KTH Royal Institute of Techonology

Mechatronics Advanced Course, Spring Term MF2058

DeLaval HK Project - The Udder Project
Spring report

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1. Introduction

This report details the pre-study completed during the fourth study period for a project commonly referred to as a HK Course (Högre Kurs, HK). The course is a cooperation between KTH Royal Institute of Technology (KTH) in Stockholm and various companies in the industry, in this case, DeLaval. The companies pitches their project to the students, who are then formed into groups.

DeLaval is a producer of dairy and farming machinery, with a head office in Tumba, Sweden, and is part of the Tetra Laval group.

1.1. Background

The use and utilization of milk and other secondary livestock products started as early as 6500 BC and is considered an essential step in the domestication of civilizations [1]. The first automatic milking systems (AMS) was introduced in the early 1990s providing an increasing milk yield, herd health, and improved managerial control [2], and is today one of the more widespread methods in the dairy industry. Among the many technologies of AMS's, one emerging and fully automatic commercial solution is the voluntary milking system (VMS) that allows the animals to voluntarily get milked multiple times a day further increasing yield and reducing labor work to the service of the machine.

One of the largest global providers and manufacturers of dairy equipment is the Swedish company DeLaval who first introduced their fully automatic robotic milking machine, the VMS300 series in the late 1990s [3]. In a collaboration between DeLaval and KTH, the authoring group of students has worked on improving and rethinking the design of the gripping mechanism and end-effector connected to the lower part of the robotic arm of the current VMS310.

Figure 1.1.: Voluntary milking system VMS310, ©2023 DeLaval. Reprinted with permission from [4].

1.2. Project description

The initial project description (included in Appendix C) given by the stakeholders state the following:

> "The HK project will investigate the possibility of use of alternative materials and technical solutions for actuators, sensors, and other parts of link 3 while stating the implications of those alternatives."

As this was considered rather open-ended, the group narrowed the areas of interest down to a selection of key technical requirements. These are further described in Section 1.2.3.

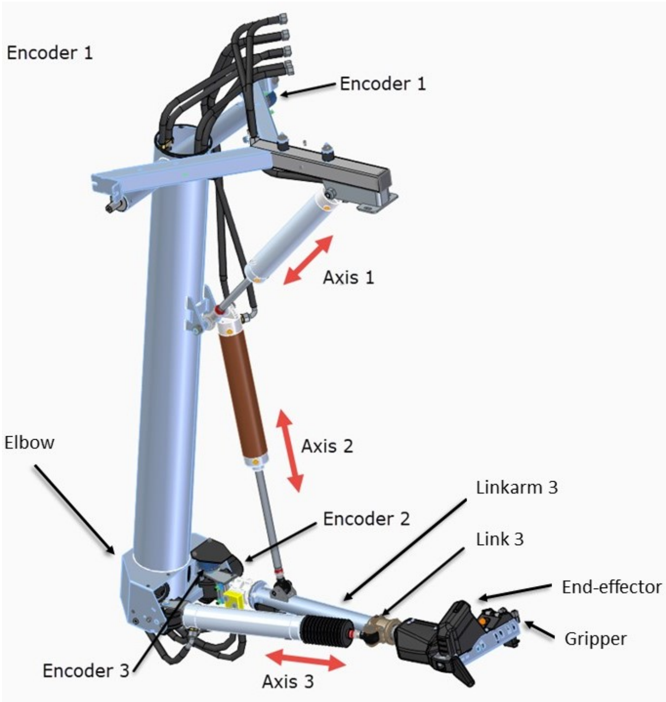


Figure 1.2.: Technical overview of the robotic milking arm. From Appendix C, reprinted with permission.

1.2.1. Scope

The scope of the HK-project was confined, by the group, to examine the existing VMS machine from DeLaval and re-imagine the end-effector. This was further limited to focusing only on the end-effector's yaw-joint and the gripping mechanism. Possibly redesigning the casing of the assembly as needed.

Key aspects that were identified as open for improvement were the following:

- Increasing the range of motion of the end-effector, see Fig. 1.2. The end-effector contains a joint, shown in Fig. 2.1b, but this is only used sparingly. The project aims to investigate if the functionality of the system can be expanded by reworking this joint.
- Improving the gripping mechanism, see Fig. 1.3, as the current design has been identified to potentially be prone to wear and tear.

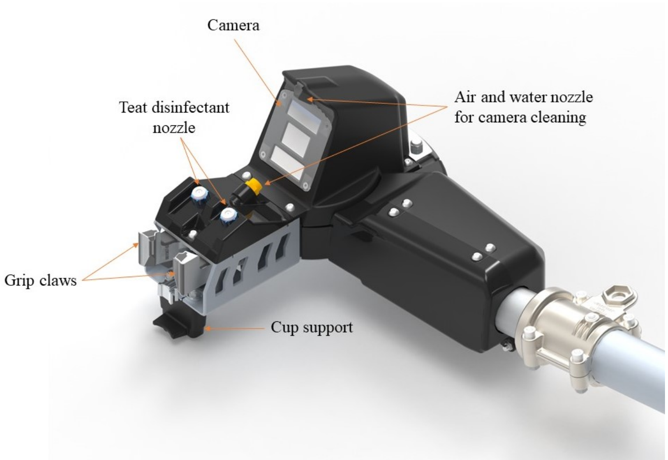


Figure 1.3.: Outside view of the end-effector. CAD models provided by DeLaval.

