Kungliga Tekniska Högskolan

MF2058 Mechatronics Advanced Course

Spring Report

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# Electronically Vacuum Regulated Shut-off Valve for Milking System

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May 23, 2022

# Abstract

This report was written for a capstone project for the Engineering Design, Mechatronics track, which is an assessment for the Spring semester component of the project, MF2058. The project will continue into its next phase in the Autumn semester in MF2059. Apart from being a course project, it is also a collaboration project with DeLaval Holding AB. DeLaval is a producer of dairy and farming machinery in over 100 countries all over the world and is a market-leading company in milking systems. Hand milking techniques have been widely used for thousands of years, but the first milking machine was invented around 150 years ago, so there are still a lot of problems needed to be solved. In this report, the general introduction related project, e.g. background, requirements, organization was included and a state of the art assessment of similar applications in controlling different valves of liquid flow was explored, as well as the potential applications in milking system. Then, the previous and current regulating methods, mechanised or not, were used for reference and insight to the research problem and to provide a new solution: an electronically vacuum regulated shut-off valve for milking system. Construction of test rig will start in September of 2022 and integrated system testing will begin in early October and planned to finalize the design be the end of November.

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# Chapter 1.

# Introduction

This project is a part of the course MF2058 given by KTH. Students are divided into groups of 8 people, tasked to solve a mechatronics' project from a stakeholder. In this chapter, the background and purpose of the project are presented as well as the established requirements given by the stakeholder and the project group´s organization.

## 1.1. Background

The main motivation for the development of machine milking was to increase the efficiency of milk production and to reduce labour requirements on dairy farms[1]. The development of milking machines started in the late 19th century[2]. Over many years exploration, the two chambered teat cup with cyclic opening and closure of a rubber liner was examined to be the best solution for machine milking[3]. The system allows the pressure (vacuum) to be changed periodically in the chamber. Around the liner is a so-called pulsation system that opens the teat cup liner to allow the milk to flow and then closes the liner around the teat again to massage the tissue and reduce congestion[4]. Vacuum is pressure below atmospheric pressure. Sometimes the term ”negative pressure” is used[5], but in milking machine measurement, a “vacuum” is any pressure below atmospheric pressure, specified as the reduction below ambient atmospheric pressure [6]. Another vacuum pump extracting air continuously from the milking machine system maintains a vacuum which allows the milk transported to the milk line[5]. The performance of the vacuum pump is assessed by measuring the quantity of air flow produced[7], so that the air flow should be standardized to make sure the test environment more accurate and milking process smoother.

Moreover, it is also possible to implement a device in vacuum system to regulate the vacuum and control the vacuum in milk to have a better milking performance. The typical vacuum regulators can allow excess air to enter the milking machine or continually remove the extra air that the milking machine does not require, or may control the capacity of the pump or, when the pump has a variable volume[8]. To achieve this function in vacuum system, the sensing techniques are essential and some technicians[9, 10, 11] have already implemented a vacuum gauge to investigate the vacuum, which was been possible to regulate the air flow in vacuum system based on the readings from vacuum gauge.

However, there is still a vacuum drop beneath the teat[12], even though the vacuum produced from vacuum system is steady. In absence of milk flow, the vacuum in the cluster is close to the full system vacuum level, whereas it drops significantly as soon as milk is present and transported in the milk tubes[13]. An accumulation of milk in the cluster and milk tubes, which needs to be transported through the system by the milk line vacuum, affects the free airflow and leads to the decrease of the vacuum beneath the teat, showing some significant changes in vacuum and the changes have been defined as either vacuum drops or vacuum fluctuations[14]. Fluctuations and drops in the teat-end vacuum occur regularly during machine milking as a result of various interactions between vacuum supply, teatcup liner movement and milk flow[15]. Milk flow dependent vacuum drops cannot completely be avoided with the currently available milking systems[16], because the milk tube is responsible for both, vacuum provision on the teat and transport of the removed milk.

Furthermore, a general drop of the vacuum level during the milking process occurs as soon as the milk flow rate increases[17]. It depends on the milk flow rate, and the characteristics of the milking system such as component size and line height[18]. However, no scientific evidence is available that vacuum drops should be completely avoided as long as the remaining vacuum is high enough to close the liner adequately, but there were researches demonstrated that the minimum cluster vacuum had the main influence on milking performance independent of the level of the system vacuum and related vacuum drops[1, 17]. There is an inverse relationship between milk flow rate and cluster vacuum with the highest cluster vacuum occurring at the lowest milk flow rate. Teat tissue stress is therefore most severe during the low flow period of milking when the teat-end vacuum level is the highest, approaching the system vacuum[19], which may not only reduce milking performance through reduced efficiency of milk removal[20] but can also compromise the teat condition and hence a reduced massage effect of the closed liner on the teat[16]. To overcome these, it is considerable to use a control strategy to regulate the vacuum in the milk line and one of research groups have shown a significant improvement on the concept[21] but the design is rather simple and mechanically controlled.

Therefore, it is favorable to apply a dynamic control strategy to adjust machine settings during milking of an individual animal, and this project intends to adjust the shut-off valve on the milk line to be electrically controlled to regulate the vacuum in the milk line. This project shall initially focus on designing an alternative shut-off valve that is electronically regulated by having a vacuum sensor in the milk system and the purpose of having a new shut-off valve that is electronically regulated is to regulate and compensate for the vacuum drop at the milking cluster. However, the control of the regulation system is also a large concern, so that the auxiliary purpose is to design a full system with proper control techniques to regulate the vacuum.

## 1.2. Scope

As this is a Mechatronics master's project at KTH with a time limit of approximately six months the team is limited to focusing on these points:

- Construction of rig for testing of possible problem solutions.
- Testing of different type of valves.
- Testing the best position for feedback sensor.

- Design of controller to stabilize the vacuum and counter the decrease of vacuum in correlation of milk flow.

The solution is suppose to be applicable to the existing milking systems that DeLaval offer to their customers, and therefor needs to be modular and cheap to achieve the requirements.

## 1.3. Requirements

In this section, detailed lists of Stakeholder Requirements (SR) and Technical Requirements (TR) are provided. The stakeholders of the project are DeLaval Holding AB.

1. **SR 1** A new shut-off valve shall be designed while considering food contact regulations and the vacuum drop over the shut-off valve shall be less than 1 kPa at 10 L/min with fully open valve.
2. **SR 2** The requirements regarding vacuum regulation concern the Low line configuration
3. **SR 3** Impose an upper limit on system vacuum
    - **TR 1** Max 55 kPa
4. **SR 4** The unwanted vacuum drop caused by milk flow shall be reduced/eliminated using sensor feedback to the new shut-off valve
    - **TR 2** At flow 0 L/min–10 L/min and a reference value between 30 kPa–50 kPa at the cluster, the vacuum variation must be less than ±1 kPa
    - **TR 3** At flow 10 L/min–14 L/min and a reference value between 30 kPa–50 kPa at the cluster, the vacuum variation must be less than ±2 kPa
5. **SR 5** The positioning of sensors and other electronics shall not limit/affect the serviceability of equipment
    - **TR 4** The design should be modular (interchangeable parts)
    - **TR 5** The design should be robust enough to withstand water, dirt, etc.
6. **SR 6** All newly designed equipment that shall be used in the system must fulfill food contact regulations (**ISO-standard 5707:2007**[7])
    - All components that are subjected to a vacuum shall be designed and constructed to withstand a minimum vacuum of 90 kPa without permanent distortion.
    - Materials that may involve danger if damaged, such as glass, shall be designed using a safety factor of 5 against external pressure (i.e. $5 * 90$ kPa).

