avoid excessive pipelines from seabed to the platform, subsea separation for water injection was introduced. The water is separated at seabed and redirected into the reservoir.

The worlds first subsea separation unit was installed on the Troll field in the North Sea in 2001. This field is operated by Statoil and the Troll C separation station (Troll pilot) is located 3.5 km from the Troll C platform at a water

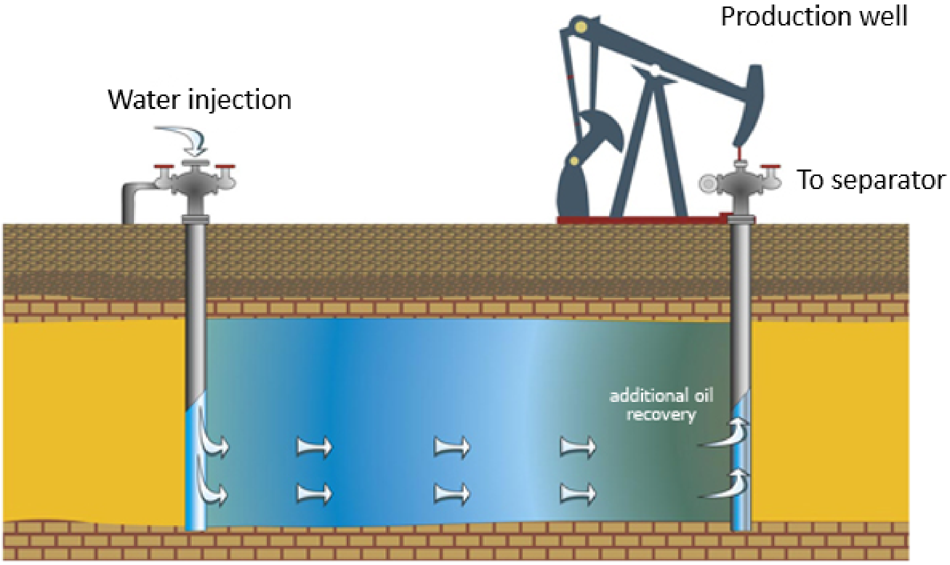


Figure 1.2: Water is pumped into the reservoir which forces the hydrocarbons to the surface [46].

depth of 340 m [66]. The well stream enters a horizontal separator and the water is directed into a centrifugal re-injection pump. This results in a further pressure increase of the water [34]. When separated from the water, the oil and gas flows back to the Troll C for further treatment and transportation to shore. [44]

1.4.2 Subsea pumping

The oldest subsea boosting methods are single and multiphase subsea pumping. As mentioned in Section 1.4.1, water injection was the first boosting method that was developed. However, this was for topside use and not subsea. The subsea multiphase pumping technology started its development in the late 1980's when the natural production rate of several oilfields started to decline. To increase the oil recovery rate, several companies investigated the possibility of installing subsea pumps to increase the kinetic energy in the oil and gas mixture. This would allow transportation over long distances.

Since the 80's, many different subsea single- and multiphase pump types have been developed. The choice depends on several factors such as gas volume fraction (GVF) in the flow, desired differential pressure, flow rate, viscosity of the flow and the particle content. Table 1.1 shows the most common pump types and their applications.

The first multiphase subsea pumping system was installed on the Draugen field in the Norwegian Sea in 1994. The field was operated by A/S Norske Shell and the system was designed by Framo Engineering.

The pump was installed 4 km from the Rogn South subsea well and 6 km

TYPE	CONFIGURATION	APPLICABILITY FOR SUBSEA BOOSTING
CENTRIFUGAL	HORIZONTAL OR VERTICAL	Highest differential pressure capability amongst pump types. Handles low Gas Volume Fractions <15 % at suction conditions.
HYBRID (CENTRIFUGAL & HELICO-AXIAL)	VERTICAL	Combination of helico-axial and centrifugal impeller stages. Primary application is for use downstream of separator or in low Gas Oil Ratio (GOR) applications where GVF is consistently <38 % at suction conditions.
MUDLINE ELECTRIC SUBMERSIBLE PUMP (ESP)	HORIZONTAL OR VERTICAL	Widely deployed technology used for boosting in wells, caissons, flowline-risers, and mudline horizontal boosting applications. Applicable for conditions of GVF <50 % (continuous) and for improved flow assurance.
HYDRAULIC SUBMERSIBLE PUMP	HORIZONTAL OR VERTICAL	Compact hydraulic drive boosting pump for wells, caissons & mudline applications. Applicable for conditions of GVF <75 % (continuous) and for improved flow assurance.
HELICO-AXIAL	VERTICAL	Applicable for higher GVF boosting applications - typical range of 30-95 % GVF at suction conditions. Moderate particle tolerance.
TWIN SCREW	HORIZONTAL OR VERTICAL	Good for handling high GVF - up to 98 % GVF at suction conditions. Preferred technology for high viscosity fluids.

Table 1.1: Different subsea pump types and their applications [37].

from the Draugen platform on an existing water injection template.

The fluid flowed through a 4 km flow line into the multiphase pump, where it was boosted to reach the Draugen platform. The installation increased the production rate from the Rogn South subsea well by 40 % [30].

The pump used in this project was a hydraulic submersible pump based on the helico-axial technology. It was selected after several years of testing and evaluation. Other alternatives such as the twin screw and piston pump were also considered. The helico-axial pump was preferred because it could operate with a gas volume fraction of up to 100 %. It had a very simple and robust design, relatively low weight and the pressure boosting capabilities were good. In addition, it was easy to deploy [47]. The technology was developed by the Poseidon group which consisted of the French Institute of Oil, Total and Statoil [45].

Since the Draugen project in 1994, many subsea single- and multiphase pumps have been installed around the world. The pumps have continued to develop from the hydraulic driven submersible pump at Rogn South subsea field. Due to heavier oil, deeper water and longer tie backs, the pump requirements have changed since the first installation. A higher differential pressure is often required and thereby also the power requirements for the pumps. The projects after Draugen have used electrically driven pumps instead of hydraulically driven. The reason for this development is to avoid excessive hydraulic lines, hydraulic reservoir and to shorten the response time.

Not only helico-axial, but also centrifugal, hybrid and twin-screw pumps are used. For example in 2013, two centrifugal pumps were installed at Tyrihans. These could provide a differential pressure of up to 225 bar. This is a massive increase compared to Draugen's 53 bar differential pressure.

1.4.3 Gas compression

Gas compression is the boosting method in gas fields. It has the same purpose as multiphase pumping in oilfields. Compression is also used to re-inject natural gas into producing oil wells to maintain reservoir pressure and lift liquids to the surface, also known as gas lift operations [75].

In recent years, subsea gas compression has been developed for increased production from gas wells and for enabling longer transport lines which again leads to drilling of wells in remote areas [31]. Subsea gas compression research has lasted for many years and for a long time it has been the next step in the subsea factory development. The challenge has been to find a compressor type that can compress a wet gas as traditional compressors are damaged by liquid. Wet gas is characterized by a water fraction of 2-20 % [42].

Today there exists two different solutions for subsea wet gas compression. One can compress wet gas and the other relies on full separation of gas and liquid before compression. These will be explained in detail in the following section.

1.5 Existing solutions

1.5.1 Ormen Lange subsea compression pilot system

The Ormen Lange field was discovered in 1997 and started production ten years later in 2007 [64]. The field is operated by A/S Norske Shell [64]. It consists completely of subsea installations and produces gas and gas condensate.

The flow is transported to the onshore process facility at Nyhamna before it is transported directly to the UK in gas transport lines on the seabed. It delivers up to 20% of the total gas consumption in the UK [48].

Since the production started, there have been plans of implementing a compression stage to increase the recovery rate when the production starts to decrease. Two alternatives were considered for the compression stage. The first alternative was to have onshore compression at Nyhamna together with infield compression using a semi-submersible rig. The other alternative was to have the same onshore compression, but rather than having the topside infield compression, subsea compression was considered. This way resources would be saved by removing the need for a rig in the field.

The subsea compression was the preferred alternative, but it introduced several new challenges. At the time, no company had field experience with subsea compression. This meant that everything had to be designed from scratch [48].

Ormen Lange is located far from shore, which causes a power distribution challenge. Since there are no topside facilities at Ormen Lange, the power distribution has to be delivered from Nyhamna. This also includes the control system for all the electrical components on the template.

To develop and test possible solutions, a full scale test rig was designed and built at Nyhamna. A/S Norske Shell worked together with Aker Solutions on the pilot project. If the testing proved successful, the system would be installed at the Ormen Lange field.

The components making up the compressor system was a centrifugal compressor, a cooler, a multiphase pump, a vertical separator, electrical motors for the compressor and the pump, and a variable speed drive for both motors. The compressor used in the system was a 12.5 MW centrifugal compressor. This compressor was not able to handle any liquid fraction in the gas, therefore the reservoir fluid was separated in a vertical separator upstream the centrifugal compressor. This was to separate sand and condensate from the gas.

The dry gas was led into the centrifugal compressor where the pressure increased from 80 barg to approximately 140 barg. After compression, the gas would be transported to shore.

The condensate and sand, that was separated from the gas, left the separator was guided to a 400 kW multiphase pump before it was rejoined with the gas in the multiphase pipeline to shore. The gas and condensate would be separated again when it reached the process facility at Nyhamna. The reason the gas and condensate would be transported together to shore was to avoid the cost of installing an extra subsea pipeline.

Figure 1.3 shows the Ormen Lange test pit.

Figure 1.3: The Ormen Lange test pit [70].

The testing seemed very promising, however, in 2014 the installation plans were postponed. The reason for this was an updated cost analysis for the project and uncertainty regarding the remaining reserves in the reservoir. [4] [43]

1.5.2 Åsgard wet gas compression system

The Statoil operated Åsgard field started production in 1999 and produces both oil, gas and condensate. The field is one of the biggest on the Norwegian Continental Shelf when it comes to infrastructure development. It consists of a production ship, a storage ship and a semi-submersible rig [60].

The Åsgard subsea compression project started in 2005, and in 2010 Aker Solutions was given the contract to deliver the compression system to Statoil.

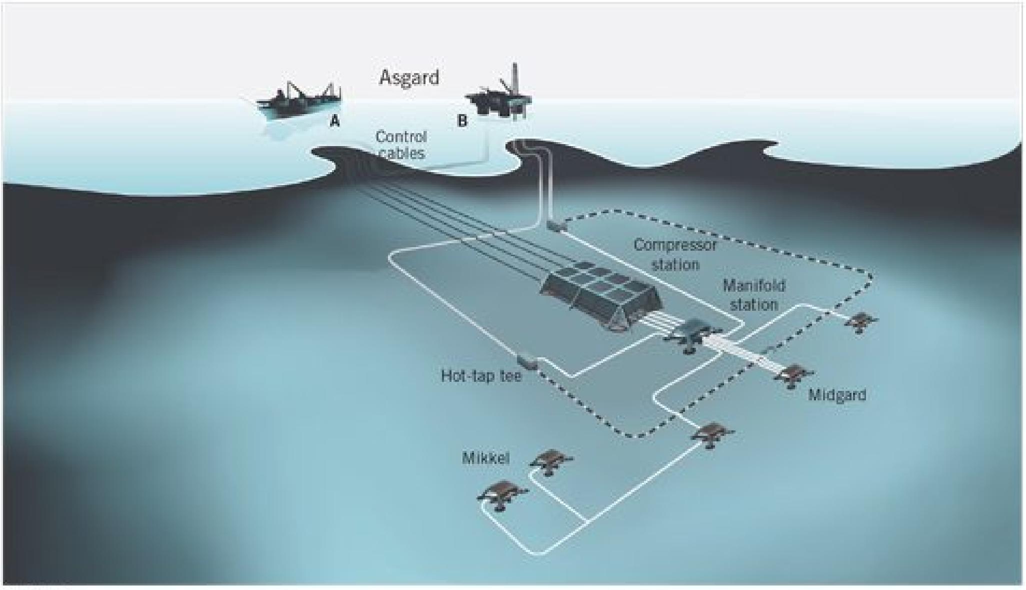
The system is based on the same design as the Ormen Lange subsea compression system where the condensate is separated from the gas before compression. The system is made up of two identical compressor trains which consists of a vertical separator, a cooler, a 10 MW centrifugal compressor and a multiphase pump. It receives power from the floating production ship Åsgard A.

The well stream flows into the separator, where the dry gas is separated before it is compressed and sent to Åsgard B for further treatment. The condensate exits the separator and flows to a multiphase pump before it joins the dry gas again for further treatment at Åsgard B.

Figure 1.4 shows the layout of the compression system.

ASGARD

FIG. 2



Source: Statoil

Figure 1.4: Field layout of Åsgard subsea wet gas compression system [23].

The final system was installed during the summer of 2015 and is expected to increase the recovery rate at the Midgard reservior from 67 % to 87 %. In addition, the system boosts the gas from the Mikkel reservoir increasing the recovery rate from 59 % to 84 %. In total, it is estimated that the subsea wet gas compression system will give an additional 306 million barrels of oil equivalents [67].

1.5.3 Gullfaks wet gas compression

The Gullfaks field is operated from three production platforms, Gullfaks A, B and C. It produces both oil and gas and production started in 1986, 1988 and 1989 respectively. Since the production started, several satellite wells have been drilled on the Gullfaks field. These are all subsea wells and are remotely operated from Gullfaks A and Gullfaks C.

The operators decided to invest in a subsea wet gas compression system in the subsea satellite wells Gullfaks Sør in 2012. The wells are connected to the Gullfaks C platform. It is estimated that the wet gas compression installation could potentially increase the recovery rate of the Gullfaks Sør field from 63 % to 73 % [63].

OneSubsea was given the task of developing the wet gas compression system for the Gullfaks Sør field, in collaboration with Statoil and Shell. They presented a solution that is especially designed for small and medium size reservoirs. In addition, the technology is very flexible which means it can be implemented in both new and existing fields. One of the goals for the wet gas compressor was to eliminate the need for subsea separation and hence make it small and compact, and more economical. To achieve this, OneSubsea had to develop a gas compressor that could handle both gas, liquid and sand. The innovative solution was a counter-rotating compressor that could handle all liquid fractions in addition to sand. The design was based on the well proven multiphase helico-axial pump that has been used for many years in subsea multiphase boosting.

Two 5 MW wet gas compressors were installed on the Gullfaks Sør template. The flow from the reservoir passes through a mixer to ensure a homogenous flow through the compressor. After the mixer, the flow passes through a cooler in order to increase the density of the gas. The increased density ensures a more efficient compression. To be able to withstand the mixed flow from the reservoir that contains gas, oil, water and even sand, the two compressors operates at a relatively low speed.

Both compressors are actuated by their own 2.5 MW electric motor, which receives its power from the Gullfaks C platform. The two compressors can be run either in parallel or in series, depending on whether a higher flow or higher pressure regime is desired. When running in parallel, the pressure increase is 32 barg. However, since this is a low pressure production, the compressors are running in series, ensuring a pressure increase of 60 barg. This is only an issue when using centrifugal compressors. [62][40]

Figure 1.5 shows the two wet gas compressors installed at Gullfaks.

Figure 1.5: The two wet gas compressors installed at Gullfaks [40].

Chapter 2

Lab objectives

The purpose of this lab is to emulate wet gas boosting as it is done in the oil and gas industry. An existing full scale wet gas compression lab is located at the Department of Energy and Process Engineering (EPT) at NTNU. The small scale lab designed in this project differs from this. It is based on educational- rather than experimental capabilities like the one at EPT. The full scale lab is often used by the industry, thus making it unavailable for students. In addition, students not belonging to EPT have to make appointments and internal rent has to be paid to conduct educational experiments.

By designing a small scale lab at the Department of Production and Quality Engineering (IPK), there will be less restrictions on the use as the system flow and pressure will be much lower than at EPT. A small scale lab can also be used as a test facility before conducting an expensive full scale experiment at EPT.

The components and the design of the lab are based on the lab objectives set in this project. At the same time keeping the design as general as possible to ensure a wide application use, both now and in the future. A presentation of the lab objectives are listed below.

Control

The main objective of the lab is to control the flow in the system. By alternating the rotational speed of the compressors and regulating the flow control valves, the flow characteristics will change. The control system can be based on pressure-, temperature- and rotational speed readings.

Wet gas compressor characteristics

Another objective is to map the compressor characteristics of the wet gas compressor with different water levels in the flow. Small scale wet gas compressor is not a typical application in the industry, therefore neither one of the compressors for the lab are especially made for this use. However, one of the compressors is assumed to handle water and mapping of the characteristics is therefore of interest.

Pre-testing facility

The lab can be used as a pre-test facility before full scale testing at EPT. This is to prove that a full scale test is necessary. This way internal rent can be saved in case of a failed pre-test.

Educational use

The lab can function as a lab and test facility for university subjects which contains control systems, compressors, anti-surge systems, motor control, valve control and temperature/pressure measurement. It will also show compression processes and valve effects in practice.

Chapter 3

Design

Section 1.5 presented the two existing system solutions for wet gas compression on the market today. The subsea boosting lab will test both of these. This lab was therefore based both on the Ormen Lange and the Gullfaks gas boosting design. In order to test the different technologies, the lab was designed as a loop with two sub-loops. The inner loop is a separation loop where the water is separated from the multiphase flow. The gas is compressed and the separated water is pumped and rejoined with the gas flow in a multiphase pipe. In the outer loop the separator is bypassed and the flow is boosted as a mixed flow.

The main components of the lab are:

- Turbocharger
- Piston compressor
- Counter flow cooler
- Gravity separator
- Gear pump
- Flow control valves

The turbocharger was assumed to handle water fractions and will be used as a wet gas compressor. This is explained in detail in Section 3.6. Figure 3.1 shows the system drawing of the lab.

3.1 Test scenarios

Before conducting experiments on the lab, the system has to be pressurized. This is to make sure there is enough air to run the compressors. The lab will test mainly three scenarios:

- **Wet gas compression with separation.**
  In this experiment, ball valve 1 is closed and ball valve 2 is open, see Figure 3.1. The air is separated from the water in the separator and leaves through the air outlet at the top through a coalescence plate. The

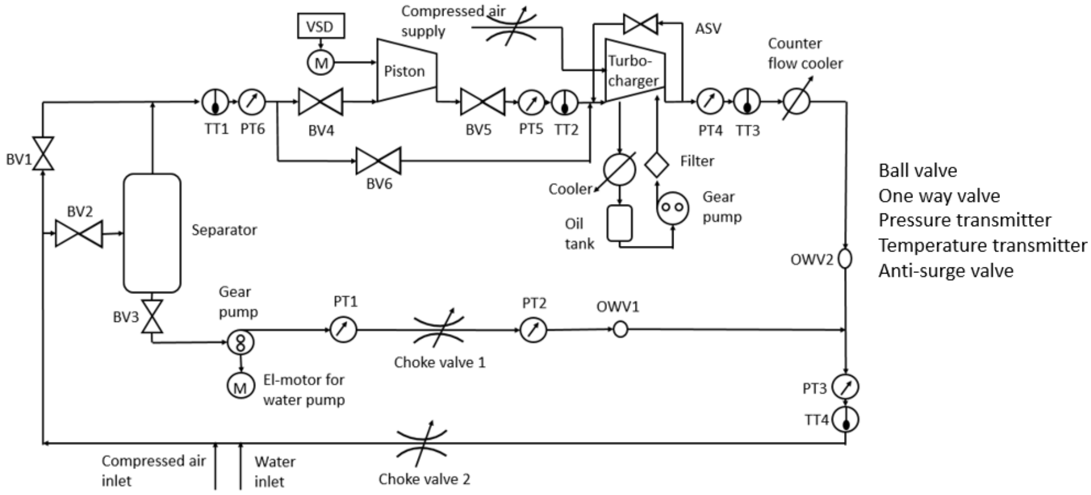


Figure 3.1: Subsea wet gas compression lab, system drawing

dry gas is then fed to the turbocharger via the piston compressor by-pass line. The gas is cooled in the counter flow cooler after the turbocharger. It is then joined by the water stream from the separator. The water level in the separator is controlled by a level transmitter which activates a gear pump.

The pressurized water flows through a choke valve that depressurizes the stream to the same pressure as the dry gas. This ensures that the two streams can mix and become wet gas again. The wet gas flows through another choke valve to reduce the pressure of the total flow before it re-enters the separator for new separation.

The reason the piston compressor is bypassed is because it is very sensitive to water and particles. The flow out of the separator cannot be controlled to a satisfying level to ensure that the air is completely dry. The piston compressor was originally intended to be part of the ”wet gas compression with separation” scenario, but after close evaluation it was decided that the risk for failure was too high. However, this is a part that can be improved at a later stage. That is why the bypass line is still a part of the system.

- **Wet gas compression without separation.**
  Before this experiment is conducted the decided water volume fraction has to be added to the system, ball valve 2 needs to be shut and ball valve 1 opened. To avoid slugs, the water inlet is located upstream the separator for longer travelling distance into the turbocharger. The piston compressor is bypassed again and the water and gas will flow into the turbocharger and be compressed as one. The compressed flow is cooled in the counter flow cooler and returned through choke valve 2 to the

turbocharger for re-compression.

- **Dry gas compression.**
  The reason for testing only dry gas is to be able to control the electrical motor of the piston compressor. The piston compressor does not handle any water. In this experiment there is no water in the system, and the separator can be bypassed. Both the piston compressor and the turbocharger will compress in series. The gas is cooled and flows through the main choke valve before it is compressed again in the same way.

It is important to know the exact water volume of the flow in the system. This is to map the compressor characteristics and to verify that the flow regime is within the turbocharger's compressor map to avoid surge and choking, see Section 3.6. The calculation procedure for calculating the water volume in the system is given in Appendix C. In addition, the excel file is found in the electronic appendix.

To alter between the three scenarios the system has to be shut down. The reason is that the adjustment is controlled by the manual ball valves and no personnel should be close to the lab during operation.

In addition to the main components, there are a lot of small components for monitoring and for control of the system. These components, as well as the main components, are explained in detail in Section 3.3.2–3.10.

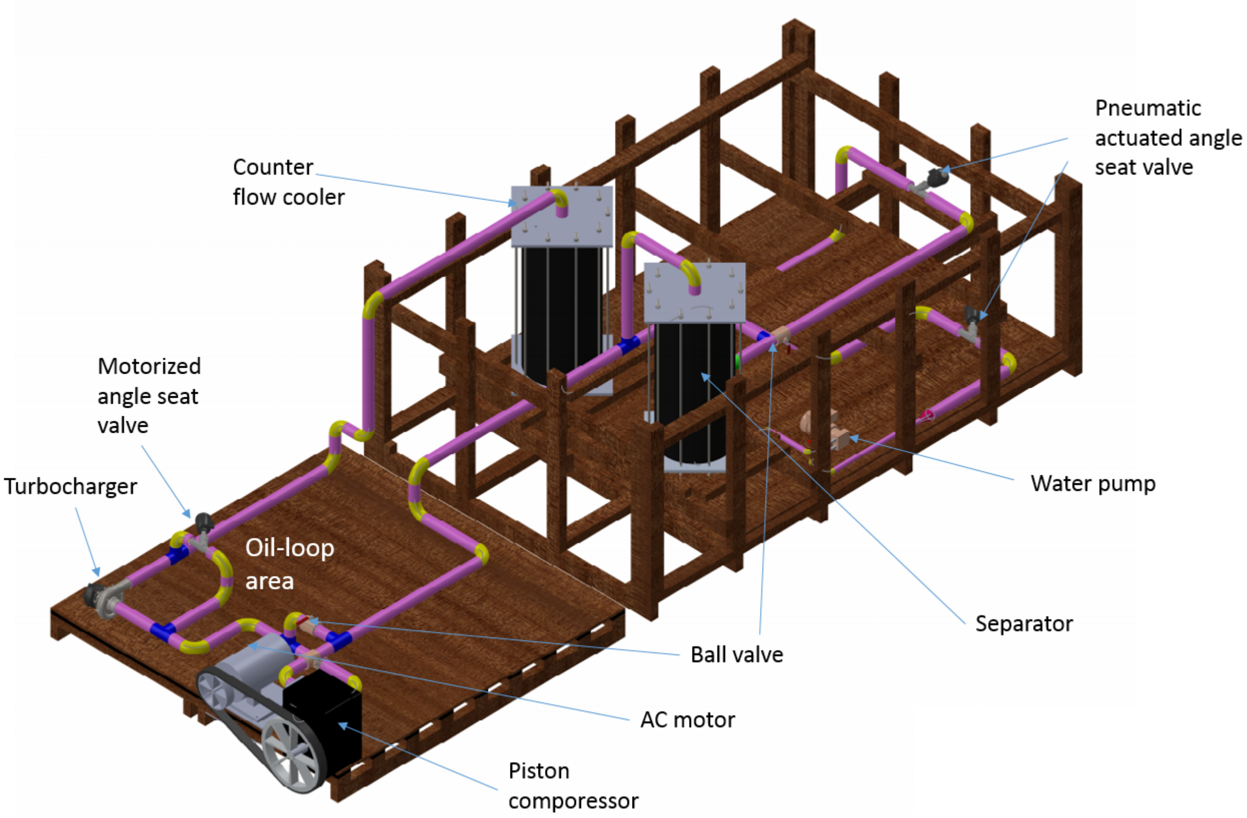


Figure 3.2: Model of the lab in Solid Works

3.2 Design limitations

There were a lot of factors that limited the design of the lab. These were chosen deliberately by the group to design and construct the lab in a satisfying manner within the given time frame. In addition, there were other limitations that influenced the design that were set by the department.

The first limitation the group set for the lab was to neglect the surrounding reservoir and hydrostatic conditions that a subsea boosting system would experience on the seabed. The lab is located in a dry environment at atmospheric pressure. In addition, the flow in the system will consist of pressurized air and water. The reason for this is their relatively similar behaviour to reservoir fluids as well as their ease to handle and obtain compared to oil and reservoir gas.

The lab was designed as a loop to avoid unnecessary spilling and waste to the environment. A flow velocity of 5 m/s was chosen to dimension a suitable turbocharger for the system. This in return gives a flow rate of 9.8 l/s based on the inner diameter of the pipes. A maximum pressure in the system of 4 barg was chosen based on the choice of using a turbocharger. This will be the maximum differential pressure that can be achieved for the system. All of the components have been chosen to ensure a pressure safety margin of at least 2 to secure safe operation when running the lab.

The budget, at NOK 150.000, was the biggest limitation set by the department. This meant the lab had to be made as economical as possible, but at the same time fulfilling the lab objectives. This influenced the choice of components greatly. Different solutions from different suppliers had to be evaluated and compared, and where the demands were not met, the student group had to design and construct the relevant components. An example of this was the construction of the separator. An offer was made from a supplier to construct a custom made separator for the system. The price of the offer was NOK 19.752, without VAT and shipping, see Appendix B. The cost of this relatively simple component would have been more than 13% of the total budget of the lab, which was not acceptable. The separator was therefore custom made by the group and the total cost ended at NOK 5.269. An overview of the laboratory expenses are given in Appendix E.

Time was another major limitation for the project. The natural time frame was two university semesters, which is about 10 months. Within this time, planning, budgeting, design, procurement, construction and report writing had to be done. Due to the relatively short period of time, a construction limitation had to be made. The group decided to focus on the hardware, while the software had to be postponed for later implementation.

The most time-consuming part of the project was the procurement phase. Every component of the system had to be carefully selected based on system requirements. The reason this phase was prolonged was due to the need for component research before a potential supplier could be contacted. In addition, the supplier had to have time and knowledge to give an offer of the correct parts. This proved to be much more time-consuming than anticipated as most of the suppliers were very busy. A selection was made, after repeatedly having to contact the same suppliers to receive an offer, based on delivery time and price.

The location and size of the lab was the last limitation set by the department. It is not yet decided where the lab location is going to be, therefore it was designed to be movable. This directly affected the size since it has to be moved by a forklift. In order to have as much space as necessary and at the same time being movable, the lab was designed in two separate modules connected via disconnectable hoses.

3.3 Separator

The calculations in the following section were obtained from the project report [17, ch.3].

As explained in the introduction of Chapter 3, both existing subsea wet gas compression technologies will be tested. Therefore, a separator had to be part of the system. Vertical separators are normally used for separation of fluids with high GVF. Due to the difference in density between water and air, a simple gravity separator with coalescence plates was designed. Figure 3.3 shows the separator mounted in the frame.

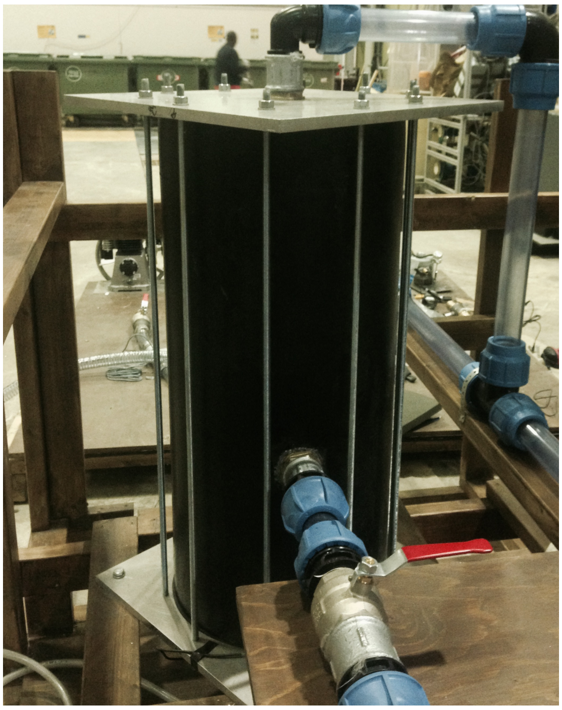


Figure 3.3: The separator mounted in the frame.

The mixed flow enters the separator where the gas, which has a much lower density than the liquid, will start to rise before it leaves at the top. The liquid will fall to the bottom. To dimension the separator, the minimum cross-sectional area had to be found based the on system specifications. The separator capacity equation was used [39, Ch.9,p.15]. It is expressed by the gas volume flow into the separator.

$$q_{Gs.c} = A_G K_s \sqrt{\frac{\rho_L - \rho_G}{\rho_G}} \left(\frac{p}{p_{s.c}}\right) \left(\frac{T_{s.c}}{T}\right) \frac{1}{z} \tag{3.1}$$

Where:

$q_{Gs.c}$	Gas volume flow at standard conditions [m^3/s]
A_G	Cross-sectional area of separator [m^2]
K_s	Separation constant [m/s]
ρ_L	Density of liquid [kg/m^3]
ρ_G	Density of gas [kg/m^3]
p	Pressure in the separator [Pa]
$p_{s.c}$	Pressure at standard conditions [Pa]
T	Temperature in the separator [K]
$T_{s.c}$	Temperature at standard conditions [K]
z	Compressibility factor

The pressure and temperature in the separator was assumed to be 3×10^5 Pa = 2 barg and 303.15 K = 30 C respectively. The separation constant, K_s, was set to 0.05 m/s, which is recommended by API [39]. Based on these values the cross-sectional area of the separator was calculated to be 35×10^{-4} m^2.

The air in the system was assumed to be an ideal gas and therefore, $z \approx 1$. This assumption was based on the generalized compressibility chart in [3, p.138]. Here the operational pressure, p_{op}, and temperature, T_{op}, has to satisfy the conditions $p_{op} << p_{cr}$ and $T_{op} > 2T_{cr}$ for a gas to be ideal. The critical pressure of air is $p_{cr} = 37.71$ barg [71], and the critical temperature is $T_{cr} = -140.5°C$ [71]. The operational pressure range for the lab is 0 barg $< p_{op} <$ 4 barg and T_{op} will never fall below the temperature of the cooling medium, see Section **??**. Hence, the conditions were satisfied and the gas could be treated as ideal.

With 35×10^{-4} m^2 as the calculated required cross-sectional area of the separator, the necessary diameter was calculated to be $d = 0.067$ m and the advised length, $L = 3\times$d$= 0.201$ m [39]. The separator was greatly over-dimensioned in the design process to have the possibility of a higher water volume in the system to ensure a sufficient flow in the pipes. It was also designed to withstand an internal pressure of 4 barg in case of a choke failure.

When choosing the materials for the separator there were different factors to consider. To limit the risk of corrosion and leakage due to poor welding, a PVC pipe was chosen as material for the outer shell. The pipe has an outer diameter of 400 mm and length 900 mm. The pipe can handle an internal pressure of 4 barg with a safety factor of 2, see Appendix B. The lids were made of aluminium. This choice is explained in Section 3.3.1.

3.3.1 Material selection of the lids

The detailed calculations and explanation of the lid material selection below were obtained from the specialization project report [17, ch.3,p.15].

For a material to be used as a lid for the separator, it had to fulfill requirements on both thickness and deflection. The maximum thickness was set to 30 mm. A thickness above this limit will make the machining process harder.

The gasket used to seal the shell is 4 mm thick. The lids were mounted to the pipe with threaded rods. In this process the lids were assumed to deflect and the gasket was assumed to compress from its original thickness, α_o =4 mm, to α_c =2 mm. The deflection could cause the plates to lose contact with the inner point of the gasket. This would increase the pressurized area inside the separator, resulting in a higher force on the lids as shown in Figure 3.5. The possibility of leakage in this case is high, and is therefore set as the deflection limit. Figure 3.4 illustrates how the maximum deflection was calculated. In reality, the lid will have a curvature shape, the straight representation is a simplification.

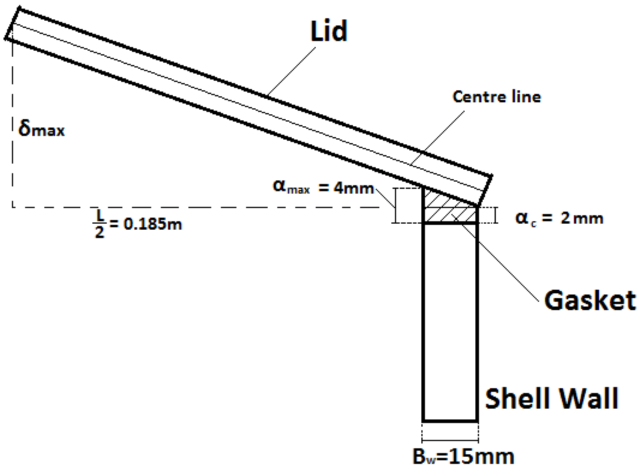


Figure 3.4: Maximum deflection of the lid

The maximum angle of deflection is given by

$$\tan(\theta_{max}) = \frac{\alpha_c}{B_w} \tag{3.2}$$

$$\tan(\theta_{max}) = \frac{\delta_{max}}{\frac{L}{2}} \tag{3.3}$$

where

θ_{max}	Maximum angle of deflection [rad]
α_c	Thickness of the compressed gasket [mm]
B_w	Wall thickness of the shell [mm]
δ_{max}	Maximum deflection [mm]

L	Length of the lid [mm]

The wall thickness of the shell is $B_w = 15$ mm and the inner diameter is 370 mm which results in $\frac{L}{2} = 185$ mm.

Inserting (3.2) into (3.3) gives a deflection limit $\delta_{max} \approx 24.6$ mm at the center of the lid.

The chosen material therefore had to fulfill the following two requirements:

- A maximum thickness H_{max}= 30 mm
- A maximum deflection of $\delta_{max} \approx 24.6$ mm

The required thickness of the lid material to withstand the internal separator conditions, was calculated by the elastic bending moment equation for a rectangular beam

$$\begin{aligned} M_{max} &= \frac{BH^2}{6}\sigma_{y,max} \\ H &= \sqrt{\frac{6M_{max}}{B\sigma_{y,max}}} \end{aligned} \tag{3.4}$$

where

M_{max}	Maximum moment on the lid [Nm]
B	Width of lid section [mm]
H	Thickness of the lid [mm]
$\sigma_{y,max}$	Maximum yield strength [MPa]

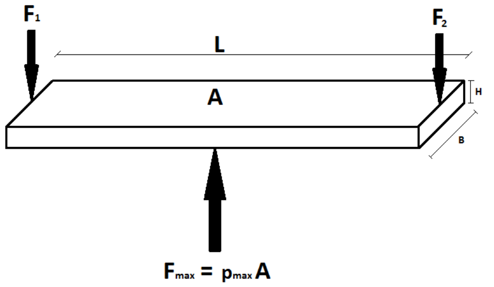


Figure 3.5: Three-point bending setup of the plate.

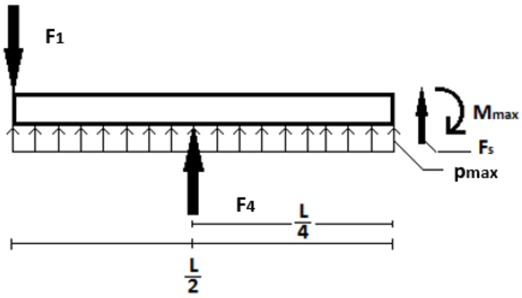


Figure 3.6: Free body diagram of the lid section.

As seen in Figure 3.5 and 3.6, the maximum pressure is an equally distributed load on the lid section, $p_{max} = 0.4$ MPa and $F_1 = F_2 = \frac{1}{2}F_{max}$. The free body diagram in Figures 3.5 and 3.6 shows the forces acting on the lids.

$$F_1 = \frac{p_{max}BL}{2} \tag{3.5}$$

where

F_1	Force acting on the lid from the threaded rods [N]
p_{max}	Maximum pressure inside separator [MPa]
B	Width of lid section [mm]
L	Length of lid [mm]

By inspection, F_4 is equal to F_1. This implies that $F_s = 0$. M_{max} is found from the moment balance-

$$\begin{aligned} \Sigma M &= 0 \\ -M_{max} - F_4\frac{L}{4} + F_1\frac{L}{2} &= 0 \\ M_{max} &= F_1\left(\frac{L}{2} - \frac{L}{4}\right) \\ M_{max} &= F_1\frac{L}{4} \end{aligned} \tag{3.6}$$

Inserting (3.5) into (3.6)

$$M_{max} = \frac{p_{max}BL^2}{8} \tag{3.7}$$

and inserting (3.7) into (3.4) results in

$$H = \sqrt{\frac{3p_{max}L^2}{4\sigma_{y,max}}} \tag{3.8}$$

The second requirement the chosen material had to fulfill was a maximum deflection $\delta_{max} = 24.6$ mm. This was calculated by

$$\delta_{max} = \frac{FL^3}{48EI} \tag{3.9}$$

where

δ_{max}	Maximum deflection of the lid [mm]
F	Maximum force on the lid [N]
E	E-modulus of the lid material [MPa]
I	Moment of inertia on the lid [kgm^2]
L	Length of the lid [mm]

$$I = \frac{BH^3}{12} \tag{3.10}$$

Inserting (3.10) into (3.9) gives

$$\delta_{max} = \frac{FL^3}{4EBH^3} \tag{3.11}$$

Polycarbonat (PC) and polymethylmethacrylate (PMMA) was considered as polymer materials for the lids.

For PC with a yield strength of $\sigma_{y,max} = 60$ MPa [6], the thickness is calculated to be $H_{PC} \approx 26mm < H_{max}$.

The E modulus for PC is $E_{PC} = 2500$ MPa [6]. This gives $\delta_{max,PC} \approx$ 41.9 mm, which exceeds the limit and therefore the material was discarded.

PMMA has a yield strength of $\sigma_{y,max} = 130$ MPa [7], which gives a required minimum thickness of $H_{PMMA} \approx 17.8$ mm $< H_{max}$ using (3.8). The E modulus for PMMA is $E_{PMMA} = 3300$ MPa and the deflection is calculated to be $\delta_{max,PMMA} \approx 101$ mm $>> \delta_{max}$. PMMA was therefore also discarded.