1.2.2. Goals

The goals for the project can be described as

- Re-imagine the yaw-joint. Increase the range of motion and implement continuous position control.
- Re-imagine the gripping mechanism. Increase robustness and serviceability.
- Produce a working prototype.

1.2.3. Delimitations

The project was limited to focus on only the linkarm 3, see Fig. 1.2. This limitation was posed by the stakeholder to retain a proper scope for the project. The group then limited the focus of the project to only concern the end-effector that is visible in Fig. 1.2. This limitation was implemented to contain the project's extent and enable a focused work structure.

The work on the end-effector was limited to focusing on the gripping mechanism and the yaw-joint, further detailed in Fig. 2.1b. The work on the parts was limited to focusing on new solutions or re-imagined parts. The camera and cleaning of the camera were to be left untouched, per discussion with the stakeholder.

1.3. Requirements

A list of stakeholder requirements was defined, based on the project pitch. This was refined further through conversations with the stakeholders during a study visit at DeLaval's premises and test farm. The stakeholder requirements, as found in Appendix A, were then the basis for the technical requirements described in this chapter. Furthermore, the course learning requirements can be found in Appendix B. According to best practices, the keyword *shall* indicates a hard requirement, and *should* a soft requirement.

Size

- The height of the end-effector (excluding the camera, cleaning, and disinfection array) shall not exceed 87 mm by more than 10%.
- The width of the end-effector shall not exceed 283 mm by more than 5%.

Weight

- The weight of the end-effector shall not exceed the current weight of approx. 4 kg (including the camera module). The demonstrator prototype should not exceed the demonstration test-rig maximum weight limit of 3 kg (excluding the camera).

Safety

- The end-effector shall comply with the regulations included in "Maskindirektivet" [5], e.g. shall not be harmful to either humans or cows. This includes:
  - The machine should not be able to pinch or crush body parts. E.g. movement of the yaw-joint should act with a force sufficiently low to not cause harm [5], which could be interpreted as approximately 150 N.
  - The end-effector should be compliant with external forces and move instead of acting stiff, e.g. when a cow or human kicks on it.
  - All the electrical parts of the end-effector should be covered and not cause potential damage to the cow.
  - There should be no crevices in the housing that allow body parts like a finger or a teat to get stuck.

Cleaning and Hygiene

- The end-effector shall be pressure-washable without causing harm to its functionality.
- The end-effector shall contain fewer dirt pockets and crevices than the current design. E.g. any corners and edges should have a round of more than r = 1 mm.

Technical solutions

- The gripper shall hold the cup in the entire process with a minimum force equivalent to the DeLaval AMR +/- 10% and the cup should be removable by hand.
- The yaw-joint shall have a controllable range of motion of more than 90 degrees.
- The position of the yaw-joint shall be fed back and continuously controllable. The gripping mechanism should feedback on the fact, that a cup is attached.
- The end-effector shall be hot-swappable to the test rig and the rest of the machine's robot arm.
- The control and logic should be entirely separated from the machine.
- The camera, cleaning, and disinfectant modules should not be changed.

1.4. Team organization

The team consists of 9 people. To maintain a good flow of information, a communication channel in WhatsApp was used. Through this, all meetings were planned and general information was discussed and shared. During the project, the group conducted weekly internal meetings, in combination with bi-weekly meetings with the stakeholders.

To better streamline the work, the group is divided into subgroups, these groups changed during the course of the project. Each subgroup received a distinct task to solve and account for. In the first study period, task groups were created focusing on documentation, state-of-the-art analysis, and concept design.

Individual assignments, such as contacting the stakeholders, gathering research on a specific topic, or preparing a presentation, were also assigned dynamically.

2. State of the art

The AMS milking process can be divided into a few distinct steps [6].

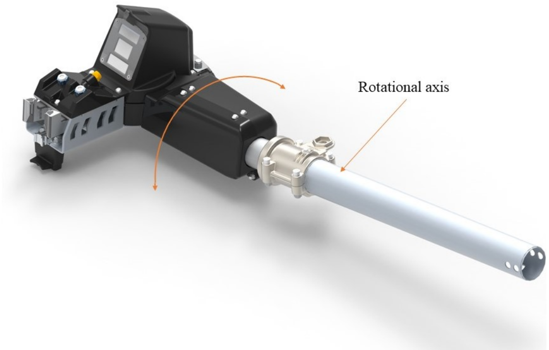
- A pre-milking activity, including cleaning and stimulating the teat.
- The milking process itself, which includes separating the initial, undesirable pre-milk from the subsequent usable milk.
- A post-milking process, which involves cleaning and spraying disinfectant on the teats.

Commonly, automated systems are implemented such that the cows voluntarily enter the machine or milking when they desire, thus alleviating the need for a farmer to be available early or late in the working day. The milking is done by a 'milking cup' attached by the robot to the teat of the cow.