- Materials in contact with milk shall meet requirements for food contact surfaces. All materials in contact with milk or cleaning solutions, whether used for rigid components or flexible components shall be constructed to withstand the maximum temperature used in the plant as specified in the user's manual. In addition, such materials, when used in accordance with the recommendations in the user's manual, shall not impart taint to the milk.
- All milk contact surfaces shall be free from engraving or embossing. All metal milk contact surfaces, except for welded seams, shall have a surface roughness, Ra, less than or equal to 2.5 µm when tested in accordance with ISO 4288. Surface roughness, Ra, on welded seams shall not exceed 16 µm.
- Copper or copper alloys shall not be used in any part of the installation that may come into contact with milk or cleaning and disinfecting fluids other than water. Materials that come into contact with cleaning and disinfecting fluids at concentrations of normal use shall be suitable for such contact.
- Materials that also come into contact with milk shall be resistant to both milk fat and cleaning and disinfecting solutions.

7. **SR 7** The vacuum regulation must be tested and pass at least one edge case.
    - **TR 6** Fall off/kick-off - the whole cluster falls of the teats. Stop vacuum.
    - **TR 7** Slip - the teat cups have some miss alignment with the teats which causes some air leak. Control vacuum so the teat cups get aligned correctly again.
    - **TR 8** Start of milking - during start of milking a temporary air inlet is created. The amount and duration are dependent of the skills of the milker, the vacuum control must handle this case.
8. **SR 8** A test rig must be built so the students can perform tests at KTH and not be dependent on being at DeLaval during the test process.

## 1.4. Project Organization

The project group consists of eight members. During the spring semester the structure of the team has for the most part been as a single unit with minor deviations. To make sure everyone has a good understanding of the project, the group had a lot of meetings with the agenda of discussing the problem and possible solutions. During research, the team was divided into smaller groups to find papers on the research topics, and during meetings the members informed the rest of the team of their findings. Different responsibilities were also assigned in the beginning, for example, when conducting meetings, some were responsible for meeting agenda, some for meeting minutes, some for meeting invitation and organization. The project leader for this semester has been Samuel Stenow and this role will rotate for the fall. Other roles, such as documentation responsible and secretary has been rotating between members the entire spring semester.

# Chapter 2.

# State of The Art

In this chapter all the relevant background and information needed to understand the project are presented. The state of the art is then acting as the foundation for the choice of Design Concept in the next chapter.

## 2.1. Current Milking System

The current design of the milking system from DeLaval is composed of milk cluster, milk meter (flow meter), pulsator and a pneumatic diaphragm valve. The milking cluster is attached to the teats of the cow and it is connected via a milk tube to a milk meter followed by a mechanical shut-off valve and then the main milk line.

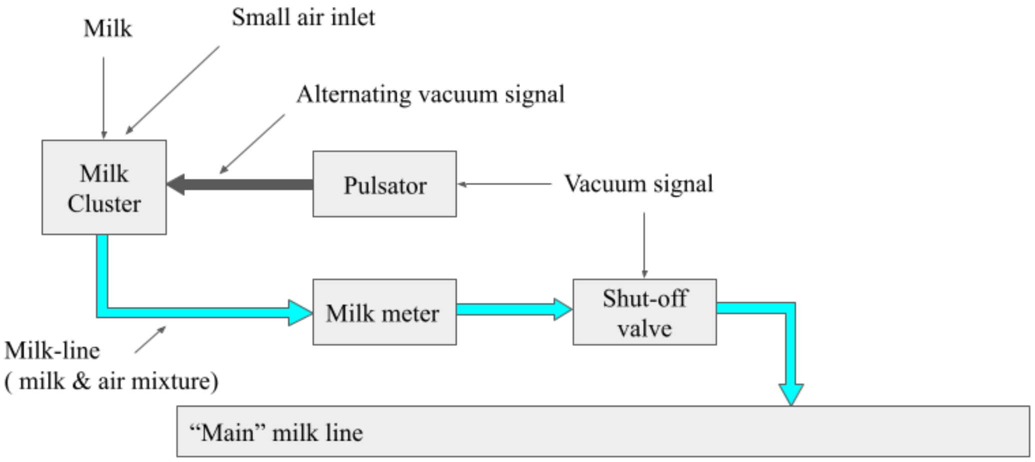


Figure 2.1.: Current design of the system, designed using Power Point

A vacuum is applied to the teats. To simulate the calf suckling, a pulsator is used. In combination with this, a small air inlet on the cluster allows milk to flow. The valve regulating milkflow is controlled using the pressure difference between the milk line and a control vacuum, opening and closing to regulate the pressure. Then, the milk is allowed to continue to a collection point. The method of driving the pulsator can vary. Pneumatics and electronics are some examples, but the functionality is the same: To provide a pulsating vacuum to the inflator of the teat cup, simulating calf suckling on the teats.

## 2.2. Competitive Technologies

In the food-, pharmaceutical- and chemical industry it is desirable to separate the flowing media from the internal mechanisms of the valve, as it could potentially trap contaminants. To avoid the dead volume and small chambers in the internal mechanics of valves, a solution is the pinch valve. The pinch valve features an internal sleeve that keeps the flow media completely protected from contaminants.

In the same industries, the diaphragm valve can be found with similar applications. A diaphragm valve has a membrane pressed or sucked down upon a surface to stop the flow. It features some geometrical disturbances but is less flow disruptive than solenoid valves. The wide selection of materials of the internal tube and membrane makes the valve customizable, which is why they can be adapted to a variety of industries depending on the material needs. When selecting sleeve and membrane materials, durability needs to be considered as well as food contact regulations. Each closing and opening cycle puts strain on the material but in abrasive and corrosive applications they often outlast alloy metal valves[22].

A pinch valve with a larger clamping area would reduce the plastic deformation and increase the durability of the valve[23]. In water and waste treatment industries, the pinch valve handles several different media containing sludge, grit, and garbage. This suggests that with proper dimensions and sleeve material the valve will be able to handle the lumps in the milk. This is mainly due to the smooth surface without obstructing pockets. Both valves can be designed proportionally, meaning that the valves can be partially open to have further control of the flow through the valves. The valves can be actuated with both vacuum signals and solenoids.

In the automotive industry, proportional valves are used for controlling the air intake to cars. The conventional way of controlling the valves is using pulse width modulation (PWM)[24]. The method must be analyzed further to determine the energy consumption. In a similar application, a pinch valve was used to regulate the air pressure in a sprayer valve. The sprayer valve was used in an agricultural watering system. The system was modeled as a linear system and initially controlled with a reduced-order observer model. However, the controller achieved a better control performance with a proportional-integral controller[25]. The research shows that a pinch valve could be a feasible alternative to use in the milking system.