A third option was to consider aluminium. Aluminum alloy 5754 has a yield strength of $\sigma_y = 160$MPa. Performing the calculations for the necessary thickness gives $H_{alu} \approx 16$ mm which is within the limits.

The E modulus for this alloy is $E = 68$GPa [1]. The deflection was calculated to be $\delta_{max,alu} \approx 6.7$ mm $< \delta_{max}$.

Aluminium can handle both heat and high pressure, is corrosion resistant in the lab environment, [5], and has good machining properties. Because of these factors, aluminum was selected.

3.3.2 Assembly of the separator

Figure 3.7 shows a model of the separator. The threaded rods were used to force the lids to the shell. Corrosion resistant metallic grids, called coalescence plates, were inserted for improved separation. Small water droplets in the air that are not separated by gravity will coalesce at the grid. This way the air at the separator outlet will be dry.

All three main in-/outlets of the separator were assembled by the same principle. They consist of a threaded fitting, a rubber sealing, and a nut with an integrated washer. The fittings were passed through the relevant hole in the separator from the inside with the rubber gasket attached. The nut was fastened from the outside compressing the flange and the rubber gasket towards the separator wall/lid.

The water and air outlets were placed in the middle of the bottom and top lid respectively. Grooves was machined into the plates to keep the rubber gaskets in place when tightening the fittings. The multiphase inlet of the separator was drilled through the PVC shell. In the bottom lid, a drain connected to a water hose with a simple ball valve, was drilled. The separator drain outlet was placed at the lowest level of the lab to secure proper drainage of the system.

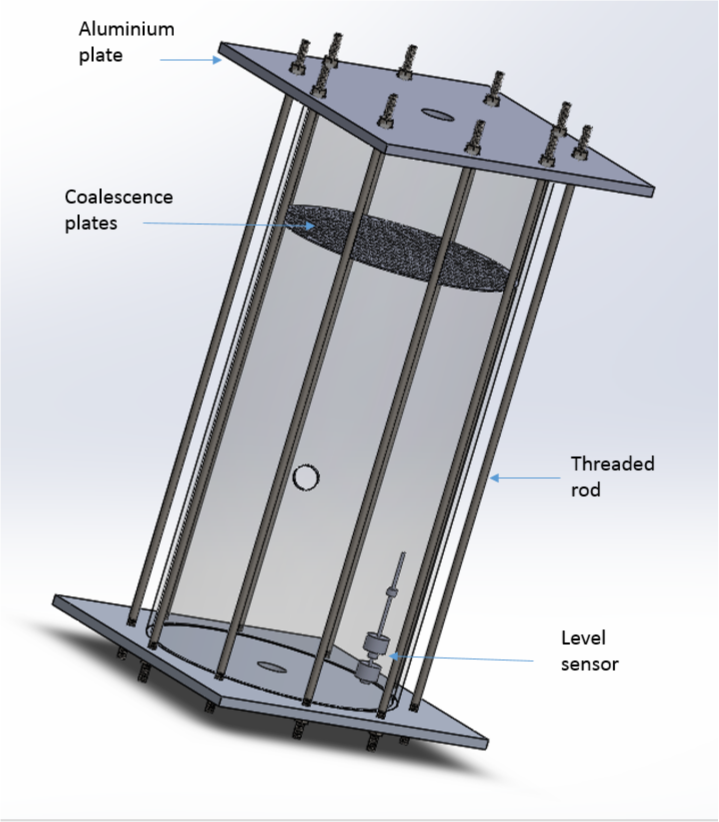


Figure 3.7: Model of the separator. The shell is made transparent to show the inside.

A level transmitter is used to control the water level in the separator. It was mounted on the inside wall as shown in Figure 3.8. The level transmitter starts or stops a gear pump that is connected to the water outlet of the separator. The transmitter consists of two floaters that behave like switches. When the water level rises, both floaters will rise and the switches are in on position. An Arduino, which is a type of micro-controller used to control physical devices, is used to signal the pump to turn on in this case.

When the water has decreased to the level where the switches are in off position, the pump will turn off. The water from the outlet is pressurized through the pump and is transported towards the choke valve.

The separator was pressure and leakage tested. When running the lab the separator will be filled with compressed air, in some situations up to 2 barg. To avoid blow outs and dangerous situations which can occur with compressed air during pressure testing, the separator was pressurized with water up to 8 barg and was sealed off for 30 minutes. The first test proved there was a leakage in the threading through the PVC wall. The rubber gasket had deformed and was pushed out from under the nut. The rubber gasket was then replaced with an aluminium gasket. During the second test there was still a small leakage in the same threading. It was decided to glue the aluminium gasket to the PVC and fasten the nut. This proved to be a good solution as there was no leakage in the third test.

Figure 3.8: Level transmitter mounted in the separator. The picture was obtained when the separator was upside down. Therefore the floaters are in the upper position.

3.4 Counter flow cooler

In a compression process, the temperature of the fluid increases significantly. A cooler was installed after the two compressors due to the temperature limitation of the PVC pipe. The pipe can only withstand a temperature of up to 60°C. Designing the cooler was a comprehensive process. High temperatures from the compressor, space, budget limitations and a requirement for no leakage were the main restrictions.

Due to its simplicity, compactness and efficiency, a standing counter flow helical-coil cooler was chosen. The outside design of the cooler was identical to the separator shell design. It was made cylindrical with aluminium lids forced together with metallic threaded rods. The gas inlet of the cooler had to be placed through the top aluminium lid because of the high temperature of the flow. If the fittings were placed through the PVC shell, a local melting risk would be introduced.

The gas outlet was placed through the bottom aluminium lid. The water inlet was placed at the same side as the gas outlet, creating a counter flow cooler. This will give hydrostatic back pressure on the water inlet keeping the chamber filled with water, ensuring continuous cooling of the coils and aluminium lids.

The cooling medium will have a low pressure inside the cooler, and therefore the requirement for the tank to withstand high pressures is not critical. The water outlet ensures an opening of the cooler at all times. If a gas leakage occurs in the coils, pressure buildup in the tank will force the water out.

The coil material was chosen to be copper due to its high thermal conductivity, low price and low yield strength which makes the pipe easy to bend into a helix shape [27], [13]. The selected copper pipe is manufactured for water and gas transport [61]. The pipe on the inlet of the cooler was chosen to be silicon due to the high temperature from the compressors. The pipe at the outlet was chosen to be PVC material due to the low temperature.

3.4.1 Calculation of copper length

The detailed calculations of the copper pipe length presented below were obtained from the specialization project [17, ch.3,p.20].

The required length of the copper pipe was dependent on the heat transfer between air and water, the logarithmic mean temperature difference and the diameter of the pipe

$$L = \frac{\dot{Q}}{U \Delta T_{LMTD} A_o} \tag{3.12}$$

where

$\dot{Q}$	Heat transfer [W]
U	Heat transfer coefficient $[\frac{\mathrm{W}}{\mathrm{Km}^2}]$
A_o	Area of heat transfer $[\mathrm{m}^2]$
ΔT_{LMTD}	Logarithmic mean temperature difference [-]
L	Length of copper pipe [m]

To find the required length, the temperature out of the compressors had to be calculated. In the industry, a compression process is considered a polytropic process [39, ch.7,p.11]. The temperature ratio is given by

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\left(\frac{k-1}{k\eta_p}\right)} \tag{3.13}$$

where

p_2	Outlet pressure [Pa]
p_1	Inlet pressure [Pa]
k	Isentropic coefficient [-]
η_p	Polytropic efficiency [-]
T_1	Inlet temperature [K]

T_2	Outlet temperature [K]

At normal conditions, the inlet temperature of the piston compressor will be 293.15 K = 20°C, and the inlet pressure will be atmospheric pressure, 101325 Pa = 0 barg. The polytropic efficiency in a reciprocating compressor is assumed to be 1, and the isentropic coefficient is 1.4 [39]. The maximum outlet pressure allowed in the system when only running the piston compressor is 4 barg. With these values, the outlet temperature of the piston compressor was calculated to be 191°C.

The polytropic efficiency of a centrifugal compressor is assumed to be 0.6 [39]. The maximum differential pressure the turbocharger can deliver is 2 barg. This means with the same inlet conditions as the piston compressor, the outlet temperature will be approximately 220°C.

When the compressors are run in series, the maximum outlet temperature of the turbocharger is 212°C. The maximum inlet temperature of the cooler is therefore 220°C.

The outlet temperature of the cooler will be 20°C. When calculating the required length of the copper pipe to cool the flow by 200°C, a flow of dry air was assumed. This assumption was based on the enthalpy of vaporization, which is the energy required to evaporate water. With constant pressure, the temperature in the water will stay constant if the liquid is at its saturation line. Further energy supplied will evaporate the water, not increase the temperature [3]. At a pressure of 2 barg, the saturation temperature of water is T_{sat} = 133.52°C [3, table A-5,p.912]. This temperature is lower than the maximum inlet temperature in the cooler, T = 220°C. The increased enthalpy of the air will therefore contribute to evaporation of water, and not increase the temperature.

The hot air in the copper pipes will be cooled by surrounding tap water. The inlet temperature of water was assumed to be 8°C. The heat transfer through the copper wall is calculated by

$$\dot{Q} = UA_o\Delta T_{LMTD} \tag{3.14}$$

where the logarithmic mean temperature difference is given by

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln\frac{\Delta T_2}{\Delta T_1}} \tag{3.15}$$

and

ΔT_2	Temperature difference at the top of the cooler
ΔT_1	Temperature difference at the bottom of the cooler

The outlet temperature of the water is dependent on the heat transfer between the two flows. To obtain the temperature, the rate of heat transfer of both flows has to be in equilibrium.

$$\dot{Q}_{air} = \dot{m}_{air}\Delta T_{air}C_{p,air} \tag{3.16}$$

$$\dot{Q}_{water} = \dot{m}_{water} \Delta T_{water} C_{p,water} \tag{3.17}$$

$$\dot{Q}_{air} = \dot{Q}_{water} \tag{3.18}$$

which gives

$$\Delta T_{water} = \frac{\dot{Q}_{air}}{\dot{m}_{water} C_{p,water}} \tag{3.19}$$

where

$\dot{Q}_{air}$	Heat transfer in air [kW]
$\dot{Q}_{water}$	Heat transfer in water [kW]
$\dot{m}_{air}$	Mass flow of air [kg/min]
$\dot{m}_{water}$	Mass flow of water [kg/min]
ΔT_{air}	Temperature difference of air [K]
ΔT_{water}	Temperature difference of water [K]
$C_{p,air}$	Volumetric heat capacity of air [kJ/kgK]
$C_{p,water}$	Volumetric heat capacity of water [kJ/kgK]

$\dot{m}_{air}$ and $\dot{m}_{water}$ was assumed to be 1.25 kg/min and 12.6 kg/min respectively. $C_{p,air} = 1.03$ kJ/kgK and $C_{p,water} = 4.19$ kJ/kgK [3]. With these values the outlet temperature of water will be 12.8°C.

The length of the copper pipe was found from (3.12) where the heat transfer was calculated to be 4.3 kW and the heat transfer coefficient, $U = 200 \ \frac{\text{W}}{\text{Km}^2}$ [39, ch.6]. The inner diameter of the copper pipe is 15 mm and the ΔT_{LMTD} was calculated to be 68.4 from (3.15). This resulted in a required pipe length of 6.7 m. With a safety factor of 2, a 15 m copper coil was purchased. To construct a compact counter flow cooler, the pipe was cut into three equal sections.

The values used for the calculation is summarized in Table 3.1.

Variable	**Value**
$\dot{m}_{air}$	1.25 kg/min
$\dot{m}_{water}$	12.6 kg/min
ΔT_{air}	200 °C
ΔT_{air}	4.8 °C
$C_{p,air}$	1.03 kJ/kgK
$C_{p,water}$	4.19 kJ/kgK
ΔT_{LMTD}	68.4
$\dot{Q}$	4.3 kW
D	15 mm
U	200 $\frac{\text{W}}{\text{Km}^2}$
L	**6.7 m**

Table 3.1: Summary of the values used to calculate the copper pipe length

Calculations were also made for different pressures, temperatures and inner diameters of the copper pipes. These are given in Appendix C.

3.4.2 Assembly of the counter flow cooler

Figure 3.9 shows the assembled cooler in SolidWorks and 3.10 shows the assembled cooler mounted in the frame.

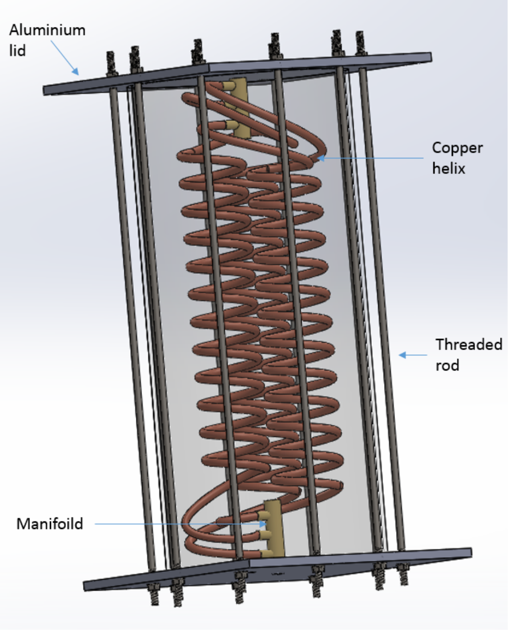


Figure 3.9: Model of the cooler. The shell is made transparent to show the copper helix inside.

Figure 3.10: The cooler mounted in the frame.

The copper pipes were coiled by hand. Salt was poured into the pipes to absorb the bending forces and prevent the copper kinking. However, the salt proved to be difficult to get in and out of the pipe properly. Finely grained sand proved to be a better alternative. The sand filled the pipe more easily and there was no corrosion risk involved. A pipe with a suitable diameter was found in the workshop, and the copper was coiled around this.

The manifolds have their inlets in the same orientation as seen in Figure 3.9. This made the copper assembly more difficult as all three coils needed different inlet angles to the manifold.

A lot of time was spent adjusting the copper pipes to fit properly into the manifold. This was to ensure that there was no leakage in the connections and that it fitted into the PVC shell.

When all the copper pipes were assembled in the manifolds, the system had to be pressure and leakage tested. One of the manifolds was sealed with a plug and the other was connected to the compressed air supply in the workshop. Due to the small volume in the copper pipes, compressed air was used rather than water. The coils were placed inside a container when pressurized to avoid dangerous situations if a major leakage was to occur.

The first pressure test was conducted in a dry environment. The system was pressurized to 5 barg and then left alone for 30 minutes. This was to detect a potential leakage in the connections. After 30 minutes the pressure in the copper coil had dropped to 3 barg which proved that it was not completely sealed. To detect in which connection point the leakage was located, the coil system was submerged in water. Two leakage points were detected in two different copper manifold connections. Figure 3.11 shows the pressure test of the copper coils.

Disassembling the coils revealed malformed ends at these two points which meant that the coil did not fit properly into the manifold. To fix the leakage, the two malformed ends had to be straightened out and made circular. This was done by heating up the end of the coil and forcing it through a premade circular hole with diameter of 15 mm in a piece of wood. The coil was then forced into the right shape and dimension. A second pressure test proved that the corrections worked.

Figure **??** shows the copper coils inside the shell of the cooler.

Figure 3.11: The final pressure test of the copper helix.

Figure 3.12: Copper helix inside the cooler shell.

The tank and the aluminium lids were sealed in the same way as the separator, with threaded rods. Both holes for the gas inlet and outlet of the cooler were threaded in order to reduce the risk of leakage. A threaded connection pipe was used through both holes to connect the main pipe to the manifolds in the cooler. Thread tape was applied to the threads to prevent leakage and a gasket was placed on the outside of both lids and compressed with a nut.

Closing the tank with the coil attached to the pipes through both aluminium lids was a great challenge. It was not possible to connect the top lid to the coil and tighten it from the inside, where the connection was located. This could be done on the bottom lid since the tank was not yet sealed.

Therefore the top lid had to be connected and tightened from the outside. To overcome this problem, a hexagonal shape was milled into the inside of the aluminium lid. This was to force the end nut on the manifold into the milled hexagonal shape so that it would not move when the threaded connection pipe was fastened through the inlet of the lid.

Figure 3.13 shows the milled hexagonal shape in the aluminium lid.

Figure 3.13: The milled hexagonal shape in the aluminium lid

To prove the cooler was leakage free, it was filled with water after it had been assembled.

Several problems occurred during the construction of the cooler. The result was a more time-consuming process than anticipated in the planning phase. The greatest challenge was the adaptation of the copper pipes and making the connections leakage free. In addition, time was spent trying to find missing parts for connection and a suitable area for the pressure test of the copper pipes. The workshop could not provide all the necessary parts, therefore both money and time was spent on equipment for testing. This was not considered or thought of during the planning of the cooler construction.

3.5 Piston compressor

A piston compressor was placed in the loop to provide a higher differential pressure when used in series with the turbocharger for dry gas compression. In addition, it was desirable to control the compressor with an electrical motor. For a turbocharger to pressurize the flow in the system, a very high rpm is required. This is not possible to achieve with an electrical motor without an expensive gear system. Therefore a motor controlled piston compressor was installed in addition to the turbocharger.

A piston compressor is a type of displacement compressor. Gas is let into a fixed volume chamber. A piston moves in a reciprocating movement, reducing the volume of the chamber and thereby compressing the gas. The compressed gas is then discharged into the system and towards the turbocharger.

The piston compressor is very sensitive to particles, dirt and water and will be damaged if exposed to these over a longer period. Therefore, it will only be run when compressing dry gas. The compressor will be bypassed when running wet gas in the system to avoid water from entering the chamber.

Since there is no humidity sensor after the separator, the compressor is bypassed even though the gas has been separated from the water in the separator. It is not possible to verify that the gas is completely dry when it leaves the separator. As mentioned in Section 3.1, this can be a potential future improvement to implement in the system.

The piston compressor is belt-driven by a 4 kW AC induction motor. The belt is attached to a pulley on the shaft of the motor and the wheel of the compressor. It will run at 1370 rpm. The motor is controlled by a frequency converter. The frequency converter alters the frequency of the alternating current (AC), which in return increases or decreases the rpm of the motor. The compressor and motor are shown in Figure 3.14.

Figure 3.14: Belt driven piston compressor with electrical motor.

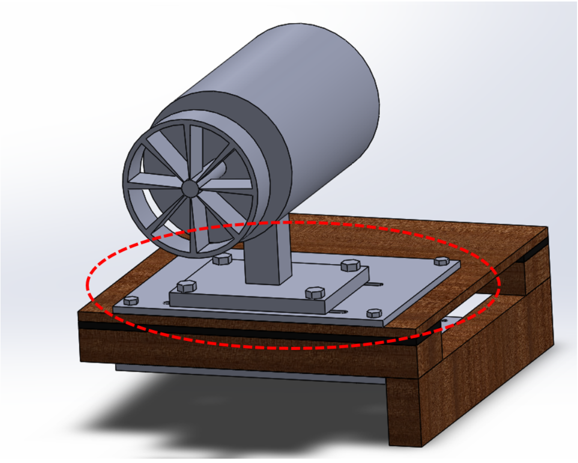


Figure 3.15: The tightening system for the motor and the piston compressor marked with the red circle.

Since the motor and compressor were bought separately, they had to be made compatible with each other. In order for the belt to be properly tight between the two components, giving the correct rpm in a safe manner, a tightening system was designed. Another reason why this was necessary is that the belt will loosen as it ages, meaning an adjustment will have to be made in the future. The design of the tightening system is shown in Figure 3.15.

The system is made up of two solid pieces of metal that are bolted together on either side of the wooden frame as seen in Figure 3.15. Two parallel 260 mm oblong holes with a diameter of 12.5 mm are drilled through the two pieces of metal and the wooden frame. The base of the motor is attached to the metal pieces through these two holes with bolts. The motor can slide up and down the oblong holes when the bolts are loose, meaning that the belt can be tightened and loosened. When the belt is properly tight, the motor can be fastened in the right position with the bolts. This design ensures easy and fast adjustment of the belt controlling the rpm of the piston compressor.

3.6 Turbocharger

A turbocharger is a device for compressing more air into the cylinders of a combustion engine than is being supplied in a traditional naturally aspirated engine. The pressure increase results in a higher density of the air, which in return increases the amount of oxygen being fed into the cylinders. This allows for more fuel injection which increases the power of the engine [32]. A turbocharger is often installed with an intercooler in series with a combustion engine in order to increase the efficiency of the turbocharger. The cooling of the air increases the density.

A turbocharger consists of a turbine and a compressor impeller connected by a common shaft. When the exhaust gases are fed into the turbine, they experience a pressure- and temperature drop between the inlet and the outlet. This pressure drop is converted by the turbine into rotational kinetic energy [18]. The rotational energy is conveyed by the shaft to the compressor impeller. The rotating impeller applies a high velocity to the gas in the compressor which increases its kinetic energy. Because of the increase in centrifugal force due to the rotation of the impeller, the static pressure of the gas increases as it moves along the impeller blades. It is then decelerated in the diffuser part of the compressor, increasing the pressure of the air due to the transformation from kinetic to potential energy [25]. The transformation giving the pressure increase of the flow is described by Bernoulli's equation

$$\frac{p_1}{\rho} + \frac{C_1^2}{2} + gz_1 = \frac{p_2}{\rho} + \frac{C_2^2}{2} + gz_2 \tag{3.20}$$

Where:

p_1	Inlet pressure [Pa]
p_2	Outlet pressure [Pa]
ρ	Density of the gas [kg/m^3]
C_1	Velocity of the gas at the inlet [m/s]

C_2	Velocity of the gas at the outlet [m/s]
g	Gravitational constant [m/s^2]
z_1	Elevation of the inlet [m]
z_2	Elevation of the outlet [m]

From (3.20), it is seen that the specific potential energy, gz, and pressure increases when the specific kinetic energy, $\frac{C_i^2}{2}$, decreases.

The challenge was to choose a turbocharger that would fit the system requirements. Turbochargers are designed for dry gas in combustion engine ambient pressures and temperatures. However, in this lab it will be exposed to other environments which directly affects the turbocharger selection.

When selecting the turbocharger, the compressor map had to be considered in order to meet the system requirements. This is a map showing the mass flow- and pressure regime on the compression side of the turbocharger. The turbocharger may experience surge or choke if the flow and pressure of the gas is outside the limits of the compressor map. Since the maximum pressure of the system is already defined, the mass flow will decide the operating point of the turbocharger. The mass flow was therefore the property with the most influence on the choice of the turbocharger. If the mass flow is too low the operating point of the turbocharger is in the surge region of the map. If it is too high it is in the choke region. Figure 3.16 shows the compressor map of the chosen turbocharger.

Surge in a centrifugal compressor, such as a turbocharger, is highly unwanted as it may damage or break the compressor. A compressor may experience surge when its operating point is moved left of the surge line in the compressor map. The surge line is the left boundary line in Figure 3.16. Surge occurs when air pockets are formed around the impellers of the compressor. The air pockets have a significantly lower rotational velocity than the surrounding air which in return reduces the air flow through the compressor. This is called rotational stall. When the flow at the outlet of the compressor is so low that it causes the pressure to drop beneath the pressure in the following pipe, the compressor will experience back flow. This is known as compressor surge. This only occurs in axial and centrifugal compressors and is not a problem for piston compressors. [25]

To avoid surge in the turbocharger, an anti-surge line was designed. The line goes from the turbocharger outlet and back to the inlet where the gas is compressed again. The line is controlled by a motor controlled angle seat valve. The opening of the valve is controlled by pressure readings from pressure sensor 4 in Figure 3.1. The valve and its behaviour is further explained in Section 3.8.

Another problem that may disrupt the flow through the compressor is choking. In the compressor map this may happen when the operating point is located on the right side of the boundary line. Choking occurs when the flow rate through the compressor is very high and the pressure is low. The velocity may be as high as sonic speed, and when this happens no further increase in flow or pressure can be achieved [29].

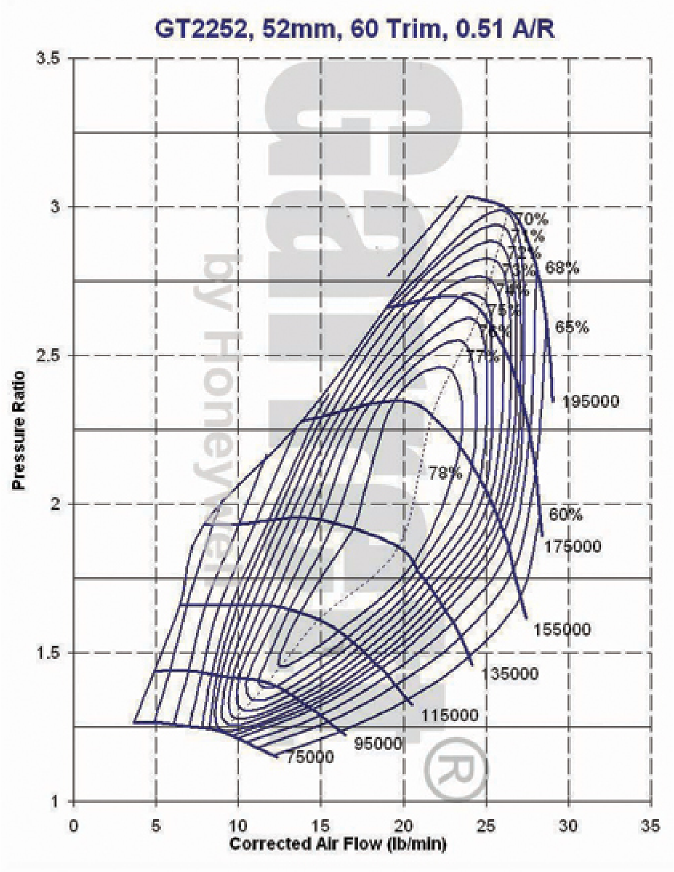


Figure 3.16: Compressor map of the chosen turbocharger, a Garrett 2252 turbocharger [72].

In order to choose a turbocharger, the mass flow had to be calculated. To do this, the mass flow of dry air at standard conditions were needed

$$\dot{m}_{in} = \dot{q}_{in}\rho_{a,sc} \tag{3.21}$$

where

$$\dot{q}_{in} = v_d A_p \tag{3.22}$$

and

$\dot{m}_{in}$	Mass flow of air into turbocharger [kg/s]
$\dot{q}_{in}$	Volume flow of air into turbocharger [m^3/s]
$\rho_{a,sc}$	Density of air at standard conditions [kg/m^3]
v_d	Velocity of air [m/s]
A_p	Cross sectional area of the inlet [m^2]

The velocity of air is 5 m/s and the inside diameter for the inlet of the turbocharger is 42 mm. This gives $A_p = 1.3854 \times 10^{-3}$ m^2. The density, $\rho_{a,sc}$, is found from the ideal gas law

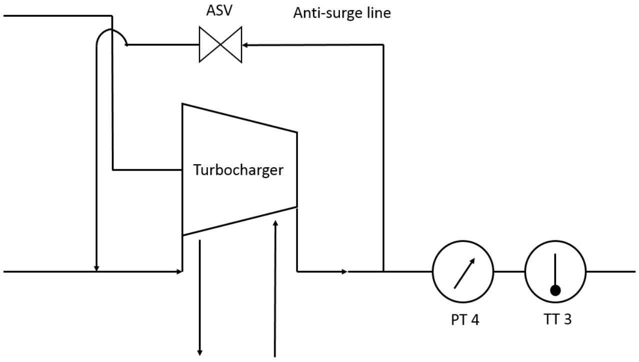


Figure 3.17: The anti-surge line

$$\rho_{sc} = \frac{p_{sc}M}{RT_{a,sc}} \tag{3.23}$$

where

p_{sc}	Pressure at standard conditions [Pa]
M	Molecular weight of air [g/mol]
R	Ideal gas constant [J/molK]
T_{asc}	Temperature of air at standard conditions [K]

$p_{sc} = 101325$ Pa, $M = 28.97$ g/mol, $R = 8.314$ J/molK, $T_{asc} = 293.15$ K. This results in $\rho_{a,sc} = 1204.8$ g/m^3. From this result, the mass flow rate was found from (3.21), as $\dot{m}_{in} = 0.708$ kg/min.

Since the main objective of the lab is to test wet gas compression, the turbocharger has to be dimensioned for a water fraction in the gas. This will dramatically increase the density, and therefore the mass of the flow running through the turbocharger. (3.21) shows that the mass flow is directly proportional to density. Therefore several calculations were made with different water fractions in the flow.

From the results, a turbocharger that fitted the widest mass flow range of the lab was chosen. To simplify the calculations, the water and air was treated as two different flows with different densities. Due to the compressibility of air, it was calculated at different pressures and therefore also density as seen in (3.23). To find the average mass flow through the turbocharger the two flows were added together. These calculations were used to find a suitable turbocharger.

As previously calculated, the minimum mass flow of air at standard conditions will be 0.708 kg/min. As the units in the compressor maps of the turbochargers were given in pounds/minute (lb/min), the mass flow therefore had to be converted into this. The converted mass flow gave 1.56 lb/min. The maximum mass flow is at 4 barg and 20 % water fraction.

The upper layer of the water is assumed to have the same velocity as the gas. Due to friction between the pipe wall and water droplets, the bottom layer of the water will have no velocity. This is called no slip condition and results in an average water velocity of $v_w = \frac{1}{2} * v_d$ [19].

With the water velocity assumption, the maximum mass flow was calculated to be 137.8 lb/min. In the turbocharger assortment at Garrett there were no turbochargers that fitted both the minimum and maximum mass flow. Therefore a turbocharger with the highest mass flow range within the system's limits was chosen. The map, Figure 3.16, shows that an experiment with only air at standard conditions will lead to surge, and therefore the system has to be pressurized before start-up. In addition, to avoid choking, the maximum water fraction in the gas is 3 % at 3 barg.

(3.23) shows that the density of air changes with temperature. When running the lab with both compressors, the inlet temperature of the turbocharger will increase. In these experiments there will be no water added as the piston compressor does not handle water. The maximum outlet temperature of the piston compression is 191°C [17], and the pressure will be 4 barg. With these conditions the density of the air will be 1.79 kg/m^3 and the mass flow will be 3.94 lb/min. In the compressor map of the chosen turbocharger it is seen that these values will result in surge. In order to avoid this situation, the system has to be pressurized to 2 barg before start-up. The relationship between pressure and temperature is given in (3.24). To be within the system maximum pressure limit, the piston compressor will only increase the pressure by 1 barg and the resulting outlet temperature will be 56°C in accordance with (3.24). This will result in a sufficient mass flow of 5.55 lb/min into the turbocharger.

$$\left(\frac{p_2}{p_1}\right)^{\left(\frac{k-1}{k\eta_p}\right)} = \frac{T_2}{T_1} \tag{3.24}$$

Where

p_1	Inlet pressure [Pa]
p_2	Outlet pressure [Pa]
k	Isentropic efficiency [-]
η_p	Polytropic efficiency [-]
T_1	Inlet temperature [K]
T_2	Outlet temperature [K]

Figure 3.18 shows the selected turbocharger.

Normally, in a two step compression, an intercooler is installed to reduce the work needed to compress the gas in the second step. (3.25) is the polytropic equation for specific work of a compressor [38], where the work is proportional with the temperature ratio. Reducing the temperature at the compressor inlet will result in a reduction of the temperature at the compressor outlet. This gives a smaller temperature ratio which, according to (3.25), will result in a reduction of the required work needed to compress the gas to the desired pressure.

Figure 3.18: The selected turbocharger [72]

$$W = p_1 v_1 \left(\frac{k\eta_p}{k-1} \right) \left[\left(\frac{p_2}{p_1} \right)^{\left(\frac{k-1}{k\eta_p} \right)} - 1 \right] \tag{3.25}$$

where

W	Specific work [J/kg]
p_1	Inlet pressure [Pa]
p_2	Outlet pressure [Pa]
v_1	Velocity [m/s]
k	Isentropic coefficient [-]
η_p	Polytropic efficiency [-]

Even though the required work is reduced when cooling the gas before compression, an intercooler was not implemented between the piston compressor and the turbocharger. Having an extra component between the compressors will increase the internal resistance of the system causing a potential pressure drop of the gas flow. Due to the low flow and pressure in the system, it is assumed that a compressor work reduction will not weigh up for the increased internal resistance an intercooler will give to the loop. In addition, this component would increase the cost and prolong the construction process of the lab, due to the need for extra connections and potential custom-made parts.

3.6.1 Oil loop

Turbochargers are normally oil lubricated from the combustion engine's lubrication system. Meaning it is added to the engine's own oil loop. In this lab, the turbocharger is disconnected from its usual environment which means it has no form of lubrication. To avoid mechanical friction and overheating of the ball-bearings, an oil loop was designed. The loop consists of an oil gear pump, filter, choke valve, oil cooler, oil reservoir, flexible hoses and fittings.

The oil is pressurized by a 250 W oil pump. The electrical motor driving the pump is connected to a gear system which lowers the rotational speed of the pump and increases the torque. This ensures high pressure and low flow of the oil. A choke valve in front of the turbocharger will be used for regulating the pressure.

The oil is filtered before it reaches the turbocharger to avoid damaging particles in the bearings. A spin on filter was used. In order to connect the oil filter to the system, an oil filter adapter was needed. The inlet and outlet fittings of the adapter was not compatible with the flexible hoses. They were therefore handmade by the students.

A ball-bearing turbocharger requires an inlet oil pressure of 2.76 to 3.10 barg [33]. From conversation with the vendor, a flow of 0.8 litres to 2.5 liters per minutes was required. If the oil pressure is too low, the metal components inside the bearing will come in contact. This will cause premature wear which leads to bearing failure. If the oil pressure exceeds 3.10 barg, it could lead to unwanted leakage in the turbocharger seals. Oil leakage into the compressor impeller will lead to contamination of the gas flow.

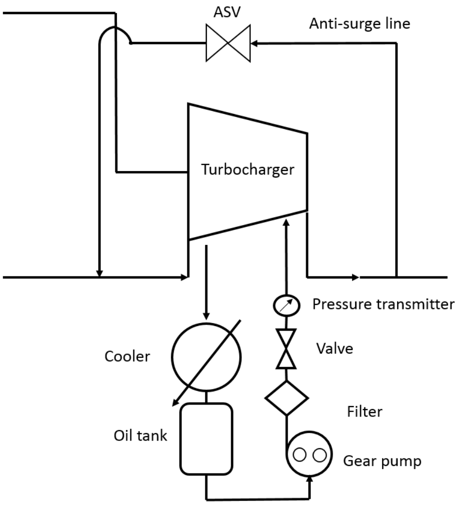


Figure 3.19: Sketch of the oil loop.

Almost all the pressure will be burned off in the turbocharger bearings and the residual pressure will be used to transport the oil into the cooler. The cooler is an air cooled heat exchanger.

The oil is transported back to the oil reservoir which has a volume of 5 liters. An air vent is located at the top of the reservoir tank and must be open during operation. This ensures no pressure build-up in the tank. In addition, the oil level can be measured from this opening. It should not be completely full to allow for thermal expansion of the oil.

The oil inlet of the reservoir tank consists of a copper pipe. The outlet of the pipe is located at the bottom of the tank ensuring a minimum amount of air bubbles mixing into the oil.

Oil is continuously fed to the turbocharger via the pump. The oil has to be replaced after a certain time to avoid damage to both the pump and the turbocharger. Figure 3.19 shows the oil loop.

3.7 Electrical system

This section covers the electrical system required to operate the electrical motors and the control valves with focus on safety and functionality. A general overview is presented and the subsystems are explained in detail.

The function of the electrical system is to safely distribute the main power supply to the electrical components in the lab. The design was a comprehensive process. No cables or other necessary components for installation were included in the motor or valve deliveries. All necessary components for power supply had to be bought separately.

Figure 3.20 shows a sketch of the physical layout of the electrical system. As explained in Section 3.2, the lab was designed to be a mobile installation. It is therefore necessary that the electrical system is movable in accordance with the two frames. A 32 A 400 VAC extension cord from the wall will be connected to a distribution board. From the distribution board, there are cables going to the relevant components such as the control valves and the motors.

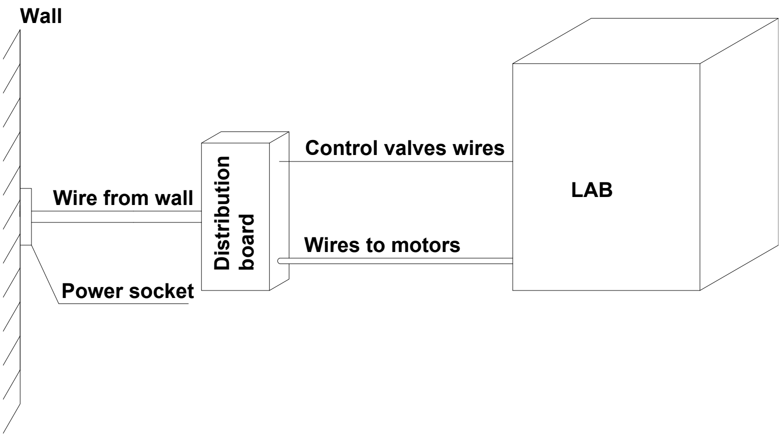


Figure 3.20: Sketch of the physical layout of the electrical system.

3.7.1 Current distribution overview

The different components require different current and voltage for operation. The parameters that affected the component selection were:

- Operation values of the motors.
- Motor control requirements.
- Valve control requirements.
- Control monitoring device requirements.
- Connection for future components.
- Electric distribution system in the workshop.

The amount of current flowing through the lines are decided by the load they are connected to. This was obtained from Ohm's law of alternating current

$$I = \frac{V}{Z} \tag{3.26}$$

where

I	Current [A]
V	Voltage [V]
Z	Impedance [Ω]

Impedance is the sum of resistance and reactance and is frequency dependent [52]. Within a range of tolerance, the voltage does not change in the supply line. This means the impedance determines the amount of current flowing through the lines.

To determine the number of electrical circuits, the maximum power, voltage and current requirements of the main components were considered. These are valid when the motors are running under full load conditions. Table 3.2 shows these requirements.

Power [W]	Voltage [V]	Current [A]	Description
4000	400	7.98	Motor for piston compressor
373	230	3.50	Motor for water pump
250	400	0.84	Motor for oil pump
150	230	2.00	24 VDC power supply for control circuits
120	230	0.52	Circuit for laptop
100	230	1.50	12 VDC power supply for control circuits

Table 3.2: Electrical requirements of the main components

The rated current, voltage and power output for the electrical motors were obtained from the nameplates located on the motors. These are shown in Appendix D. The rated current, voltage and power output for the power supplies were provided by the vendor [73], [74].

The system was designed based on its critical point, meaning when every electrical component is running at its maximum potential. In order to power extra equipment, the system was designed with two extra power outlets of 230 VAC with a current capacity of 13 A.

The main circuit breaker was determined by the total rated current from the electrical components in the system. The total current is found by adding the branch currents [26]

$$I_{tot} = I_{C1} + I_{C2} + I_{C3} + I_{C4} + I_{C5} + I_{C6} + I_{C7} \tag{3.27}$$

where

I_{tot}	Total current [A]
I_{C1}	Branch current for the piston compressor [A]
I_{C2}	Branch current for the water pump [A]
I_{C3}	Branch current for the oil loop [A]
I_{C4}	Branch current for the PC [A]
I_{C5}	Branch current for the 24 VDC power supply [A]
I_{C6}	Branch current for the 12 VDC power supply [A]
I_{C7}	Branch current for the extra power socket [A]

$I_{tot} = 29.34$ A. A main contactor and a main circuit breaker were selected in accordance with the total current in the system and the principle of selectivity. The contactor has an operating current of 40 A in an ambient temperature of 40 °C [55]. A 30 A circuit breaker with a tripping characteristic class C was selected. This means it has an instantaneous tripping current of 5 to 10 times the nominal current, I_n, and a thermal tripping current of 1.13 to 1.45 times I_n [41].