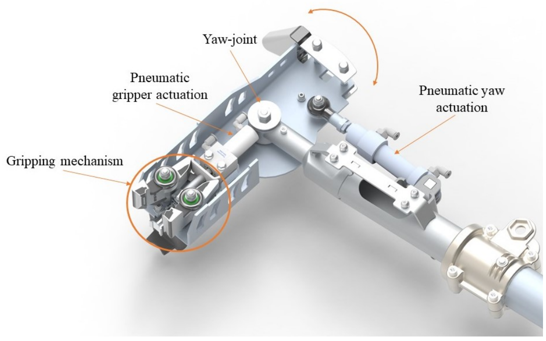
2.1. The DeLaval VMS310

The AMS by DeLaval consists of a cage-like structure, as visible in Fig. 1.1, where the cow enters to be milked. Two gates on the back left and right allow the cow to enter and exit the machine. Multiple compartments on the front house the main computer, electronics, hydraulics, and milking technology that are needed. On the front left, the large robot arm is mounted right beside the storage location of the tubes and two types of cups. The robot arm consists of multiple linkarms and rotational axes that, apart from the end-effector, are moved by hydraulic actuators. An overview of the robot arm can be seen in Fig. 1.2. The areas that are interesting for the project are linkarm 3 and the end-effector.

The end-effector, see Fig. 2.1, has the purpose of fetching the cleaning and milking cups from their resting position on the machine and attaching them to the teats of the cow.



(a) Rotational axis for the end-effector



(b) Inside view of the end-effector

Figure 2.1.: Current design of the end-effector. CAD-models provided by DeLaval.

During the aforementioned steps in the milking process, the end-effector and linkarm 3 perform the following actions. Firstly, to pick up the upside-down-hanging cups, the end-effector rotates 180° along the axis of linkarm 3, see Fig. 2.1a. This motion is performed by a rotational hydraulic motor. The gripper is then actuated, by a pneumatic cam mechanism, to grip the cup, see Section 2.6.2. The robot arm then locates the teats with the 3D-camera module, which is able to move 15° in a yaw-motion (shown in Fig. 2.1b) in case the teats are not visible for the camera. This camera yaw movement is produced by a pneumatic piston. The end-effector remains static relative to the robot arm throughout the motion and attachment to the teats. This process is repeated for all cups and teats. Lastly, the milking cups are detached by retracting the tubes into the machine, and the end-effector moves under each teat to apply a disinfectant spray.

2.2. Alternative Products

In a dairy sector where more than half of all newly constructed farms in Europe choose to implement an AMS [7], a multitude of different automatic solutions for the milking process can be found. This report will feature a few of the alternative solutions to the VMS310 for a brief overview and in order to reference and compare alternative technical solutions.

2.2.1. DeLaval AMR

The DeLaval Automated Milking Rotary (AMR) is a large carousel where several cows can be milked simultaneously [8]. This enables a larger throughput on the machine, but perhaps more of interest in the context of this report is the usage of several different arms to each do the different tasks of pre-cleaning, attaching milking cups, and post-cleaning. Because of their specialized nature, these arms have features and solutions that are interesting when looking at the VMS310. Fig. 2.2 shows the magnetic gripping mechanism of the AMR that stands in contrast to the traditional mechanical gripper from the VMS310. The electromagnets attach directly to the ferromagnetic steel in the milking cups.

Figure 2.2.: DeLaval AMR magnetic Gripper, ©2023 DeLaval. Reprinted with permission from [8].

2.2.2. Lely Astronaut Series

Lely is a Dutch agricultural machine and robots manufacturer [9], and a competitor to DeLaval. Their AMS is called *Astronaut* [10]. Their solution differs from DeLaval's AMR in a few key aspects that might be of interest to this project.

Notably, the arm holds all four milking cups instead of attaching one at a time. This makes it potentially faster to attach the milking cups. However, their individual freedom of movement is lower.

Cleaning is achieved by applying a motorized brush individually on each teat, as opposed to DeLavals solution of using a specific cleaning cup and a mixture of liquid and air.

2.2.3. GEA

GEA Group AG is a German corporation mostly active in the food and beverages sector [11]. Their current AMS is called the *DairyRobot R9500 Robotic Milking System*, and like Lely, uses an arm that holds all four milking cups at the same time. However, unlike Lely, these also do cleaning and other pre- and post-processes in one single attachment [12].

2.3. Actuation

Various forms of actuation have different prerequisites, advantages and disadvantages, therefore the project investigates different alternatives. These alternatives were evaluated based on their suitability for the application in the project.

2.3.1. Pneumatics

Pneumatic actuators use compressed gas to achieve motion. This method is most commonly used in the form of pneumatic pistons, but rotary actuation is also possible [13].

Pneumatic actuation has the advantages of being suitable for quick motions and can use air, which is a readily available gas. Furthermore, gases are compressible, so there will be a bit of spring compliance in a pneumatically actuated joint.

The disadvantages of pneumatic actuation are that compressed gases contain large quantities of stored energy which can be dangerous should the system malfunction or break. Further, gas lines can be prone to leakage, and require pressure/vacuum tanks which can be bulky and expensive. However, as one set of pumps and tanks can be used by several actuators, this disadvantage is diminished as the number of actuators increases. Positional control of a pneumatic actuator is also harder because of uncertainties and spring-like compliance.

2.3.2. Electric

Electric actuation is available in several forms that could be of interest to this project. Including but not limited to rotary motors, solenoids, and linear actuators. Electric actuators draw power from a voltage supply and translate it into mechanical motion. An advantage of electric actuators is that they are easily controllable with high precision through embedded control [13].