## 2.3. Valve

The valve currently used for controlling is a shut-off valve, which is an ON/OFF valve. An ON/OFF valve is the fluid equivalent to an electrical switch, a device that either allows unimpeded flow or acts to prevents flow altogether. These valves are often used for routing process fluid to different locations, starting and stopping batch processes, and engaging automated safety (shutdown) functions. With this binary feature, the actuator is required to respond very quickly so as to create an equivalent effect to PWM control, reducing the average power delivered by an electrical signal. By effectively chopping the signal into discrete parts, the regulated flow becomes as smooth and accurate as required.

However, liquid is not an ideal medium for PWM implementation compared to electricity. Some state of the art valves and mechanisms are presented below.

### Globe Valve

Globe valves work by lifting a plug out of the flow path. As the globe valve is fully opened, it barely restricts the flow of fluid along the pipe axis. It is most commonly (to provide pressure on the sealing surface) when the gate faces are parallel.

While being superior in terms of control and precision, downsides exist in this solution: There are dead volumes located both at the bottom of the duct and the gap between the control rod and the wall, see Figure 2.2, which thus make it hard to clean after use and does not comply with food contact regulations [7].

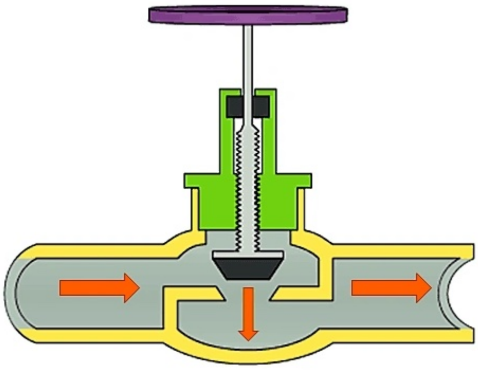


Figure 2.2.: Globe valve

### Solenoid Actuator

A solenoid actuator is an electrically controlled actuator. The actuator features a solenoid, which is an electric coil with a movable ferromagnetic core (plunger) in its center. In the rest position, the plunger closes off a small orifice. An electric current through the coil creates a magnetic field. The magnetic field exerts an upwards force on the plunger opening the orifice proportionally to the input.

### Pinch Valve

Pinch valves are usually pneumatically actuated but there are variations where the valve is actuated by a solenoid. It utilizes pressurized air to open and close the valve, which can be seen in picture 2.3. In the open position, the valve has no restrictions and allows a wide range of media to pass through the valve. The flexible internal food safe rubber sleeve in the valve keeps the media isolated preventing the risk of contamination. [26]

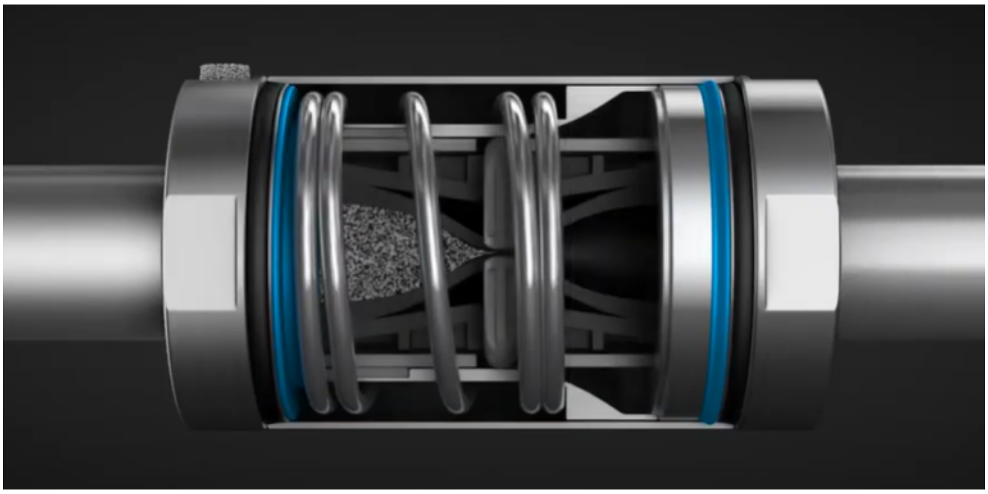


Figure 2.3.: Pneumatic pinch valve [26]

### Diaphragm Valve

The diaphragm of the valve is a flexible pressure-responsive part. This part delivers force to regulate, shut, or open the valve. This type of valve is very similar to a pinch valve, but it uses an elastic membrane instead of a flexible liner to isolate the fluid flow from the closure part. The valve can be actuated by either air pressure or a solenoid.

## 2.4. Sensors

There are two different types of sensors to be used in this project. A ceramic pressure sensor to read the vacuum level in the system and a flow meter to get readings on the flow of water through the system. The Metallux pressure sensor will be moved around in the system to get a picture of how the pressure changes throughout the system in relation to the pressure at the teat.

The ceramic pressure sensor that will be used is from Metallux, see Appendix A.2. It collects readings from the reactive movement of the membrane inside of the housing and converts it to electric signal following the piezoresistive principle. In this case it will react to the vacuum which originates from the difference between the atmospheric pressure and the pressure in the milk line. This specific sensor is applicable to the food industry, because the flush-front diaphragms makes for easy cleaning, which is an important requirement for sensors used in the food industry.

A different sensor used in the industry is the milk meter, it is used in the current system to measure the condition off the milk using infrared technology, see Appendix A.3. This helps the farmer to monitor the herds health and milk production. This type of sensor will not be utilized in the scope of this project for two reasons. Because of the infrared technology, the sensor only works with milk and not water, which will be used in the test rig. The milk condition data it collects is also of no use when it comes to regulating the vacuum level in the system. It will however be a part of the test rig, in order to simulate the vacuum drop it generates.

The flow meter would be absent in a commercial design, but is present in the test rig in order to measure the performance of the control system and how the flow affects the vacuum levels. This will be positioned on the milk line.

## 2.5. Controller

The successful implementation of control valves within hydraulic systems in the chemical industry[27] gives an indication of the applicability of control in the context of automated milking systems. In the chemical process industry, extreme precision is required compared to the type of control needed for automated milking due to the impact it has on the final product. Hence, it becomes trivial that implementing a controller in automated milking machine systems is of great interest, as it has not been done in state of the art systems as of 2021 [21].

## 2.6. Test Rig Design

DeLaval's test rig will be replicated at KTH in order to be able to test proposed design concepts without being dependent on DeLaval. This is also a requirement from the stakeholders, see stakeholder requirement 8. As quite a lot of research groups[28, 29] have deployed mechanical cows in laboratory to simulate the milking behavior successfully, it is possible for us to build a test rig representing the mechanical cow in our lab. The test rig is used to simulate the milk flow at different flow rates. For practical reasons the test rig will use water instead of milk as the characteristics of the liquids are similar enough for the scope of the project. A conceptual drawing of the test rig can be seen from figure A.1 in Appendix A.

Water is supplied to the system from the starting tank which is sucked by the vacuum pressure in the milk line. The vacuum is generated by a vacuum generator powered by pressurized air. The water is sucked into the cluster. The cups of the cluster are connected to the vacuum source via a pulsator which generates a massaging motion on the cups. The water continues to flow through a milk meter and a flow meter before it reaches the valve and finally an end water tank. Between each disruptive equipment in the system, vacuum sensors are placed to monitor the pressure drop over each component. The sensor marked in red is the sensor planned to be used as a controller reference. The water is re-circulated to the start tank with a water pump.