The principle of selectivity states that the circuit breaker closest to a component with a failure will trip before the main circuit breaker [41]. Therefore, the main circuit breaker was chosen to handle the maximum current in the system and will work as a backup protection in case of an adjacent circuit breaker failure. The principle of selectivity was then fulfilled.

3.7.2 Design of distribution box

Figure 3.21 shows the line diagram of the electrical system, and Table 3.3 is the corresponding parts list. It gives an overview of the connections between the electrical components and how they operate together. The dashed line, X, at the top of the drawing and the solid line at the bottom, Y, illustrates the physical surfaces of the distribution box. The components between these lines are placed inside the distribution box. The components attached to or placed on the two lines, are located in the door of the box. L1-, L2-, L3- and the N-line in Figure 3.21, originates from the power supply cable. The L-lines are hot leads, meaning they are electrically powered, while the N-line is neutral.

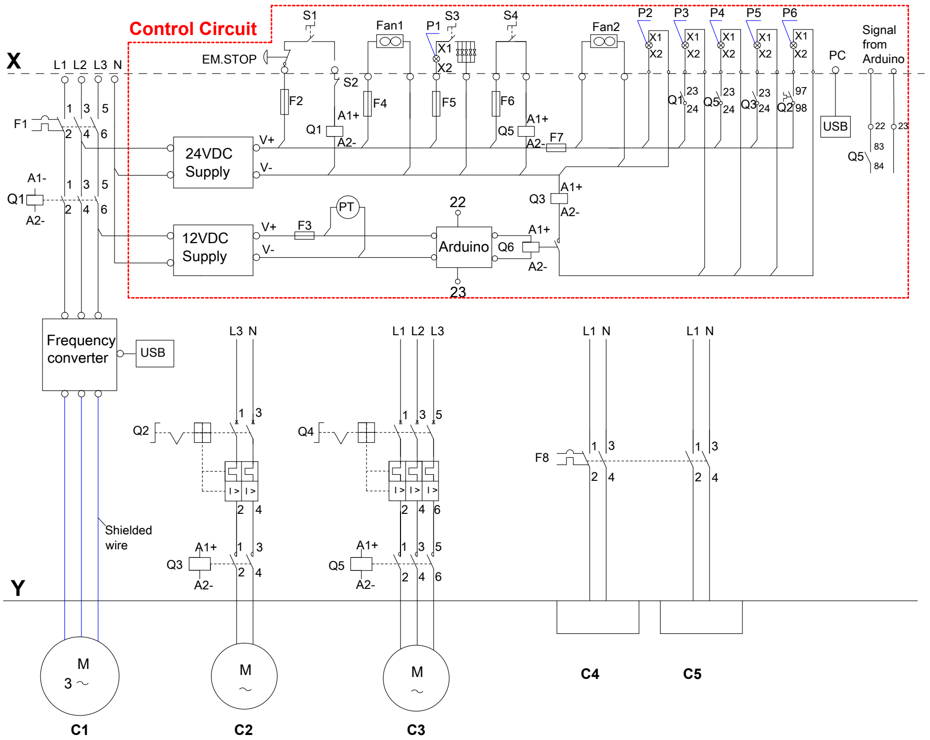


Figure 3.21: Line diagram of the electrical system

The line diagram is divided into two categories; power circuit and control circuit as seen in Figure 3.21.

3.6.2.1 Power circuit

The function of the power circuit is to power the electrical components that require 230 VAC or 400 VAC. It is divided into five sub circuits; C1, C2, C3, C4 and C5 as illustrated in Figure 3.22. The distribution system in the workshop is 400 VAC TN-S. For a TN-S system, a neutral wire and a PE-wire are separated into two single and isolated wires. The PE-wire is connected to earth. In practice, this means that there are five wires in the supply cable; L1, L2, L3, N and PE. The PE-wire is not illustrated in Figures 3.21 or 3.22.

The power circuits were designed to withstand the maximum flow of current the lab experiences. These situations occur during start-up of electrical motors and continuous drive with maximum load.

During a motor start-up, the load current can increase by 3 to 7 times the normal full-load current. This phenomena is called inrush current or starting current [51], [2], and is due to the magnetization required to overcome the high inertia of the electrical motor at standstill.

During continuous operation under full load conditions, the motor draws the rated current labeled on the nameplate.

PARTS LIST	
ITEM	**PART NAME**
Q1	Safety relay
Q2	Circuit breaker
Q3	Contactor
Q4	Motor protection relay
Q5	Contactor
Q6	Arduino relay
S1	Safety door switch
S2	System switch
S3	Valve switch
S4	Oil loop switch
P1	Signal lamp
P2	Signal lamp
P3	Signal lamp
P4	Signal lamp
P5	Signal lamp
P6	Signal lamp
F2	Fuse
F3	Fuse
F4	Fuse
F5	Fuse
F6	Fuse
F7	Fuse
A1+	24 VDC in
A2-	24 VDC out
PT	Pressure transmitter

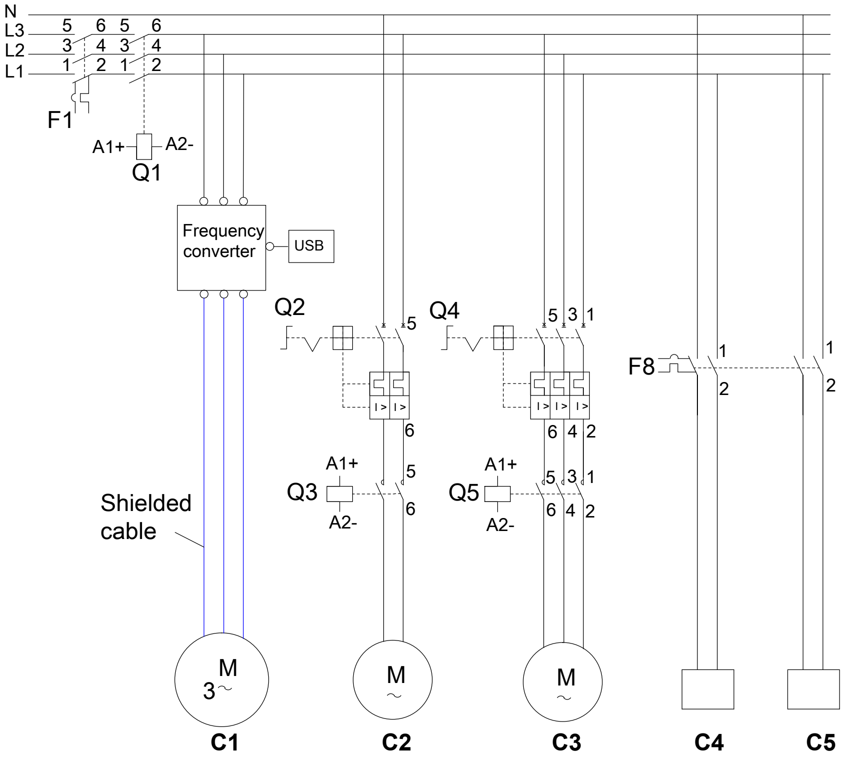
Table 3.3: Parts litst for the line diagram.

According to the standard NEK 400 part 430.3, it is required that a circuit is protected against current overloading and short circuiting. In case of overloading, all the hot leads should be disconnected. Selection of contactors, circuit breakers and circuit breakers for motor protection was done with support from Siemens.

C1 - piston compressor circuit

C1 consists of a 400 VAC three phase induction motor with 4 kW power connected in series with a frequency converter. The function of the circuit is to convey power to the motor via the frequency converter. By regulating the frequency, the torque and speed of the motor changes. The converter alters the frequency by manipulating the AC. AC is converted to direct current (DC). This causes a pulsating signal which has to be smoothed by a filtering device. By pulse width modulation (PWM) of the smoothed DC, the converter can reproduce AC with different frequencies [35].

The frequency converter in the system, Sinamics G120C with capacity of



Parts List	
ITEM	File Name
Q1	Main contactor
Q2	Circuit Breaker for motor protection
Q3	Contactor
Q4	Circuit breaker for motor protection
Q5	Contactor
L1	Phase one wire
L2	Phase two wire
L3	Phase three wire
N	Neutral wire
PE	Earth wire
A1+	24 VDC contactor inlet
A2-	24 VDC contacor outlet
C1	Circuit one
C2	Circuit two
C3	Circuit three
C4	Circuit four
C5	Circuit five
USB	Signal Cable
F1	30 A Fuse
F8	Circuit Breaker
1 to 6	Connection points

Figure 3.22: Power circuit.

4 kW, has an upper frequency limitation of 240 Hz [58].

The rated current of the motor is 7.98 A [21]. The converter is equipped with two fail safe digital ports [57]. These can be used as an emergency shutdown system for the 4 kW motor. The Sinamics G120C is a compact converter, meaning that it has every necessary and required components included in the design. It was therefore not required to implement a circuit breaker or a motor protection device in C1.

In order to implement the frequency converter into the system, a cable with electromagnetic compatibility for connection to the motor was required. This is a shielded cable. The converter generates strong electromagnetic emissions which results in major interference with the distribution network, data transfer and other devices [54]. The shielded cable protects the system against these emissions and it is illustrated as the three blue wires in Figure 3.22.

In order to connect the computer to the converter, a compatible USB-cable was needed.

C2 - Water pump circuit

The C2-circuit consists of a 230 VAC single phase induction motor, the contactor, Q3, and the circuit breaker for the motor protection, Q2. The circuit will convey power to the waterpump on the command from an Arduino.

A contactor is an electromagnetic relay. It functions as a switch when it is powered by its control terminals. When the Arduino sends its command signal, the contactor, Q3, is powered and closes the C2-circuit. Q2 protects the motor and circuit in the case of short circuiting or current overload. A normal circuit breaker utilizes two different principles to break the circuit. In case of short circuiting, an electromagnetic relay is activated which breaks the circuit [41]. When current overload occurs, bi-metal strips are affected by the heat generation and activates a trip function causing the circuit to break.

A two-wired cable is required to implement the motor in the circuit consisting of one hot lead and one neutral. L3 was chosen in order to balance the load as equally as possible between the hot leads. The contactor and the circuit breaker was chosen as a three-pole component instead of a two-pole component, due to price. By correct wiring, the three-pole component could be used in a two-wired circuit. The rated current for the motor is 3.5 A. Therefore, a circuit-breaker, SZ S00, for motor protection in the range of 2.8–4 A was chosen.

C3 - Oil loop circuit

C3 consists of an induction motor, a contactor, Q5, and a circuit breaker, Q4, for motor protection. The motor is compatible with 230 VAC or 400 VAC, and single- or three-phase. For the lab, it was decided to use the 400 VAC three-phase connection alternative as this draws the least current. Q4 is the circuit breaker for motor protection which ensures protection of the motor in case of overloading or short circuiting. A rotary switch is used to activate the contactor Q5 that closes the circuit. The dimension of the circuit breaker is based on the properties of the motor. The motor draws 0.84 A when star connected with 400 VAC applied. Therefore, a circuit breaker for motor protection in the range of 0.7–1 A from Siemens was chosen.

C4 - Extra power socket

C4 consists of four power sockets and the circuit breaker F7. The function of the circuit is to supply power to extra equipment that requires electrical power of 230 VAC. Both of the power sockets share the same circuit breaker. This is illustrated by the dashed line between the switch symbols to the right in figure 3.22. F7 is a two-pole circuit breaker with tripping characteristic class C.

The circuit is designed for extra equipment such as electrical tools. A circuit breaker with C-characteristics was therefore desired. The tools may differ in size, but a normal requirement is approximately 1000-2500 W [14][15][12]. A circuit breaker with 13 A rated current, and therefore a power capacity of 2990 W, was chosen. For comparison, a normal household circuit breaker is in the range of 10–16 A [28].

C5 - Power socket for PC

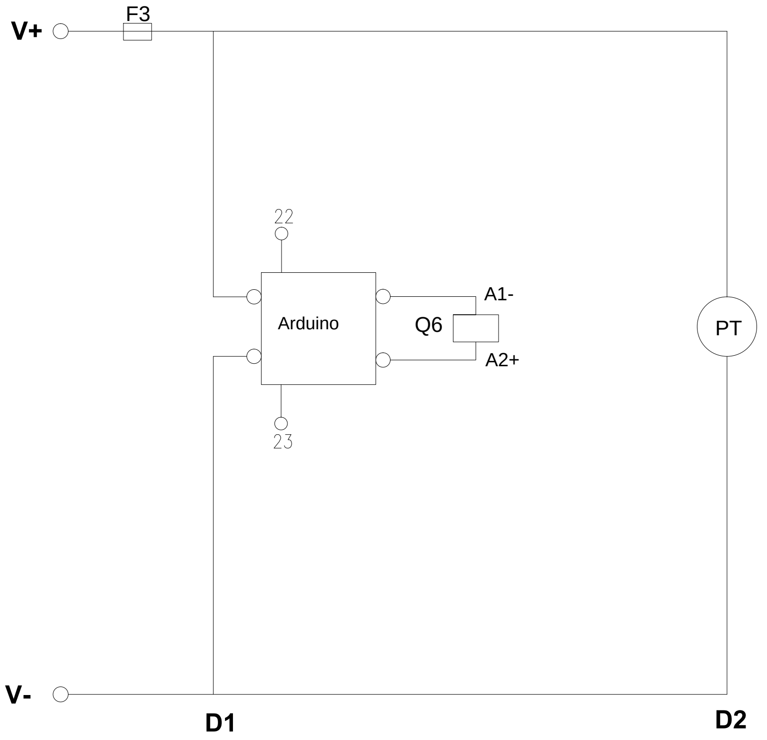
C5 is the same circuit as C4, but assigned for the PC in the system.

3.6.2.2 Control circuits

The control circuits will control the power circuit and supply power to components that is dependent on 12 VDC and 24 VDC. Therefore, the control circuit is divided into a 12 VDC and a 24 VDC circuit.

12 VDC circuit

The function of the 12 VDC circuit is to power the Arduino and the pressure transmitter, PT, located in the oil loop. The circuit consists of two branches, D1 and D2. D1 contains the Arduino which is connected to the Arduino relay. D2 consists of the oil pressure transmitter. The components are powered with power supply. This converts 230 VAC current to 12 VDC and is illustrated in Figure 3.23 with its terminals V+ and V-.



Parts List

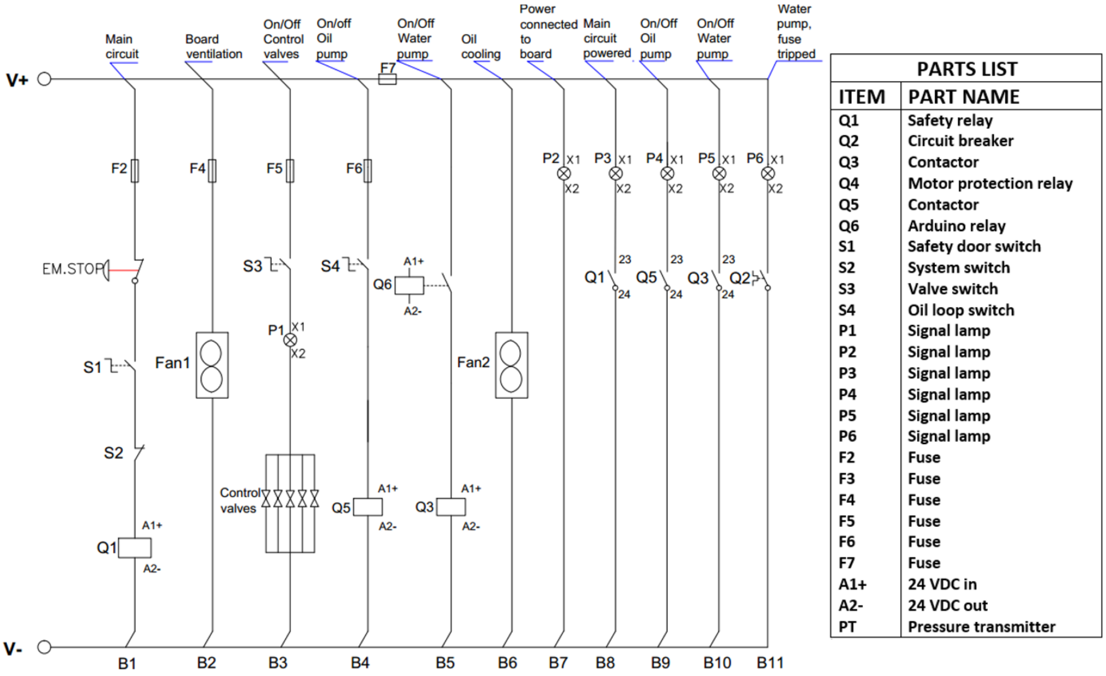
ITEM	File Name
Q6	Arduino relay
22&23	Signal wires
V+&V-	Power supply terminals
A1+	Control circuit inlet for Arduino relay
A2-	Control circuit for Arduino relay
PT	Oil pressure transmitter
D1	Circuit 1
D2	Circuit 2
F3	Circuit breaker

Figure 3.23: 12 VDC Control circuit powering the Arduino and the oil pressure transmitter.

24 VDC circuit

Figure 3.24 shows the 24 VDC circuit layout.

The main function of the 24 VDC circuit is to enable operation of the electrical components in the lab. In addition, the circuit conveys power to the



PARTS LIST	
ITEM	**PART NAME**
Q1	Safety relay
Q2	Circuit breaker
Q3	Contactor
Q4	Motor protection relay
Q5	Contactor
Q6	Arduino relay
S1	Safety door switch
S2	System switch
S3	Valve switch
S4	Oil loop switch
P1	Signal lamp
P2	Signal lamp
P3	Signal lamp
P4	Signal lamp
P5	Signal lamp
P6	Signal lamp
F2	Fuse
F3	Fuse
F4	Fuse
F5	Fuse
F6	Fuse
F7	Fuse
A1+	24 VDC in
A2-	24 VDC out
PT	Pressure transmitter

Figure 3.24: 24 VDC Control Circuit

indication lamps that gives the status of many components. The system is designed with 24 VDC components due to simplicity, compatibility and price. Most 24 VDC components are less expensive compared to similar 230 VDC components. In addition, unskilled personnel can legally connect components below 50 VDC as long as the power does not exceed 200 W [10]. This made the assembly process less expensive and less time consuming.

B1

B1 consists of the fuse, F2, an emergency shut down switch, a main power switch, S1, a safety door switch, S2, and the main contactor, Q1. This circuit has several functions. When activating S1, B1 becomes a closed circuit which powers the contactor in the circuit. When activating Q1, the power circuit becomes a closed circuit meaning that voltage is applied over the electrical motors in the system. This can be seen from Figure 3.22. Paragraph 29, in the Norwegian regulations for low voltage facilities, states that a quick manual disconnection is required to prevent hazardous situations [11]. For the electrical system, this is solved by implementing a certified emergency shut down switch in B1. This is a highly reliable normally closed switch, meaning that it is conducting electrical current in normal situations. It opens when it is activated, resulting in an open circuit which powers off the power circuit via Q1.

S2 is a spring loaded door switch which acts a safety disconnection switch. When the door of the distribution board is opened, B1 is powered off. This ensures that the main power is always disconnected from the electrical motors when the door is opened.

F2 is a fuse that will trip in case of a failure in the circuit. This will result in a disconnection of the power circuit.

B2

B2 consists of the fuse F4 and a fan, Fan1. The function of the circuit is to drive the fan which ventilates the distribution board. F4 ensures disconnection of B2 if an electrical failure causing overloading occurs. Since it is connected in parallel, it will not interrupt any of the other circuits when disconnected. This fan will start ventilating when the extension cord is connected to the wall.

B3

B3 is the circuit that powers the control valves. It consists of the fuse F5, the rotary switch S3, the green diode P1, and a distribution system for the control valves. F5 has the same function as the fuses in B1 and B2. S3 ensures manual start of the valves. The distribution system consists of terminal blocks which are joined, creating a common node.

B4

B4 controls the oil pump. It is designed to be manually powered by a rotary switch. The circuit consists of the fuse F6, the rotary switch, S4, and the contactor, Q5. When S4 is switched on, B4 becomes a closed circuit which powers Q5. Q5 activates and closes the power circuit C3 illustrated in Figure 3.22.

B5

B5 controls the water pump. The circuit consists of the contactor Q3 and the Arduino relay Q6. The fuse F7, located between B4 and B5 covers all the circuits form B5 to B11. If one of these circuits experience an electrical failure, F7 disconnects every circuit it covers.

When the Arduino receives a signal from the level transmitter that the separator is full, it powers Q6 which activates Q3. This results in a closed circuit of C2, applying voltage over the water pump.

When the separator is emptied, the Arduino receives a signal from the level transmitter, which opens the Arduino relay. B5 is then opened, and Q3 disconnects C2, stopping the water pump.

B6

B6 supplies power to the fan, Fan2, for the oil cooler.

B7

B7 is an indication circuit. It consist of a green diode P1 that will be lit when the distribution board is connected to the wall. Thus, if one of these circuits is exposed to an electrical failure, this will disconnect every circuit from B5 to B11.

B8

B8 indicates if the main circuit is powered. The contactor Q1 is equipped with two auxiliary contacts, a normally open (NO) and a normally closed (NC). B8 is connected to the NO contact. When the Q1 is activated, B8 becomes a closed circuit and the green diode P2 is lit.

B9

B9 is a circuit that indicates when the oil loop is manually powered. The circuit consists of the green diode P3 and the NO contact located in the Q5 contactor. When the rotary switch S4 is closed, Q5 is activated, which closes the B9 circuit and P3 is lit.

B10

B10 indicates if the water pump is powered. The circuit consists of the green diode P5 and the NO contact in the Q3 contactor. When Q3 is powered by the Arduino system, the NO contact closes B10 and P5 is lit.

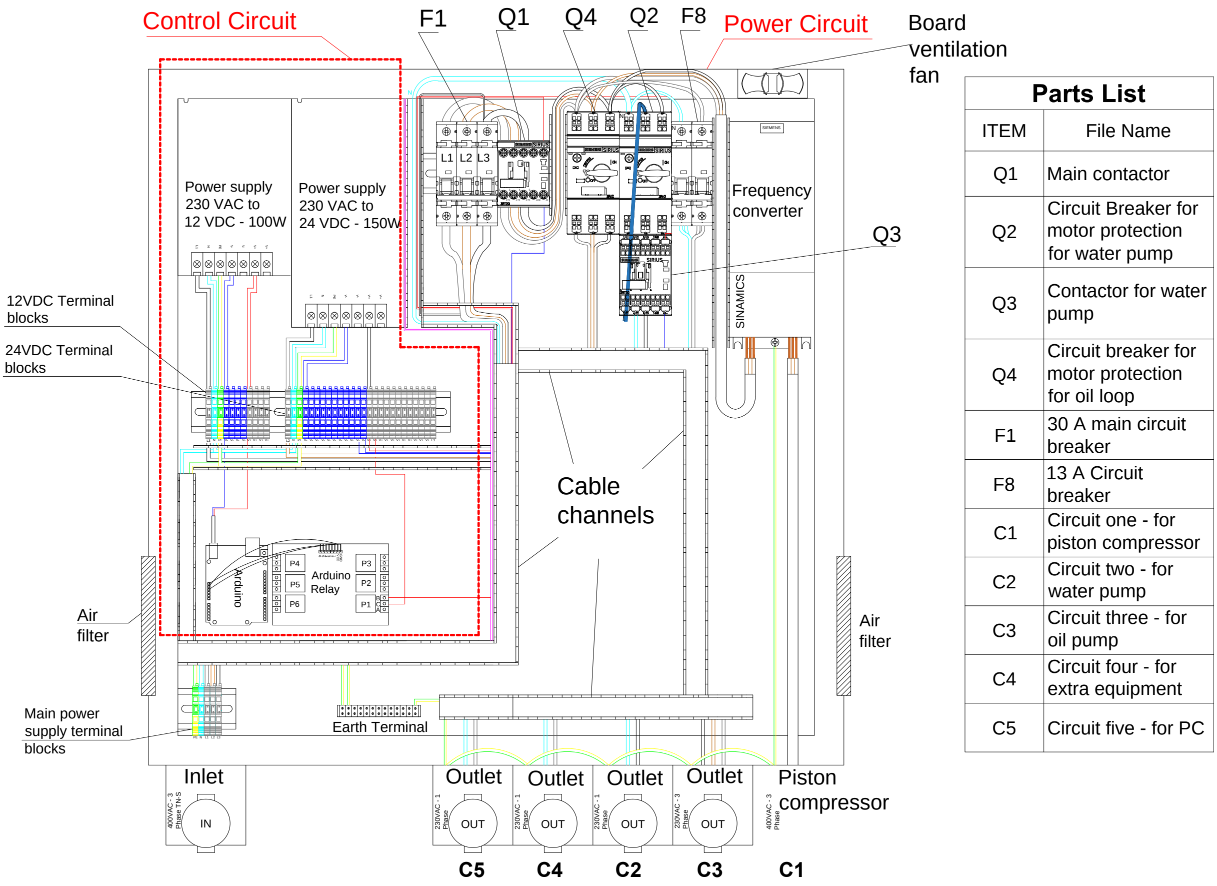
B11

B11 indicates if the fuse for motor protection, Q2, is tripped. The circuit consists of a red diode P6 and a NO contact in Q2. When Q2 trips, this contact closes and P6 is lit.

3.7.3 Assembly of the electrical system

The main component of the electrical system is the distribution box. This component distributes power from the wall to all its connected equipment. All of the components in the line diagram, Figure 3.21, except the motors with its associated cables, are located in the distribution box. To construct the box, research and ordering of the correct components had to be done before the physical layout could be designed. AutoCad was the preferred design software for the physical layout as drawings of the circuit breakers and contactors could be downloaded from the vendors' web page. The rest of the components were drawn by the students. Figure 3.25 shows the physical layout of the distribution box.

The distribution box consists of a 60 × 60 × 38 cm metal cabinet with a mounting plate on the inside for component assembly. Similarly to the line diagram in Figure 3.21, the distribution box is divided into a power circuit and a control circuit. The power circuit is located to the right in Figure 3.25, while the control circuit is placed to the left, separated by a cable channel in the middle.



Parts List

ITEM	File Name
Q1	Main contactor
Q2	Circuit Breaker for motor protection for water pump
Q3	Contactor for water pump
Q4	Circuit breaker for motor protection for oil loop
F1	30 A main circuit breaker
F8	13 A Circuit breaker
C1	Circuit one - for piston compressor
C2	Circuit two - for water pump
C3	Circuit three - for oil pump
C4	Circuit four - for extra equipment
C5	Circuit five - for PC

Figure 3.25: AutoCad drawing of the components in the distribution box.

The terminal blocks for the power supply was mounted in the bottom left corner of the distribution box, Figure 3.25. The five TN-S power cord wires require one terminal block each. For the PE wire, an earthed terminal block was required. This is equipped with a metal grab ensuring proper metal contact to the box and has the same colour indication as the wire; yellow and green. The blue neutral wire was connected to the blue terminal block. L1, L2, and L3 were connected to the grey blocks.

From the L1, L2, L3 terminal blocks, wires were connected to the main circuit breaker, F1. From F1, wires were connected to the main contactor, Q1. This is the main circuit. The 24 VDC circuit is the only branch that was connected between F1 and Q1. This circuit operates Q1 and must therefore be powered at all times. If an electrical failure occurs in this circuit, it will be protected by F1.

The circuits for the 12 VDC control circuit, oil pump, water pump, extra power sockets and for the piston compressor were connected in parallel after Q1.

The electrical system was designed to be mobile. This was solved by implementing a power inlet for the supply cable, and by distributing the power to the electrical motors for the oil pump, water pump and for the extra equipment through power outlets. These are illustrated at the bottom of Figure

3.25. Further, the electrical motors for the oil pump and the water pump will be equipped with power plugs. Thus, the electrical motors could be connected to the distribution box via extension cords. To reduce the possibility of electromagnetic interference of the components in the distribution box, the frequency converter will not be equipped with a power outlet. The converter will be connected to the motor with an uninterrupted shielded cable. If the lab has to be moved, this cable must be manually disconnected from the motor.

The wires drawn are coloured according to the standard colour code [68]. L1, is coloured black, L2 is brown and L3 is grey .

During the board construction, some improvements to the physical layout were made. The main improvements are shown in Figure 3.26 with the red numbered rectangles.

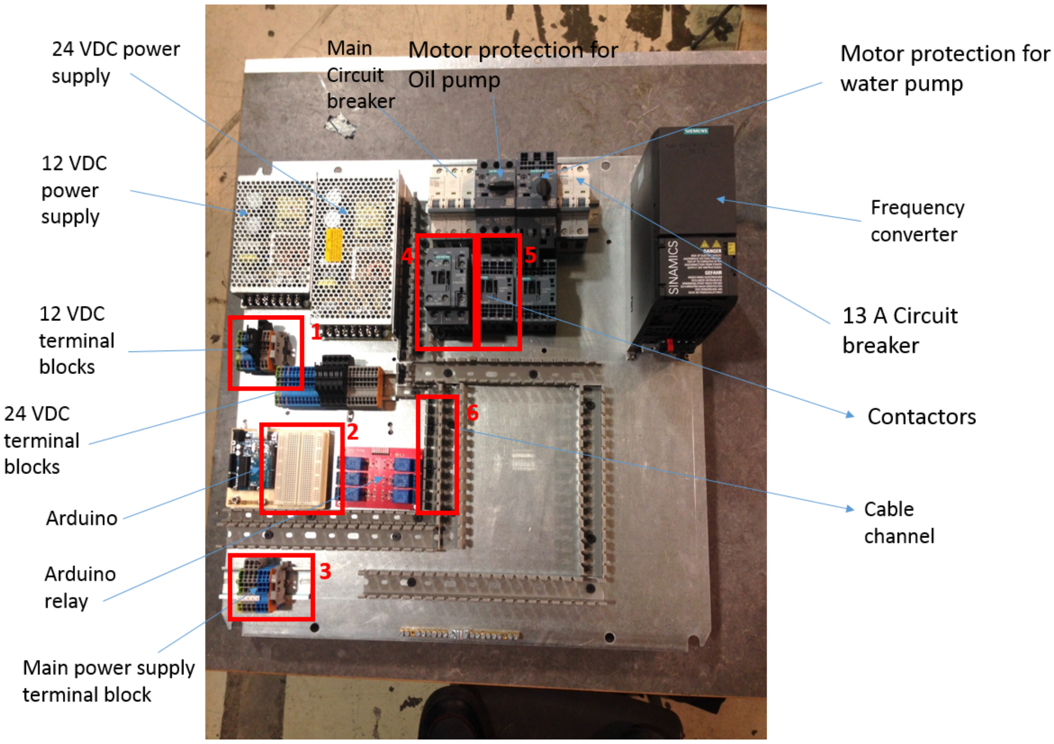


Figure 3.26: The mounting plate with the installed components.

Number 1 shows the new position of the 12 VDC terminal blocks. The change was due to the installation bolts on the mounting plate. Number 2 shows the added Arduino breadboard. This can be convenient for future arrangements. Number 3 shows the two extra neutral terminal blocks for connection of components requiring the neutral wire. Number 4 shows the repositioning of the main contactor, Q1. This resulted in better space on the din rail and made the wiring easier. Number 5 shows the extra contactor, Q5, for the oil loop. This will be controlled by a switch in the front panel. Number 6 shows the small parallel cable channel intended for the control circuit wires.

The front panel of the distribution box is the interface between the electrical system and the lab personnel. The switches, signal lamps and the emergency shut-down button were mounted in the front panel. Figure 3.27 shows the component layout of the front panel.

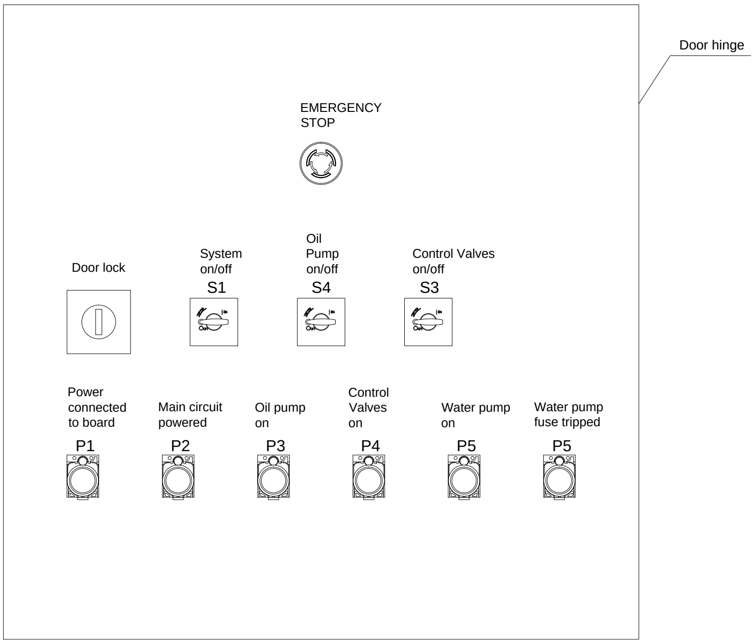


Figure 3.27: Schematic view of the physical layout of the front panel.

The standard NEK400, part 537.4.2.7, states that equipment for emergency shut-down should be positioned in such a way that it should be simple to identify and easy to handle. It was therefore determined to place the emergency shut-down button at the top of the panel.

The on/off switches for the system, oil pump and control valves is positioned in the middle row. Each switch has an associated signal lamp which is positioned below the relevant switch. If a signal lamp is lit, the associated circuit is powered.

P1 to P5 are green, while P6 is red. P1 indicates when the supply cable into the distribution board is connected to a power outlet. This means the lab is powered when P1 is lit.

P2 indicates when the main circuit is powered by the switch S1. This means that power is applied to the power outlets at the bottom of the distribution box.

P3 indicates that the oil pump is turned on by the switch S4.

P4 indicates that the power to the control valves is turned on. The water pump is controlled by an Arduino located inside the metal cabinet, therefore no water pump switch is located in the front panel. This makes it harder to diagnose the status of the water pump circuit, C2. Therefore, a red alarm lamp is mounted into an auxiliary contact in the circuit breaker Q2. If Q2 trips, the red signal lamp is lit.

All of the components inside the distribution box are generating heat due to power loss. The most heat generating component is the frequency converter.

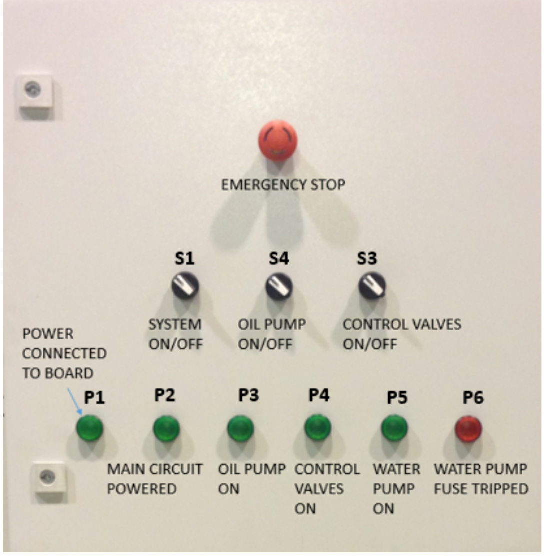


Figure 3.28: Physical layout of the front panel

According to its data sheet, it experiences a power loss of 0,150kW [56] and requires an air flow of 18 m^3/h for cooling. The increase in temperature affects the circuit breakers negatively. With increasing temperature, the current overload mechanism in the circuit breakers will trip prematurely [41]. Therefore, a 24 VDC fan with a maximum volumetric airflow of 23.5 m^3/h [69] was placed at the top of the metal cabinet. This will ensure that the temperature inside the cabinet is kept as close to the outside ambient temperature as possible.

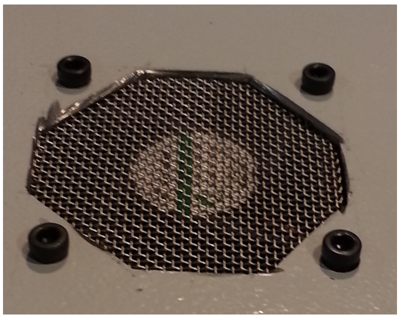


Figure 3.29: Board ventilation fan with protection at the top of the distribution box.

To protect the fan from outside physical impacts, a steel mesh was placed in front of the fan as shown in Figure 3.29. Two air filters ensures that the air is filtered reducing dust exposure to the electrical components inside the box. Figure 3.30 shows the distribution box from the outside.

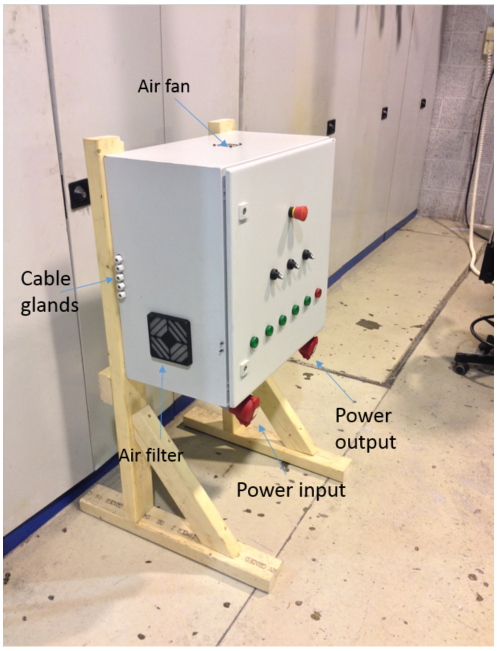


Figure 3.30: The distribution box from the outside

3.8 Valves

In total there are four actuated valves and nine manual valves in the lab. The actuated valves are used for flow control, while the manual valves are used to decide which scenario is to be tested, see Section 3.1. The actuated control valves are angle seat valves and are used for three different purposes. Two valves are used for pressure reduction of the flow, one valve is used for pressure control of pressurized air into the turbocharger and the last is used as an anti-surge valve. There are two types of manual valves in the system, ball valves and one-way valves. The one-way valves are installed to ensure no backflow in the pipes. The system drawing, Figure 3.1, shows the placement of the valves.

The valve used for pressure reduction of the flow is an ASCO 290 proportional 2/2 valve NC. It has an actuator and a positioner to control the opening of the valve. One is located after the water pump and is used to choke the water pressure down to the same pressure as the flow coming out of the cooler. Figure 3.31 shows the valve [9].

The other is located just before the separator and is used to depressurize the system flow before it enters or bypasses the separator. This is to ensure that there is no uncontrolled pressure buildup in the system. The valve is pneumatically controlled by the actuator. This means that the actuator receives pressurized air from the workshop and uses it to open or close the valve without the possibility to regulate the opening. The valve is normally closed, meaning when the air supply from the actuator is shut off, the valve automatically closes as a fail safe mechanism.

It is desirable to regulate the pressure of the flow in the system. To do this

Figure 3.31: Asco 290 angle seat valve with actuator and positioner [9].

the valve opening has to be controllable, meaning that the seat of the valve has to be able to stop in every position. A positioner is used to achieve this. The positioner controls the air supply to the valve in order to keep the seat in a certain position between open and closed.

The opening of the valve will be regulated based on pressure readings from pressure transmitters 2, 3 and 6 in Figure 3.1. The sensor signals are sent to the control software on the computer. The pressure readings are analysed and based on this, the controller sends a signal to the positioner of the valve controlling the seat opening. The response time for the valve from open to closed position is 2 seconds. From closed to open position the response time is 2.5 seconds. The dimension of the valve is 1 1/2 inches. The reason for choosing this dimension was to reduce the venturi effect as much as possible, which will cause a pressure drop in the pipe.