A notable disadvantage of electrical actuators is that they often require power to hold a position. An exception to this is motor-driven screw mechanisms, which instead are rather rigid and not compliant with external forces.

2.4. Transmission

The use of transmissions can be beneficial for the separate placement of motors and actuated parts, and for increasing speed or torque as needed. The simplest solution is a direct drive mechanism but, as this is not always suitable, the following options have also been evaluated.

2.4.1. Bowden cables

Bowden cables are composed of a cable enclosed within a flexible sheath and are typically used to project motion over a distance by displacing the wire within the fixed sheath. The cables are commonly used in robotics for remote actuation, particularly in tight or inaccessible spaces. They can also be applied for sensing purposes.

The use of Bowden cables does however come with a series of limiting factors. One big obstacle is that they can only transmit unidirectional motion and force, meaning they can only “pull” with significant force and precision, which limits their application in certain robotic applications. A possible solution for this is using a pair of cables, one for each direction of actuation. In addition, they are not well-suited for applications where high precision, speed, or force is required, mainly due to their flexibility and the inherent friction between wire and casing. This also implies the length of the cables impacts the performance, making them challenging to use for long-distance transmission. In terms of robustness, Bowden cables can be prone to wear and tear, which can cause them to break, or otherwise fail to operate according to expectations, over time if they are not properly maintained [14].

2.4.2. Chain drive

Chain drives are mechanical systems typically used for transmitting motion between two rotating shafts. Chain drives, in this configuration, are unidirectional and can therefore rotate in both directions and handle moderate to fast speeds and forces. The interface between the shafts and chain drive usually consists of gears. Depending on the gears and the size of the links in the chain, the precision in rotational motion will vary. One disadvantage of chain drives is the need for regular maintenance, such as lubrication. Furthermore, the alignment of the drive needs to be good to minimize vibrations, and an enclosure is required to protect the chain from objects and the harsh environment.

2.5. Sensors

In this project, sensors will primarily be used to measure the position of the actuator movement, either in the yaw-joint or the gripper mechanism. Additionally, sensors can also be used to detect whether the gripper has successfully attached to the object.

2.5.1. Encoders

An encoder is a device that translates mechanical motion to an electrical signal. The signal can then be processed to determine position, speed, count, or direction [13]. An encoder can be utilized to accurately measure the position of the yaw-joint allowing for real-time monitoring of the position of the end-effector. Linear encoders could be interesting to implement in combination with a linear actuator and rotary encoders together with a type of motor to measure the rotational movement.

2.5.2. Limit switches

Limit switches are electromechanical devices that emit a signal when triggered. The limit switch is capable of detecting whether an object is present or absent and can be utilized to restrict the movement of actuators so as not to cause damage to the mechanism. Two types of limit switches have been identified for possible implementation in the yaw-joint or gripper mechanism. The first type is a mechanical switch and the other is a proximity limit switch (or proximity sensor).

The choice of the limit switch depends on the specific requirements of the mechanical mechanism to be limited. Mechanical limit switches are more suitable for applications where a part of the mechanism can make direct contact with the switch, while proximity switches are more appropriate for applications where the parts are not in direct contact with the switch itself.

2.6. Gripping mechanisms

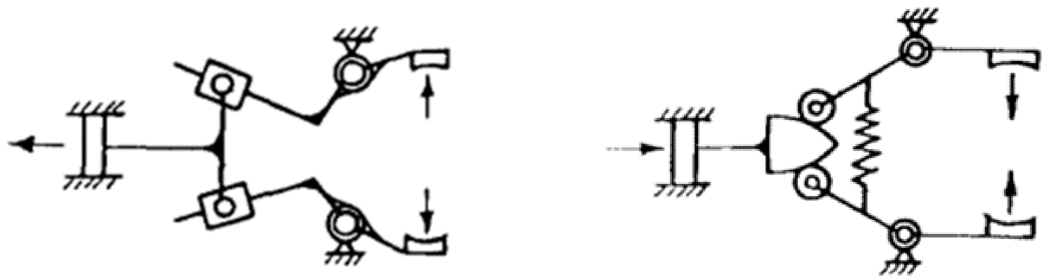
The most intricate mechanism in this project is expected to be the gripping mechanism, i.e. the mechanism on the end-effector that attaches to the milking cups. Some methods of achieving this functionality are discussed in this chapter.

2.6.1. Linkage gripping mechanism

The linkage gripping mechanism provides gripping action through the movement of an assembly of links that are connected by joints. The movement of the links is caused by an actuator which can be electric, pneumatic, or hydraulic. One example of a linkage gripping mechanism can be seen in Fig. 2.3a. Some advantages of linkage gripping mechanisms are that they have low computational complexity and high gripping force. Disadvantages of the linkage mechanism are that it typically has a high cost, requires much space to be implemented, and is not very robust due to the complexity of the structure [15].