# Chapter 3.

# Concept Evaluation

This project is based on the milk line from DeLaval and the proposed design concept should address the issues in the existing systems of their production line. Therefore, the new concept should be designed to eliminate the vacuum drop in the milkline or at least mitigate the disturbance. In this chapter, several concepts of the solution to vacuum drops are discussed and evaluated.

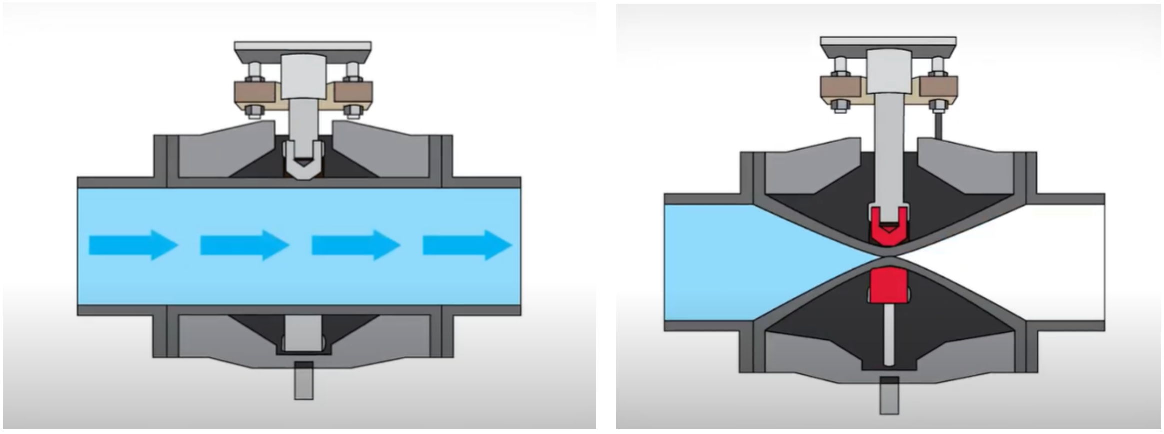
The selection of a valve for the system is limited by the requirements put forward by the stakeholders. Stakeholder requirement 6 states that all newly designed equipment used in the system must fulfill food contact regulations. The food contact regulations taken into consideration are the ISO-standard 5707:2007.

In practice, this means that the valve must ensure adequate volume for circulation. Therefore, the selected valve should not have small chambers or internal parts which could trap milk. Additionally, the material in contact with the milk must be food-safe and resistant to milk fat and disinfectant. There are also restrictions on the material's surface roughness and durability to temperature and pressure.

## 3.1. Design 1 (Pinch Valve)

Pinch valves are generally used for viscous and lumpy fluids [30], it might therefore not work as desired with milk as a medium. Pinch valves are however commonly found in the food-industry. As shown in figure 3.1, only the sleeve itself will be in contact with the flow medium and thus circumvent many potential problems with food-contact regulation. Another benefit of this solution is that the pressure drop over the valve is low due to the fact that the flow is completely unimpeded when the valve is completely open.

Although there are some commercially available pinch valves that can be controlled using either vacuum or electronics, there are some concerns regarding the price of food-safe versions. The alternatives that the group has found thus far either fail to specify price, and are therefore assumed to be expensive, or simply are expensive. No budget has been specified, but the consensus is that the price should be moderate. Therefore, constructing a custom pinch valve might be necessary in order to both have food-safe materials and the sought-after ability to control, i.e. using a proportional solenoid to regulate the flow by clamping the tube.



(a) Actuator released, valve open (b) Actuator applied, valve closed

Figure 3.1.: Pinch Valve

## 3.2. Design 2 (Solenoid Diaphragm Hybrid)

As described in section 2.1, the current commercially used valve is a diaphragm valve. The valve is opened and closed using a vacuum signal that pulls the membrane away from the opening, allowing fluid to flow through the valve. This signal is slow and can be hard to control accurately enough for a regulator to be effective. The idea of a solenoid diaphragm hybrid valve is to combine an electronically controlled proportional solenoid with the already existing diaphragm valve and use the solenoid instead of a vacuum source for actuation of the diaphragm, see Figure 3.2. The benefits of using a solenoid is primarily the actuation speed and retraction precision. Using a regular solenoid valve without the food safe property of the diaphragm valve is not suitable for this type of application. The commonly used solenoid valves have confined spaces for sand and dirt to get stuck, and are consequently more difficult to clean. In this hybrid alternative, the membrane that separates the solenoid piston from the milk maintains the food-safe quality of the diaphragm valve commercially in use today. The major problem with this design is that the piston needs to be attached to the membrane in order to be able to actuate the valve. As an initial concept validation for this type of valve, the piston will be glued to the membrane.

Another possible solenoid/diaphragm hybrid solution is to use the solenoid for a controlled inlet of air. By making an inlet on top of the valve and letting the piston of the solenoid seal/open the inlet, the inflow of air could be controlled. By applying a constant vacuum and letting the solenoid control the effect of the vacuum on the membrane, this could result in a faster on/off function of the valve. However, this solution possesses the same binary actuation characteristic as are sought to be decommissioned and replaced by proportional actuation in order to achieve more accurate control.

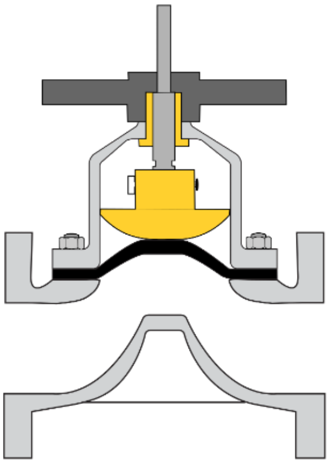


Figure 3.2.: Solenoid Diaphragm Hybrid

## 3.3. Placement of Sensors

One of the sensors will be positioned at the synthetic teat, since this is where the vacuum is to be regulated, See Appendix A.1. There will be two pressure sensors on the milk line, positioned at different distances from the valve. These will be used to create a mathematical model of how the readings differ depending on sensor placement. The one furthest away from the cluster will then be used as input for the control system.

The ceramic pressure sensor will be fitted on the milk line with a modular solution using a custom built housing, which needs to allow the sensor full access to read the vacuum levels while causing as little disturbance in the system as possible in addition to avoiding any leakage. To achieve this, the housing will be a 3D-printed part that will easily be attached to tubes on both ends. The inside will be cylindrical to not cause too much disturbance on the flow and have a cutout for the sensor in the middle, see Figure 3.3.

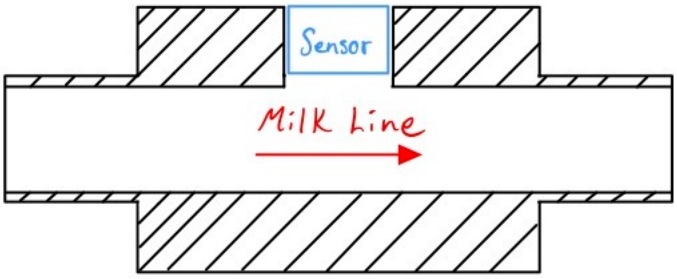


Figure 3.3.: Sensor housing.