Asco 290 2/2 motorized valve is used for both the anti-surge valve and the pressurized air valve for the turbocharger. The reason this valve was preferred is because it has a lower response time than ASCO 2/2 proportional valve. This valve works with the same principle as the ASCO 290 proportional 2/2 valve NC. However, it is electrically controlled rather than pneumatically controlled. Figure 3.32 shows the valve.

The response time for the valve from closed to open position is 1.1 seconds. In order to avoid surge, a valve with as low response time as possible was desired. This way the valve will react to the surge pressure readings before surge occurs. In addition, it is important to be able to alter the rpm of the turbocharger without a long time delay. There were no actuated valves with a dimension of 1 1/2 inches that satisfied the response time requirements. Therefore, a valve with a dimension of 3/4 inches was chosen to achieve a faster response time. The reduction of the valve dimension will not impact the pressure in the system, since the anti-surge line is normally closed unless the turbocharger experiences surge. The pressurized air line is not a part of the main system as it only feeds air to the turbine of the turbocharger.

Figure 3.32: Asco 290 2/2 motorized valve [8].

The valve controlling the pressurized air is controlled by the desired rpm of the turbocharger. The turbocharger has a built-in rpm transmitter that signals the computer. A logic converts the rpm into the necessary mass flow of air needed to achieve the desired rpm, which again controls the seat position of the valve.

The anti-surge valve opening is based on pressure readings from pressure transmitter PT 4 in Figure 3.1. As described in Section 3.6, surge occurs in a compressor when the pressure at the outlet is so low that a backflow occurs through the compressor. The pressure transmitter has continuous readings of the flow out of the turbocharger. If a sudden pressure drop were to happen, a logic sends a signal to the anti-surge valve to open. The flow will then be guided through the valve back to the turbocharger inlet.

3.9 Pipes and connections

There were several important factors to consider when choosing the pipes and pipe connections for the lab. The most important factors for the material selection were the system pressure and temperature.

There is a high pressure and high temperature side and a low pressure and low temperature side in the lab. Because of this, different materials were chosen for the pipes in different places. Due to a wide range of dimensions and components, many different types of pipe connections are used. Where it was not possible to find a compatible connection between components, connections were handmade by the students.

The number of connections in the lab made water and gas leakage a serious concern for the integrity. This was a big challenge when constructing the lab. Leakage tests were performed during construction and improvements were made where necessary to ensure leakage-free operation of the lab.

The large frame has both a high pressure and low pressure side. However, the temperature is much lower compared to the small frame. The temperature will never exceed 20°C as explained in Section 3.4.1. To be able to visually characterize the flow, transparent PVC pipes with an outer diameter of 50 mm were chosen. The pipe can withstand a pressure of up to 10 barg and a temperature up to 60°C [50]. This is well within the requirements for the pipe material in this frame.

To bend and connect the transparent pipe, quick-connect connections in PVC were used. These are especially designed for high pressure water systems. These were also used to install the two choke valves, manual valves and the pressure transmitters in the large frame. Using the PVC connections along with the PVC pipe has advantages compared to using metal. Perhaps the biggest advantage is the elimination of corrosion. The connections are very easy and quick to install and disconnect, in addition to being relatively low priced.

Figures 3.33 and 3.34 shows examples of how pipes were connected in the system.

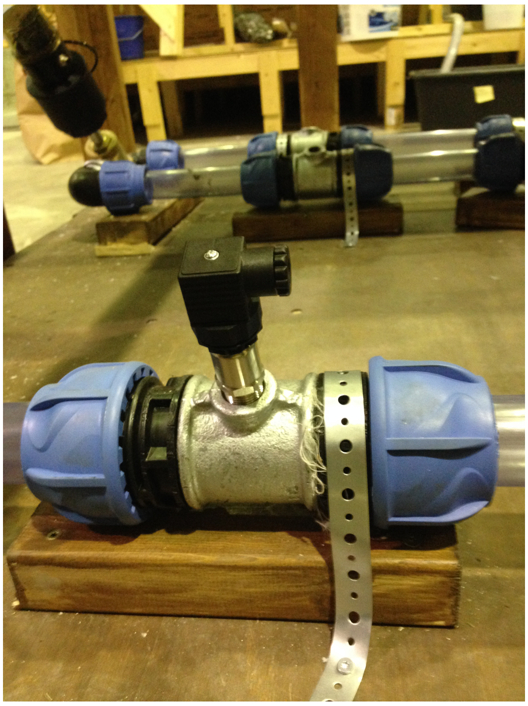


Figure 3.33: Pressure transmitter installed in the system

Figure 3.34: Pipe connections with one-way valve located on the big frame.

In the small frame there are both high and low pressure and temperature zones. This means that the material selection for both connections and pipes had higher requirements than the equivalent in the big frame. Section 3.4.1 shows that the maximum temperature at the outlet of the turbocharger will be approximately 220°C. The PVC pipe used in the large frame was therefore not applicable for the small frame. Stainless steel was considered. However, this would complicate the installation process since the students would have to rely on help from external personnel for welding. In order to achieve a simple installation process and to avoid external assistance, silicon hose was chosen. This ensured an easy connection and disconnection with hose clamps and it removed the need for bend-connections. In addition, time would saved as the students can install the hoses themselves.

Some of the components in the small frame did not have compatible inlets or outlets with regular threaded hose nipples. To connect the silicon hose to the relevant component, the connections were handmade. This was done for the turbocharger turbine inlet and both the inlet and outlet of the piston compressor. A connection for a pressure transmitter was also made in the piston compressor inlet. Otherwise it was made in the same way as the turbocharger turbine inlet connection.

3.10 Instrumentation

Instrumentation will be an essential part for running and control of the lab. However, the implementation of software and logic has to be at a later stage due to time limitations as explained in Section 3.2. The instrumentation will consist of components such as pressure-, rpm-, temperature- and level-transmitters in addition to software interface and logic systems for component control. Without this, the lab will just be a loop without the possibility for control and no means of recording results in accordance with the lab objectives.

There are a total of six pressure transmitters, four temperature transmitters, one level transmitter and one rpm transmitter in the system. The purpose of all these transmitters are explained in the relevant system descriptions they are part of. They will therefore not be explained in detail in this section apart from component specifications and scope. The data sheets for all transmitters are found in Appendix A.

The chosen pressure transmitter is a Siemens SITRANS P200 transmitter. The transmitter has a pressure range from 0 to 10 barg and can be used in both the low pressure and high pressure side of the lab. In addition, the transmitter has a measurement accuracy of more than 99.75 %. To measure the pressure difference, the transmitter uses a piezoresistive measuring cell with a diaphragm. It converts the pressure that is exerted on the piezoresistive measuring cell into electric charge which is sent to the computer software for further translation.

Figure 3.35 shows the pressure transmitter installed in the system.

When selecting the temperature transmitters, the difference in temperature range had to be accounted for. As two of the transmitters were to be placed in the low temperature side of the lab, the need to withstand high temperatures was not present. Therefore there are two different types of temperature transmitters used in the lab. The low temperature transmitter is a Jumo PT100 transmitter with a temperature range from -5 to 80 °C. The high temperature transmitter is a Lutron PT100 transmitter with a temperature range from -50 to 400 °C.

Figures 3.36 and 3.37 shows the two different temperature transmitters installed in the system.

Figure 3.35: Siemens SITRANS P200 transmitter [59].

Figure 3.36: Lutron temperature transmitter [24].

Figure 3.37: Jumo temperature transmitter [20].

As described in Section 3.8, an rpm transmitter is mounted on the turbine shaft of the turbocharger in order to give rpm readings that can be used to control the mass flow of air into the turbocharger. The transmitter was machined into the shaft by the workshop personnel with instructions from the manufacturer. It measures the frequency of compressor blades passing. The number of blades in the turbine is known, and the rpm can therefore be calculated from the frequency.

A level transmitter will be used to control the water level in the separator. The function of the transmitter is explained in detail in Section 3.3.2.

Chapter 4

HSE

During the design and construction of this laboratory there were many health, safety and environment (HSE) aspects to consider. The main concern was to prevent personnel injuries, both when running the lab as well as when constructing it. Preventing unnecessary damage to equipment and lab area was also important. NTNU has their own HSE measures that have to be followed by personnel using the workshop and lab area. For example, safety goggles have to be worn when handling tools and materials that creates ricochet particles. Protection shoes has to be worn at all times when walking around in the workshop.

The lab was designed with two modules that can be disconnected and transported separately if necessary. The electrical- and rotating components were separated from the wet components such as the cooler and separator. This was to avoid the risk of short circuiting the electrical components in case of a water leakage. The exception is the water pump which is a part of the separation loop and therefore had to be located on the wet frame.

All electronics were chosen in accordance with regulations and will connected by a professional.

Both frames were coated to ensure that the wood can withstand a water leakage. The frame containing the rotating components has a pulse absorbing layer in order to minimize the vibrations on the frame which can have a negative impact on the pipes. The rotating components were also bolted to metal plates instead of the wood to ensure that the bolts stayed in place.

All adjustable components that need adjustments during operation were made automatic and controllable from a computer interface. Examples of this are the two actuator controlled choke valves. The opening of the valve will be controlled based on pressure readings from the pressure transmitters. In addition, these two valves ensure no uncontrolled pressure buildup in the system.

Any manual adjustments have to be made when the system is shut down, e.g. the manual ball valves that decides which loop is being used. An emergency stop button is installed in the distribution box to shut down the whole system in case of an emergency.

4.1 Risk analysis

To create the lab as safely as possible, and to ensure no damage to personnel or equipment during construction and running of the lab, potential unwanted incidents had to be mapped. By doing this, the lab and the building process was designed and planned based on the probability and consequences for the unwanted incidents to happen. This is essential to prevent damage to personnel. In addition, potential unwanted incidents concerning only the system were mapped. This way the most critical components were identified and these have to be monitored more carefully than the less critical components. Risk analysis was used to find and analyse the potential unwanted incidents that can happen to personnel and the system during construction and running of the lab.

Risk analysis is a method of defining a threat or a hazard to people or a system and identifying the probability and consequence for the event to happen. The higher the probability and consequence the higher risk of the event. This analysis is an important tool in improvement of the HSE-level in a workplace. By identifying the risk, precautions can be made to prevent it from happening.

The analysis can be qualitative or quantitative based on the component's average lifetime or probabilities of an unwanted event to happen. If there are no numbered probabilities, the analysis is made qualitative. The risks are then based on the likelihood and the consequence of them to occur.

Table 4.2 shows a risk matrix which is used in a qualitative risk analysis. The red areas indicates high risk meaning that the system has to be monitored at all times in order to prevent the events from happening. Yellow is a moderate risk and personnel must to be aware of the incidents that may take place in order to prevent them from happening. The green area indicates an acceptable level of risk.

		Impact				
		Very Low	Low	Medium	High	Very High
Likelihood	Very High	🟨	🟨	🟥	🟥	🟥
	High	🟩	🟨	🟨	🟥	🟥
	Medium	🟩	🟨	🟨	🟥	🟥
	Low	🟩	🟩	🟨	🟨	🟥
	Very Low	🟩	🟩	🟩	🟩	🟨

Table 4.1: Risk matrix where an event is categorized by the likelihood and impact on personnel, equipment and surroundings [16].

Table 4.1 was used as a model to identify the risk level of each of the identified unwanted incidents concerning both personnel and the system. To place each event in the risk matrix, the impact and likelihood of the events were categorized in Table 4.2.

	Very low	**Low**	**Medium**	**High**	**Very high**
Likelihood	Once per 100 years	Once per 10 years	Once per year	Once per 6 months	Once per month
Impact	Minimal or no damage to system or personnel. For example a dent in the wooden frame.	Minor damage to system components or personnel. For example bruising of skin.	Some damage to system components or personnel. For example leakage in the compressed air supply for the turbocharger. The system may not work optimal.	Severe damage to system or personnel. For example damage to personnel causing them to be hospitalized.	Very severe damage to the system or several people. For example the wooden frame catching fire.

Table 4.2: Description of the different categories in the risk matrix.

When designing the lab, two risk analysis were conducted. One for personnel and one for the system while the lab is running.

Table 4.3 shows the complete risk analysis for the system components when the lab is running. There are a few incidents that have "very high" or "high" impact on the system which will lead to total system failure. The reason not all of these are in the high risk category is that the likelihood for these to happen are "low" or "very low". This means that the events are either in the green risk area or the yellow risk area of the risk matrix. The three high risk events must be monitored while running the lab to prevent them from taking place.

Risk analysis for the system when the lab is running			
Incident	**Likelihood**	**Impact**	**Risk**
Wooden frame catches fire	Very low	Very high	Moderate
The vee belt on the piston compressor and motor breaks	Low	High	Moderate
The bolts securing the piston compressor to the wooden frame loosens	Very low	Medium	Low
Inlet or outlet leakage of piston compressor	Low	Low	Low
Motor or piston compressor wheel goes off	Very low	Very high	Moderate
Failure to start motor	Low	High	Moderate
Bolts securing the motor to the wooden frame loosens	Low	Low	Low
Bolts securing the turbocharger to the wooden frame loosens	Low	Low	Low
Leakage in compressed air inlet of turbocharger	Low	Medium	Moderate
Leakage of cooling medium from the cooler	Medium	Low	Low
Leakage of water onto electrical components	Medium	High	High
Oil pump failure	Low	High	Moderate
Main choke failure	Low	Very high	High
Separator blow out	Very low	High	Low
Pipe connections blow out	Low	Very high	High
Leakage from separator and pipe connections	Medium	Low	Moderate
Broken oil filter	Low	High	Moderate
Compressed air choke valve failure	Low	High	Moderate
Copper coil leakage	Medium	Low	Moderate
Water pump failure	Low	Medium	Moderate
Water choke failure	Low	Medium	Moderate
Level transmitter failure	Low	Medium	Moderate

Table 4.3: Risk analysis of the system when the lab is running

Risk analysis for personnel when the lab is running			
Incident	Likelihood	Impact	Risk
Wooden frame catches fire	Very low	Very high	Moderate
The belt on the piston compressor and motor breaks	Low	High	Moderate
The bolts securing the piston compressor to the wooden frame loosens	Very low	Medium	Low
Inlet or outlet leakage of the piston compressor	Low	Medium	Moderate
Motor or piston compressor wheel goes off	Very low	Medium	Low
Electricution of personnel when handling the motor due to grounding fault	Very low	High	Low
Bolts securing the motor to the wooden frame loosens	Low	Low	Low
Bolts securing the turbocharger to the wooden frame loosens	Low	Low	Low
Leakage in compressed air inlet of turbocharger	Low	Medium	Moderate
Leakage of cooling medium from the cooler	Medium	Very low	Low
Electricution of personnel when handling the water pump	Low	High	Moderate
Electricution of personnel when handling the oil pump	Low	High	Moderate
Main choke failure	Low	Medium	Moderate
Separator blow out	Very low	High	Low
Pipe connections blow out	Low	High	Moderate
Leakage from separator and pipe connections	Medium	Very low	Low
Pressure transmitter failure	Low	Medium	Moderate
Temperature transmitter failure	Low	Medium	Moderate

Table 4.4: Risk analysis for personnel when the lab is running

Table 4.4 shows the completed risk analysis for personnel operating the lab. As opposed to high risk system events, unwanted high risk personnel events are not acceptable as this can lead to severe injuries or death of personnel. The analysis gave no high risk events for personnel when operating the lab. However, there were many moderate risks for unwanted events. Since these risks can lower the personnel safety, they are highly unwanted and safety precautions should be made to lower the risk level from moderate to low.

Based on the risk matrix for personnel when the lab is running, the design of the lab was altered in order to create a safer environment. It was clear from the risk matrix that different moderate risk level components had to have safety and fail safe mechanisms.

According to the risk matrix, there is a moderate risk for a pipe connection blow-out. To lower the risk, pressure relief valves will be installed. These are located in the separator as this is the most critical component if a blow-out were to occur. If the pressure reaches its upper limit, the relief valves will vent the pressure to an acceptable level. The reason the valves are placed in the separator is because of its big volume. The separator contains about 100 l of compressed air which will cause a huge force when expanded.

To ensure the safety of personnel and equipment if a blow out were to happen, in spite of the pressure relief valves, the lab will be protected with walls. The walls are made of wood with a window made out of polycarbonate with a high impact strength [6].

Installing the safety wall around the lab also impacts the risk of other incidents. The impact of all incidents involving blow out, component ricochets and gas leakage are lowered, resulting in a reduced risk.

The water pump is built in a housing to protect the electronics from water in case of a water leakage on the frame.

Table 4.5 shows the updated risk matrix for personnel during operation. It shows that many of the moderate risks in the first matrix have been reduced to low risk after the precautions were implemented in the design.

Risk analysis after preventive actions for personnel when the lab is running			
Incident	**Likelihood**	**Impact**	**Risk**
Wooden frame catches fire	Very low	Very high	Moderate
The vee belt on the piston compressor and motor breaks	Low	Low	Low
The bolts securing the piston compressor to the wooden frame loosens	Very low	Low	Low
Inlet or outlet leakage in piston compressor	Low	Very low	Low
Motor or piston compressor wheel goes off	Very low	Low	Low
Electricuting of personnel when handling the motor due to grounding fault	Very low	High	Low
Bolts securing the motor to the wooden frame loosens	Low	Low	Low
Bolts securing the turbocharger to the wooden frame loosens	Low	Low	Low
Leakage in compressed air inlet of turbocharger	Low	Low	Low
Leakage of cooling medium from the cooler	Medium	Very low	Low
Electricution of personnel when handling the water pump	Low	High	Moderate
Electricution of personnel when handling the oil pump	Low	High	Moderate
Main choke failure	Low	Low	Low
Separator blow out	Very low	Meduim	Low
Pipe connections blow out	Low	Low	Low
Leakage from separator and pipe connections	Medium	Very low	Low
Pressure transmitter failure	Low	Low	Low
Temperature transmitter failure	Low	Low	Low

Table 4.5: Risk analysis for personnel when running the lab after safety precautions were made to the design

A risk analysis was also performed to map potential unwanted incidents to personnel during construction of the lab. The results are shown in Table 4.6.

Risk analysis for personnel during construction			
Incident	Likelihood	Impact	Risk
Tool drop on bodyparts	High	Low	Moderate
Injuries to personnel when using sharp tools	Low	High	Moderate
Injuries to personnel when carrying heavy objects	Low	Low	Low
Splint ricochet when cutting metal or wood	Low	Low	Low
Hair stuck in rotating tools	Low	Medium	Moderate
Untidy workplace causing personnel to trip	Medium	Medium	Moderate
Damage to bodyparts due to improper securement of drill element	Low	Medium	Moderate
Squeeze fingers	High	Medium	Moderate
Damage to fingers when releasing a quick release clamp	Low	Low	Low
Wooden frame catches fire	Very low	Very high	Moderate
Personnel hit by a forklift	Low	High	Moderate
Spilling of chemicals onto skin	Low	Low	Low
Contaminated compressed air in unwanted places	Low	Low	Low
Hearing injuries	Low	Medium	Moderate

Table 4.6: Risk analysis for personnel during construction of the lab

This analysis is made under the assumption that no protection clothing is worn in order to find the most probable impact it will have on a person. It shows that there are a lot of moderate risks for damage during construction. By using the correct protection equipment such as goggles, shoes, gloves, hair tie and hearing protection, the risks for the relevant incidents are lowered. The analysis proves the importance of appropriate protection equipment.

The risk analysis shows the importance of HSE focus when designing and constructing a test facility. If HSE is neglected, the danger of serious injuries to personnel and system breakdown is increased.

Chapter 5

Results

The main purpose of the lab is to emulate wet gas boosting as it is performed today, the laboratory was designed with two loops with two different compressors to emulate the two different existing solutions. The two compressors are a turbocharger and a piston compressor. The turbocharger will work as the wet gas compressor while the piston compressor will be used for motor control and increased system pressure when running dry gas.

After compression, the temperature of the gas will increase and a cooler is needed. Both the separator and cooler was designed and constructed by the students due to expensive pre-fabricated alternatives.

The flow in the system will be controlled by the two compressors and the two choke valves in the system. The rpm of the compressors will be adjustable by an electrical motor and pressurized air. The two choke valves have adjustable openings for better control of the flow.

Since there are no small scale wet gas compressors, it is desirable to be able to map the compressor characteristics of the turbocharger with different water fractions in the gas. To achieve this, pressure transmitters were installed before and after the turbocharger. The mass flow through the turbocharger will be calculated from the water volume in the system. The water volume must be carefully added via the water inlet.

HSE greatly affected the design of the lab. It is designed to ensure the safety of all personnel using it and its surroundings. Risk analysis have been performed in order to find where the greatest risks for component and personnel damage were. Based on the results from these analysis, improvements of the design were made to ensure the safety of both personnel and equipment. It became clear that safety measures such as a safety wall and a safety housing for rotating equipment was necessary. By implementing this in the design, the risk for personnel damage decreased considerably.

Many challenges arose during the design and construction phase of the project that caused the construction of the relevant component to exceed the estimated time schedule it had been given in the planning phase. One example of such a challenge was the construction of the cooler. Fitting the copper coils inside the cooler in the right place proved to be much more difficult than anticipated. Due to small leakages in the connection points that could not be visually detected, a lot of time was spent assembling and disassembling the cooler. This meant that the design and construction of other components had to be postponed until the cooler was finished.

Another time consuming challenge in the project was the procurement phase. A lot of time was spent trying to select components based on the system requirements. In addition, when contacting a potential supplier, the students were dependent on the supplier's time schedule and "good will" for help to pick out the correct parts. Suppliers often had to be contacted several times before an offer could be made. The time spent on the procurement phase was perhaps underestimated by the group.

Figure 5.1 and 5.2 shows the laboratory at the end of the project.

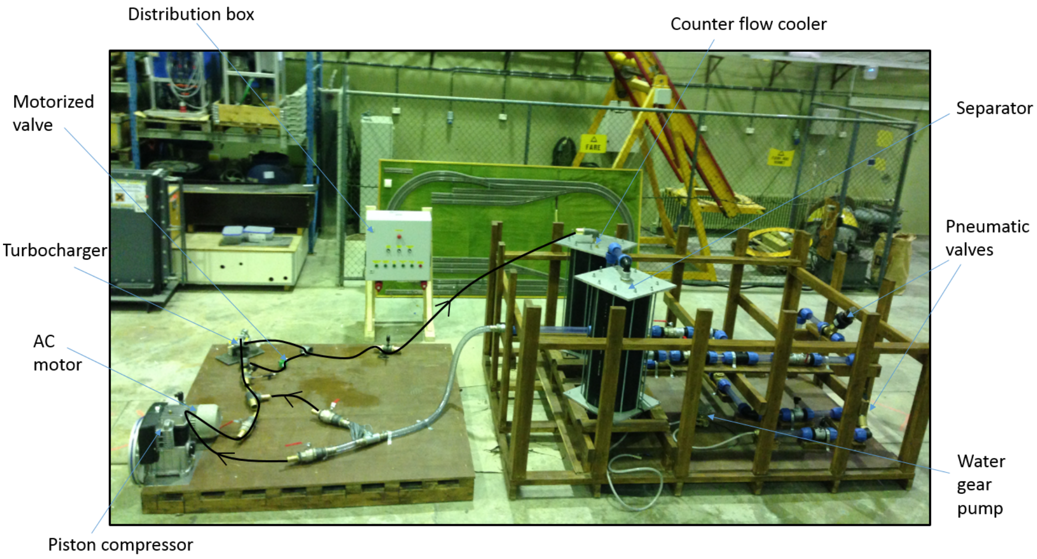


Figure 5.1: The lab with the intended silicon hoses illustrated with black lines.

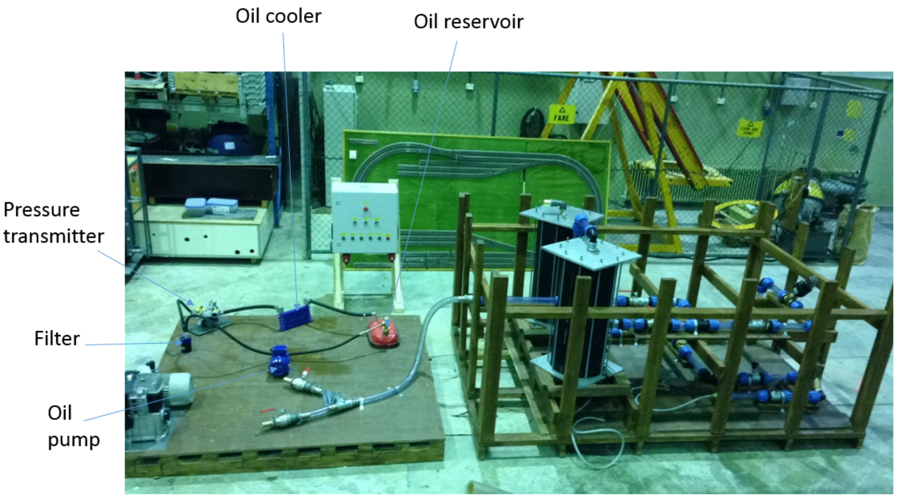


Figure 5.2: The lab with the oil loop.

5.1 Future work

There are still some construction and installation work that has to be done before the lab is fully operable. The main reason for this is time restriction. The design and construction process took more time to finish than anticipated as explained in Chapter 3. Another reason why the lab is uncompleted is that there is still no specific allocated area for it to be placed. This means that the ordering of certain components had to be postponed.

The turbocharger currently has no compressed air hose connecting the wall to the turbine side. The reason for this is the uncertainty of the placement of the lab. The necessary length of the hose is not possible to decide before the placement is certain. A long hose could have been bought, but due to a relatively high price per meter the group decided to postpone the purchase to avoid unnecessary costs. All of the components that are necessary for connecting a compressed air hose to the turbocharger and the pressurized air valve, such as hose nipples, are provided.

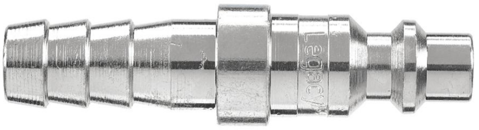


Figure 5.3: Compressed air nipple [36].

The hose must have an inner diameter of 3/4 inch that can withstand a pressure of up to 10 barg. The hose has to be cut in two pieces in appropriate lengths to be connected to the compressed air outlet in the workshop, pressurized air valve and the turbocharger. The hose is connected to the valve and turbocharger with hose clamps on the hose nipples. A compressed air nipple, Figure 5.3, has to be attached to the hose with hose clamps in order to connect it to the compressed air outlet in the workshop. Figure 5.4 shows where the compressed air hose with nipple is to be connected to the turbocharger.

In addition to the turbocharger pressure hose, the hose to pressurize the system has to be purchased. The length of this is also dependent on the placement of the lab. There are no special requirements on the diameter of this hose as long as it can withstand a pressure of up to 10 barg. In order to connect it to the compressed air supply in the workshop, compressed air nipples has to be attached on both sides of the hose. Figure 5.5 shows the connection point for this hose in the system. It is important to monitor the pressure in the system through the pressure transmitter to ensure it does not exceeds the system limit.

The silicon hoses for the high pressure and high temperature side of the small frame was not delivered in time to be installed. These have to be attached to the appropriate parts with the corresponding 2- and $\frac{3}{4}$ inch nipples that are provided. To ensure leakage free connections, hose clamps must be fastened to the connection points of the nipple and hose.

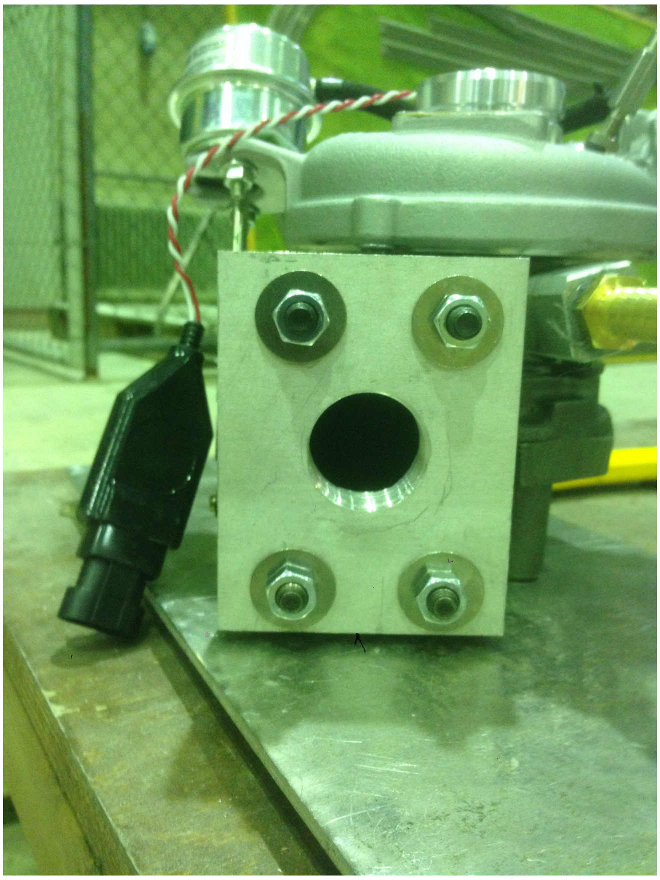


Figure 5.4: Compressed air inlet of the turbocharger.

The two pneumatic valves also needs a compressed air supply. This has to be supplied from the workshop. Installation instructions for implementation of compressed air supply hoses to the valves are found in the instructions manual for the valves in Appendix A.

The oil loop must be installed on the small frame and be connected to the turbocharger. The choke valve has to be purchased and added to the loop as seen in Section 3.6.1. This valve could be a manual choke valve.

The 24 VDC cooling fan for the oil cooler has to be installed. The fan is provided.

The most important part that remains to be implemented into the system is the control and monitoring of the lab. This means all the software that is going to be used. This part of the lab was deliberately postponed early in the construction phase. The reason for this was that it became clear, at an early stage, that it was not possible to complete everything within the given time frame. The main focus was to complete the building of the lab so that the software development could be started the following semester by a different student group.

As explained in Chapter 4, the lab was designed with protective walls and housing around rotary and electrical equipment in order to protect personnel close to the lab. These protective measures came after performing a risk anal-

Figure 5.5: The compressed air connection point in the system.

ysis of the lab. They still have to be designed and built before start-up. This includes:

- Protective wall around the whole lab.
- Protective housing for the piston compressor.
- Protective housing for the turbocharger.
- Safety valves in the separator.
- Protective housing for the water pump after the separator.

The lab cannot be run or tested before these safety features have been built and implemented where they belong.

Due to the complexity of the electrical system of the lab, the construction was not finished. However, the design of the system was completed and the majority of the components were ordered and installed. The wires to the electrical motors and inside the distribution box have not been dimensioned or ordered. This has to be done when all the components have been installed.

The wiring of the power- and control circuits for the distribution board, described in Section 3.7, remains. A qualified electrician is required to perform the wiring of the power circuit while the control circuit can be wired by unskilled personnel.

Ordering and installation of the cables going in and out of the distribution box, have intentionally been postponed. Due to the unknown allocation of the lab, the length of the cables could not be decided.

Wiring of the power inlet and outlets located at the bottom of distribution box remain. These wires have to be carried through the bottom of the metal cabinet via cable glands.

Wiring the electrical motors remain. Power plugs for the oil pump and for the water pump is provided.

The terminal blocks on the distribution board has to be marked. A corresponding terminal block table explaining the function of every terminal block must be added to the distribution box.

5.2 Concluding remarks

As an oil or gas field ages, the reservoir pressure naturally decreases. To extract more hydrocarbons from these fields, enhanced oil recovery was introduced. Early on in the offshore oil industry, water injection was introduced as an EOR method. Water was injected into the reservoir to increase the pressure and force oil to the surface. This method is still used today.

Another method that is widely used is multiphase pumping, either topside or subsea. The idea is to reduce the back pressure on the wellhead, which will allow more oil from the reservoir to be extracted. In later years, more gas fields have been discovered and as these fields naturally age, their production decreases. Therefore, like in oil fields, a method of extracting more gas is needed.

Unlike oil, gas is compressible, hence a compressor has to be used to boost the flow. Most gas found offshore is wet, which means that it contains a liquid fraction of 2–20 %. A traditional compressor cannot handle any liquid, and therefore new solutions for gas boosting had to be developed.

This report has described in detail the two existing subsea gas boosting technologies on the market today. These are the Gullfaks wet gas compressor and Åsgard wet gas compression system. In the Gullfaks field, a wet gas compressor was developed which is based on the design of subsea multiphase pumps. The Åsgard solution separates oil and gas before the dry gas is compressed in a centrifugal compressor. Gullfaks, unlike the system at Åsgard, is specifically designed to avoid separation of the flow. This means it can handle any liquid fraction in the gas flow. Based on these two solutions a subsea gas boosting laboratory was designed and constructed.

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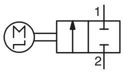
Appendix A – Relevant data sheets

MOTORISED VALVES

stainless steel body

threaded ports, 3/8 - 1/2 - 3/4



2/2
Series
290

FEATURES

- *High flow due to angled seat design*
- *Anti-waterhammer design (fluid entry under the disc)*
- *Actuator rotatable through 360°*
- *In option closing of the valve in case of power failure*
- *Fluid isolation between electrical actuator and valve body*
- *LED valves status display*
- *The valves satisfy Pressure Equipment Directive 2014/68/EU, article 3.3*
- *The motorised valves comply with the essential requirements of EMC Directive 2014/30/EU (EN-IEC 61000-6-2 and EN-IEC 61000-6-4) and Low Voltage Directive 2014/35/EU (EN-IEC 60730)*
- *Vacuum operation up to 10^{-2} mbar*
- *The valves satisfy all relevant EC Directives and with the provisions of the Directive RoHS 2*

D

GENERAL

Differential pressure	See «SPECIFICATIONS» [1 bar =100 kPa]
Maximum allowable pressure	10 bar
Ambient temperature range	-10°C to +50°C -10°C to +40°C (for steam at 145°C)
Maximum viscosity	600 cSt (mm^2/s)
Actuating time	< 1,3 s (opening) / < 1,3 s (closing)

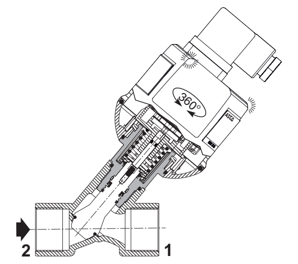
fluids (∗)	temperature range (TS)	seal materials (∗)
air and gas groups 1 & 2 water, oil, liquids groups 1 & 2	-10°C to +90°C	NBR (nitrile)
steam	up to +145°C	FPM (fluoroelastomer)

CONSTRUCTION

MATERIALS IN CONTACT WITH FLUID

(∗) Ensure that the compatibility of the fluids in contact with the materials is verified

	NBR / PBT «K»	FPM / 316L «X»
Valve body	AISI 316L	AISI 316L
Stuffing box housing	PBT, GF reinforced	AISI 316L
Stem valve	AISI 316L	AISI 316L
Stuffing box packing	NBR	FPM
Wiper seal	NBR	FPM
Disc seal	NBR	FPM



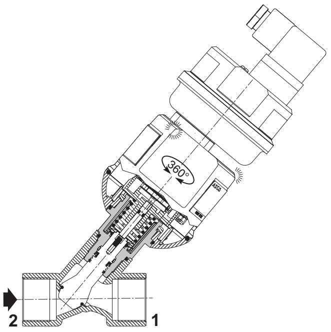
DC construction

OTHER MATERIALS

Top cover operator	Translucent polyamide (PA)
AC to DC housing (AC)	PA66, GF reinforced

ELECTRICAL CHARACTERISTICS

Connector	Spade plug (cable Ø 6-10 mm)
Connector specification	ISO 4400 / EN 175301-803, form A
Motor consumption	12 W in operation, 0 W hold Max. peak current: 0,7 A
Visualisation valve (switching)	LED
Electrical safety (adapter AC to DC)	IEC 335 (EN-IEC 60730), class 2
Electrical enclosure protection	IP65 (EN 60529)
Standard voltages	DC (=) : 24V ±10 %, max. ripple 5%
(EN-IEC 61131-2)	AC (~) : 110V to 250V / 50-60 Hz 24V to 48V ±10 % / 50-60 Hz



AC construction

RECOMMENDATION FOR MAXIMUM DUTY CYCLE FOR NBR / PBT "K" VERSION

Ambient temperature: +20°C	9 cycles/min (1)
+50°C (max.)	4 cycles/min (1)

RECOMMENDATION FOR MAXIMUM DUTY CYCLE FOR FPM / 316L "X" VERSION

Ambient temperature: +20°C	9 cycles/min (1)	**fluid temp.:**	**+20°C**
+50°C (max.)	4 cycles/min (1)		**+50°C**
+50°C (max.)	2 cycles/min (1)		**+120°C**
+40°C (max.)	2 cycles/min (1)		**+145°C**

(∗) **Ensure that the compatibility of the fluids in contact with the materials is verified.**

(1) For other cycles, contact us.

ACCESSORIES

AC to DC adapter: 110V to 250V/50-60 Hz
code: **P290CA430078001**
24V to 48V ±10 % / 50-60 Hz
code: **P290CA438907001**

OPTIONS

Fail closed (closing of the valve in case of power failure)
M12 connector adapter [1]

[1] Contact us.

SPECIFICATIONS

piping (ISO 6708)		flow coefficient Kv		operating pressure differential (bar)			operator diameter	thread type	dimensions / type [1]	15-DIGIT PRODUCT CODE			
pipe size	DN	(m³/h)	(l/min)	min.	max. air, water, oil (✱)	max. steam	(mm)			basic code	voltage code 24 V...48 V / 50-60 Hz	110 V...250 V / 50-60 Hz	24 V/DC
Motorised valve, entry under the disc - NBR / PBT «K» version													
3/8	10	2,7	45	0	6	-	67	G*	1	**E290C52V0KA00**	**UA**	**VW**	**V1**
1/2	15	3,8	63	0	5	-	67	G*	1	**E290C53V0KA00**			
3/4	20	6	100	0	4	-	67	G*	1	**E290C54V0KA00**			
Motorised valve, entry under the disc - FPM / 316L «X» version													
3/8	10	2,7	45	0	6	4	67	G*	1	**E290C52V0XA00**	**UA**	**VW**	**V1**
1/2	15	3,8	63	0	5	4	67	G*	1	**E290C53V0XA00**			
3/4	20	6	100	0	4	4	67	G*	1	**E290C54V0XA00**			

[1] For dimensions, see drawing(s) for each construction type on the following page(s).

(✱) Ensure that the compatibility of the fluids in contact with the materials is verified.