2.6.2. Cam gripping mechanism

Cam-actuated grippers produce parallel movement of the grippers, by the links (followers) that are in contact with the cam. One example of the cam-actuated grippers is shown in Fig. 2.3b. The common aspect is that there is usually a preloaded force (normally provided by a spring). The advantage of using the cam and follower mechanism is that it has a wide range of designs for different applications, including high shock and vibration resistance. Disadvantages of the cam gripping mechanism include the frequent tool changes due to the wear from the friction between the cam and the follower. It also requires high accuracy and has a high cost of manufacturing [16]. The cam mechanism shown in Fig. 2.3b corresponds to the current solution used in the VMS300-series.



(a) Example of a linkage gripping mechanism. (b) Example of a cam gripping mechanism.

Figure 2.3.: Example designs of mechanical gripper mechanisms [17].

2.6.3. Magnetic gripping mechanism

A magnetic gripping mechanism is commonly used for gripping ferrous materials. Two types of magnetic grippers are considered of interest for the project, electromagnetic and permanent magnetic. The main parts of the electromagnetic gripper are the ferromagnetic core and coil. The ferromagnetic core gives a high magnetic flux density when it is exposed to the coil's magnetic field. The magnetic field within the coil is generated by the current flow caused by a voltage source. In contrast to electromagnetic grippers, a permanent magnetic gripper does not require a voltage source. Instead, it releases the object either by using a push-off pin that is controlled mechanically or by pneumatically moving the magnet, see Fig. 2.4. By moving the magnet, each side becomes periodically magnetic. This can be utilized to grip and release materials.

Some advantages of using a magnetic gripping mechanism are the fast actuation time, the low number of moving parts, and the possibility for an enclosure sealed from the environment. One drawback of using a magnetic gripper is the residual magnetic field that can affect other devices in the vicinity [18].

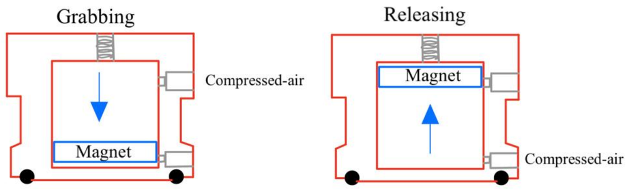


Figure 2.4.: Permanent magnet solution.

2.7. Control

Apart from very crude on/off controllers, some more sophisticated methods for control of the actuators are presented and examined in this section.

2.7.1. PID control

PID control is one of the most commonly used types of controllers. PID controllers utilize the proportional error, the change of the error (derivative) and the sum of the error over time (integral) to produce a control signal. The use of PID controllers is widespread and applicable to pneumatic and hydraulic systems, achieving results with sufficient accuracy. However, PID controllers are not the most robust for handling disturbances and uncertainties which can be present in dynamic systems [19].

2.7.2. Other alternatives

Sliding mode controller is a type of controller used to control dynamic systems where uncertainties can be present, such as with pneumatics or hydraulics. The drawback with a sliding mode controller is its implementation, which involves the creation of sliding surfaces and switching control strategies which, if not implemented in a good manner, hampers performance.

Model predictive control-based control system can be used to control position, however, the control system is built upon a model to predict the future states. This type of controller requires a model to be able to predict future states and it can therefore be hard to take uncertainties and disturbances into account.

Hybrid control is a control method that deals with hybrid systems with both event-triggered and time-triggered systems. To implement this method, a system must be modeled as a hybrid automation which consists of different states, equations that describe physical properties and switching conditions.

3. Conceptual designs

3.1. Concept for yaw-joint

The concepts in development regarding the yaw-joint focus on implementing feedback control and a wider range of motion. The leading designs use either pneumatic or electric motors to achieve motion. The primary focus will be the implementation of the pneumatic alternative, mainly due to the pre-existing availability of pneumatics in the system and the energy efficiency of pneumatics. The main challenge with this design is expected to arise in the position control, as the physics of a pneumatic motor inherently provides spring-compliance, introducing unwanted poles in the control system. This spring-like behavior could, however, prove to be a benefit from a safety standpoint as it could perform like an impact dampener.

In case the designs prove to be too heavy or large, the actuator part of the concept could be moved further up on linkarm 3. This would introduce the need for a transmission, such as a chain drive or Bowden cables, to transmit motion between the motor and the yaw-joint. This would increase the complexity of the solution and will therefore be avoided if possible. Some sketches for these alternatives can be seen in Appendix D.

3.2. Concepts for gripper

The conceptual solution for the gripper incorporates magnetism due to its low complexity and the capability to function while fully enclosed.

3.2.1. Concept 1: Permanent magnet

The permanent magnet solution is based on a pneumatic lifting magnet. The solution proposes a permanent magnet that is actuated between two positions within a pneumatic cylinder, for reference see Fig. 2.4. When the magnet is at an engaged position, the magnetic field should be strong enough at the end point of the gripper to hold the milking and cleaning cups. When the magnet is disengaged it should not affect the gripper in a noticeable way. The tubing needed to supply pressurized air is already present in DeLaval's current VMS310 design.

One risk to consider with this design can arise when cups are attached to adjacent teats. Their proximity to each other and to the gripper may cause the magnetic field to affect other cups in unwanted ways. Furthermore, this conceptual design must take external factors like contaminated surfaces and fast movements into account to eliminate the risk of the cups slipping off. Another drawback of this concept is that even if the magnet is disengaged, there still exists a weak magnetic field at the gripper and a strong magnetic field inside the end-effector, which may influence other components.