## 3.4. Evaluation

In order to evaluate the design concepts discussed in the previous section, a design evaluation matrix was made in which each criteria of the concepts is weighted and scored. This will help in the process of choosing which concepts to realize and prioritize. See table 3.1.

| Criteria | | Concept | | |
|---|---|---|---|---|
| | Weight(1-5) | Pinch | Hybrid | Current |
| Ease of implementation | 5 | 3 | 3 | 4 |
| Cost | 3 | 2 | 3 | 5 |
| Maintainance cost | 3 | 3 | 4 | 3 |
| Food safety | 5 | 5 | 3 | 1 |
| Easy to control | 3 | 4 | 2 | 4 |
| Easy to clean | 4 | 5 | 5 | 1 |
| Future explandability | 1 | 5 | 4 | 1 |
| Edge case function | 3 | 3 | 1 | 3 |
| Total | | 101 | 84 | 75 |

Table 3.1.: The evaluation assessment

Where pinch represents the concept utilizing a pinch valve, hybrid the concept with a solenoid/diaphragm hybrid and the current solution the solution that is employed today.

The most prominent concept turned out to be the Pinch control valve. It scored the highest in the criterias that were considered most important, why it will be the main priority upon realization of the project. The current solution is obviously not satisfactory, so it could be disregarded completely.

# Chapter 4.

# Future Work

So far in the project, some critical areas have been researched and several designs have been proposed and evaluated. Further investigations will need to be made as the project continues. In this chapter, a time plan for the coming fall is covered, the arrangement of the test rig is discussed and planned ahead, together with the organization of works and the risk analysis.

## 4.1. Proposed time plan

The ordering of all components will take place before summer and the transport of the components will be handled during summer. From the start of the fall semester, a test rig will be built. Once the test rig is set up. The test rig will be verified in parallel with the controller system implementation. Different solutions will be evaluated until a solution can be finalized. The tasks and ideal deadlines for the tasks are displayed in table 4.1.

| **Task** | **Ideal Due Date** |
|---|---|
| Order parts | Mid June |
| Transport parts | Mid August |
| Build test rig | Mid September |
| Verify the test rig | Late September |
| Implement the solution | Late October |
| Controller system finalized | Early November |
| Finalize the solution | Late November |

Table 4.1.: Future plan roughly

## 4.2. Work arrangement

Organizational structure for the fall will be to divide the project into sub-projects for different areas of development. These are *test rig construction*, *valve development* and *software/control design*. The details of these are yet to be decided, as well as which team members will be involved in which sub-projects, but a visualization can be seen in Figure 4.1. The members are also meant to be moved around in the different sub-projects, so that everyone get the chance to expand their knowledge in the different areas.

The project management method that the team will use

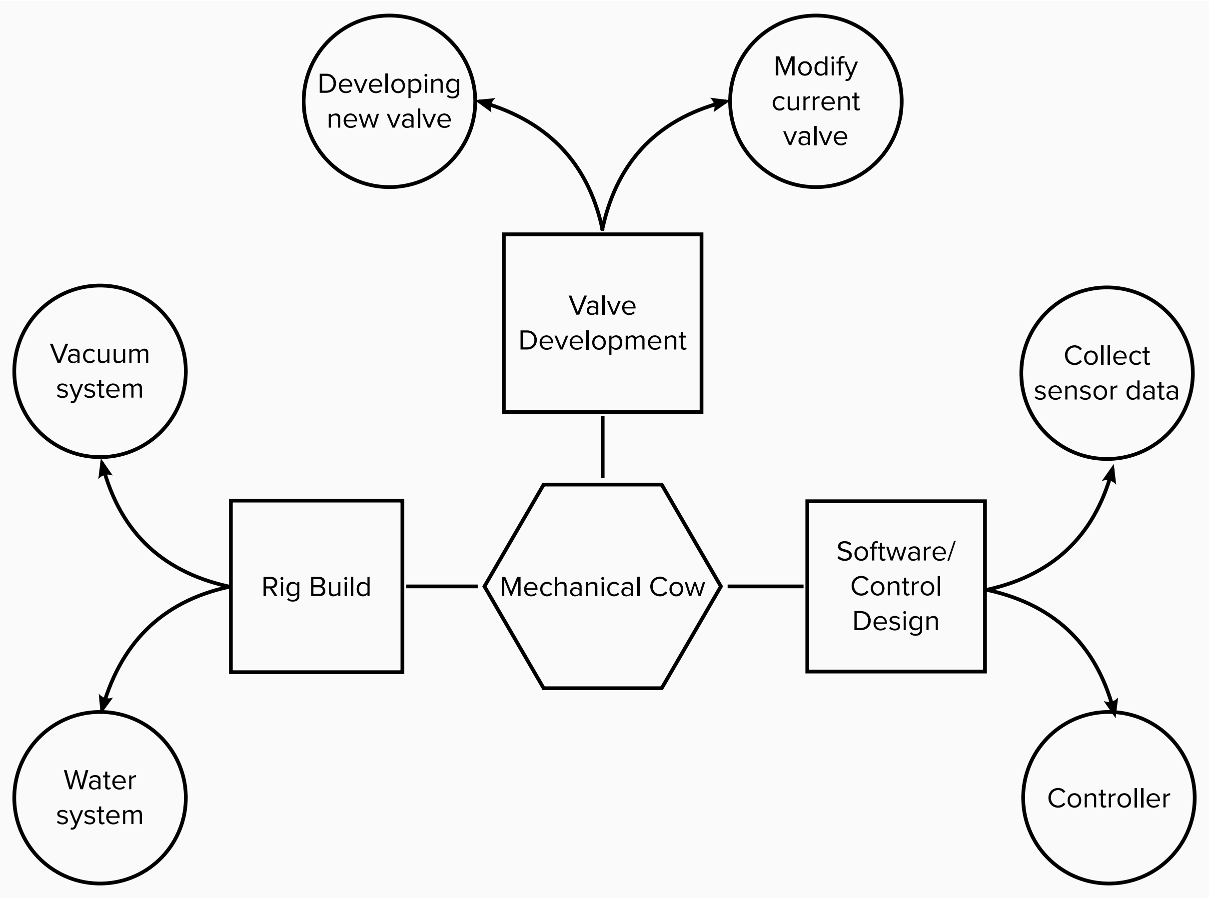


Figure 4.1.: Visualization of work structures

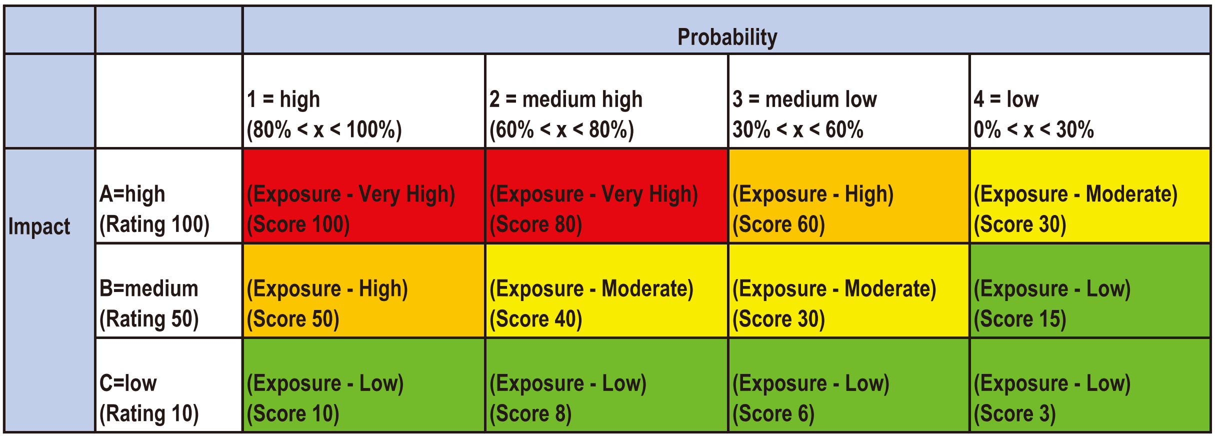
## 4.3. Risk analysis

As far as possible, it has been planned to build the test rig on KTH campus and verify it before end of September. This plan leads to a number of different risks because the construction area is still not clear and the cooperation is needed from KTH and DeLaval. Many risk factors needed to be accounted for and prepared for in different ways. A risk analysis was a viable solution to minimize avoidable risks and securing a satisfying delivery to the stakeholders within time. The risk analysis was done following a similar method as the Project Management Institute [31]. Starting with dividing the risk factors into four different categories, as shown in table 4.2.