15-DIGIT PRODUCT CODE

E 290 C 5 4 V 0 K A00 V1

Pipe thread
E = ISO 228/1 & ISO 7/1 (combination thread)
8 = NPT (on request)

Product series
290

Revision letter
C = Initial release

Fonction
5 = Standard

DN
2 = DN 10
3 = DN 15
4 = DN 20

Motorised operator dia.
V = Ø 67 mm

Voltage
V1 = 24 V DC - class B
VW = 110 V...250 V 50/60 Hz - class B
UA = 24 V...48 V 50/60 Hz - class B

A00 = Standard
Options
EFC = Fail closed

C12 = M12 (contact us)

Materials
K = AISI 316L body,
SS 316L stem,
PBT stuffing box & NBR
X = AISI 316L body,
SS 316L stem,
AISI 316L stuffing box & FPM

Port
0 = 2 way

INSTALLATION

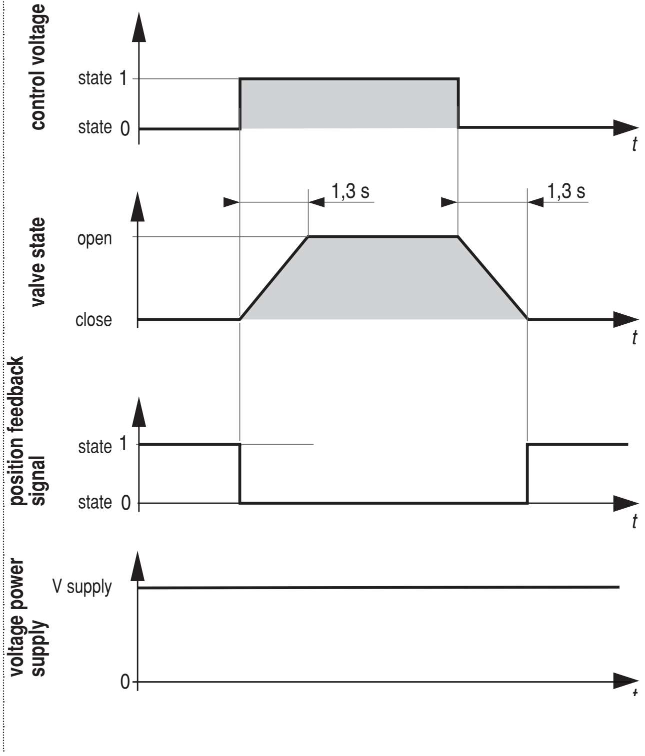
- The valves can be mounted in any position without affecting operation
- Pipe connections (G*) have standard combination thread according to ISO 228/1 and ISO 7/1
- Other pipe connections are available on request
- Installation/maintenance instructions are included with each valve
- 2D/3D CAD models - *In 3D*
- LED indicators for operating status display

status		
	valve OPEN	green
	valve CLOSED	orange
	valve moves to open	green flashing
	valve moves to close	orange flashing

MOTORISED VALVES SERIES 290

OPERATING DIAGRAM

standard

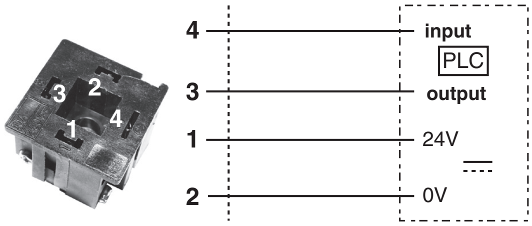


WIRING DC

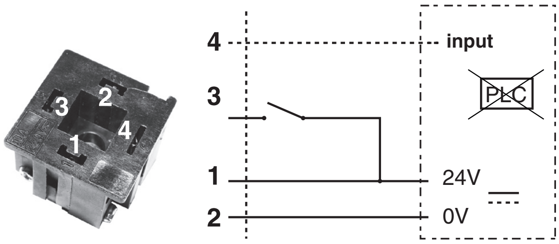
24 V ±10 % / DC

1	24 V / DC
2	0 V
3	control
4	feedback signal

With PLC

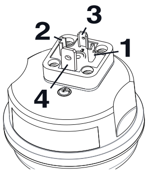


Without PLC



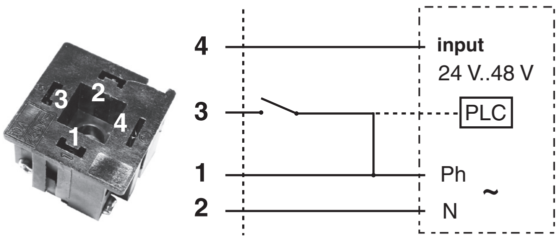
WIRING AC

24 V...48 V ±10 % / AC 50/60 Hz

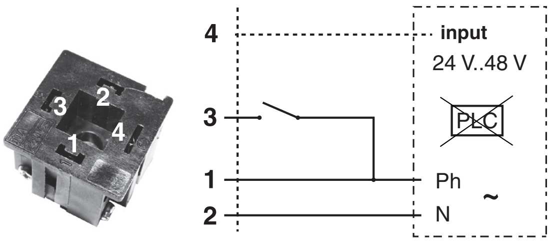


1	phase (Ph)
2	neutral (N)
3	control
4	feedback signal

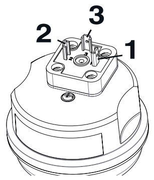
With PLC



Without PLC

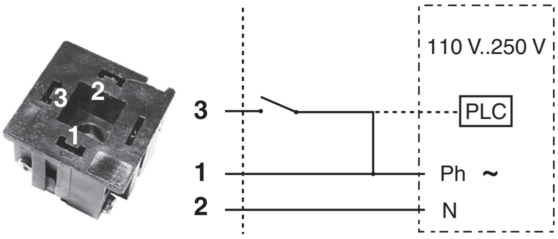


110 V...250 V / AC 50/60 Hz

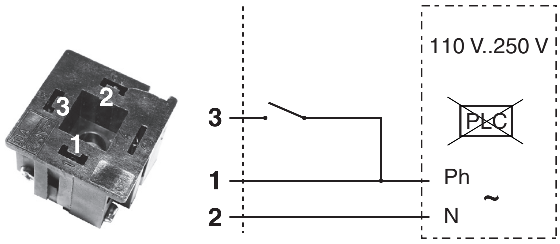


1	phase (Ph)
2	neutral (N)
3	control
-	-

With PLC

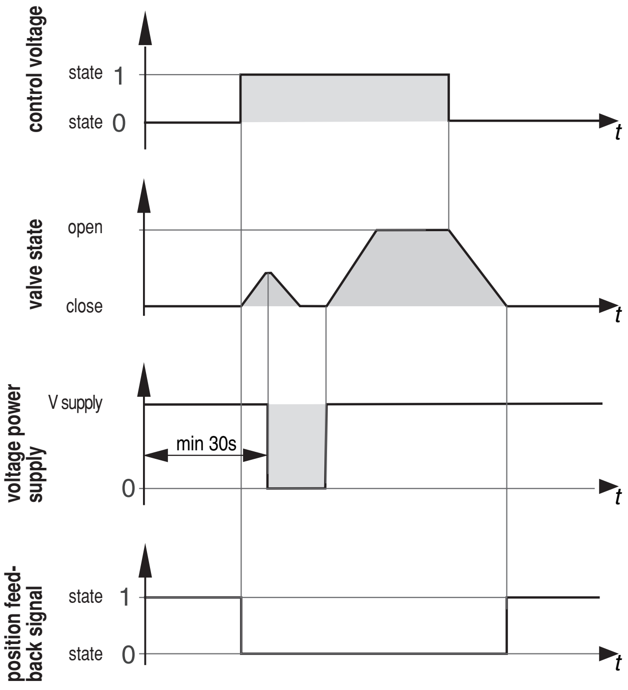


Without PLC



OPERATING DIAGRAM

fail closed



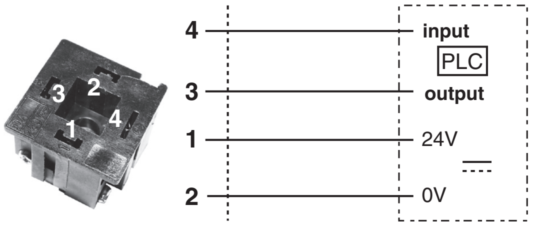
(*) Initialisation

WIRING DC

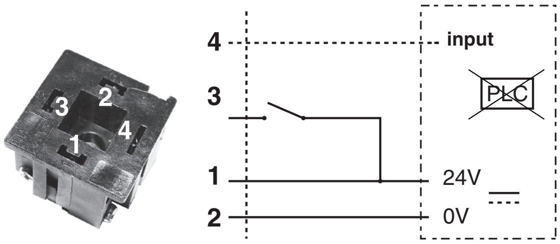
24 V ±10 % / DC

1	24 V / DC
2	0 V
3	control
4	feedback signal

With PLC

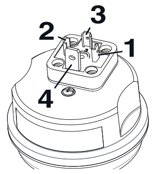


Without PLC



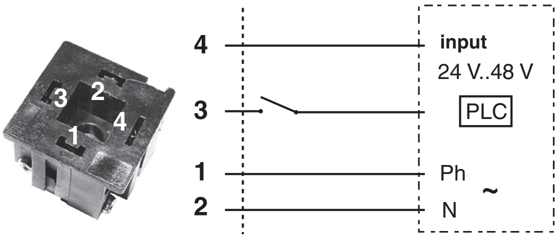
WIRING AC

24 V...48 V ±10 % / AC 50/60 Hz

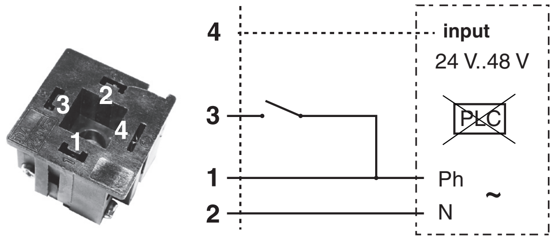


1	phase (Ph)
2	neutral (N)
3	control
4	feedback signal

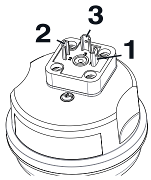
With PLC



Without PLC

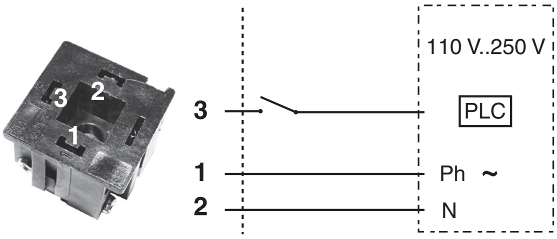


110 V...250 V / AC 50/60 Hz

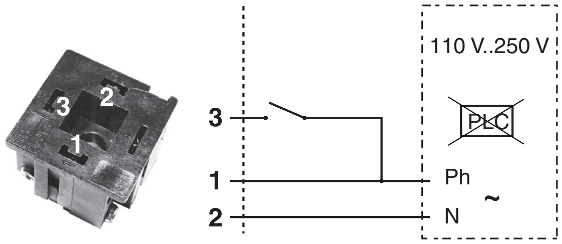


1	phase (Ph)
2	neutral (N)
3	control
-	-

With PLC



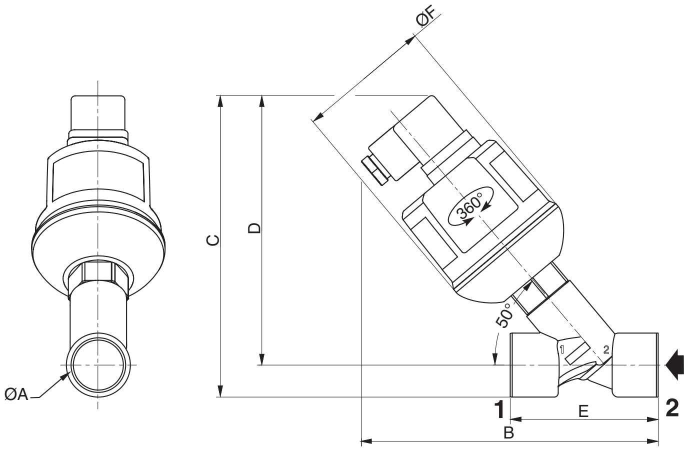
Without PLC



DIMENSIONS (mm), **WEIGHT** (kg)

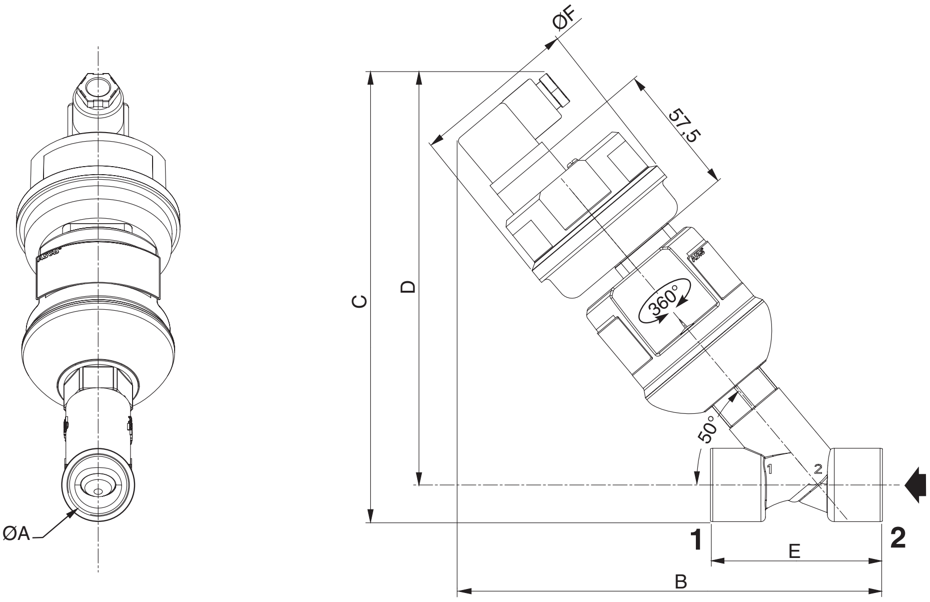
TYPE 01

DC version
67 mm motorised operator
Fluid entry: under the disc at 2
ISO 4400 connector



TYPE 02

AC version (accessories)
67 mm motorised operator with AC adapter
Fluid entry: under the disc at 2
ISO 4400 connector



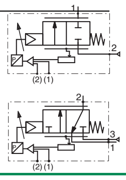
type	Ø A	B	C	D	E	Ø F	weight [(1)]	
							NBR / PBT «K»	FPM / 316L «X»
DC version								
01	3/8	135	141	129	55	67	0,40	0,45
	1/2	142	145	131	65	67	0,45	0,55
	3/4	150	152	136	75	67	0,55	0,65
AC version								
02	3/8	171	189	175	55	71	0,50	0,60
	1/2	178	191	177	65	71	0,55	0,65
	3/4	186	196	180	75	71	0,65	0,75

(1) Incl. connector.

PROPORTIONAL VALVES WITH POSITIONER^{D}

pressure operated
all standard connection types

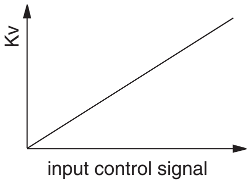
NC



2 way
3 way
Series
290/390

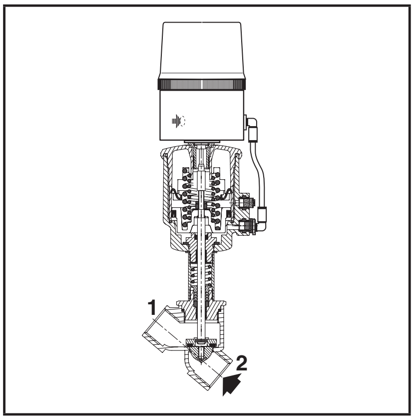
FEATURES

- *Precise, quick-acting and robust valve suitable for use in outside industrial environments*
- *Exceptional long service life*
- *Variable flow proportional to the control signal*
- *Real-time control*
- *Ready-to-use valve*
- *The positioner can be directly connected to an external sensor (double loop control)*
- *Power saving function and no air consumption when position is reached*
- *Manual valve operator*
- *LED indicators for valve status display*



GENERAL

Differential pressure	0 to 16 bar [1 bar =100 kPa]
Maximum allowable pressure	16 bar
Ambient temperature range	0°C to +50°C
Maximum viscosity	600 cSt (mm^2/s)
Pilot fluid	Air or inert gas, filtered 25 µm, unlubricated, condensate-free and water-free (observe the pressure dew point) (6)
Pilot pressure	4 to 8 bar
Pilot fluid temperature	0°C to +50°C
Response time	See page V402-7
Fluids	For type, temperature and materials compatibility, see the catalogue pages for the standard valves V410, V420, V431 and V703



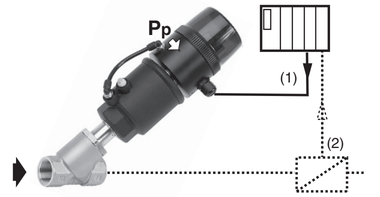
ELECTRICAL CHARACTERISTICS

Setpoint reached output	ON/OFF, 24 V PNP / max. 500 mA
Analog position feedback signal	0-10 V / 4-20 mA
Analog setpoint	0-10V (R_{in} = 200 kΩ); 4-20 mA (R_{in} = 250 Ω)
Nominal supply voltage	24 V DC ± 10%, max. ripple 10%
Power	7,6 W (3,6 W, setpoint reached)
Connection	Screw terminals, cable gland (cable Ø 5-10 mm) or connection M12 (CNOMO E03.62.520.N)
Degree of protection	IP66 (EN 60529)
Electromagnetic compatibility	EMC 2004/108/EC
Regulation characteristics	Hysteresis < 2% ; Accuracy < 2 % ; Repeatability < 1 %

CONSTRUCTION

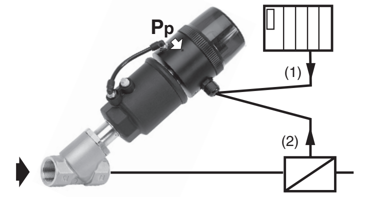
Valve construction	See sections D and F
Valve disc (2/2)	Profiled disc, stainless steel and PTFE
Valve disc (3/2)	Standard disc
Positioner body	Aluminium anodised
Cable gland	Plastic (cable Ø 5-10 mm)
Cover	PA 12, transparent

single loop



open or closed loop control

double loop for positioner with directly connected external sensor



closed loop control

(1) Setpoint
(2) Value measured by the process sensor

SPECIFICATIONS (NC valves, fluid entry under the disc)

analog setpoint	suffix for proportional valve and positioner (3) delivered assembled							
	fail in last position (4)				fail close (5)			
	2 way		3 way (7)		2 way		3 way (7)	
	cable gland	M12	cable gland	M12	cable gland	M12	cable gland	M12
Positioner^{D}, single loop								
0 - 10 V DC	**PDB64**	**PDB68**	**B64**	**B68**	**PDB66**	**PDB70**	**B66**	**B70**
4 - 20 mA	**PDB65**	**PDB69**	**B65**	**B69**	**PDB67**	**PDB71**	**B67**	**B71**
Positioner^{D}, double loop								
0 - 10 V DC	-	-	-	-	**PDB72**	**PDB74**	**B72**	**B74**
4 - 20 mA	-	-	-	-	**PDB73**	**PDB75**	**B73**	**B75**

---

(3) Place the indicated suffix after the catalogue number of the valve selected.
(4) Valve disc remains in its last position on loss of power.
(5) Valve returns to closed position on loss of power.
(6) The actuator exhaust air is used to ventilate the electronics housing.
(7) Top orifice of this version is not tight, for the tight version contact us.

PROPORTIONAL VALVE + Positioner^D SERIES 290/390

VALVE SPECIFICATIONS

pipe size (DN)	orifice size	pilot pressure (bar)			operator diameter	flow coefficient (Kv), programmable opening of proportional valve					
		min.		max. (1)		2 way, threaded		2 way, flanges		3 way, threaded	
						bronze, stainless steel (E290) (V410) clamp / butt welding (S290) (V420)		bronze (T290) (V431)		bronze (E390) (V703)	
	(mm)	2 way (2)	3 way		(mm)	(m^3/h)	(l/min)	(m^3/h)	(l/min)	(m^3/h)	(l/min)
NC - Normally closed, entry under the disc											
1/2 (15)	15	3 / 5	2 / 3	8	63	4,6	77	-	-	6	100
3/4 (20)	20	3 / 5	-	8	63	7,1	118	-	-	-	-
		-	3 / 5	8	63	-	-	-	-	9,6	160
1 (25)	25	3 / 5	3 / 5	8	63/90	15	250	11	183	16,2	270
1 1/4 (32)	32	3 / 5	5	8	63/90	21	350	14	233	24	400
		3 / 5	3 / 5	8	125	22	367	15	250	-	-
1 1/2 (40)	40	4	3 / 5	8	63/90	29	483	21	350	42,9	715
		4	5	8	125	44	733	32	533	42,9	715
2 (50)	50	4	5	8	63/90	40	667	26,5	442	52,8	880
		4	5	8	125	66	1100	44	733	52,8	880
2 1/2 (65)	65	4	-	8	90	72	1200	-	-	-	-
		4	-	8	125	84	1400	-	-	-	-

(1) For best control loop operation, we recommend the following pilot pressures:
max. 3 bar (valve with 1,5 bar operator) ; max. 5 bar (valve with 2,5 bar operator) ; max. 7 bar (valve with 4 bar operator)

(2) 3 bar (valve with 2,5 bar operator) ; 5 bar or 4 bar (valve with 4 bar operator)

OPTIONS AND ACCESSORIES

- Standard 2/2 NC valve, fluid entry under the disc, with profiled disc only, use suffix PD, example: E290A016PD
-

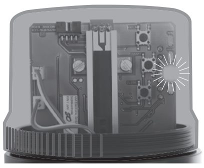
		Female M12 connector:	straight
- 5 pins, with screw terminals,		catalogue number:	**88100256**
- Supply cable 5 m,	5 x 0,25 mm²,	catalogue number:	**88130212**
- Supply cable 5 m,	6 x 0,5 mm²,	catalogue number:	**88100728**
- Supply cable 10 m,	6 x 0,5 mm²,	catalogue number:	**88100730**

- APC software for modification of control parameters (software required for double loop control) available for download at: www.asconumatics.eu
- RS-232 converter, 2 m cable with 9 pin Sub-D connector for PC link, catalogue number **88100732**
- Oxygen service (except DN 65), pressure limited to 15 bar, temperature limited to + 60°C, suffix **N**
- Vacuum applications up to 1,33 10^{-3} mbar, suffix **VM**
- Other pipe connections are available on request

INSTALLATION

- Pilot port G 1/8 according to ISO 228/1
- Compatible with ASTM 1, 2 and 3 oils
- Installation/maintenance instructions are included with each valve
- LED indicators for operating status display and diagnostic functions (Unit can be rotated through 360° around the centreline of the valve operator)

status	hold position
	valve OPEN
	valve CLOSED
	valve moves to open
	valve moves to close
	positioner in initialisation mode
	positioner in manual mode
diagnostics	setpoint > 20,5 mA / 10,25 V
	setpoint < 3,5 mA
	positioner not initialised
	component error

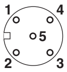


Electrical connection:

Positioner^D, single loop

screw terminals

M12

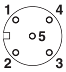


1	+ 24 V DC, supply	**1**
2	GND supply	**3**
3	+ setpoint (0-10 V or 4-20 mA)	**2**
4	GND setpoint	**3**
6	disc position feedback	**4**
7	+ 24V ON/OFF output	**5**

Positioner^D, double loop

screw terminals

M12



1	+ 24 V DC, supply	**1**
2	GND supply	**3**
3	+ setpoint (0-10 V or 4-20 mA)	**2**
4	GND setpoint	**3**
5	external sensor input	**4**
7	+ 24V ON/OFF output	**5**

SPARE PARTS KITS

	spare parts kit no. Positioner^D only	
	cable gland (cable Ø 5-10 mm)	connection M12
Fail position maintained, single loop		
0-10 V	**60566108**	**60567108**
4-20 mA	**60566308**	**60567308**
Fail close, single loop		
0-10 V	**60566118**	**60567118**
4-20 mA	**60566318**	**60567318**
Fail close, double loop		
0-10 V	**60566418**	**60567418**
4-20 mA	**60566518**	**60567518**
Mounting kit		
all	**C140423**	**C140423**

pipe size (DN)	spare parts kit no.		
	bronze, stainless steel (E290) clamp / butt welding (S290)	bronze (T290)	bronze (E390)
Valve disc seals			
1/2 (15)	**C131204** (1)	-	**C140021** (1)
3/4 (20)	**C131205** (1)	-	**C140022** (1)
1 (25)	**C131206** (1)	**C140017** (1)	**C140023** (1)
1 1/4 (32)	**C131207** (1)	**C140018** (1)	**C140024** (1)
1 1/2 (40)	**C131208** (1)	**C140019** (1)	**C140025** (1)
2 (50)	**C131209** (1)	**C140020** (1)	**C140026** (1)
2 1/2 (65)	**C131622** (1)	-	-

(1) Standard suffix VM is also applicable to kits (see V435).
- Not available.

ORDERING EXAMPLES:

E 290 **A** 016 **PDB64**
E 390 **A** 016 **B64**
E 290 **A** 059 **PDB68**
E 290 **A** 102 **PDB71**

pipe thread
basic number
suffix

ORDERING EXAMPLES KITS:

C131204
C140206
C140205 **VM**

basic number
suffix

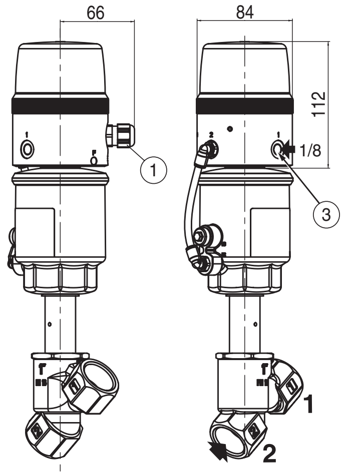
DIMENSIONS (mm), WEIGHT (kg)

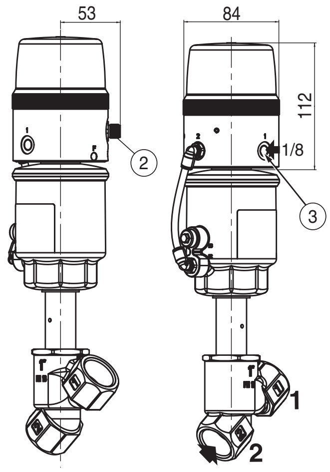
TYPE 01

Enclosure with cable gland
63 to 125 mm operator
Fluid entry:
under the disc at 2

TYPE 02

Enclosure with M12 connection
63 to 125 mm operator
Fluid entry:
under the disc at 2





① M16 x 1,5 mm cable gland (cable Ø 5-10 mm)
② M12 connection
③ G 1/8 pilot connection

Weight of positioner without valve: 0,3 kg

Installation instructions for ASCO 290

GB

GENERAL SAFETY, ASSEMBLY, OPERATING, USE, AND MAINTENANCE INSTRUCTIONS

CE

**⚠ These general instructions complete the specific instructions for each device, and the operating instructions or documents delivered with the product.
Malfunctions, damage, or injury may occur if these instructions are not followed.
See our technical documentation and installation instructions at www.asconumatics.eu.**

1 - GENERAL REMARKS

This component is not a safety accessory, it is intended only for the compliant use either as an individual component or incorporated in apparatus, machinery and installations.
ASCO Numatics components are designed to be operated in accordance with the limits specified on the nameplate, in the operating and maintenance instructions, or in the documents delivered with the product.
All applicable directives, legislation, orders and standards, as amended from time to time, as well as state-of-the-art practices and procedures must be observed for the intended scope of application of the product. Where applicable, take all appropriate measures to ensure the requirements are met.
This device complies with the essential requirements of the EU Pressure Equipment Directive 97/23/EC. A Declaration of Conformity is available on request.
All assembly, operation, use, and maintenance must be performed by qualified, authorised personnel.
Personnel working with the components must be familiar with the applicable safety regulations and requirements relating to the components, apparatus, machinery and electrical installations (for valves, solenoid valves, electronic control equipment, air service equipment). In case of problems, please contact ASCO Numatics or one of its authorised representatives.
⚠ For specific additional instructions concerning solenoid valves and air service equipment, see section 7: "Special Instructions".

2 - ASSEMBLY
PREPARATION

- Check the preliminary storage conditions required for the component. They must be in accordance with the product's specifications.
- Carefully remove the components from their packaging.
- **Power off and depressurise the apparatus**, machinery, or installation designed to receive the component. Stipulate power off and depressurisation requirements to guard against any unauthorised intervention.
- Make sure that the unit, its components, and their environment are clean, and protect them against deterioration.
- Do not modify the device.
- Make sure that the fluid is compatible with the materials it contacts.
  Air, water, or oil is used in general (in cases where oil is used as a fluid, make sure that it does not vaporise within the component's operating temperature range).
  The operator or user must make sure that the gas or liquid group corresponds to the product's classification. (Oxygen is a hazardous group 1 gas. It can lead to higher classifications: contact us for more information.)

CONNECTION

- Connect all the ports of the component that may come in contact with the fluid.
- Clean the conduits that will connect to the component.
- Be sure to observe the direction of flow of the fluid.
- Use only the provided connection possibilities.
- Ensure that no foreign matter enters the circuit, in particular when making the connection leakproof.
- Be sure to observe the allowed bend radius for tubing; do not restrict the ports for fluid circulation.
- Tubes and connection elements must not exert any force, torque, or strain on the product.
- Use appropriate tools and locate assembly tools as close as possible to the connection point.
- Be sure to observe the recommended torque when tightening tubing connections.
- Connections must be made to last.

⚠ Improper installation may cause undesirable hydraulic effects that can reduce the life of the device (erosion, cavitation, waterhammer etc.)

3 – OPERATION

Operation is authorised only after having duly verified that the apparatus, machinery or installation in which the component has been incorporated complies with the applicable directives, legislation, orders and standards, as amended from time to time.

4 - USE

- Do not subject the components to loads or forces other than those for which they are designed.
- Do not operate the component under pressure unless its ports are connected to conduits.
- This component is not designed to operate submerged in a liquid. Make sure that water cannot enter the control system.
- Make sure to prevent the device from freezing in the event that temperatures fall below +5°C.

5 - MAINTENANCE

We recommend you to periodically check the correct operation of the components and clean them. The checking and cleaning frequency depends on the type of fluids used, and the operating and environmental conditions.
Depending on the device used, spare part kits are available.
Before any maintenance work is done, **power off and depressurise** the component, apparatus, machinery or installation to prevent any unauthorised intervention.
Make sure that the component and its environment are clean.
If problems arise during maintenance, please contact ASCO Numatics or one of its official representatives.

6 - ENVIRONMENT

Components must be disposed of in compliance with applicable environmental regulations when taking apparatus or machinery out of service and carrying out their final destruction, or dismantling the installation.

7 - SPECIAL INSTRUCTIONS
SOLENOID VALVES

Remarks concerning voltage spikes:
Due to their physical design, all solenoids, solenoid-actuated valves, or relays have a coil which produces an inductance.
Switching off the current will create inductive voltage spikes liable to cause electrostatic discharge in nearby wiring.
The only way to eliminate these parasitic voltages is for the user to use appropriate attenuation devices such as, in particular, diodes, Zener diodes, varistors, RC (resistor/capacitor) components, or filters.
The characteristics and wiring of these devices depend exclusively on specific requirements, which can only be determined individually by the user. Additional protective measures may be required according to the assembly method and the location where the device is used.
Our solenoid valves and pilot valves are designed to operate with devices compliant with EN 61131-2.

This product complies with the essential requirements of EMC Directive 2004/108/EC and Low Voltage Directive 2006/95/EC. A Declaration of Conformity is available on request.

⚠ If the solenoid valve is fitted with a solenoid operator for explosive atmospheres, it must be installed in compliance with the general rules set out in the European Standard EN 60079-0, EN 60079-14 and the particular standards relating to its mode of protection. For compliance with ATEX Directive 94/9/EC, refer to the specific operating instructions delivered with our products.

Assembly:
- In order to protect the equipment, install an adequate strainer or filter upstream from and as close as possible to the component.
- All power cables must have a sufficient cross-section and a sufficient insulation. They must be installed in a compliant manner.
- Electrical connections must be made by qualified personnel and according to local standards and regulations.
- **Before any intervention, turn off the electrical current to power off the components.**
- All screw terminals must be tightened to the appropriate torque prior to operation.
- Depending on the voltage, electrical components must be grounded according to local standards and regulations.

The electrical connection is either made by detachable spade plug connectors with an IP65 protection rating (when properly mounted), by screw terminals embedded in a coil with metal enclosure, by spade terminals, or by flying leads/cables embedded in the coil.
Operation: Before pressurising the circuit, perform an electrical test. Apply power to the coil several times and listen for the metallic "click" indicating the solenoid operator is working.
Personnel working with the components must be familiar with electric controls, such as redundancies and feedback (electronic controls), where applicable.
Use: The coils are designed for continuous operation and may therefore become hot.
If the solenoid valve is easily accessible, provide for means of protection to prevent accidental contact that may cause burns.
Maintenance: Before any maintenance work is done, turn off the electrical current to power off the components.

AIR SERVICE EQUIPMENT

Assembly: All ports on the device that may come in contact with pressurised fluids must be connected to a conduit or an associated component (example: exhaust silencer, etc.)
Use: Personnel working with the components must be familiar with electric controls, such as redundancies and feedback (electronic controls), where applicable.
Environment: In order to prevent noise nuisance due to system purging by certain components (especially with compressed air), it is recommended to use noise reduction systems.

3834386-B - IMGEN-01-X (05/10) (123620-130)

ASCO numatics™

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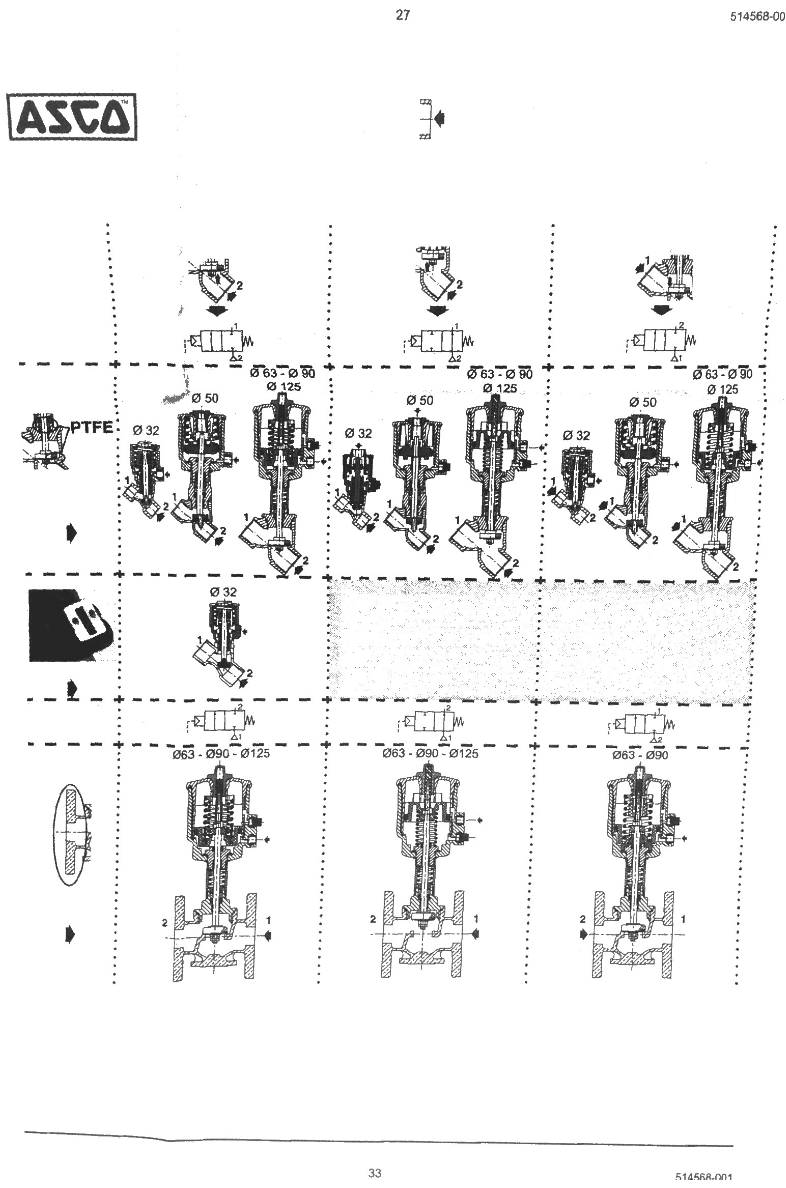
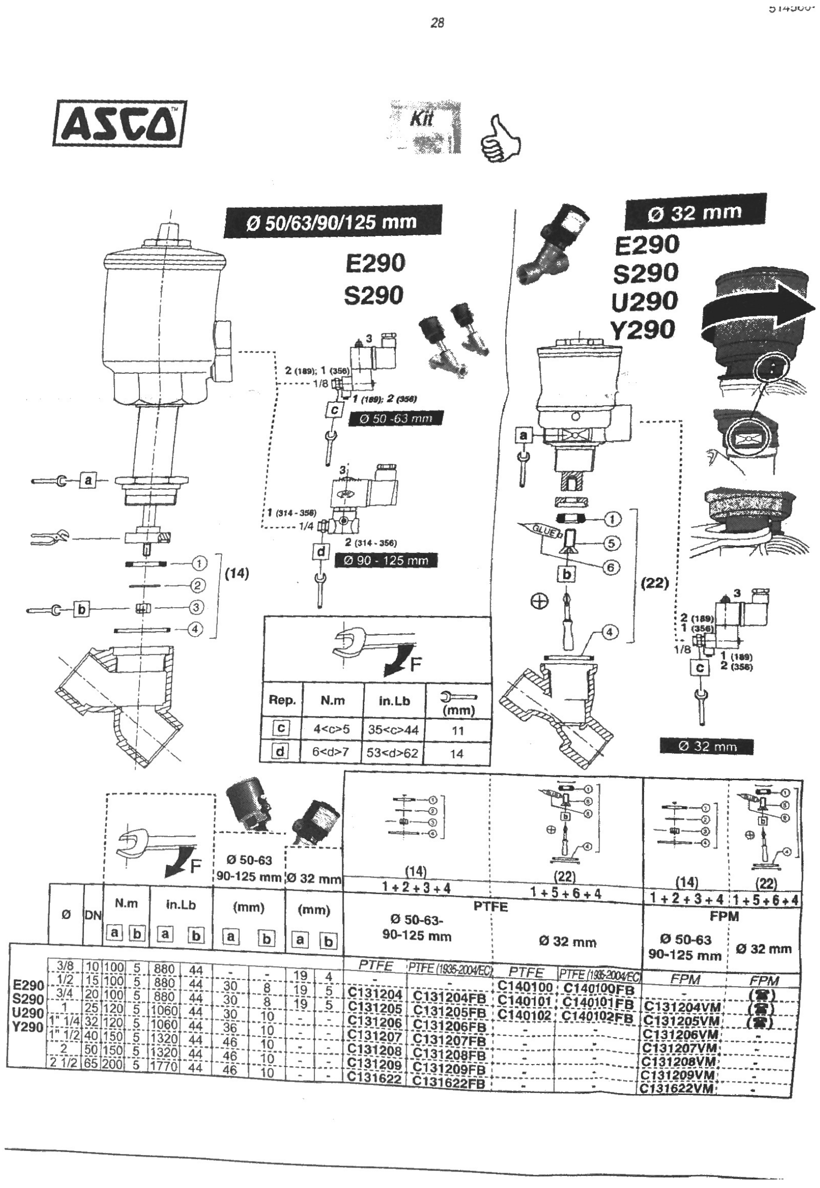
Installation instructions for ASCO 290