3.2.2. Concept 2: Electromagnet

The magnetic field of the electromagnet is generated by current flow through a coil around ferromagnetic material. The magnetic flux density of the core can be controlled by the voltage applied to the coil. An issue that needs to be addressed with this solution is magnetic remanence [20], when the core material gains a permanent magnetization and the magnetic field remains after turning off the voltage. Thus, a demagnetization procedure is needed after releasing the cup each time by applying to alternate decreasing current [21]. Two main concerns with this design are the power consumption, which is expected to be high compared to other solutions, and the electromagnetic emission that might spread through the device and disturb sensor readings.

3.3. Test rig

To be able to test and demonstrate the performance of the prototype, a test rig is to be constructed. The concept for the test rig is to use an existing ABB IRB 120 [22] where the end-effector prototype can be mounted hot-swappable with the original VMS310 end-effector. The robotic arm's goal is to simulate the general motion of the VMS310s robotic arm and make it possible for the constructed end-effector to grab milking cups and move them to a pre-determined location.

A potential problem is the fact, that the ABB arm only is dimensioned for up to 3.4 kg [22], which according to the technical requirements will be the approximate goal weight for the prototype. If the ABB arm should not work, an alternative solution is the construction of a rail that mimics the movements of the VMS310's robot arm.

4. Conclusion

After examining the different gripper designs, the pneumatically actuated permanent magnet gripper was considered the best fit. This alternative can be encapsulated within a protective shell to shield it from the environment, unlike many mechanical gripping solutions, and also does not require continuous energy usage as it is actuated by pneumatics only when switching between the states of engagement and disengagement. Because of the harsh environment where the machine is operated, a gripper shielded from the environment is preferred and because of the stakeholder's requirement of minimal energy usage, the solution with a pneumatically actuated permanent magnet was chosen as the most promising design.

Multiple factors have been taken into account when examining the choice for the actuation of the yaw-joint. The machine is required by the stakeholder to be compliant, the use of pneumatic actuators is therefore preferred over electric actuators as they have built-in compliance as the driving medium can be compressed and with overpressure valves, the pneumatic actuators can be moved. To achieve the same behavior with an electric actuator, further sensors, and control are needed. The use of an electric motor is preferred for its precise positioning and therefore it will be investigated further. However, the use of a pneumatic motor is relevant since there is a soft requirement to not introduce too many electronics in the end-effector. This in addition to the already existing pressurized air makes the pneumatic motor worth investigating.

When evaluating the use of different controllers for the actuator of the yaw-joint, some different parameters have to be taken into account, such as precision, ease of implementation, and how fast it can reach a steady state. from research, it has shown that sliding mode controllers can reach higher precision than a PID controller [19]. However, the implementation of a sliding surface for the sliding mode controller is deemed to be hard to implement and the performance difference between PID and sliding mode controllers is not a major concern in the current application. Model predictive control controllers will not be used due to the lack of a model, and where an empirical model is too costly to develop. Hybrid control will not be used either, due to the lack of clearly defined states.

5. Future work

This chapter describes the future work that is up ahead in the second semester covered by this project. The work done during the first study period provides a base and general plan for the upcoming project. Work to be done will include further evaluation of the proposed concepts and work on implementation and the construction of a prototype.

5.1. Future organization

During the fall semester, the concept prototype will be developed and a test rig will be constructed. The approaches of splitting work and dividing the group into sub-groups will continue to be used to make work more effective.

The initial focus will be on the gripping mechanism and the yaw-joint respectively. It is planned to book weekly meetings with the stakeholders and more frequent meetings with the coach.

At the start of the fall semester, more time will be dedicated to deciding on one concept approach. The rest of the project run-time will cover the continuous development of our conceptual design. The group will be mainly divided into two parts, some will focus on actuation, and the rest will focus on the mechanical design of the gripper.

5.2. BOM and Purchasing

An overview of the expected bill of materials (BOM) and purchasing list is the following:

- Actuators, including servo motors (electric or pneumatic) and linear actuators
- Electric components and MCU for control of the actuator
- Sensors for position detection
- Materials for gripper

5.3. Project plan for fall term

From September on, the main focus of the group will be concretizing the general conceptual choices and getting started with the design process. As soon as the design of the prototype is completed, work on a test rig for demonstration purposes will be started and run in parallel with the construction of the prototype. The report writing is aimed to be conducted continuously. Towards the end of the semester, the construction of the prototype and test rig will be the main focus together with the report writing. From the key dates provided to the group by the course responsible, a preliminary GANTT chart has been created in the planning software JIRA, included in Appendix E.

5.4. Risk analysis

Conducting a proper and concurrent risk analysis is important in all project work. The risks need to be identified, evaluated, and appropriately dealt with. A model for evaluating risk is the risk assessment matrix. Where on one axis is the likelihood for the risk to occur and on the other is the severity of the risk. The severity as well as the likelihood can be divided into four different levels (1-4). To create a proper evaluation each risk is given a risk value (RV) calculated as.

$$\text{RV} = \text{likelihood level} \cdot \text{severity level}.$$

The risks can then be divided into different categories depending on their risk value. A higher risk value means a more closely observed risk. In the first part of the project, the following risks were identified, evaluated, and ranked. There are multiple actions to be taken when considering risk management, risks can be avoided, reduced, accepted, or moved. It is also necessary to integrate risk planning into project planning [23].