| Risk Category | Extended categories |
|---|---|
| Technical | Requirements, Technology, Interfaces, Performance, Quality, etc. |
| External | Customer, contract, Market, Supplier, etc. |
| Organizational | Project Dependencies, Logistics, resources, Budget, etc. |
| Project Management | Planning, Schedule, Estimation, Controlling, Communication, etc. |

Table 4.2.: Four risk categories

The Risk exposure or risk score is then calculated by multiplying the impact rating with the highest risk probability according to figure 4.2. The risk with the highest ”exposure score” should be the one that needs the most attention from the group.



| | | Probability | | | |
|---|---|---|---|---|---|
| | | 1 = high<br>(80% < x < 100%) | 2 = medium high<br>(60% < x < 80%) | 3 = medium low<br>30% < x < 60% | 4 = low<br>0% < x < 30% |
| Impact | A=high<br>(Rating 100) | (Exposure - Very High)<br>(Score 100) | (Exposure - Very High)<br>(Score 80) | (Exposure - High)<br>(Score 60) | (Exposure - Moderate)<br>(Score 30) |
| | B=medium<br>(Rating 50) | (Exposure - High)<br>(Score 50) | (Exposure - Moderate)<br>(Score 40) | (Exposure - Moderate)<br>(Score 30) | (Exposure - Low)<br>(Score 15) |
| | C=low<br>(Rating 10) | (Exposure - Low)<br>(Score 10) | (Exposure - Low)<br>(Score 8) | (Exposure - Low)<br>(Score 6) | (Exposure - Low)<br>(Score 3) |

Figure 4.2.: Impact-Probability Matrix

The Risk Assessment on a few common or plausible risks, can be found in appendix B.1.

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# Appendix A.

# Design

## A.1. Test rig design

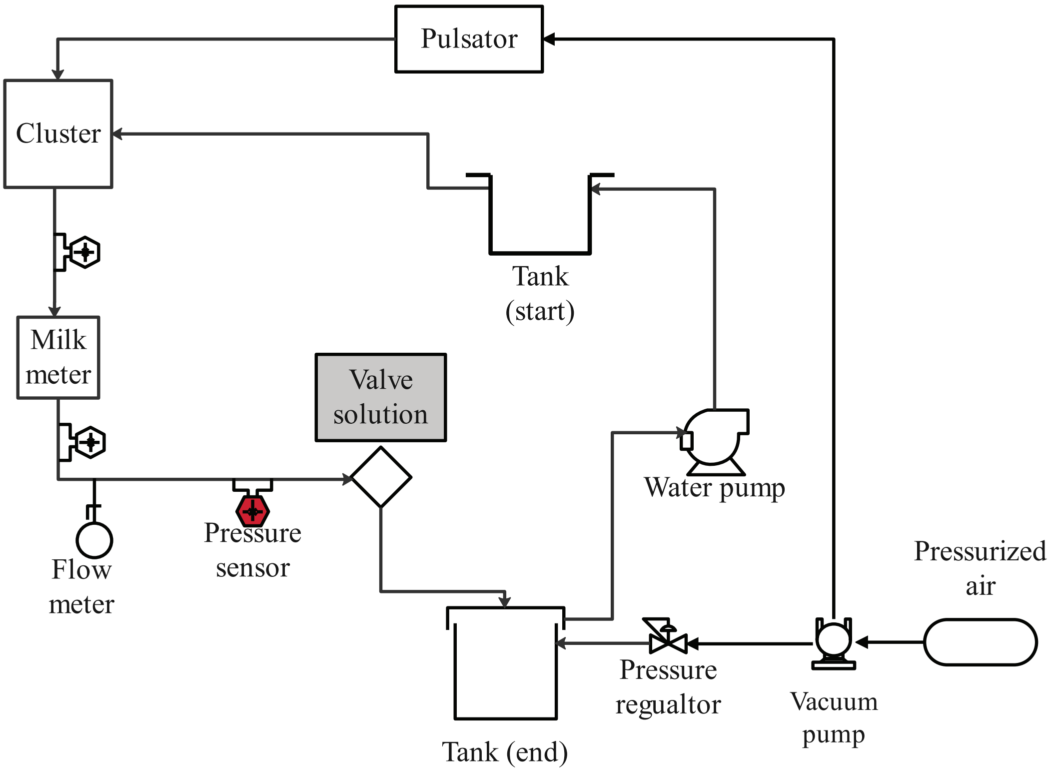


Figure A.1.: The design of the test rig, designed using EdrawSoft

## A.2. Ceramic sensor

Metallux Product Catalogue Pressure Sensor CPS2184

# CERAMIC STANDARD PRESSURE SENSOR CPS 2184

The CPS 2184 sensors with front-flush diaphragm seal are suitable for measurement of relative as well as absolute pressures. The flush-front diaphragm makes for easy cleaning, an important requirement for sensors used in the medical and food industry.

The sensors are also available with diaphragms with 99.6 % aluminium oxide, for applications with extremely aggressive media.

## TECHNICAL SPECIFICATIONS

| | |
|---|---|
| **Supply voltage** | 3 – 30 VDC |
| **Impedance** | 10 kOhm ± 20 % |
| **FS output (Span)** | Min. 1.5 / typ. 3.2 / max. 6 mV/V |
| **Offset** | 0 ± 0.2 mV/V |
| **Therm. offset shift** | Typ. 0 ± 0.015 / max. 0 ± 0.03 % FS/K (25 – 85 °C) |
| **Therm. span shift** | 0 – -0.013 % FS/K (0 – 70 °C)<br>0 – -0.015 % FS/K (-20 – 0 °C / 70 – 85 °C)<br>0 – -0.018 % FS/K (-40 – 0 °C / 85 – 135 °C) |

| | |
|---|---|
| **Insulating resistor** | >1 Gohm @ 500 VDC, RT, 70 % rH (mounting 16.00mm) |
| **Insulating voltage** | > 0.5 kVDC with minimal membrane thickness, from medium to printed circuit |
| **Body material** | $Al_2O_3$ 96 % |
| **Operating temperature** | -40 – +135 °C |
| **Storage temperature** | -40 – +150 °C |

Mechanical and electrical characteristics are customisable. Specifications are subject to change without notice. We recommend that customers perform their own tests for new or untested applications.