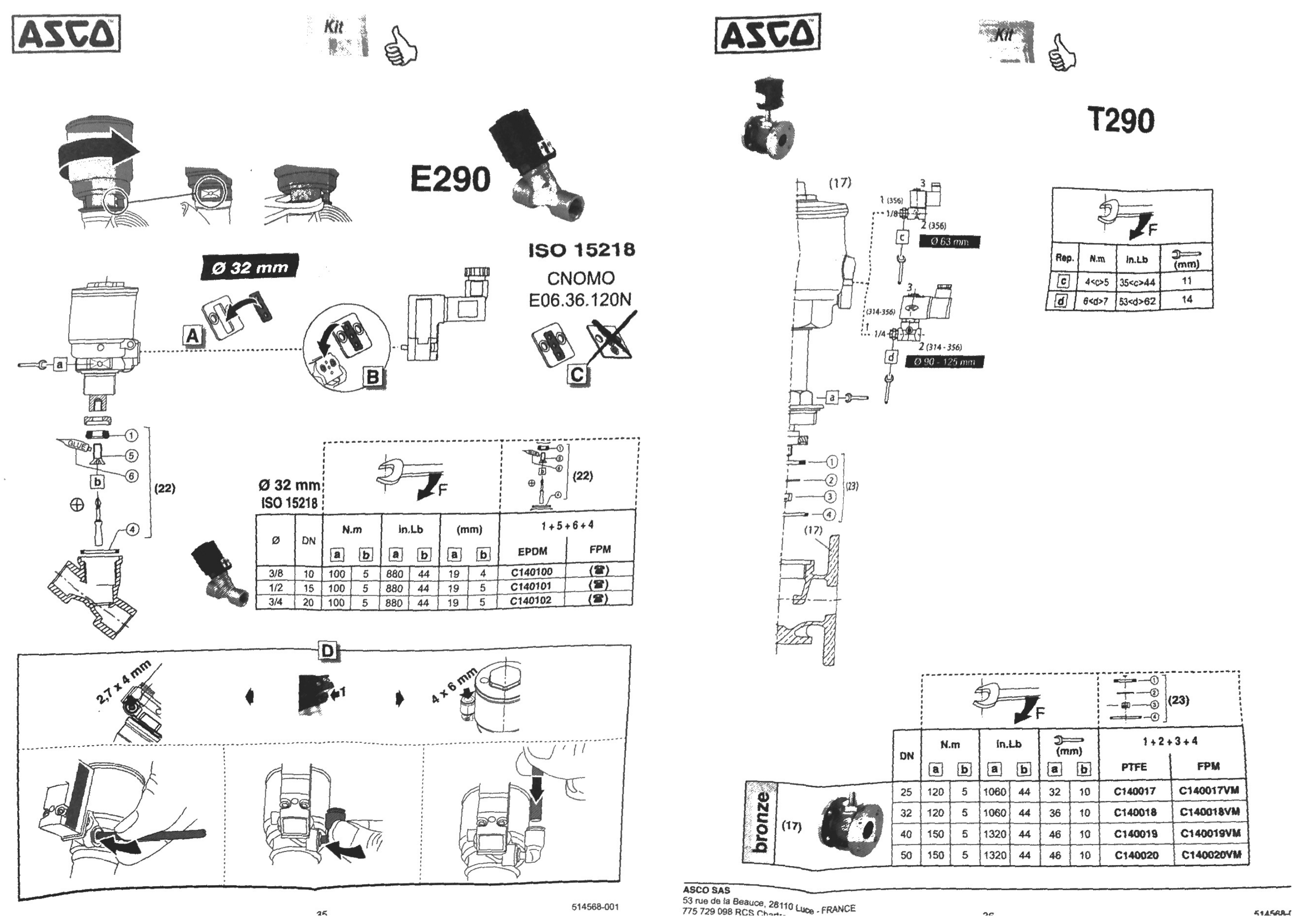




Rep.	N.m	in.Lb	(mm)
c	4<c>5	35<c>44	11
d	6<d>7	53<d>62	14

	Ø	DN	N.m		in.Lb		Ø 50-63 90-125 mm (mm)		Ø 32 mm (mm)		PTFE (14) 1 + 2 + 3 + 4 Ø 50-63-90-125 mm		PTFE (22) 1 + 5 + 6 + 4 Ø 32 mm		FPM (14) 1 + 2 + 3 + 4 Ø 50-63 90-125 mm	FPM (22) 1 + 5 + 6 + 4 Ø 32 mm
			a	b	a	b	a	b	a	b	PTFE	PTFE (1935-2004/EC)	PTFE	PTFE (1935-2004/EC)	FPM	FPM
E290 S290 U290 Y290	3/8	10	100	5	880	44	-	-	19	4	-	-	C140100	C140100FB	-	(☎)
	1/2	15	100	5	880	44	30	8	19	5	C131204	C131204FB	C140101	C140101FB	C131204VM	(☎)
	3/4	20	100	5	880	44	30	8	19	5	C131205	C131205FB	C140102	C140102FB	C131205VM	(☎)
	1	25	120	5	1060	44	30	10	-	-	C131206	C131206FB	-	-	C131206VM	-
	1" 1/4	32	120	5	1060	44	36	10	-	-	C131207	C131207FB	-	-	C131207VM	-
	1" 1/2	40	150	5	1320	44	46	10	-	-	C131208	C131208FB	-	-	C131208VM	-
	2	50	150	5	1320	44	46	10	-	-	C131209	C131209FB	-	-	C131209VM	-
	2 1/2	65	200	5	1770	44	46	10	-	-	C131622	C131622FB	-	-	C131622VM	-

Installation instructions for ASCO 290



E290

Ø 32 mm

ISO 15218
CNOMO
E06.36.120N

Ø 32 mm
ISO 15218

Ø	DN	N.m		in.Lb		(mm)		1 + 5 + 6 + 4	
		a	b	a	b	a	b	EPDM	FPM
3/8	10	100	5	880	44	19	4	C140100	(☎)
1/2	15	100	5	880	44	19	5	C140101	(☎)
3/4	20	100	5	880	44	19	5	C140102	(☎)

35

514568-001

T290

Rep.	N.m	in.Lb	(mm)
c	4<c>5	35<c>44	11
d	6<d>7	53<d>62	14

bronze

DN	N.m		in.Lb		(mm)		1 + 2 + 3 + 4	
	a	b	a	b	a	b	PTFE	FPM
25	120	5	1060	44	32	10	C140017	C140017VM
32	120	5	1060	44	36	10	C140018	C140018VM
40	150	5	1320	44	46	10	C140019	C140019VM
50	150	5	1320	44	46	10	C140020	C140020VM

ASCO SAS
53 rue de la Beauce, 28110 Luce - FRANCE
775 729 098 RCS Char

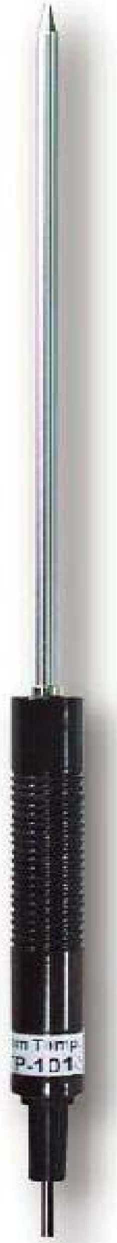
36

514568-

3 wires, optional Pt 100 ohm Temp. probe for TM-946 , TM-947SD

PT 100 ohm TEMP. PROBE

Model : TP-101 *ISO-9001, CE, IEC1010*



LUTRON ELECTRONIC

The Art of Measurement

Pt 100 TEMPERATURE PROBE

Model : TP-101

Features	Cooperate with an 0.00385 alpha coefficient, meet DIN IEC 751.	
0 ℃ resistance	100 ohm.	
Measuring Range	-50 to 400 ℃. -58 to 752 ℉.	
Plug/Wires	Ear phone plug, 3 pins/3 wires.	
Class	Class A.	
Accuracy	± (0.15 + (0.002 x T))℃. T : measuring temperature. ***For example :*** Accuracy is 0.15 ℃ for 0 ℃ reading. Accuracy is 0.35 ℃ for 100 ℃ reading. Accuracy is 0.95 ℃ for 400 ℃ reading.	
Dimension	Sensing head	152 mm tube, 3.2 mm Dia.
	Probe handle length	130 mm.
	Cable length	1000 mm.
Remark	TP-101 is the optional Pt 100 Temp. probe for TM-946, TM-947SD.	

* Appearance and specifications listed in this brochure are subject to change without notice. 1301-TP101

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Fax: 315-697-5867
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Internet: www.jumo.us

Push-in RTD Temperature Probe with Connecting Cable

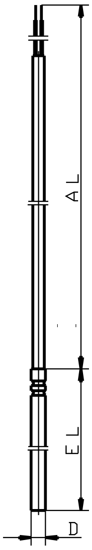
- **Temperature range from -50 to +400 °C**
- **As single or double RTD temperature probe**
- **In 2-wire, 3-wire or 4-wire-circuit**
- **Connecting cable PVC, silicone, PTFE, metal braiding**

Push-in RTD temperature probes are mainly used for measuring temperature in liquids and gasses. The application areas, among others, are the air conditioning and refrigeration industry, in the construction of heating systems/furnaces/equipment, and in laboratory technology.
Depending on the version, the connection cables are suitable for dry or moist rooms with a temperature range between -50 to +400 °C. The connecting cable transition points are strain-relieved. An anti-kink protection is available as an option.
A Pt100 temperature sensing element according to DIN EN 60751, class b in 2-wire circuit is used as a measuring insert by default – versions with Pt500 or Pt1000 are also possible. The connection is also available in 3-wire and 4-wire circuits as an option.

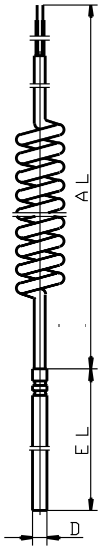
Technical data

Connection	Cable ends stripped bare, with ferrules available with push-on contacts or multi-pole plug connector
Connecting cable	PVC, ambient temperature -5 to +80 °C (+105 °C) PUR, ambient temperature -5 (+5) to +105 °C Silicone, ambient temperature -50 to +180 °C PTFE, ambient temperature -50 to +260 °C Metal braiding, ambient temperature -50 to +260 °C (+350 °C / +400 °C)
Protection tube	Stainless steel 1.4571, Ø 3 mm, Ø 4 mm, Ø 5 mm, Ø 5.2 mm, Ø 6 mm, and Ø 8 mm
Measuring insert	Pt100 temperature sensing element, DIN EN 60751, class B, 2-wire circuit
Response times	In water 0.4 m/s / in air 3.0 m/s Ø 6 mm: water $t_{0.5}$ approx. 4 s, $t_{0.9}$ approx. 10 s / in air $t_{0.5}$ approx. 32 s, $t_{0.9}$ approx. 98 s Ø 8 mm: water $t_{0.5}$ approx. 7 s, $t_{0.9}$ approx. 18 s / in air $t_{0.5}$ approx. 50 s, $t_{0.9}$ approx. 140 s
Accessories	For pipe screw connections and flanges refer to data sheet 909750

Dimensions



Basic type 902150/10



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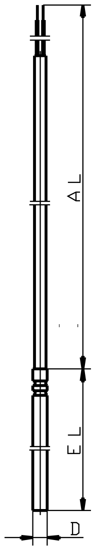
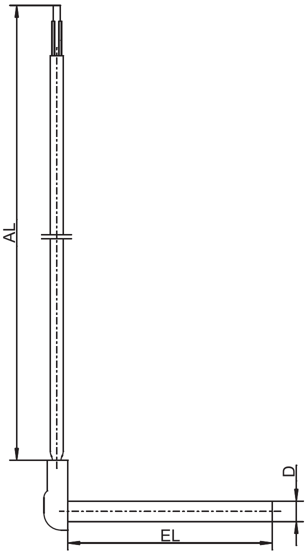
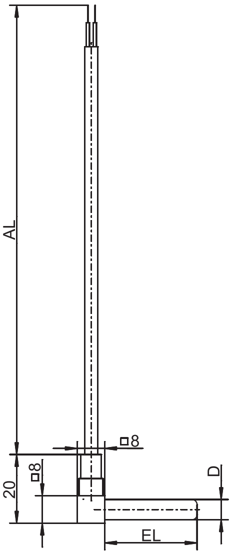


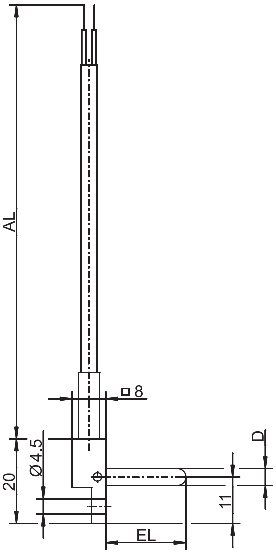
Basic type 902150/30



Basic type 902150/40

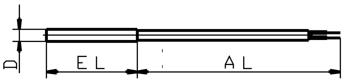
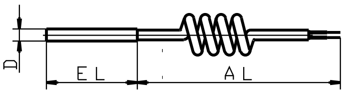


Basic type 902150/42



Basic type 902150/44

Order details: Push-in RTD temperature probe with connecting cable

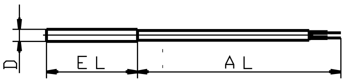
			(1) Basic type
		902150/10	Push-in RTD temperature probe with connecting cable, single-section protection tube made of stainless steel 
		902150/20	Push-in RTD temperature probe with spiral connecting cable, single-section protection tube made of stainless steel 
			(2) Operating temperature in °C/connecting cable
x		378	-50 to +180 °C / silicone
x		386	-50 to +260 °C / PTFE
x		388	-50 to +260 °C / metal braiding
x		402	-50 to +400 °C / metal braiding
x		724	-5 to +80 °C / PVC
x	x	730	-5 to +105 °C / PVC or PUR
x		912	5 to +105 °C / PUR (only with 1x Pt100 in 2-wire circuit)
			(3) Measuring insert
x		1001	1x Pt 100 in 3-wire-circuit
x	x	1003	1x Pt 100 in 2-wire circuit
x		1011	1x Pt 100 in 4-wire circuit
x		2001	2x Pt 100 in 3-wire-circuit
x		2003	2x Pt 100 in 2-wire circuit
			(4) Tolerance class according to DIN EN 60751
x	x	1	Class B (standard)
x	x	2	Class A
			(5) Protection tube diameter D in mm
x		3	Ø 3 mm (only as 1x Pt100 in 2-wire circuit with PTFE connecting cable)
x		4	Ø 4 mm (only as 1x Pt100 in 2-wire circuit with silicone, PTFE connecting cable, or metal braid)
x		5	Ø 5 mm
x		5.2	Ø 5.2 mm
x	x	6	Ø 6 mm
			(6) Insertion length EL in mm
x		30	30 mm (standard with D 3 mm and D 4 mm)
x		45	45 mm (standard with D 5 mm and D 5.2 mm)
x	x	50	50 mm (not for D < 6 mm)
x		60	60 mm (not for D < 6 mm)
			(7) Connecting cable end
x	x	03	Blank connection wires
x	x	11	Ferrules (standard)
x	x	13	Push-on contact 6.3
x	x	80	Multi-pole plug connector (specify type in plain text)
			(8) Connecting cable length AL in mm (AL 500 to 500,000 mm for basic type 902150/10
	x	1100	1,100 mm (effective)
x		1500	1,500 mm
x		2500	2,500 mm
x		...	Please specify in plain text (500 mm steps)
			(9) Extra codes
x	x	000	Without extra code
x		315	Strain relief spring
x		316	Strain-relief spring hose
x	x	317	Shielded connecting cable
x		858	Waterproof, protection type IP65 (only for EL 60 mm with PUR or silicone connecting cable)

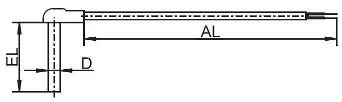
	(1)		(2)		(3)		(4)		(5)		(6)		(7)		(8)		(9)	
Order code		-		-		-		-		-		-		-		/		, ...[1]
Order example	902150/10	-	378	-	1001	-	1	-	6	-	50	-	11	-	2500	/	000	

---

[1] List extra codes in sequence, separated by commas.

Order details: Push-in RTD temperature probe with connecting cable





		(1)	**Basic type**
		902150/30	Push-in RTD temperature probe with connecting cable, multi-part protection tube (welded) made of stainless steel
		902150/40	Push-in RTD temperature probe with connecting cable, multi-part protection tube right-angled (welded) made of stainless steel
		(2)	**Operating temperature in °C / connecting cable**
x		378	-50 to +180 °C / silicone
x		386	-50 to +260 °C / PTFE
x		388	-50 to +260 °C / metal braiding
	x	397	-50 to +350 °C / metal braiding
x		402	-50 to +400 °C / metal braiding
x		724	-5 to +80 °C / PVC
x		912	5 to +105 °C / PUR (only with 1x Pt100 in 2-wire circuit)
		(3)	**Measuring insert**
x		1001	1x Pt 100 in 3-wire-circuit
x	x	1003	1x Pt 100 in 2-wire circuit
x		1011	1x Pt 100 in 4-wire circuit
x		2001	2x Pt 100 in 3-wire-circuit
x	x	2003	2x Pt 100 in 2-wire circuit
		(4)	**Tolerance class according to DIN EN 60751**
x	x	1	Class B (standard)
x	x	2	Class A
		(5)	**Protection tube diameter D in mm**
x	x	6	Ø 6 mm
x		8	Ø 8 mm
		(6)	**Insertion length EL in mm (EL 50 to 500 mm)**
x	x	50	50 mm
x	x	60	60 mm
x	x	100	100 mm
x	x	150	150 mm
x	x	200	200 mm
x	x	...	Please specify in plain text (50 mm steps)
		(7)	**Connecting cable end**
x	x	03	Blank connection wires
x	x	11	Ferrules (standard)
x	x	13	Push-on contact 6.3
x	x	80	Multi-pole connector (specify type in plain text)
		(8)	**Connecting cable length AL in mm (500 to 500,000 mm)**
x	x	2500	2,500 mm
x	x	...	Please specify in plain text (500 mm steps)
		(9)	**Extra codes**
x		000	Without extra code
x		310	Protection tube offset
x		315	Strain relief spring
x		316	Strain-relief spring hose
x	x	317	Shielded connecting cable

	(1)		(2)		(3)		(4)		(5)		(6)		(7)		(8)		(9)	
Order code	☐	-	☐	-	☐	-	☐	-	☐	-	☐	-	☐	-	☐	/	☐	, ...[1]
Order example	902150/30	-	378	-	1001	-	1	-	6	-	50	-	11	-	2500	/	000	

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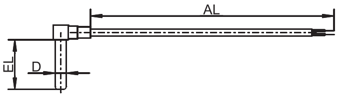
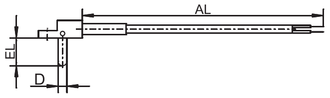
[1] List extra codes in sequence, separated by commas.

Order details: Push-in RTD temperature probe with connecting cable





			(1) Basic type
		902150/42	Push-in RTD temperature probe with connecting cable, single-section protection tube right-angled made of stainless steel
		902150/44	Push-in RTD temperature probe with connecting cable and mounting borehole, single-section protection tube right-angled made of stainless steel
			(2) Operating temperature in °C / connecting cable
x	x	388	-50 to +260 °C / metal braiding
			(3) Measuring insert
x	x	1003	1x Pt 100 in 2-wire circuit
x		1011	1x Pt 100 in 4-wire circuit
x		2003	2x Pt 100 in 2-wire circuit
			(4) Tolerance class according to DIN EN 60751
x	x	1	Class B (standard)
x	x	2	Class A
			(5) Protection tube diameter D in mm
	x	4	Ø 4 mm
x		6	Ø 6 mm
			(6) Insertion length EL in mm
	x	9	9 mm
	x	12	12 mm
x		20	20 mm
x		50	50 mm
			(7) Connecting cable end
x	x	03	Blank connection wires
x	x	11	Ferrules (standard)
x	x	13	Push-on contact 6.3
x	x	80	Multi-pole connector (specify type in plain text)
			(8) Connecting cable length AL in mm (500 to 500,000 mm)
x	x	2500	2,500 mm
x	x	...	Please specify in plain text (500 mm steps)
			(9) Extra codes
x	x	000	Without extra code
x	x	315	Strain relief spring
x	x	317	Shielded connecting cable

	(1)		(2)		(3)		(4)		(5)		(6)		(7)		(8)		(9)	
Order code	☐	-	☐	-	☐	-	☐	-	☐	-	☐	-	☐	-	☐	/	☐	, ...[1]
Order example	902150/42	-	388	-	1003	-	1	-	6	-	20	-	03	-	2500	/	000	

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[1] List extra codes in sequence, separated by commas.

Stock versions

(1)		(2)		(3)		(4)		(5)		(6)		(7)		(8)		(9)	Part no.
902150/10	-	378	-	1003	-	1	-	5.2	-	45	-	11	-	2500	/	000	00326037
902150/10	-	378	-	1003	-	1	-	6	-	50	-	11	-	2500	/	000	00389771
902150/10	-	378	-	1003	-	1	-	6	-	50	-	11	-	1500	/	000	00085313
902150/10	-	378	-	1001	-	1	-	6	-	50	-	11	-	2500	/	000	00392513
902150/10	-	378	-	1003	-	1	-	6	-	60	-	11	-	2500	/	631	00492541
902150/10	-	402	-	1003	-	1	-	6	-	50	-	11	-	1500	/	317	00085311
902150/10	-	724	-	1003	-	1	-	6	-	50	-	11	-	2500	/	000	00059085
902150/10	-	724	-	1003	-	1	-	6	-	50	-	11	-	1500	/	000	00085315
902150/10	-	730	-	1003	-	1	-	6	-	50	-	11	-	1500	/	000	00085316
902150/10	-	730	-	1003	-	1	-	6	-	60	-	11	-	2500	/	631	00492539
902150/20	-	730	-	1003	-	1	-	6	-	50	-	11	-	1100	/	000	00065495
902150/30	-	388	-	1003	-	1	-	6	-	50	-	11	-	2500	/	315.317	00055718
902150/30	-	388	-	1003	-	1	-	6	-	100	-	11	-	2500	/	315.317	00055719
902150/30	-	388	-	1001	-	1	-	6	-	50	-	11	-	2500	/	315.317	00065451
902150/30	-	388	-	1001	-	1	-	6	-	100	-	11	-	2500	/	315.317	00065453
902150/30	-	402	-	1001	-	1	-	6	-	150	-	11	-	2500	/	315.317	00549701
902150/40	-	397	-	1003	-	1	-	6	-	60	-	11	-	2500	/	317	00055715

Pressure Measurement

Transmitters for basic requirements

SITRANS P200 for gauge and absolute pressure

Overview

The SITRANS P200 pressure transmitter measures the gauge and absolute pressure of liquids, gases and vapors.

- Ceramic measuring cell
- Gauge and absolute measuring ranges 1 to 60 bar (15 to 1000 psi)
- For general applications

Benefits

- High measuring accuracy
- Rugged stainless steel enclosure
- High overload withstand capability
- For aggressive and non-aggressive media
- For measuring the pressure of liquids, gases and vapors
- Compact design

Application

The SITRANS P200 pressure transmitter for gauge and absolute pressure is used in the following industrial areas:

- Mechanical engineering
- Shipbuilding
- Power engineering
- Chemical industry
- Water supply

Design

Device structure without explosion protection

The pressure transmitter consists of a piezoresistive measuring cell with a diaphragm installed in a stainless steel enclosure. It can be used with a connector per EN 175301-803-A (IP65), a round plug M12 (IP67), a cable (IP67) or a cable quick screw connection (IP67) connected electrically. The output signal is between 4 and 20 mA or 0 and 10 V.

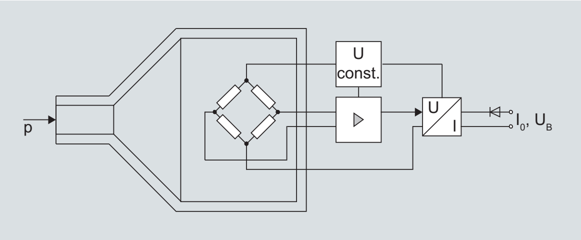
Device structure with explosion protection

The pressure transmitter consists of a piezoresistive measuring cell with a diaphragm installed in a stainless steel enclosure. It can be used with a connector per EN 175301-803-A (IP65) or a round plug M12 (IP67) connected electrically. The output signal is between 4 and 20 mA.

Function

The pressure transmitter measures the gauge and absolute pressure of liquids and gases as well as the level of liquids.

Mode of operation



SITRANS P200 pressure transmitters (7MF1565-...), functional diagram

The ceramic measuring cell has a thin-film resistance bridge to which the operating pressure p is transmitted through a ceramic diaphragm.

The voltage output from the measuring cell is converted by an amplifier into an output current of 4 to 20 mA or an output voltage of 0 to 10 V DC.

The output current and voltage are linearly proportional to the input pressure.

Pressure Measurement

Transmitters for basic requirements

SITRANS P200
for gauge and absolute pressure

Technical specifications

Application	
Gauge and absolute pressure measurement	Liquids, gases and vapors
Mode of operation	
Measuring principle	Piezo-resistive measuring cell (ceramic diaphragm)
Measured variable	Gauge and absolute pressure
Inputs	
Measuring range	
• Gauge pressure	
- Metric	1 … 60 bar (15 … 870 psi)
- US measuring range	15 … 1000 psi
• Absolute pressure	
- Metric	0.6 … 16 bar a (10 … 232 psia)
- US measuring range	10 … 300 psia
Output	
Current signal	4 ... 20 mA
• Load	(U_B - 10 V) / 0.02 A
• Auxiliary power U_B	DC 7 ... 33 V (10 ... 30 V for Ex)
Voltage signal	0 ... 10 V DC
• Load	≥ 10 kΩ
• Auxiliary power U_B	12 ... 33 V DC
• Power consumption	< 7 mA at 10 kΩ
Characteristic curve	Linear rising
Measuring accuracy	
Error in measurement at limit setting incl. hysteresis and reproducibility	• Typical: 0.25 % of full-scale value • Maximum: 0.5 % of full-scale value
Step response time T_{99}	< 5 ms
Long-term stability	
• Lower range value and measuring span	0.25 % of full-scale value/year
Influence of ambient temperature	
• Lower range value and measuring span	0.25 %/10 K of full-scale value
• Influence of power supply	0.005 %/V
Conditions of use	
Process temperature with gasket made of:	
• FPM (Standard)	-15 ... +125 °C (+5 ... +257 °F)
• Neoprene	-35 ... +100 °C (-31 ... +212 °F)
• Perbunan	-20 ... +100 °C (-4 ... +212 °F)
• EPDM	-40 ... +145 °C (-40 ... +293 °F), usable for drinking water
Ambient temperature	-25 ... +85 °C (-13 ... +185 °F)
Storage temperature	-50 ... +100 °C (-58 ... +212 °F)
Degree of protection (to EN 60529)	• IP 65 with connector per EN 175301-803-A • IP 67 with M12 connector • IP 67 with cable • IP 67 with cable quick screw connection
Electromagnetic compatibility	• acc. EN 61326-1/-2/-3 • acc. NAMUR NE21, only for ATEX versions and with a max. measuring deviation ≤ 1 %

Design	
Weight	Approx. 0.090 kg (0.198 lb)
Process connections	See dimension drawings
Electrical connections	• Connector per EN 175301-803-A Form A with cable inlet M16x1.5 or ½-14 NPT or Pg 11 • M12 connector • 2 or 3-wire (0.5 mm^2) cable (∅ ± 5.4 mm) • Cable quick screw connection
Wetted parts materials	
• Measuring cell	Al_2O_3 - 96 %
• Process connection	Stainless steel, mat. No. 1.4404 (SST 316 L)
• Gasket	• FPM (Standard) • Neoprene • Perbunan • EPDM
Non-wetted parts materials	
• Enclosure	Stainless steel, mat. No. 1.4404 (SST 316 L)
• Rack	Plastic
• Cables	PVC
Certificates and approvals	
Classification according to pressure equipment directive (PED 97/23/EC)	For gases of fluid group 1 and liquids of fluid group 1; complies with requirements of article 3, paragraph 3 (sound engineering practice)
Lloyds Register of Shipping (LR)	Applied
Germanischer Lloyds Register of Shipping (GL)	Applied
American Bureau of Shipping (ABS)	Applied
Bureau Veritas (BV)	Applied
Det Norske Veritas (DNV)	Applied
Drinking water approval (ACS)	Applied
GOST	Applied
Explosion protection	
Intrinsic safety "i" (only with current output)	Ex II 1/2 G Ex ia IIC T4 Ga/Gb Ex II 1/2 D Ex ia IIIC T125 °C Da/Db
EC type-examination certificate	SEV 10 ATEX 0146
Connection to certified intrinsically-safe resistive circuits with maximum values:	$U_i \leq 30$ V DC; $I_i \leq 100$ mA; $P_i \leq 0.75$ W
Effective internal inductance and capacity for versions with plugs per EN 175301-803-A and M12	$L_i = 0$ nH; $C_i = 0$ nF

Pressure Measurement

Transmitters for basic requirements

SITRANS P200
for gauge and absolute pressure

Selection and ordering data Order No. Order code

SITRANS P 200 pressure transmitters for pressure and absolute pressure for general applications D) **7MF1565-■■■■■-■■■■ ■■■**
Characteristic curve deviation typ. 0.25 %

Wetted parts materials: Ceramic and stainless steel + sealing material

Non-wetted parts materials: stainless steel

Measuring range		Overload limit				Burst pressure			Order No.	Order code
		Min.		Max.						
For gauge pressure										
0 ... 1 bar	(0 ... 14.5 psi)	-0.4 bar	(-5.8 psi)	2.5 bar	(36.26 psi)	> 2,5 bar	(> 36.3 psi)	▶	3BA	
0 ... 1.6 bar	(0 ... 23.2 psi)	-0.4 bar	(-5.8 psi)	4 bar	(58.02 psi)	> 4 bar	(> 58.0 psi)	▶	3BB	
0 ... 2.5 bar	(0 ... 36.3 psi)	-0.8 bar	(-11.6 psi)	6.25 bar	(90.65 psi)	> 6,25 bar	(> 90.7 psi)	▶	3BD	
0 ... 4 bar	(0 ... 58.0 psi)	-0.8 bar	(-11.6 psi)	10 bar	(145 psi)	> 10 bar	(> 145 psi)	▶	3BE	
0 ... 6 bar	(0 ... 87.0 psi)	-1 bar	(-14.5 psi)	15 bar	(217 psi)	> 15 bar	(> 217 psi)	▶	3BG	
0 ... 10 bar	(0 ... 145 psi)	-1 bar	(-14.5 psi)	25 bar	(362 psi)	> 25 bar	(> 362 psi)	▶	3CA	
0 ... 16 bar	(0 ... 232 psi)	-1 bar	(-14.5 psi)	40 bar	(580 psi)	> 40 bar	(> 580 psi)	▶	3CB	
0 ... 25 bar	(0 ... 363 psi)	-1 bar	(-14.5 psi)	62.5 bar	(906 psi)	> 62,5 bar	(> 906 psi)	▶	3CD	
0 ... 40 bar	(0 ... 580 psi)	-1 bar	(-14.5 psi)	100 bar	(1450 psi)	> 100 bar	(> 1450 psi)	▶	3CE	
0 ... 60 bar	(0 ... 870 psi)	-1 bar	(-14.5 psi)	150 bar	(2175 psi)	> 150 bar	(> 2175 psi)	▶	3CG	
Other version, add order code and plain text: Measuring range: ... up to... bar (psi)									9AA	H1Y
For absolute pressure										
0 ... 600 bar a	(0 ... 8.7 psia)	0 bar a	(0 psia)	3 bar a	(43.51 psia)	> 2,5 bar a	(> 36.3 psia)		5AG	
0 ... 1 bar a	(0 ... 14.5 psia)	0 bar a	(0 psia)	2.5 bar a	(36.26 psia)	> 2,5 bar a	(> 36.3 psia)	▶	5BA	
0 ... 1.6 bar a	(0 ... 23.2 psia)	0 bar a	(0 psia)	4 bar a	(58.02 psia)	> 4 bar a	(> 58.0 psia)	▶	5BB	
0 ... 2.5 bar a	(0 ... 36.3 psia)	0 bar a	(0 psia)	6.25 bar a	(90.65 psia)	> 6,25 bar a	(> 90.7 psia)	▶	5BD	
0 ... 4 bar a	(0 ... 58.0 psia)	0 bar a	(0 psia)	10 bar a	(145 psia)	> 10 bar a	(> 145 psia)	▶	5BE	
0 ... 6 bar a	(0 ... 87.0 psia)	0 bar a	(0 psia)	15 bar a	(217 psia)	> 15 bar a	(> 217 psia)	▶	5BG	
0 ... 10 bar a	(0 ... 145 psi)	0 bar a	(0 psia)	25 bar a	(362 psia)	> 25 bar a	(> 362 psia)	▶	5CA	
0 ... 16 bar a	(0 ... 232 psi)	0 bar a	(0 psia)	40 bar a	(580 psia)	> 40 bar a	(> 580 psia)	▶	5CB	
Other version, add order code and plain text: Measuring range: ... up to ... mbar a (psia)									9AA	H1Y
Measuring ranges for gauge pressure (only for US market)										
	(0 ... 15 psi)		(-5.8 psi)		(35 psi)		(> 35 psi)		4BB	
	(3 ... 15 psi)		(-5.8 psi)		(35 psi)		(> 35 psi)		4BC	
	(0 ... 20 psi)		(-5.8 psi)		(50 psi)		(> 50 psi)		4BD	
	(0 ... 30 psi)		(-5.8 psi)		(80 psi)		(> 80 psi)		4BE	
	(0 ... 60 psi)		(-11.5 psi)		(140 psi)		(> 140 psi)		4BF	
	(0 ... 100 psi)		(-14.5 psi)		(200 psi)		(> 200 psi)		4BG	
	(0 ... 150 psi)		(-14.5 psi)		(350 psi)		(> 350 psi)		4CA	
	(0 ... 200 psi)		(-14.5 psi)		(550 psi)		(> 550 psi)		4CB	
	(0 ... 300 psi)		(-14.5 psi)		(800 psi)		(> 800 psi)		4CD	
	(0 ... 500 psi)		(-14.5 psi)		(1400 psi)		(> 1400 psi)		4CE	
	(0 ... 750 psi)		(-14.5 psi)		(2000 psi)		(> 2000 psi)		4CF	
	(0 ... 1000 psi)		(-14.5 psi)		(2000 psi)		(> 2000 psi)		4CG	
Other version, add order code and plain text: Measuring range: ... up to ... psi									9AA	H1Y
Measuring ranges for absolute pressure (only for US market)										
	(0 ... 10 psia)		(0 psia)		(35 psia)		(> 35 psia)		6AG	
	(0 ... 15 psia)		(0 psia)		(35 psia)		(> 35 psia)		6BA	
	(0 ... 20 psia)		(0 psia)		(50 psia)		(> 50 psia)		6BB	
	(0 ... 30 psia)		(0 psia)		(80 psia)		(> 80 psia)		6BD	
	(0 ... 60 psia)		(0 psia)		(140 psia)		(> 140 psia)		6BE	
	(0 ... 100 psia)		(0 psia)		(200 psia)		(> 200 psia)		6BG	
	(0 ... 150 psia)		(0 psia)		(350 psia)		(> 350 psia)		6CA	
	(0 ... 200 psia)		(0 psia)		(550 psia)		(> 550 psia)		6CB	
	(0 ... 300 psia)		(0 psia)		(800 psia)		(> 800 psia)		6CC	
Other version, add order code and plain text: Measuring range: ... up to ... psia									9AA	H1Y

▶ Available ex stock

Pressure Measurement

Transmitters for basic requirements

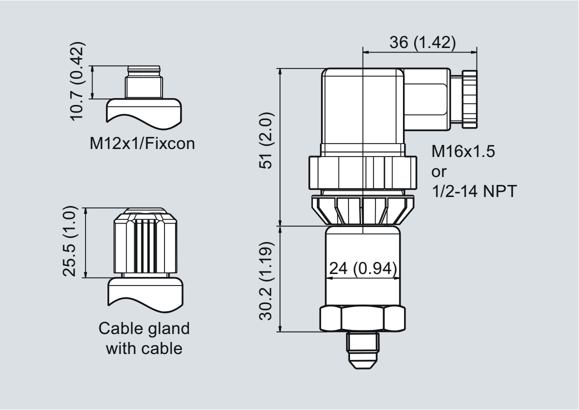
SITRANS P200
for gauge and absolute pressure

Selection and ordering data		Order No.	Order code
SITRANS P 200 pressure transmitters for pressure and absolute pressure for general applications Accuracy typ. 0.25 % Wetted parts materials: Ceramic and stainless steel + sealing material Non-wetted parts materials: stainless steel	D)	**7MF1565-■■■■■-■■■■**	**■■■**
Output signal			
4 ... 20 mA; two-wire system; power supply 7 ... 33 V DC (10 ... 30 V DC for ATEX versions)	▶	**0**	
0 ... 10 V; three-wire system; power supply 12 ... 33 V DC	▶	**1 0**	
Explosion protection (only 4 ... 20 mA)			
None	▶	**0**	
With explosion protection EEx ia IIC T4	▶	**1**	
Electrical connection			
Connector per DIN EN 175301-803-A, stuffing box thread M16 (with coupling)	▶	**1**	
Round connector M12 per DIN EN 60139-9 (not for gauge pressure ranges ≤ 16 bar)		**2**	
Connection via fixed mounted cable, 2m (not for type of protection "Intrinsic safety i")		**0 3**	
Cable quick screw connection PG9 (not for type of protection "Intrinsic safety i")		**0 4**	
Connector per DIN EN 175301-803-A, stuffing box thread 1/2"-14 NPT (with coupling)		**5**	
Connector per DIN EN 175301-803-A, stuffing box thread PG11 (with coupling)		**6**	
Special version		**9**	**N1Y**
Process connection			
G½" male per EN 837-1 (½" BSP male) (standard for metric pressure ranges mbar, bar)	▶	**A**	
G½" male thread and G1/8" female thread		**B**	
G¼" male per EN 837-1 (¼" BSP male)		**C**	
7/16"-20 UNF male		**D**	
¼"-18 NPT male (standard for pressure ranges inH_2O and psi)		**E**	
¼"-18 NPT female		**F**	
½"-14 NPT male		**G**	
½"-14 NPT female		**H**	
7/16"-20 UNF female		**J**	
M20x1.5 male		**P**	
Special version		**Z**	**P1Y**
Sealing material between sensor and enclosure			
Viton (FPM, standard)	▶	**A**	
Neoprene (CR)		**B**	
Perbunan (NBR)		**C**	
EPDM		**D**	
Special version		**Z**	**Q1Y**
Version			
Standard version	▶	**1**	
Further designs			
Supplement the order no. with "**-Z**" and add order code.			
Manufacturer's test certificate M per DIN 55340, Part 18 and ISO 8402 (calibration certificate) supplied		**C11**	
Oxygen application, oil and grease-free cleaning (only in conjunction with the sealing material Viton between sensor and enclosure)		**E10**	

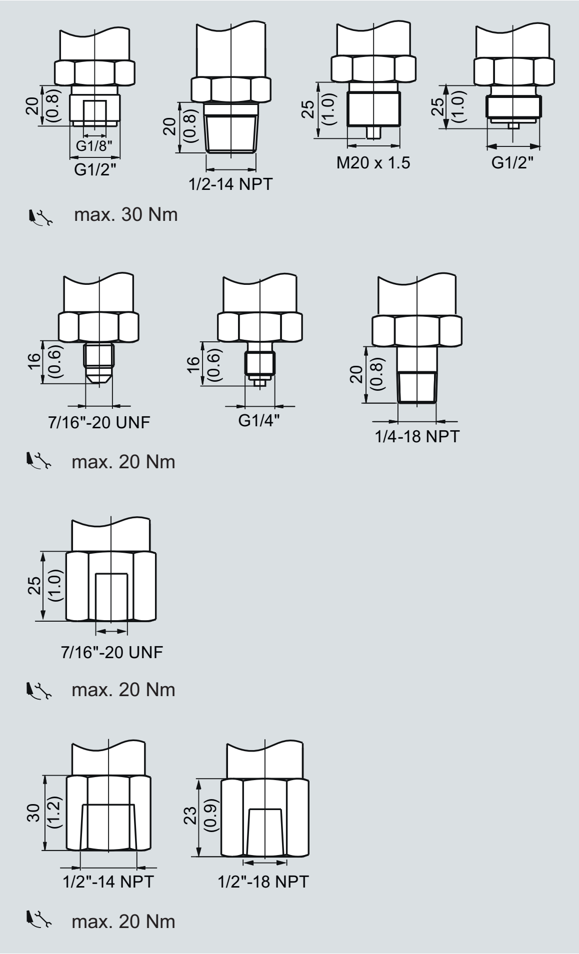
▶ Available ex stock

D) Subject to export regulations AL: N, ECCN: EAR99H.