Table 5.1.: Risk analysis in Fall semester

Risk	Likelihood	Severity	Risk value	Action
ABB Arm not functional	3	4	12	Monitor actively
Delivery problems of parts	3	3	9	Monitor closely
Scope creep	2	3	6	Stakeholder meetings
No group alignment	3	4	12	Weekly meetings

During the spring semester, there have not been many areas where risks were present or imminent. However, since the project is open-ended and continuous over a long period risks will arise. Raising the need for good and conscious risk assessment during future work in the fall semester.

Bibliography

[1] Richard P. Evershed et al. "Earliest date for milk use in the Near East and southeastern Europe linked to cattle herding". In: *Nature* 455.7212 (Sept. 2008). Number: 7212 Publisher: Nature Publishing Group, pp. 528–531. ISSN: 1476-4687. DOI: 10.1038/nature07180.

[2] Alessia Cogato et al. "Challenges and Tendencies of Automatic Milking Systems (AMS): A 20-Years Systematic Review of Literature and Patents". In: *Animals* 11.2 (Jan. 31, 2021), p. 356. ISSN: 2076-2615. DOI: 10.3390/ani11020356.

[3] *20 Years of VMS - DeLaval*. URL: https://www.delaval.com/en-au/learn/campaigns/20-years-of-vms/ (visited on 04/27/2023).

[4] *DeLaval VMS™ Series - DeLaval*. URL: https://www.delaval.com/en-gb/discover-our-farm-solutions/milking/delaval-vms-series/ (visited on 04/27/2023).

[5] SIS - Svenska Institutet för Standarder. *General principles for design – Risk assessment and risk reduction*. Nov. 22, 2010.

[6] Shannon Baker. *How Cows Are Milked*. The Dairy Alliance. Mar. 24, 2021. URL: https://thedairyalliance.com/blog/how-cows-are-milked/ (visited on 05/03/2023).

[7] Janet Beekman Robert Bodde. *Milking automation is gaining popularity*. Dairy Global. Jan. 15, 2015. URL: https://www.dairyglobal.net/dairy/milking/milking-automation-is-gaining-popularity/ (visited on 04/28/2023).

[8] *amr-a-system-approach.pdf*. URL: https://www.delaval.com/globalassets/inriver-resources/document/brochure/amr-a-system-approach.pdf (visited on 05/03/2023).

[9] *Lely (company)*. In: *Wikipedia*. Page Version ID: 1151924464. Apr. 27, 2023.

[10] Lely. *lely_astronaut_a5_e_en.pdf*. URL: https://www.lely.com/media/filer_public/88/fc/88fca176-5afb-40eb-bf73-bfe77999c383/lely_astronaut_a5_e_en.pdf (visited on 05/03/2023).

[11] *GEA Group*. In: *Wikipedia*. Page Version ID: 1151801042. Apr. 26, 2023.

[12] *GEA DairyRobot R9500 Milking Robot — Intelligent Automatic Milking*. GEA engineering for a better world. URL: https://www.gea.com/en/products/milking-farming-barn/dairyrobot-automated-milking/dairyrobot-r9500-robotic-milking-system.jsp (visited on 05/03/2023).

[13] D. Kumar. *Mechanical Engineering and Mechatronics Handbook*. MLI Handbook Ser. Bloomfield: Mercury Learning & Information, 2022. ISBN: 978-1-5231-4742-7.

[14] Pierre Letier et al. *Bowden Cable Actuator for Torque-Feedback in Haptic Applications.*

[15] Liam Cope. *Advantages and Disadvantages Of Mechanical Linkages*. Engineer Fix. May 16, 2022. URL: https://engineerfix.com/mechanical/linkages/advantages-and-disadvantages-of-mechanical-linkages/ (visited on 05/01/2023).

[16] *Cam and Follower: Know Working, Types, Advantages, Applications*. Testbook. URL: https://testbook.com/mechanical-engineering/cam-and-follower-mechanism-types-and-application (visited on 05/01/2023).

[17] Fan Yu Chen. "Gripping mechanisms for industrial robots". In: *Mechanism and Machine Theory* 17.5 (Jan. 1982), pp. 299–311. ISSN: 0094114X. DOI: 10.1016/0094-114X(82)90011-8.

[18] Santhakumar Raja. *Magnetic Grippers in Robotics*. Theteche.com. Mar. 18, 2022. URL: https://theteche.com/magnetic-grippers-in-robotics-theteche-com/ (visited on 04/30/2023).

[19] Chia-Hua Lu and Yean-Ren Hwang. "Modeling of an air motor servo system and robust sliding mode controller design". In: *Journal of Mechanical Science and Technology* 26.4 (Apr. 2012), pp. 1161–1169. ISSN: 1738-494X, 1976-3824. DOI: 10.1007/s12206-012-0220-2.

[20] Guangbin Shao et al. "3D printed magnetically-actuating micro-gripper operates in air and water". In: *Additive Manufacturing* 38 (Feb. 1, 2021), p. 101834. ISSN: 2214-8604. DOI: 10.1016/j.addma.2020.101834.

[21] *Demagnetization - Basics and Know-How — Maurer Magnetic AG*. Maurer Magnetic. URL: https://maurermagnetic.com/en/demagnetizing/technology/demagnetisation-technology/ (visited on 05/15/2023).