| PRESSURE RANGE (BAR) | LONG THERM STABILITY * | LINEARITY / HYSTERESIS (TYP./MAX.) (% FS) ** | BURST PRESSURE (BAR) | OVER-PRESSURE (BAR) *** | VACUUM CAPABILITY (BAR) | TYPE |
|---|---|---|---|---|---|---|
| 0.5 | ± 0.25 | ± 0.3 / 0.6 | ≥ 1,5 | ≤ 1 | -0.1 | Rel. |
| 1 | ± 0.25 | ± 0.25 / 0.6 | ≥ 2,5 | ≤ 1,5 | -0.4 | Rel. / Abs. |
| 2 | ± 0.2 | ± 0.2 / 0.5 | ≥ 5 | ≤ 3 | -0.6 | Rel. / Abs. |
| 5 | ± 0.2 | ± 0.2 / 0.5 | ≥ 12 | ≤ 7,5 | -1 | Rel. / Abs. |
| 10 | ± 0.2 | ± 0.2 / 0.4 | ≥ 25 | ≤ 15 | -1 | Rel. / Abs. |
| 20 | ± 0.15 | ± 0.2 / 0.4 | ≥ 40 | ≤ 30 | -1 | Rel. / Abs. |
| 50 | ± 0.2 | ± 0.2 / 0.4 | ≥ 100 | ≤ 75 | -1 | Rel. / Abs. |
| 100 | ± 0.25 | ± 0.25 / 0.5 | ≥ 250 | ≤ 150 | -1 | Sealed gauge |
| 200 | ± 0.25 | ± 0.25 / 0.6 | ≥ 400 | ≤ 300 | -1 | Sealed gauge |
| 400 | ± 0.25 | ± 0.25 / 0.6 | ≥ 600 | ≤ 500 | -1 | Sealed gauge |
| 600 | ± 0.25 | ± 0.3 / 0.6 | ≥ 700 | ≤ 700 | -1 | Sealed gauge |

* 1000 hours @ 150 °C | 50 million pressure cycles @ 80 °C, 10 – 90 % FS @ 2.5 Hz | 3 thermal shocks +125 °C/-20 °C, 3 K/sec | 50 thermal cycles +135 °C/-40 °C, 2 K/min.

** For indipendent linearity 10 points are measured and compared to an ideal straight line. | For all measurements, DUT's are mounted in Metallux standard Housing according to "mounting proposa CPS 2184-ND-HD".

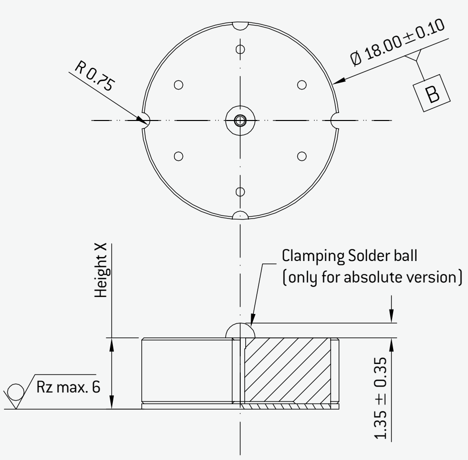
*** Over-Pressure indicates the maximum (short time < 1 s) operating pressure within no irreversible damage to the printed circuit are expected.

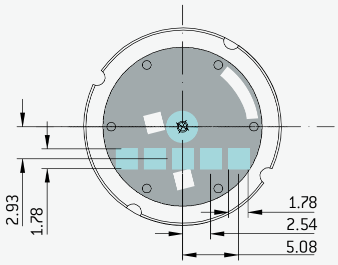
## SAMPLE ORDER

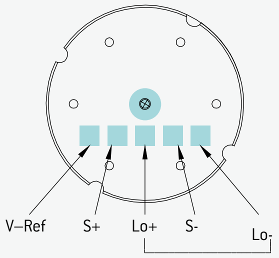
| Type | Pressure range (bar) | Pressure type | Electrical connection (acc. to drawing) |
|---|---|---|---|
| CPS 2184 | 100 bar | A/R/SG | Solder pads |

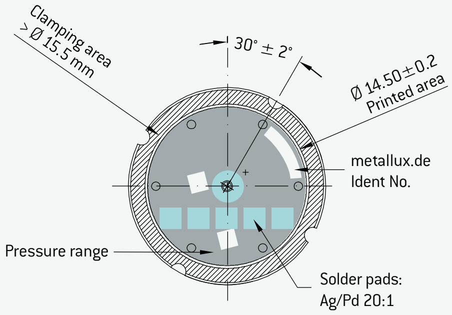
Other dimensions and electrical specifications on request.

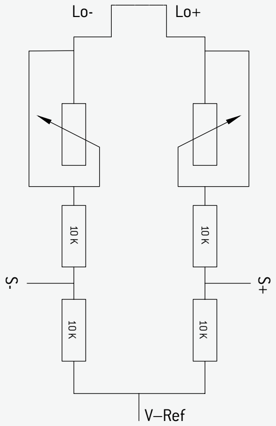
## DIMENSIONAL DRAWINGS / CONNECTOR SCHEMATIC / ELECTRICAL CONNECTORS









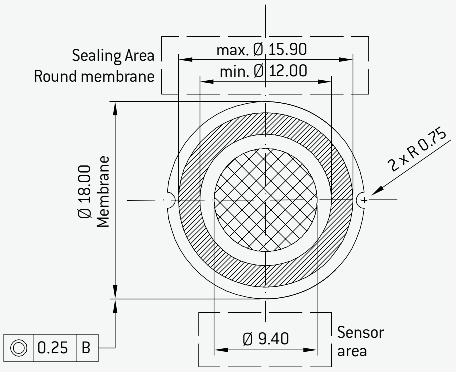


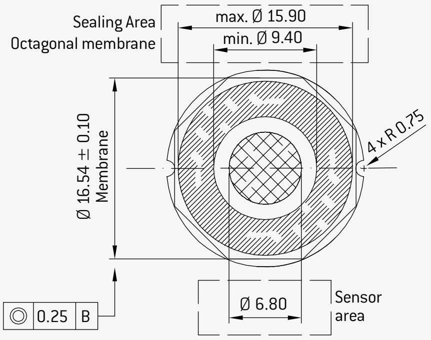
### TABLE FOR HEIGHT X ROUND (MM)

| | | |
|---|---|---|
| 0 – 0.5 bar | 6.13 | ± 0.15 |
| 0 – 1 bar | 6.20 | ± 0.15 |
| 0 – 2 bar | 6.25 | ± 0.15 |
| 0 – 5 bar | 6.30 | ± 0.15 |
| 0 – 10 bar | 6.35 | ± 0.15 |
| 0 – 20 bar | 6.55 | ± 0.15 |
| 0 – 50 bar | 6.70 | ± 0.15 |

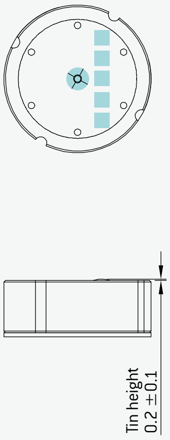
### TABLE FOR HEIGHT X OCTAGONAL (MM)

| | | |
|---|---|---|
| 0 – 100 bar | 6.70 | ± 0.15 |
| 0 – 200 bar | 7.05 | ± 0.15 |
| 0 – 400 bar | 7.35 | ± 0.2 |
| 0 – 600 bar | 7.55 | ± 0.2 |