Dimensional drawings



SITRANS P200, electrical connections, dimensions in mm (inch)



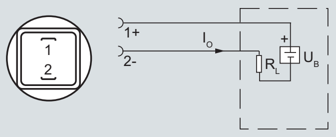
SITRANS P200, process connections, dimensions in mm (inch)

Pressure Measurement

Transmitters for basic requirements

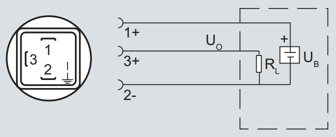
SITRANS P200
for gauge and absolute pressure

Schematics



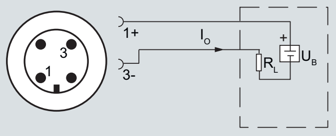
Connection: 1 (+),
2 (-)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and connector per EN 175301



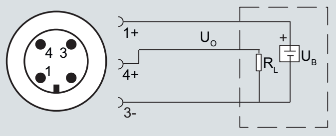
Connection: 1 ($+U_B$),
2 (-),
3 ($+U_O$)
U_O Output voltage
R_L Load
U_B Power supply

Connection with voltage output and connector per EN 175301



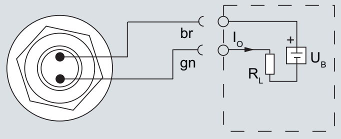
Connection: 1 (+),
3 (-)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and connector M12x1



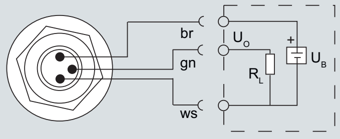
Connection: 1 ($+U_B$),
3 (-),
4 ($+U_O$)
U_O Output voltage
R_L Load
U_B Power supply

Connection with voltage output and connector M12x1



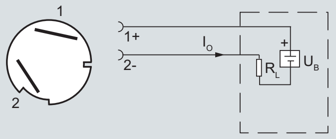
Connection: br (brown),
gn (green)
I_O Output current
U_B Power supply
R_L Load

Connection with current output and cable



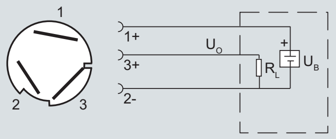
Connection: br ($+U_B$, brown),
gn ($+U_O$, green),
ws (-, white)
U_O Output voltage
U_B Power supply
R_L Load

Connection with voltage output and cable



Connection: 1 (+),
2 (-)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and cable quick screw connection

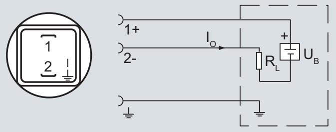


Connection: 1 ($+U_B$),
3 (-),
2 ($+U_O$)
U_O Output voltage
R_L Load
U_B Power supply

Connection with voltage output and cable quick screw connection

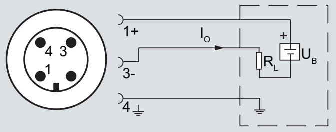
Version with explosion protection: 4 ... 20 mA

The grounding connection is conductively bonded to the transmitter enclosure



Connection: 1 (+),
2 (-)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and connector per EN 175301 (Ex)



Connection: 1 (+),
3 (-),
4 (⏚)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and connector M12x1 (Ex)

Overview

The pressure transmitter SITRANS P210 measures the gauge pressure of liquids, gases and vapors.

- Stainless steal measuring cell
- Measuring ranges 100 to 600 mbar (1.45 to 8.7 psi) relative
- For low-pressure applications

Benefits

- High measuring accuracy
- Rugged stainless steel enclosure
- High overload withstand capability
- For aggressive and non-aggressive media
- For measuring the pressure of liquids, gases and vapors
- Compact design

Application

The pressure transmitter SITRANS P210 for gauge pressure is used in the following industrial areas:

- Mechanical engineering
- Shipbuilding
- Power engineering
- Chemical industry
- Water supply

Design

Device structure without explosion protection

The pressure transmitter consists of a piezoresistive measuring cell with a diaphragm installed in a stainless steel enclosure. It can be used with a connector per EN 175301-803-A (IP65), a round plug M12 (IP67), a cable (IP67) or a cable quick screw connection (IP67) connected electrically. The output signal is between 4 and 20 mA or 0 and 10 V.

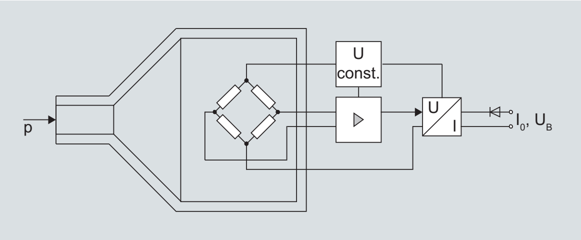
Device structure with explosion protection

The pressure transmitter consists of a piezoresistive measuring cell with a diaphragm installed in a stainless steel enclosure. It can be used with a connector per EN 175301-803-A (IP65) or a round plug M12 (IP67) connected electrically. The output signal is between 4 and 20 mA.

Function

The pressure transmitter measures the gauge pressure of liquids and gases as well as the level of liquids.

Mode of operation



SITRANS P210 pressure transmitters (7MF1566-...), functional diagram

The stainless steel measuring cell has a thin-film resistance bridge to which the operating pressure p is transmitted through a stainless steel diaphragm.

The voltage output from the measuring cell is converted by an amplifier into an output current of 4 to 20 mA or an output voltage of 0 to 10 V DC.

The output current and voltage are linearly proportional to the input pressure.

Pressure Measurement

Transmitters for basic requirements

SITRANS P210
for gauge pressure

Technical specifications

Application	
Gauge measurement	Liquids, gases and vapors
Mode of operation	
Measuring principle	Piezoresistive measuring cell (stainless steel diaphragm)
Measured variable	Gauge pressure
Inputs	
Measuring range	
• Gauge pressure	100 … 600 mbar (1.5 … 8.7 psi)
Output	
Current signal	4 ... 20 mA
• Load	(U_B - 10 V) / 0.02 A
• Auxiliary power U_B	DC 7 ... 33 V (10 ... 30 V for Ex)
Voltage signal	0 ... 10 V DC
• Load	≥ 10 kΩ
• Auxiliary power U_B	12 ... 33 V DC
• Power consumption	< 7 mA at 10 kΩ
Characteristic curve	Linear rising
Measuring accuracy	
Error in measurement at limit setting incl. hysteresis and reproducibility	• Typical: 0.25 % of full-scale value • Maximum: 0.5 % of full-scale value
Step response time T_{99}	< 5 ms
Long-term stability	
• Lower range value and measuring span	0.25 % of full-scale value/year
Influence of ambient temperature	
• Lower range value and measuring span	• 0.25 %/10 K of full-scale value • 0.5 %/10K of full-scale value for a measuring range 100 … 400 mbar
• Influence of power supply	0.005 %/V
Conditions of use	
Process temperature with gasket made of:	
• FPM (Standard)	-15 ... +125 °C (+5 ... +257 °F)
• Neoprene	-35 ... +100 °C (-31 ... +212 °F)
• Perbunan	-20 ... +100 °C (-4 ... +212 °F)
• EPDM	-40 ... +145 °C (-40 ... +293 °F), usable for drinking water
Ambient temperature	-25 ... +85 °C (-13 ... +185 °F)
Storage temperature	-50 ... +100 °C (-58 ... +212 °F)
Degree of protection (to EN 60529)	• IP 65 with connector per EN 175301-803-A • IP 67 with M12 connector • IP 67 with cable • IP 67 with cable quick screw connection
Electromagnetic compatibility	• acc. EN 61326-1/-2/-3 • acc. NAMUR NE21, only for ATEX versions and with a max. measuring deviation ≤ 1 %
Mounting position	upright

Design	
Weight	Approx. 0.090 kg (0.198 lb)
Process connections	See dimension drawings
Electrical connections	• Connector per EN 175301-803-A Form A with cable inlet M16x1.5 or ½-14 NPT or Pg 11 • M12 connector • 2 or 3-wire (0.5 mm²) cable (∅ ± 5.4 mm) • Cable quick screw connection
Wetted parts materials	
• Measuring cell	Stainless steel, mat.-No. 1.4435
• Process connection	Stainless steel, mat. No. 1.4404 (SST 316 L)
• Gasket	• FPM (Standard) • Neoprene • Perbunan • EPDM
Non-wetted parts materials	
• Enclosure	Stainless steel, mat. No. 1.4404 (SST 316 L)
• Rack	Plastic
• cables	PVC
Certificates and approvals	
Classification according to pressure equipment directive (PED 97/23/EC)	For gases of fluid group 1 and liquids of fluid group 1; meets requirements as per article 3, paragraph 3 (good engineering practice)
Lloyds Register of Shipping (LR)	Applied
Germanischer Lloyds Register of Shipping (GL)	Applied
American Bureau of Shipping (ABS)	Applied
Bureau Veritas (BV)	Applied
Det Norske Veritas (DNV)	Applied
Drinking water approval (ACS)	Applied
GOST	Applied
Explosion protection	
Intrinsic safety "i" (only with current output)	Ex II 1/2 G Ex ia IIC T4 Ga/Gb Ex II 1/2 D Ex ia IIIC T125 °C Da/Db
EC type-examination certificate	SEV 10 ATEX 0146
Connection to certified intrinsically-safe resistive circuits with maximum values:	$U_i \leq 30$ V DC; $I_i \leq 100$ mA; $P_i \leq 0.75$ W
Effective internal inductance and capacity for versions with plugs per EN 175301-803-A and M12	$L_i = 0$ nH; $C_i = 0$ nF

Selection and ordering data

Selection and ordering data					Order No.	Order code
SITRANS P 210 pressure transmitters for gauge pressure for low pressure applications Accuracy typ. 0.25 % Wetted parts materials: Stainless steel + sealing material Non-wetted parts materials: stainless steel					D) **7MF1566-■■■■■-■■■■**	**■■■**
Measuring range	**Overload limit**		**Burst pressure**			
	min.	**max.**				
For gauge pressure						
0 ... 100 mbar (0.58 psi)	-40 mbar (-0.58 psi)	250 mbar (3.63 psi)	0.5 bar (7.25 psi)	▶	**3AA**	
0 ... 160 mbar (2.32 psi)	-40 mbar (-0.58 psi)	400 mbar (5.8 psi)	0.5 bar (7.25 psi)	▶	**3AB**	
0 ... 250 mbar (3.63 psi)	-80 mbar (-1.16 psi)	625 mbar (9.06 psi)	1 bar (14.5 psi)	▶	**3AC**	
0 ... 400 mbar (5.8 psi)	-80 mbar (-1.16 psi)	1000 mbar (14.5 psi)	1 bar (14.5 psi)	▶	**3AD**	
0 ... 600 mbar (8.7 psi)	-100 mbar (-1.45 psi)	1500 mbar (21.76 psi)	2.5 bar (36.26 psi)	▶	**3AG**	
Other version, add order code and plain text: Measuring range: ... up to ... mbar (psi)					**9AA**	**H1Y**
Output signal						
4 ... 20 mA; two-wire system; power supply 7 ... 33 V DC (10 ... 30 V DC for ATEX versions)				▶	**0**	
0 ... 10 V; three-wire system; power supply 12 ... 33 V DC				▶	**1 0**	
Explosion protection (only 4 ... 20 mA)						
None				▶	**0**	
With explosion protection EEx ia IIC T4				▶	**1**	
Electrical connection						
Connector per DIN EN 175301-803-A, stuffing box thread M16 (with coupling)				▶	**1**	
Round connector M12 per DIN EN 60139-9 (not for gauge pressure ranges ≤ 16 bar)					**2**	
Connection via fixed mounted cable, 2 m (not for type of protection "Intrinsic safety i")					**0 3**	
Cable quick screw connection PG9 (not for type of protection "Intrinsic safety i")					**0 4**	
Connector per DIN EN 175301-803-A, stuffing box thread 1/2"-14 NPT (with coupling)					**5**	
Connector per DIN EN 175301-803-A, stuffing box thread PG11 (with coupling)					**6**	
Special version					**9**	**N1Y**
Process connection						
G½" male per EN 837-1 (½" BSP male) (standard for metric pressure ranges mbar, bar)				▶	**A**	
G½" male thread and G1/8" female thread					**B**	
G¼" male per EN 837-1 (¼" BSP male)					**C**	
7/16"-20 UNF male					**D**	
¼"-18 NPT male (standard for pressure ranges inH$_2$O and psi)					**E**	
¼"-18 NPT female					**F**	
½"-14 NPT male					**G**	
½"-14 NPT female					**H**	
7/16"-20 UNF female					**J**	
M20x1.5 male					**P**	
Special version					**Z**	**P1Y**
Sealing material between sensor and enclosure						
Viton (FPM, standard)				▶	**A**	
Neoprene (CR)					**B**	
Perbunan (NBR)					**C**	
EPDM					**D**	
Special version					**Z**	**Q1Y**
Version						
Standard version				▶	**1**	
Further designs						
Supplement the order no. with "**-Z**" and add order code.						
Manufacturer's test certificate M per DIN 55340, Part 18 and ISO 8402 (calibration certificate) supplied					**C11**	

▶ Available ex stock

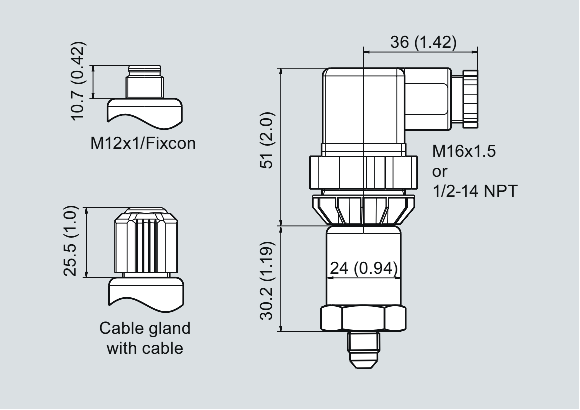
D) Subject to export regulations AL: N, ECCN: EAR99H.

Pressure Measurement

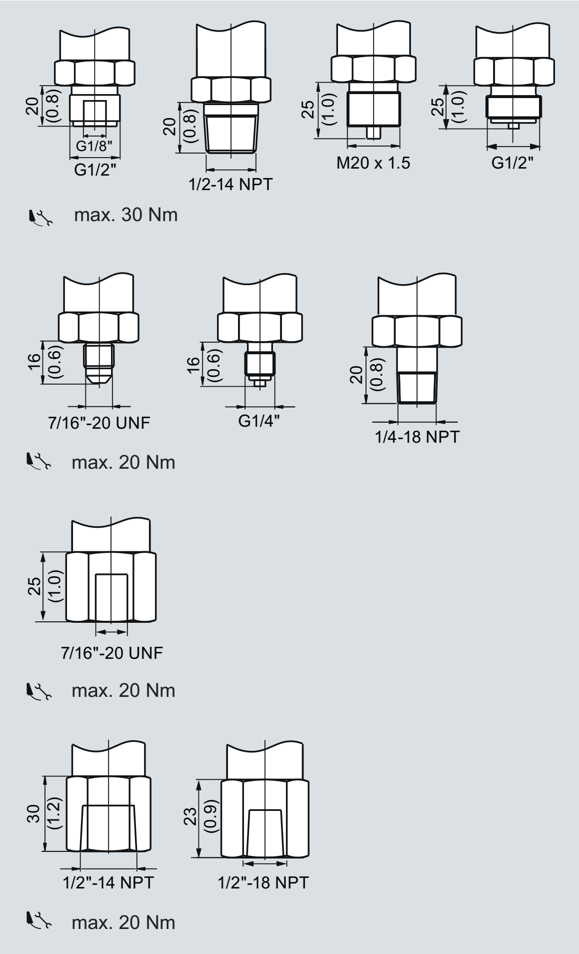
Transmitters for basic requirements

SITRANS P210
for gauge pressure

Dimensional drawings

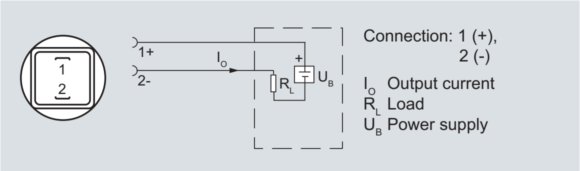


SITRANS P210, electrical connections, dimensions in mm (inch)



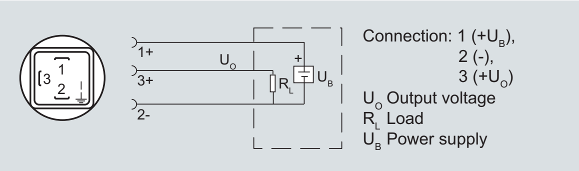
SITRANS P210, process connections, dimensions in mm (inch)

Schematics



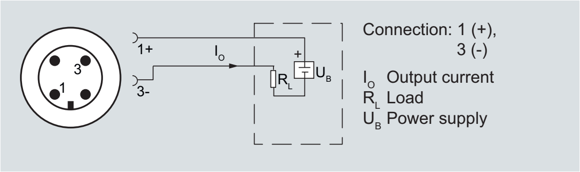
Connection: 1 (+),
2 (-)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and connector per EN 175301



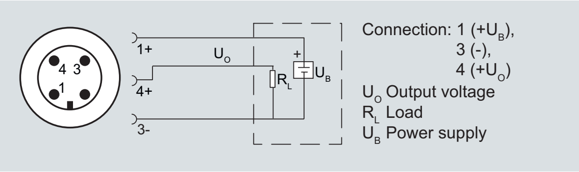
Connection: 1 ($+U_B$),
2 (-),
3 ($+U_O$)
U_O Output voltage
R_L Load
U_B Power supply

Connection with voltage output and connector per EN 175301



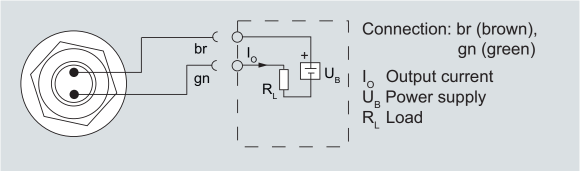
Connection: 1 (+),
3 (-)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and connector M12x1



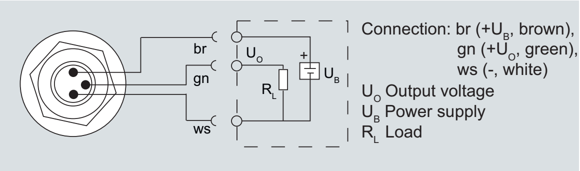
Connection: 1 ($+U_B$),
3 (-),
4 ($+U_O$)
U_O Output voltage
R_L Load
U_B Power supply

Connection with voltage output and connector M12x1



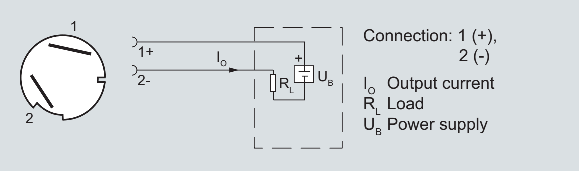
Connection: br (brown),
gn (green)
I_O Output current
U_B Power supply
R_L Load

Connection with current output and cable



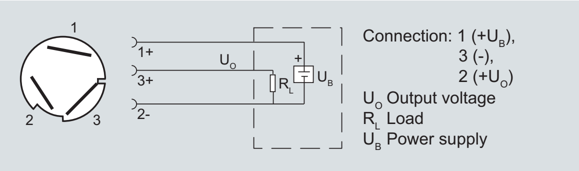
Connection: br ($+U_B$, brown),
gn ($+U_O$, green),
ws (-, white)
U_O Output voltage
U_B Power supply
R_L Load

Connection with voltage output and cable



Connection: 1 (+),
2 (-)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and cable quick screw connection

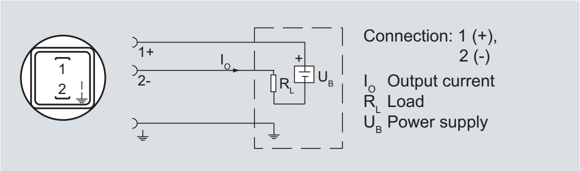


Connection: 1 ($+U_B$),
3 (-),
2 ($+U_O$)
U_O Output voltage
R_L Load
U_B Power supply

Connection with voltage output and cable quick screw connection

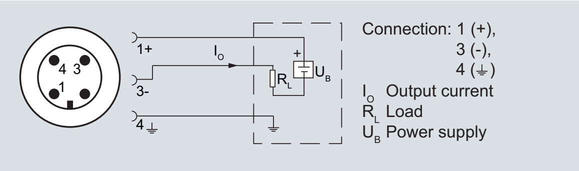
Version with explosion protection: 4 ... 20 mA

The grounding connection is conductively bonded to the transmitter enclosure



Connection: 1 (+),
2 (-)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and connector per EN 175301 (Ex)



Connection: 1 (+),
3 (-),
4 (⏚)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and connector M12x1 (Ex)

Pressure Measurement

Transmitters for basic requirements

SITRANS P220 for gauge pressure

Overview

The pressure transmitter SITRANS P220 measures the gauge pressure of liquids, gases and vapors.

- Stainless steel measuring cell, fully welded
- Measuring ranges 2.5 to 600 bar (36.3 to 8702 psi) relative
- For high-pressure applications and refrigeration technology division

Benefits

- High measuring accuracy
- Rugged stainless steel enclosure
- High overload withstand capability
- For aggressive and non-aggressive media
- For measuring the pressure of liquids, gases and vapors
- Compact design
- Gasket-less

Application

The pressure transmitter SITRANS P220 for gauge pressure is used in the following industrial areas:

- Mechanical engineering
- Shipbuilding
- Power engineering
- Chemical industry
- Water supply

Design

Device structure without explosion protection

The pressure transmitter consists of a piezoresistive measuring cell with a diaphragm installed in a stainless steel enclosure. It can be used with a connector per EN 175301-803-A (IP65), a round plug M12 (IP67), a cable (IP67) or a cable quick screw connection (IP67) connected electrically. The output signal is between 4 and 20 mA or 0 and 10 V.

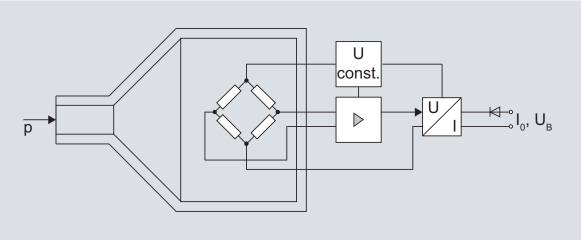
Device structure with explosion protection

The pressure transmitter consists of a piezoresistive measuring cell with a diaphragm installed in a stainless steel enclosure. It can be used with a connector per EN 175301-803-A (IP65) or a round plug M12 (IP67) connected electrically. The output signal is between 4 and 20 mA.

Function

The pressure transmitter measures the gauge pressure of liquids and gases as well as the level of liquids.

Mode of operation



SITRANS P220 pressure transmitters (7MF1567-...), functional diagram

The stainless steel measuring cell has a thick-film resistance bridge to which the operating pressure p is transmitted through a stainless steel diaphragm.

The voltage output from the measuring cell is converted by an amplifier into an output current of 4 to 20 mA or an output voltage of 0 to 10 V DC.

The output current and voltage are linearly proportional to the input pressure.

Pressure Measurement

Transmitters for basic requirements

SITRANS P220
for gauge pressure

Technical specifications

Application	
Gauge pressure measurement	Liquids, gases and vapors
Mode of operation	
Measuring principle	Piezoresistive measuring cell (stainless steel diaphragm)
Measured variable	Gauge pressure
Inputs	
Measuring range	
• Gauge pressure	
- Metric	2.5 … 600 bar (36 … 8700 psi)
- US measuring range	30… 8700 psi
Output	
Current signal	4 ... 20 mA
• Load	(U_B - 10 V) / 0.02 A
• Auxiliary power U_B	DC 7 ... 33 V (10 ... 30 V for Ex)
Voltage signal	0 ... 10 V DC
• Load	≥ 10 kΩ
• Auxiliary power U_B	12 ... 33 V DC
• Power consumption	< 7 mA at 10 kΩ
Characteristic curve	Linear rising
Measuring accuracy	
Error in measurement at limit setting incl. hysteresis and reproducibility	• Typical: 0.25 % of full-scale value • Maximum: 0.5 % of full-scale value
Step response time T_{99}	< 5 ms
Long-term stability	
• Lower range value and measuring span	0.25 % of full-scale value/year
Influence of ambient temperature	
• Lower range value and measuring span	0.25 %/10 K of full-scale value
• Influence of power supply	0.005 %/V
Conditions of use	
• Process temperature	-30 ... +120 °C (-22 ... +248 °F)
• Ambient temperature	-25 ... +85 °C (-13 ... +185 °F)
• Storage temperature	-50 ... +100 °C (-58 ... +212 °F)
• Degree of protection (to EN 60529)	• IP 65 with connector per EN 175301-803-A • IP 67 with M12 connector • IP 67 with cable • IP 67 with cable quick screw connection
Electromagnetic compatibility	• acc. EN 61326-1/-2/-3 • acc. NAMUR NE21, only for ATEX versions and with a max. measuring deviation ≤ 1 %

Design	
Weight	Approx. 0.090 kg (0.198 lb)
Process connections	See dimension drawings
Electrical connections	• Connector per EN 175301-803-A Form A with cable inlet M16x1.5 or ½-14 NPT or Pg 11 • M12 connector • 2 or 3-wire (0.5 mm^2) cable (∅ ± 5.4 mm) • Cable quick screw connection
Wetted parts materials	
• Measuring cell	Stainless steel, mat.-No. 1.4016
• Process connection	Stainless steel, mat. No. 1.4404 (SST 316 L)
Non-wetted parts materials	
• Enclosure	Stainless steel, mat. No. 1.4404 (SST 316 L)
• Rack	Plastic
• cables	PVC
Certificates and approvals	
Classification according to pressure equipment directive (PED 97/23/EC)	For gases of fluid group 1 and liquids of fluid group 1; complies with requirements of article 3, paragraph 3 (sound engineering practice)
Lloyds Register of Shipping (LR)	Applied
Germanischer Lloyds Register of Shipping (GL)	Applied
American Bureau of Shipping (ABS)	Applied
Bureau Veritas (BV)	Applied
Det Norske Veritas (DNV)	Applied
Drinking water approval (ACS)	Applied
GOST	Applied
Explosion protection	
Intrinsic safety "i" (only with current output)	Ex II 1/2 G Ex ia IIC T4 Ga/Gb Ex II 1/2 D Ex ia IIIC T125 °C Da/Db
EC type-examination certificate	SEV 10 ATEX 0146
Connection to certified intrinsically-safe resistive circuits with maximum values:	$U_i \leq 30$ V DC; $I_i \leq 100$ mA; $P_i \leq 0.75$ W
Effective internal inductance and capacity for versions with plugs per EN 175301-803-A and M12	$L_i = 0$ nH; $C_i = 0$ nF

Pressure Measurement

Transmitters for basic requirements

SITRANS P220
for gauge pressure

Selection and ordering data					Order No.	Order code
SITRANS P 220 pressure transmitters for gauge pressure, high-pressure and refrigeration applications, fully-welded version Accuracy typ. 0.25 % Wetted parts materials: stainless steel Non-wetted parts materials: stainless steel					D) **7MF1567-■■■■■-■■A■**	**■■■**
Measuring range	**Overload limit**		**Burst pressure**			
	Mini-mum	**Max.**				
For gauge pressure						
0 ... 2.5 bar (0 ... 36.3 psi)	-0.8 bar (-11.6 psi)	6.25 bar (90.7 psi)	25 bar (363 psi)	▶	**3BD**	
0 ... 4 bar (0 ... 58 psi)	-0.8 bar (-11.6 psi)	10 bar (145 psi)	40 bar (870 psi)	▶	**3BE**	
0 ... 6 bar (0 ... 87 psi)	-1 bar (-14.5 psi)	15 bar (217 psi)	60 bar (522 psi)	▶	**3BG**	
0 ... 10 bar (0 ... 145 psi)	-1 bar (-14.5 psi)	25 bar (362 psi)	60 bar (870 psi)	▶	**3CA**	
0 ... 16 bar (0 ... 232 psi)	-1 bar (-14.5 psi)	40 bar (580 psi)	96 bar (1392 psi)	▶	**3CB**	
0 ... 25 bar (0 ... 363 psi)	-1 bar (-14.5 psi)	62.5 bar (906 psi)	150 bar (2176 psi)	▶	**3CD**	
0 ... 40 bar (0 ... 580 psi)	-1 bar (-14.5 psi)	100 bar (1450 psi)	240 bar (3481 psi)	▶	**3CE**	
0 ... 60 bar (0 ... 870 psi)	-1 bar (-14.5 psi)	150 bar (2175 psi)	360 bar (5221 psi)	▶	**3CG**	
0 ... 100 bar (0 ... 1450 psi)	-1 bar (-14.5 psi)	250 bar (3625 psi)	600 bar (8702 psi)		**3DA**	
0 ... 160 bar (0 ... 2320 psi)	-1 bar (-14.5 psi)	400 bar (5801 psi)	960 bar (13924 psi)		**3DB**	
0 ... 250 bar (0 ... 3625 psi)	-1 bar (-14.5 psi)	625 bar (9064 psi)	1500 bar (21756 psi)		**3DD**	
0 ... 400 bar (0 ... 5801 psi)	-1 bar (-14.5 psi)	1000 bar (14503 psi)	2400 bar (34809 psi)		**3DE**	
0 ... 600 bar (0 ... 8702 psi)	-1 bar (-14.5 psi)	1500 bar (21755 psi)	2500 bar (36260 psi)		**3DG**	
Other version, add order code and plain text: Measuring range: ... up to... bar (psi)					**9AA**	**H1Y**
Measuring ranges for gauge pressure (only for US market)						
(0 ... 30 psi)	(-5.8 psi)	(75 psi)	(360 psi)		**4BE**	
(0 ... 60 psi)	(-11.5 psi)	(150 psi)	(580 psi)		**4BF**	
(0 ... 100 psi)	(-14.5 psi)	(250 psi)	(580 psi)		**4BG**	
(0 ... 150 psi)	(-14.5 psi)	(375 psi)	(870 psi)		**4CA**	
(0 ... 200 psi)	(-14.5 psi)	(500 psi)	(1390 psi)		**4CB**	
(0 ... 300 psi)	(-14.5 psi)	(750 psi)	(2170 psi)		**4CD**	
(0 ... 500 psi)	(-14.5 psi)	(1250 psi)	(3480 psi)		**4CE**	
(0 ... 750 psi)	(-14.5 psi)	(1875 psi)	(5220 psi)		**4CF**	
(0 ... 1000 psi)	(-14.5 psi)	(2500 psi)	(5220 psi)		**4CG**	
(0 ... 1500 psi)	(-14.5 psi)	(3750 psi)	(8700 psi)		**4DA**	
(0 ... 2000 psi)	(-14.5 psi)	(5000 psi)	(13920 psi)		**4DB**	
(0 ... 3000 psi)	(-14.5 psi)	(7500 psi)	(21750 psi)		**4DD**	
(0 ... 5000 psi)	(-14.5 psi)	(12500 psi)	(34800 psi)		**4DE**	
(0 ... 6000 psi	(-14.5 psi)	(15000 psi)	(34800 psi)		**4DF**	
(0 ... 8700 psi)	(-14.5 psi)	(21000 psi)	(52200 psi)		**4DG**	
Other version, add order code and plain text: Measuring range: ... up to ... psi					**9AA**	**H1Y**
Output signal						
4 ... 20 mA; two-wire system; power supply 7 ... 33 V DC (10 ... 30 V DC for ATEX versions)				▶	**0**	
0 ... 10 V; three-wire system; power supply 12 ... 33 V DC				▶	**1 0**	
Explosion protection (only 4 ... 20 mA)						
None				▶	**0**	
With explosion protection EEx ia IIC T4				▶	**1**	
Electrical connection						
Connector per DIN EN 175301-803-A, stuffing box thread M16 (with coupling)				▶	**1**	
Round connector M12 per DIN EN 60139-9 (not for gauge pressure ranges ≤ 16 bar)					**2**	
Connection via fixed mounted cable, 2 m (not for type of protection "Intrinsic safety i")					**0 3**	
Cable quick screw connection PG9 (not for type of protection "Intrinsic safety i")					**0 4**	
Connector per DIN EN 175301-803-A, stuffing box thread 1/2"-14 NPT (with coupling)					**5**	
Connector per DIN EN 175301-803-A, stuffing box thread PG11 (with coupling)					**6**	
Special version					**9**	**N1Y**

▶ Available ex stock

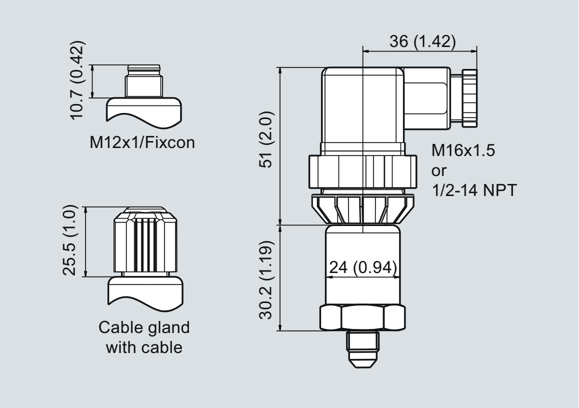
Selection and ordering data		Order No.	Order code
SITRANS P 220 pressure transmitters for gauge pressure, high-pressure and refrigeration applications, fully-welded version Accuracy typ. 0.25 % Wetted parts materials: stainless steel Non-wetted parts materials: stainless steel	D)	**7MF1567-■■■■■-■■A■**	**■■■**
Process connection			
G½" male per EN 837-1 (½" BSP male) (standard for metric pressure ranges mbar, bar)	▶	**A**	
G½" male thread and G1/8" female thread		**B**	
G¼“ male per EN 837-1 (¼“ BSP male)		**C**	
7/16"-20 UNF male		**D**	
¼"-18 NPT male (standard for pressure ranges inH$_2$O and psi)		**E**	
¼"-18 NPT female (Only for measuring ranges ≤ 60 bar (870 psi))		**F**	
½"-14 NPT male		**G**	
½"-14 NPT female (Only for measuring ranges ≤ 60 bar (870 psi))		**H**	
7/16"-20 UNF female		**J**	
M20x1.5 male		**P**	
Special version		**Z**	**P1Y**
Version			
Standard version	▶	**1**	
Further designs			
Supplement the order no. with "**-Z**" and add order code.			
Manufacturer’s test certificate M per DIN 55340, Part 18 and ISO 8402 (calibration certificate) supplied		**C11**	
Oxygen application, oil and grease-free cleaning		**E10**	

▶ Available ex stock

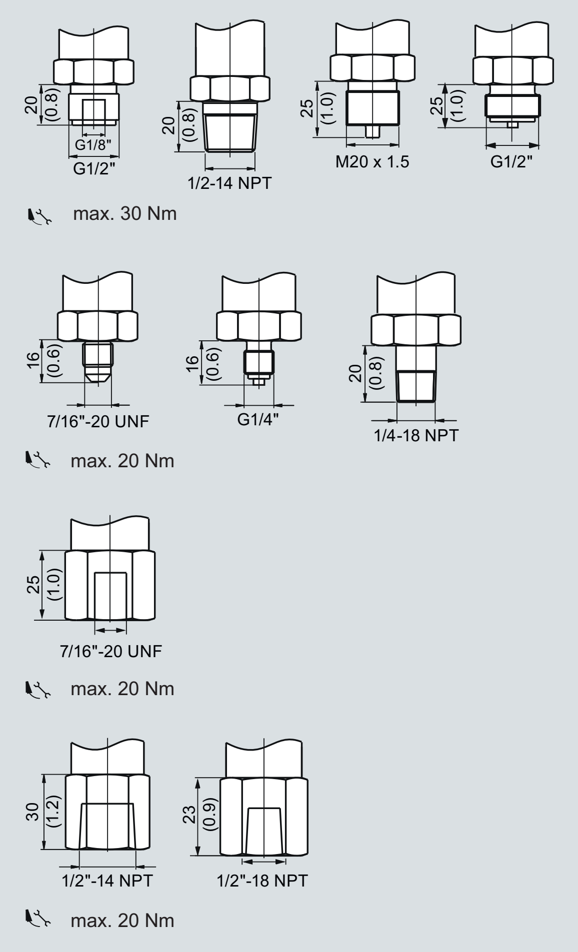
D) Subject to export regulations AL: N, ECCN: EAR99H.

Pressure Measurement
Transmitters for basic requirements
SITRANS P220
for gauge pressure

Dimensional drawings

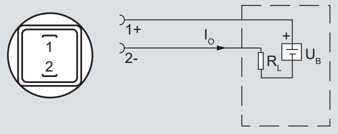


SITRANS P220, electrical connections, dimensions in mm (inch)



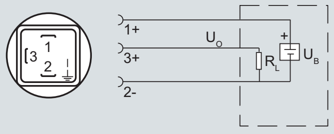
SITRANS P220, process connections, dimensions in mm (inch)

Schematics



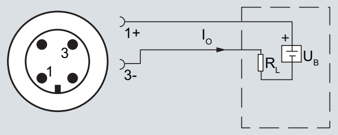
Connection: 1 (+),
2 (-)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and connector per EN 175301



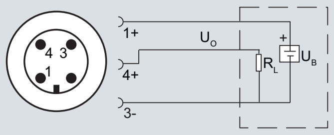
Connection: 1 ($+U_B$),
2 (-),
3 ($+U_O$)
U_O Output voltage
R_L Load
U_B Power supply

Connection with voltage output and connector per EN 175301



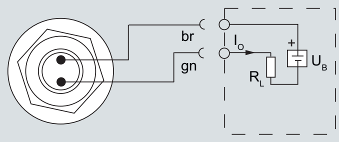
Connection: 1 (+),
3 (-)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and connector M12x1



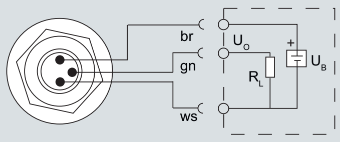
Connection: 1 ($+U_B$),
3 (-),
4 ($+U_O$)
U_O Output voltage
R_L Load
U_B Power supply

Connection with voltage output and connector M12x1



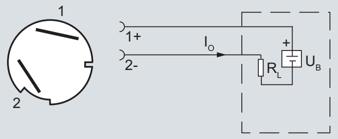
Connection: br (brown),
gn (green)
I_O Output current
U_B Power supply
R_L Load

Connection with current output and cable



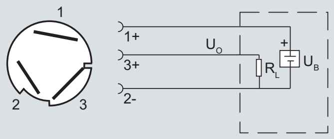
Connection: br ($+U_B$, brown),
gn ($+U_O$, green),
ws (-, white)
U_O Output voltage
U_B Power supply
R_L Load

Connection with voltage output and cable



Connection: 1 (+),
2 (-)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and cable quick screw connection

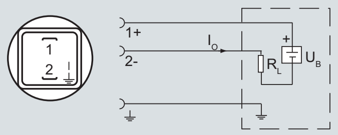


Connection: 1 ($+U_B$),
3 (-),
2 ($+U_O$)
U_O Output voltage
R_L Load
U_B Power supply

Connection with voltage output and cable quick screw connection

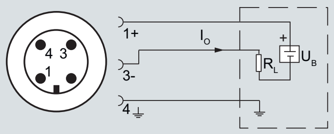
Version with explosion protection: 4 ... 20 mA

The grounding connection is conductively bonded to the transmitter enclosure



Connection: 1 (+),
2 (-)
I_O Output current
R_L Load
U_B Power supply

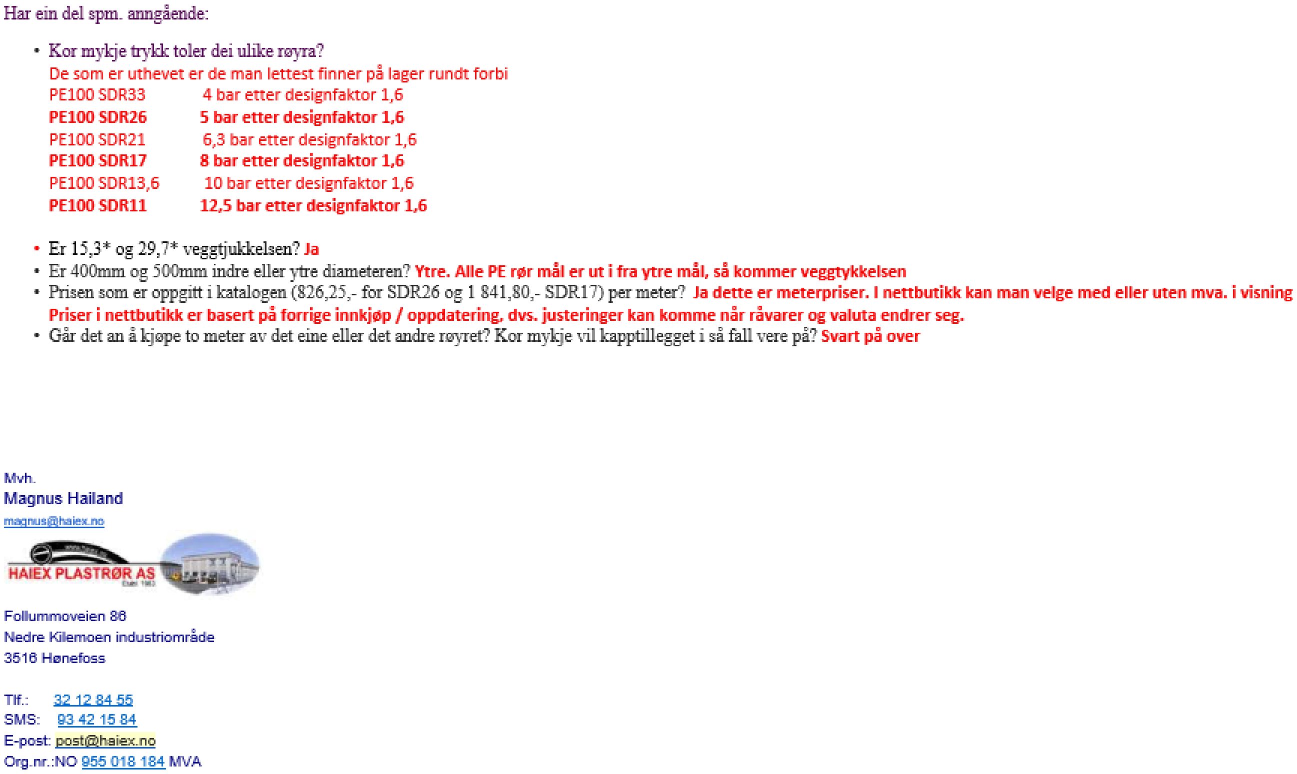
Connection with current output and connector per EN 175301 (Ex)



Connection: 1 (+),
3 (-),
4 (⏚)
I_O Output current
R_L Load
U_B Power supply

Connection with current output and connector M12x1 (Ex)

Appendix B – Documentation sent by mail



Har ein del spm. anngående:

- Kor mykje trykk toler dei ulike røyra?
  De som er uthevet er de man lettest finner på lager rundt forbi

PE100 SDR33	4 bar etter designfaktor 1,6
PE100 SDR26	**5 bar etter designfaktor 1,6**
PE100 SDR21	6,3 bar etter designfaktor 1,6
PE100 SDR17	**8 bar etter designfaktor 1,6**
PE100 SDR13,6	10 bar etter designfaktor 1,6
PE100 SDR11	**12,5 bar etter designfaktor 1,6**

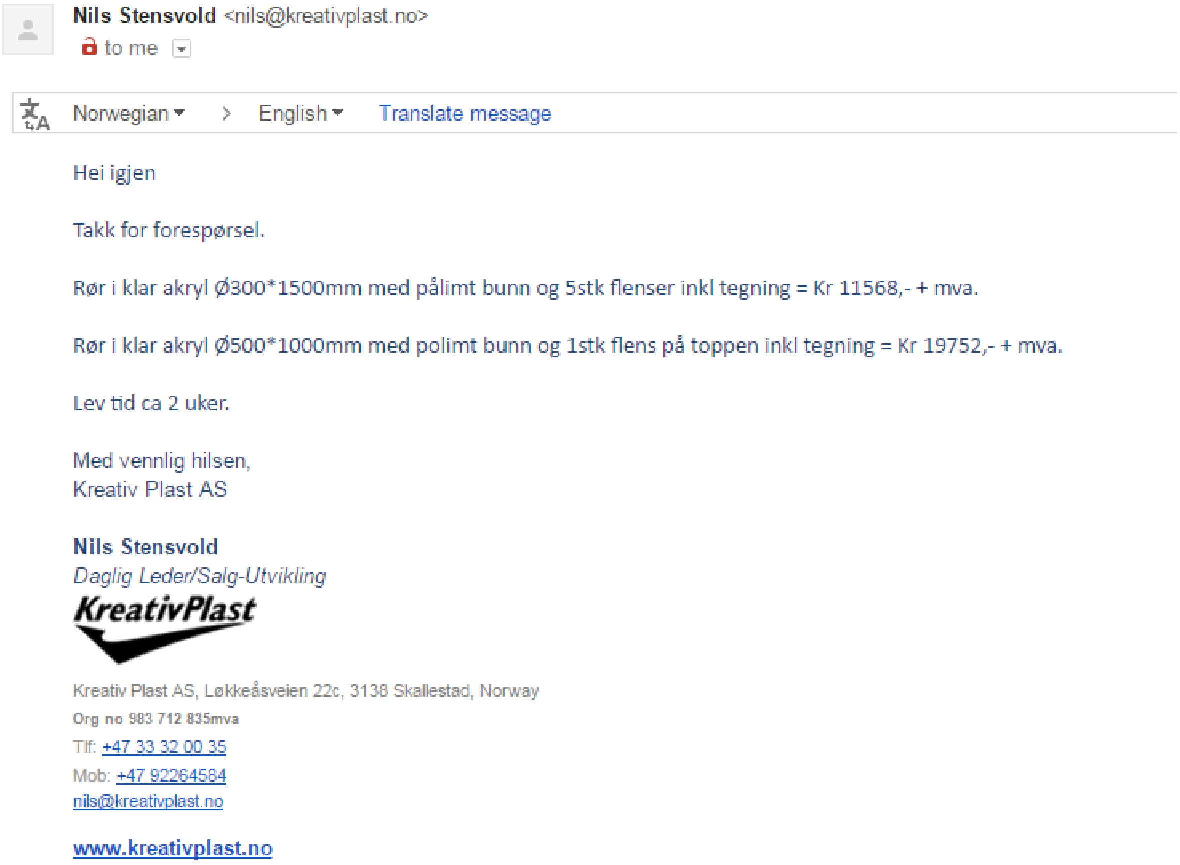
- Er 15,3* og 29,7* veggtjukkelsen? **Ja**
- Er 400mm og 500mm indre eller ytre diameteren? **Ytre. Alle PE rør mål er ut i fra ytre mål, så kommer veggtykkelsen**
- Prisen som er oppgitt i katalogen (826,25,- for SDR26 og 1 841,80,- SDR17) per meter? **Ja dette er meterpriser. I nettbutikk kan man velge med eller uten mva. i visning Priser i nettbutikk er basert på forrige innkjøp / oppdatering, dvs. justeringer kan komme når råvarer og valuta endrer seg.**
- Går det an å kjøpe to meter av det eine eller det andre røyret? Kor mykje vil kapptillegget i så fall vere på? **Svart på over**

Mvh.
Magnus Hailand
magnus@haiex.no

HAIEX PLASTRØR AS

Follummoveien 86
Nedre Kilemoen industriområde
3516 Hønefoss

Tlf.: 32 12 84 55
SMS: 93 42 15 84
E-post: post@haiex.no
Org.nr.:NO 955 018 184 MVA



Nils Stensvold <nils@kreativplast.no>

Hei igjen

Takk for forespørsel.

Rør i klar akryl Ø300*1500mm med pålimt bunn og 5stk flenser inkl tegning = Kr 11568,- + mva.

Rør i klar akryl Ø500*1000mm med polimt bunn og 1stk flens på toppen inkl tegning = Kr 19752,- + mva.

Lev tid ca 2 uker.

Med vennlig hilsen,
Kreativ Plast AS

Nils Stensvold
Daglig Leder/Salg-Utvikling
KreativPlast

Kreativ Plast AS, Løkkeåsveien 22c, 3138 Skallestad, Norway
Org no 983 712 835mva
Tlf: +47 33 32 00 35
Mob: +47 92264584
nils@kreativplast.no

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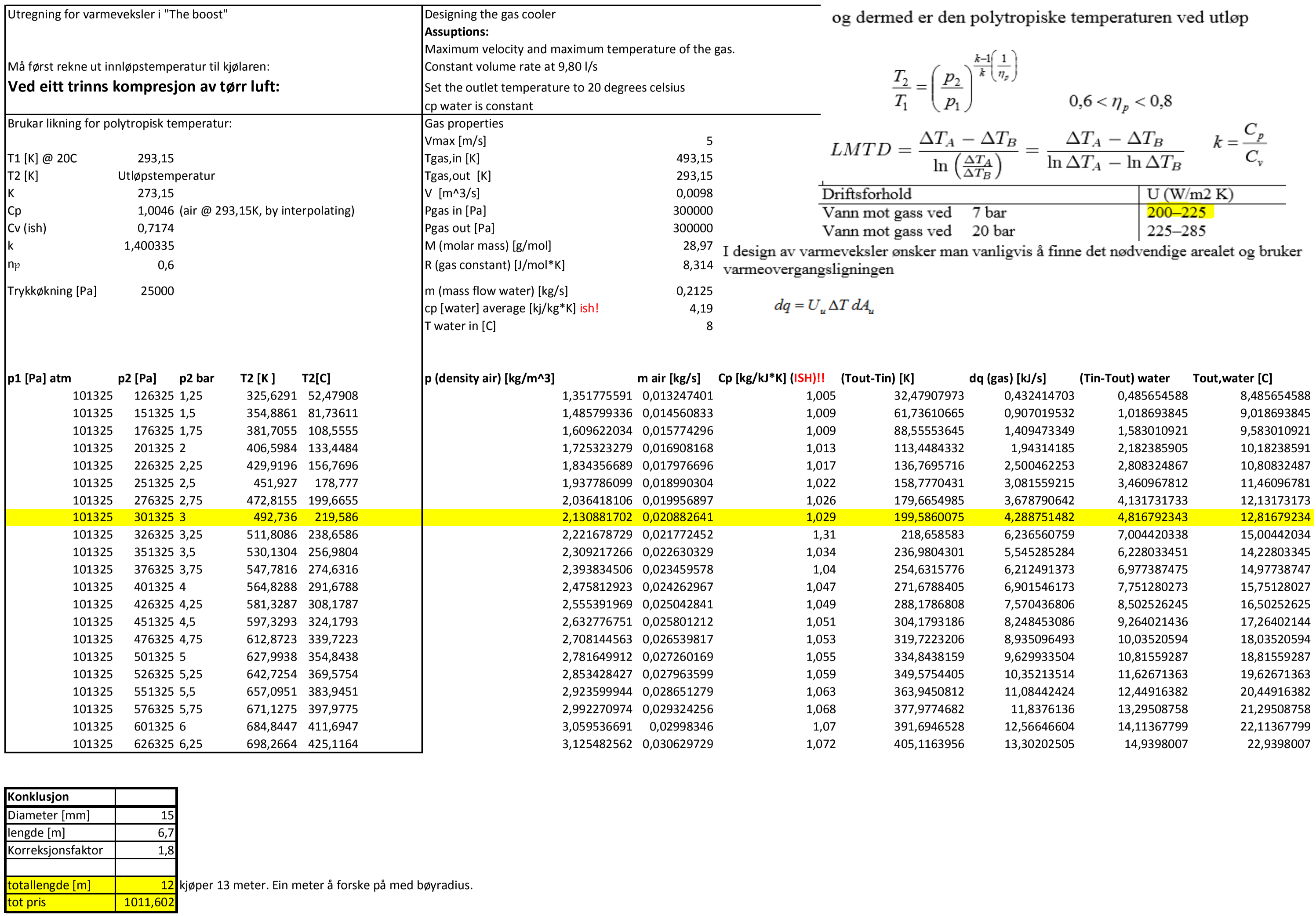
Appendix C – Complete calculations



Utregning for varmeveksler i "The boost"

Må først rekne ut innløpstemperatur til kjølaren:

Ved eitt trinns kompresjon av tørr luft:

Brukar likning for polytropisk temperatur:

T1 [K] @ 20C	293,15	
T2 [K]	Utløpstemperatur	
K	273,15	
Cp	1,0046	(air @ 293,15K, by interpolating)
Cv (ish)	0,7174	
k	1,400335	
η_p	0,6	
Trykkøkning [Pa]	25000	

Designing the gas cooler

Assuptions:

Maximum velocity and maximum temperature of the gas.

Constant volume rate at 9,80 l/s

Set the outlet temperature to 20 degrees celsius

cp water is constant

Gas properties

Vmax [m/s]	5
Tgas,in [K]	493,15
Tgas,out [K]	293,15
V [m^3/s]	0,0098
Pgas in [Pa]	300000
Pgas out [Pa]	300000
M (molar mass) [g/mol]	28,97
R (gas constant) [J/mol*K]	8,314
m (mass flow water) [kg/s]	0,2125
cp [water] average [kj/kg*K] ish!	4,19
T water in [C]	8

og dermed er den polytropiske temperaturen ved utløp

$$\frac{T_2}{T_1}=\left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}\left(\frac{1}{\eta_p}\right)} \qquad 0{,}6<\eta_p<0{,}8$$

$$LMTD=\frac{\Delta T_A-\Delta T_B}{\ln\left(\frac{\Delta T_A}{\Delta T_B}\right)}=\frac{\Delta T_A-\Delta T_B}{\ln \Delta T_A-\ln \Delta T_B} \qquad k=\frac{C_p}{C_v}$$

Driftsforhold		U (W/m2 K)
Vann mot gass ved	7 bar	200–225
Vann mot gass ved	20 bar	225–285

I design av varmeveksler ønsker man vanligvis å finne det nødvendige arealet og bruker varmeovergangsligningen

$$dq=U_u\,\Delta T\,dA_u$$

p1 [Pa] atm	p2 [Pa]	p2 bar	T2 [K]	T2[C]	p (density air) [kg/m^3]	m air [kg/s]	Cp [kg/kJ*K] (ISH)!!	(Tout-Tin) [K]	dq (gas) [kJ/s]	(Tin-Tout) water	Tout,water [C]
101325	126325	1,25	325,6291	52,47908	1,351775591	0,013247401	1,005	32,47907973	0,432414703	0,485654588	8,485654588
101325	151325	1,5	354,8861	81,73611	1,485799336	0,014560833	1,009	61,73610665	0,907019532	1,018693845	9,018693845
101325	176325	1,75	381,7055	108,5555	1,609622034	0,015774296	1,009	88,55553645	1,409473349	1,583010921	9,583010921
101325	201325	2	406,5984	133,4484	1,725323279	0,016908168	1,013	113,4484332	1,94314185	2,182385905	10,18238591
101325	226325	2,25	429,9196	156,7696	1,834356689	0,017976696	1,017	136,7695716	2,500462253	2,808324867	10,80832487
101325	251325	2,5	451,927	178,777	1,937786099	0,018990304	1,022	158,7770431	3,081559215	3,460967812	11,46096781
101325	276325	2,75	472,8155	199,6655	2,036418106	0,019956897	1,026	179,6654985	3,678790642	4,131731733	12,13173173
101325	301325	3	492,736	219,586	2,130881702	0,020882641	1,029	199,5860075	4,288751482	4,816792343	12,81679234
101325	326325	3,25	511,8086	238,6586	2,221678729	0,021772452	1,31	218,658583	6,236560759	7,004420338	15,00442034
101325	351325	3,5	530,1304	256,9804	2,309217266	0,022630329	1,034	236,9804301	5,545285284	6,228033451	14,22803345
101325	376325	3,75	547,7816	274,6316	2,393834506	0,023459578	1,04	254,6315776	6,212491373	6,977387475	14,97738747
101325	401325	4	564,8288	291,6788	2,475812923	0,024262967	1,047	271,6788405	6,901546173	7,751280273	15,75128027
101325	426325	4,25	581,3287	308,1787	2,555391969	0,025042841	1,049	288,1786808	7,570436806	8,502526245	16,50252625
101325	451325	4,5	597,3293	324,1793	2,632776751	0,025801212	1,051	304,1793186	8,248453086	9,264021436	17,26402144
101325	476325	4,75	612,8723	339,7223	2,708144563	0,026539817	1,053	319,7223206	8,935096493	10,03520594	18,03520594
101325	501325	5	627,9938	354,8438	2,781649912	0,027260169	1,055	334,8438159	9,629933504	10,81559287	18,81559287
101325	526325	5,25	642,7254	369,5754	2,853428427	0,027963599	1,059	349,5754405	10,35213514	11,62671363	19,62671363
101325	551325	5,5	657,0951	383,9451	2,923599944	0,028651279	1,063	363,9450812	11,08442424	12,44916382	20,44916382
101325	576325	5,75	671,1275	397,9775	2,992270974	0,029324256	1,068	377,9774682	11,8376136	13,29508758	21,29508758
101325	601325	6	684,8447	411,6947	3,059536691	0,02998346	1,07	391,6946528	12,56646604	14,11367799	22,11367799
101325	626325	6,25	698,2664	425,1164	3,125482562	0,030629729	1,072	405,1163956	13,30202505	14,9398007	22,9398007

Konklusjon		
Diameter [mm]	15	
lengde [m]	6,7	
Korreksjonsfaktor	1,8	
totallengde [m]	12	kjøper 13 meter. Ein meter å forske på med bøyradius.
tot pris	1011,602	

		Pris per meter
rør diameter [	0,01	50
rør diameter [	0,012	64,5
rør diameter [	0,015	84,5

Delta T(A)	**Delta T(B)**	**LMTD**	**Uu [W/m^2*K]**	**Au [m^2]**	**Lengde røyr d=0,01 [m]**	**L/3**	**Pris [kr]**	**Lengde på kjølar**	**Lenge røyr d=0,012 [m]**	**L/3**	**Pris [kr]**	**Lengde på kjølar**	**Lenge røyr d=0,**	**L/3**	**Pris [kr]**
43,99342514	12	24,62674	200	0,087793733	2,8	0,9	139,7		2,3	0,8	150,2		1,9	0,6	157,4
72,7174128	12	33,70055	200	0,134570433	4,3	1,4	214,2		3,6	1,2	230,2		2,9	1,0	241,3
98,97252553	12	41,22046	200	0,170967673	5,4	1,8	272,1		4,5	1,5	292,5		3,6	1,2	306,6
123,2660473	12	47,76518	200	0,203405678	6,5	2,2	323,7		5,4	1,8	348,0		4,3	1,4	364,7
145,9612467	12	53,61807	200	0,233173448	7,4	2,5	371,1		6,2	2,1	398,9		4,9	1,6	418,1
167,3160753	12	58,94397	200	0,26139731	8,3	2,8	416,0		6,9	2,3	447,2		5,5	1,8	468,7
187,5337668	12	63,85247	200	0,288069582	9,2	3,1	458,5		7,6	2,5	492,9		6,1	2,0	516,6
206,7692152	12	68,41938	200	0,313416428	10,0	3,3	498,8		8,3	2,8	536,2		6,7	2,2	562,0
223,6541627	12	72,35559	200	0,430966056	13,7	4,6	685,9		11,4	3,8	737,3		9,1	3,0	772,8
242,7523967	12	76,73496	200	0,361327196	11,5	3,8	575,1		9,6	3,2	618,2		7,7	2,6	647,9
259,6541901	12	80,55251	200	0,385617485	12,3	4,1	613,7		10,2	3,4	659,8		8,2	2,7	691,5
275,9275602	12	84,1812	200	0,409922072	13,0	4,3	652,4		10,9	3,6	701,3		8,7	2,9	735,0
291,6761546	12	87,65251	200	0,431843688	13,7	4,6	687,3		11,5	3,8	738,8		9,2	3,1	774,4
306,9152972	12	90,97648	200	0,453328858	14,4	4,8	721,5		12,0	4,0	775,6		9,6	3,2	812,9
321,6871147	12	94,16781	200	0,474424133	15,1	5,0	755,1		12,6	4,2	811,7		10,1	3,4	850,7
336,028223	12	97,23895	200	0,495168544	15,8	5,3	788,1		13,1	4,4	847,2		10,5	3,5	887,9
349,9487269	12	100,1959	200	0,516594779	16,4	5,5	822,2		13,7	4,6	883,9		11,0	3,7	926,3
363,4959174	12	103,0519	200	0,537807597	17,1	5,7	855,9		14,3	4,8	920,1		11,4	3,8	964,4
376,6823807	12	105,8125	200	0,559367362	17,8	5,9	890,3		14,8	4,9	957,0		11,9	4,0	1003,0
389,5809748	12	108,4951	200	0,579125795	18,4	6,1	921,7		15,4	5,1	990,8		12,3	4,1	1038,5
402,1765949	12	111,0986	200	0,598658507	19,1	6,4	952,8		15,9	5,3	1024,3		12,7	4,2	1073,5

Constants		Unit
M	29	kg/kmol
R	8.314	J/K*mol
T	293	K
v	5	m/s
A	0.00196	m^2
q	0.0098	m^3/s
rho water	1000	kg/m^3
V separator	0.09676890771	m^3
V pipes	0.02042820623	m^3
V total	0.1171971139	m^3

$$\rho_{sc} = \frac{p_{sc} M}{R T_{a,sc}}$$

$$\dot{m}_{in} = \dot{q}_{in} \rho_{a,sc}$$

Density of air at 4 barg and 191 degrees		
3043.246487		
Flow	**1.789428934**	kg/min
	3.936743656	lb/min

Water volume in system

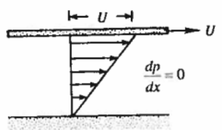
Water percenta	Volume with se	Volume without separation [l]
2%	2.343942279	0.196
3%	3.515913418	0.294
5%	5.859855697	0.49
10%	11.71971139	0.98
15%	17.57956709	1.47
20%	23.43942279	1.96

Dry air

Air pressure in (Pa)	Density(g/m^3)	Density (kg/m^3)	Mass flow(kg/min)	Mass flow (lb/min)
101325	1204.834787	1.204834787	0.7084428546	1.55857428
202650	2409.669573	2.409669573	1.416885709	3.11714856
303975	3614.50436	3.61450436	2.125328564	4.67572284
405300	4819.339147	4.819339147	2.833771418	6.23429712

Water

Water fraction in syste	Water flow (m^3/s)	Water mass flow(kg/min	Water mass flow(lb/min)	101325	202650	303975	405300
2%	0.000098	5.88	12.936	14.46340279	18.1312476	20.7288714	23.3264952
3%	0.000147	8.82	19.404	20.91581705	24.54623487	27.1173523	29.68846974
5%	0.000245	14.7	32.34	33.82064557	37.37620941	39.89431411	42.41241882
10%	0.00049	29.4	64.68	66.08271685	69.45114576	71.83671863	74.22229151
15%	0.000735	44.1	97.02	98.34478814	101.5260821	103.7791232	106.0321642
20%	0.00098	58.8	129.36	130.6068594	133.6010184	135.7215277	137.8420369



(c) Plane Couette flow

Figure 9.4 Various cases of parallel flow in a channel.

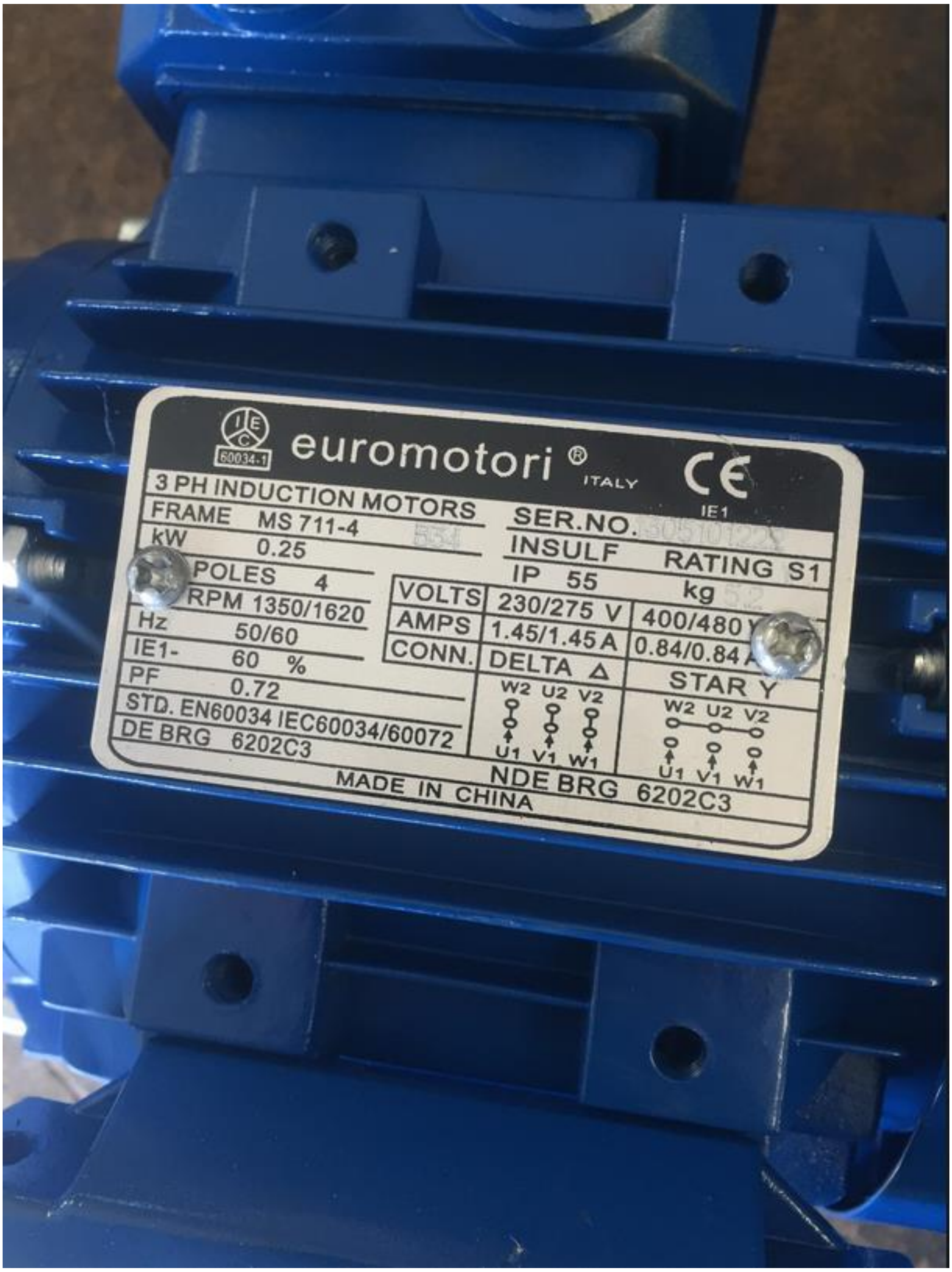
so that the average velocity is

Appendix D – Nameplates for the electrical motors

Nameplate for 4000kW induction motor for piston compressor

Nameplate for 373W induction motor for water pump

Nameplate for 250W induction motor for oil pump



euromotori ® ITALY

3 PH INDUCTION MOTORS

FRAME MS 711-4 554

kW 0.25

POLES 4

RPM 1350/1620

Hz 50/60

IE1- 60 %

PF 0.72

STD. EN60034 IEC60034/60072

DE BRG 6202C3

SER.NO. 130510122[illegible]

INSULF

RATING S1

IP 55

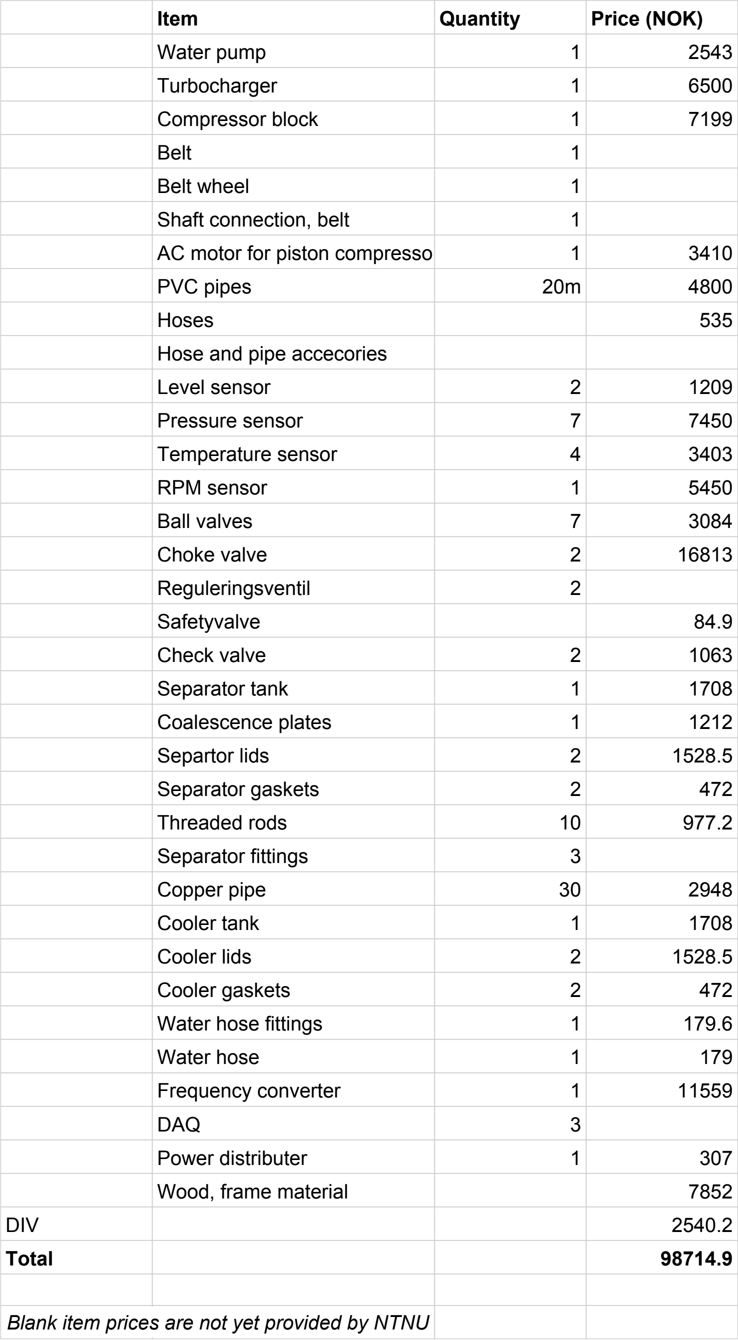
kg 5.2

VOLTS	230/275 V	400/480 V
AMPS	1.45/1.45 A	0.84/0.84 A
CONN.	DELTA Δ	STAR Y

NDE BRG 6202C3

MADE IN CHINA

Appendix E – Laboratory expenses



	Item	Quantity	Price (NOK)
	Water pump	1	2543
	Turbocharger	1	6500
	Compressor block	1	7199
	Belt	1	
	Belt wheel	1	
	Shaft connection, belt	1	
	AC motor for piston compresso	1	3410
	PVC pipes	20m	4800
	Hoses		535
	Hose and pipe accecories		
	Level sensor	2	1209
	Pressure sensor	7	7450
	Temperature sensor	4	3403
	RPM sensor	1	5450
	Ball valves	7	3084
	Choke valve	2	16813
	Reguleringsventil	2	
	Safetyvalve		84.9
	Check valve	2	1063
	Separator tank	1	1708
	Coalescence plates	1	1212
	Separtor lids	2	1528.5
	Separator gaskets	2	472
	Threaded rods	10	977.2
	Separator fittings	3	
	Copper pipe	30	2948
	Cooler tank	1	1708
	Cooler lids	2	1528.5
	Cooler gaskets	2	472
	Water hose fittings	1	179.6
	Water hose	1	179
	Frequency converter	1	11559
	DAQ	3	
	Power distributer	1	307
	Wood, frame material		7852
DIV			2540.2
Total			**98714.9**
Blank item prices are not yet provided by NTNU			

Vare	Leverandør	Stk pris	Antall	Rabatt	Pris	Artikkelnr
Power socket 400V for inlet (32A)	Ahlsell		1			
Power plug 400V for oil pump (16A)	Ahlsell		1			
Power soket 400V for oil pump (16A)	Ahlsell		1			
Power socket 230V for water pump (16A)	Ahlsell		1			
Power plug for 230V water pump (16A)	Ahlsell		2			
Power socket 230V for extra equipment	Ahlsell		2			
Merking/klistermerker for rekkeklemmer	Ahlsell		package			
Cable ties	Ahlsell		package			
Earth terminal rail	Ahlsell		1			
Kabelmuffe M16 x 1.5 4. . .8 mm 8 mm Polyamid grå, RAL 7035 IP 68	Elfa	6,58	3		19,74	155-01-226
Kabelmuffe M20 x 1.5 6. . .12 mm 9 mm Polyamid grå, RAL 7035 IP 6	Elfa	8,09	3		24,27	155-01-234
Kabelmuffe M25 x 1.5 13. . .18 mm 9 mm Polyamid grå, RAL 7035 IP	Elfa	12,4	2		24,8	155-01-242
Endeklemme, uten skrue, 0249-0116, Wago	Elfa	6,04	4		24,16	14829999
Rekkeklemme Blå 0.25. . .1.5 mm², 2001-1204, Wago	Elfa	6,90	4		27,6	14829810
Endeplate;oransje, 2002-1292, Wago	Elfa	4,10	8		32,8	14829816
DC-aksialvifte 60 x 60 x 25 mm 24 VDC, MB60252V1-000U-A99, Sunc	Elfa	83,10	1		83,1	15413494
Sokkelterminal 5P, 222-415, Wago	Elfa	7,22	8		57,76	136-50-082
Sokkelterminal 3P, 222-413, Wago	Elfa	4,74	4		18,96	136-50-074
Betjeningsverktøy, type 2, 3,5x0,5mm, 0210-0720, Wago	Elfa	60,8	1		60,8	180-29-162
Sikring 5 x 20 mm: 3.15 A fast-blow, RND 170-00003, RND Componer	Elfa	2,53	10		25,3	300-43-423
Sikring 5 x 20 mm: 3.15 A slow-blow, RND 170-00008, RND Compone	Elfa	3,17	10		31,7	300-43-428
Merkingsliste for rekkeklemme, uten påskrift ST1.5, ST1.5 BU, ST1.5-	Elfa	6,68	1		6,68	148-28-063
Sikring 5 x 20 mm: 630 mA fast-blow, RND 170-00023, RND Compone	Elfa	3,15	10		31,5	300-43-443
Automatvekslende strømforsyning 100 W 1 utgang, RS-100-12, Mean Well	Elfa	246	1		246	16905923
Hovudkurs (11kW - 400VAC - trefase)						
CIRCUIT BREAKER 400V 10KA, 3-POLE, C, 25A, D=70MM	Siemens	542,00	1	0,333	180,486	1642517
CONTACTOR, AC-3, 11KW/400V, 1NO+1NC, DC 24V, 3-POLE **(25A)**	Siemens	1350,00	1	0,333	449,55	4161764
Vannpumpekurs (373W - 3,5A - 230VAC - einfase)				0,333	0	
Kortsluttingsvern/motorvern 2.8A - 4A	Siemens	751,00	1	0,333	250,083	4331214
Kontaktor 3KW/400V, 1NO, DC 24V	Siemens	401,00	1	0,333	133,533	4161708
Oljepumpekurs (ca. 400W - 4A - 230VAC - trefase)				0,333	0	

Motorvernbryter 0.7 - 1A	Siemens	679,00	1	0,333	226,107	4330876
Tilleggskurs				0,333	0	
CIRCUIT BREAKER 400V 10KA, 2-POLE, C, 13A, D=70MM	Siemens	401,00	1	0,333	133,533	1642495
Betjeningsmateriell				0,333	0	
Grønn alarmlampe 24VDC	Siemens	159,00	4	0,333	211,788	4331639
Grønn alarmlampe 230VAC	Siemens	225,00	1	0,333	74,925	4314390
Raud alarmlampe 24VDC	Siemens	159,00	1	0,333	52,947	4331637
Nødstoppaktuator	Siemens	239,00	1	0,333	79,587	4314436
Holder - Nødstoppaktuator	Siemens	21,30	1	0,333	7,0929	4333086
NC Kontaktmodul til nødstoppbryter	Siemens	66,70	1	0,333	22,2111	4333150
Div				0,333	0	
NO-modul til korstluttingsvernet 3RV2011-1EA20	Siemens	115,00	1	0,333	38,295	4331011
Linkmodul mellom motorverbrytar 3RV2011-1EA20 og kontaktor 3R	Siemens	73,00	1	0,333	24,309	4160474
Passende dreiebryter (S1)	Siemens	193,00	2	0,333	128,538	4314309
Passende dørbryter (S2)	Siemens	243,00	1	0,333	80,919	
Kabelmuffe M16 x 1.5 4. . .8 mm 8 mm Polyamid grå, RAL 7035 IP 68	Elfa	6,58	3		19,74	155-01-226
Kabelmuffe M20 x 1.5 6. . .12 mm 9 mm Polyamid grå, RAL 7035 IP 6	Elfa	8,09	3		24,27	155-01-234
Kabelmuffe M25 x 1.5 13. . .18 mm 9 mm Polyamid grå, RAL 7035 IP	Elfa	12,4	2		24,8	155-01-242
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Sokkelterminal 3P, 222-413, Wago	Elfa	4,74	4		18,96	136-50-074
Betjeningsverktøy, type 2, 3,5x0,5mm, 0210-0720, Wago	Elfa	60,8	1		60,8	180-29-162
Sikring 5 x 20 mm: 3.15 A fast-blow, RND 170-00003, RND Componer	Elfa	2,53	10		25,3	300-43-423
Sikring 5 x 20 mm: 3.15 A slow-blow, RND 170-00008, RND Compone	Elfa	3,17	10		31,7	300-43-428
Merkingsliste for rekkeklemme, uten påskrift ST1.5, ST1.5 BU, ST1.5-	Elfa	6,68	1		6,68	148-28-063
Sikring 5 x 20 mm: 630 mA fast-blow, RND 170-00023, RND Compone	Elfa	3,15	10		31,5	300-43-443
SUM					**3278,244**	