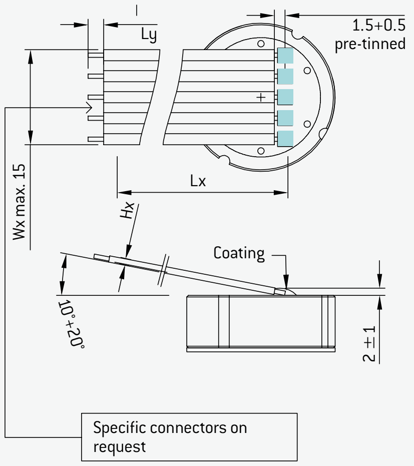




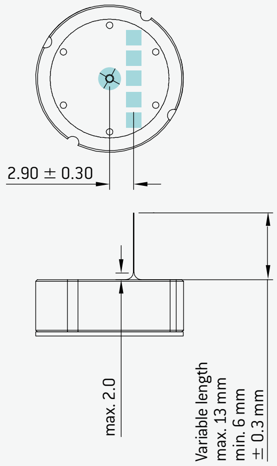
**Standard:**
**Tin plated: Sn95.6; Ag3.8; Cu0.6**



**Type of connection:**
**flat cable**



**Type of connection:**
**Pins 0.5 x 0.27mm**



## A.3. Milkmeter

(a) DeLaval milk flow indicator HFC designed for heavy duty milking

(b) DeLaval flow sensor FI2 design to view in the background

(c) DeLaval yield indicator FI7 designed for data synchronization for efficient herd management

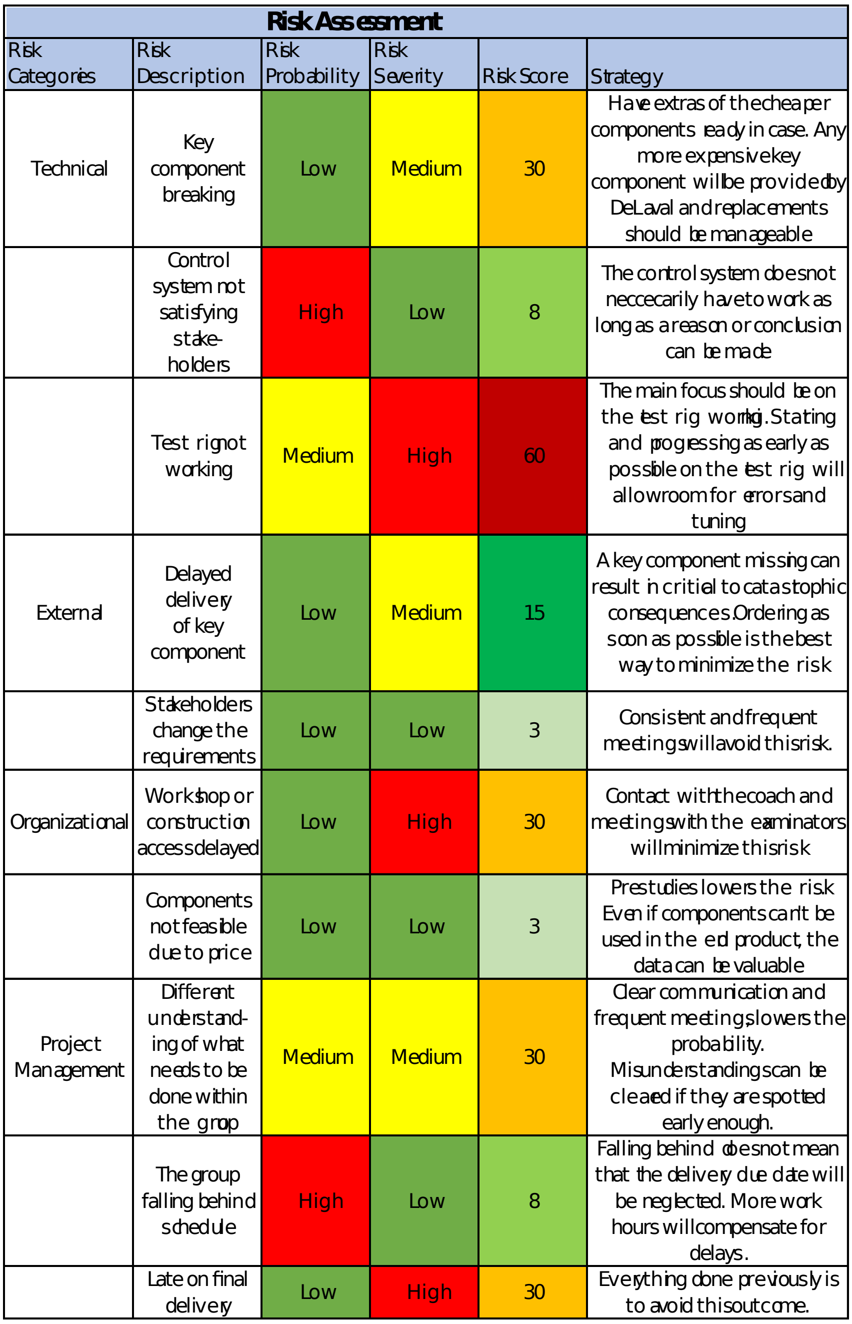
(d) DeLaval milk meter MM27BC designed for accurate ICAR approved milk meter

Figure A.2.: Milkmeter on the market from DeLaval

# Appendix B.

# Risk Assessment

## B.1. Risk analysis



| Risk Assessment | | | | | |
|---|---|---|---|---|---|
| Risk Categories | Risk Description | Risk Probability | Risk Severity | Risk Score | Strategy |
| Technical | Key component breaking | Low | Medium | 30 | Have extras of the cheaper components ready in case. Any more expensive key component will be provided by DeLaval and replacements should be manageable |
| | Control system not satisfying stake-holders | High | Low | 8 | The control system does not neccecarily have to work as long as a reason or conclusion can be made |
| | Test rig not working | Medium | High | 60 | The main focus should be on the test rig working. Starting and progressing as early as possible on the test rig will allow room for errors and tuning |
| External | Delayed delivery of key component | Low | Medium | 15 | A key component missing can result in critical to catastophic consequences. Ordering as soon as possible is the best way to minimize the risk |
| | Stakeholders change the requirements | Low | Low | 3 | Consistent and frequent meetings will avoid this risk. |
| Organizational | Workshop or construction access delayed | Low | High | 30 | Contact with the coach and meetings with the examinators will minimize this risk |
| | Components not feasible due to price | Low | Low | 3 | Prestudies lowers the risk. Even if components can't be used in the end product, the data can be valuable |
| Project Management | Different understand-ing of what needs to be done within the group | Medium | Medium | 30 | Clear communication and frequent meetings, lowers the probability.<br>Misunderstandings can be cleared if they are spotted early enough. |
| | The group falling behind schedule | High | Low | 8 | Falling behind does not mean that the delivery due date will be neglected. More work hours will compensate for delays. |
| | Late on final delivery | Low | High | 30 | Everything done previously is to avoid this outcome. |

Figure B.1.: Impact-Probability Matrix