[22] ABB Robotics. *Product specification - IRB 120*. Mar. 9, 2023.

[23] Ganesh Vaidyanathan. *Project Management Process, Technology, and Practice*. Pearson Education, 2012. 672 pp. ISBN: 978-0-13-305545-0.

A. Stakeholder requirements

The stakeholder DeLaval has several requirements for the deliverable of the project. The following requirements have been discussed and decided on:

- Robustness:
  - The arm should be robust enough to sustain cows stepping on it and kicking it.
  - The arm should be robust enough to sustain the barn environment, consisting of various chemicals, pressure washing, straw and manure, and a temperature range of -5 till + 45°C.
- The machine should be safe according to "Maskindirektivet".
- Dynamics:
  - The overall range of motion of the complete robot should not be affected.
  - The state of the robot arm and end-effector should remain feedback-controlled.
- The size (especially height and width) and weight of the end-effector shall not increase too much and preferably be equal or lower. }
- Hygiene:
  - The design of the end-effector shall include few dirt pockets and crevices.
  - The design of the end-effector should make it easy to clean with a pressure washer.
- The prototype should be serviceable and easy to assemble.
- The prototype should be demonstrated on a test rig.
- The prototype should perfectly hold the cups.

B. Course learning requirements

The HK Course aims to:

- Provide the student with the professional skills needed to create innovative mechatronics products.
- Through a close cooperation with an industrial or research partner, the student is expected to work on a complex product development project, while learning to get organized within a large development team.
- This multidisciplinary work is realized by combining mechanical design, with control, electronics, and software engineering.

The student should after the course be able to:

- Apply knowledge and skills from earlier courses, as well as learn to acquire new ones on demand.
- Identify, compare and critically assess aspects of an engineering problem, towards making design decisions.
- Describe, compare and critically examine various product development processes.
- Work through all aspects of an engineering development process from requirements engineering to verification and validation.
- Apply and evaluate support methods in complex product development.
- Design and develop prototypes.
- Use professional tools necessary for the development of mechatronics products.
- Get organized, lead and become part of a cross-technical and complex development project.

C. Project description

The project description included on the following pages is the brief initially presented by DeLaval at the stakeholder pitch.

Background

This project focuses on the third link of the robotic arm (fig 1b) of DeLaval´s VMS V300 Milking System. The working range of the robot must be within reach of the cow, as well as the area where human operators can be present. This requires the robotic arm to be tough enough to sustain force and impact from cows kicking and stepping on it, yet still be compliant (soft) so as not to hurt animals or humans.

The robotic arm must be able to cope with the barn environment, which consists of various chemicals, pressure washing, straw and manure, and a temperature range of -5 till + 45-degrees C.

The robot has three proportional controlled hydraulic cylinders with encoders for positioning link 1-3. On the third link the are two additional links which can both reach two discrete positions. No positioning sensors are put on the link four and five.

The end effector of the robot arm carries a camera for vision control, a gripper to carry cleaning and milk cups, spray nozzles for teat treatment, a tube holder and a gripper sensor to indicate if the cup is fetched properly.

The main function of the robotic arm is to attach milk cups onto the teats of the cow. To prepare the teats for milking the robot also cleans the teats by holding a specific cleaning cup onto the teats. The arm also supports milk tubes during milking and after milking is complete, the robot applies disinfectant onto the teats to protect the cow from infections and bacteria present in the barn environment.

Figure 1a: DeLaval VMS

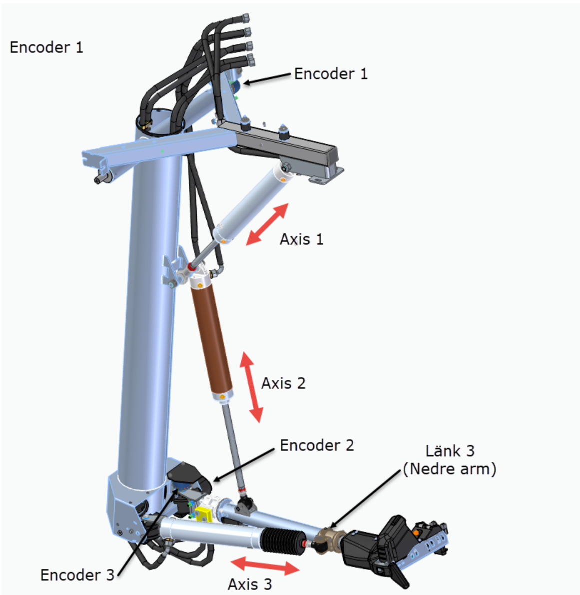


Figure 1b: DeLaval VMS Robotic arm

Project scope

1. HK project will investigate possibility for use of alternative materials and technical solutions for actuators, sensors and other parts of link 3 while sate the implications of those alternatives.
2. Make a physical robotic link of the suggested concept.

Stakeholder Contact Information

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Key words:

- Range of motion must be kept.
- Fewer details.
- Feedback of position.
- Hygienic design, meaning few dirt pockets and possible to easily wash of.
- Cow friendly.
- Energy sufficient and sustainable.
- Low weight.
- Robust.
- Serviceable.

Overview of link 3, current design

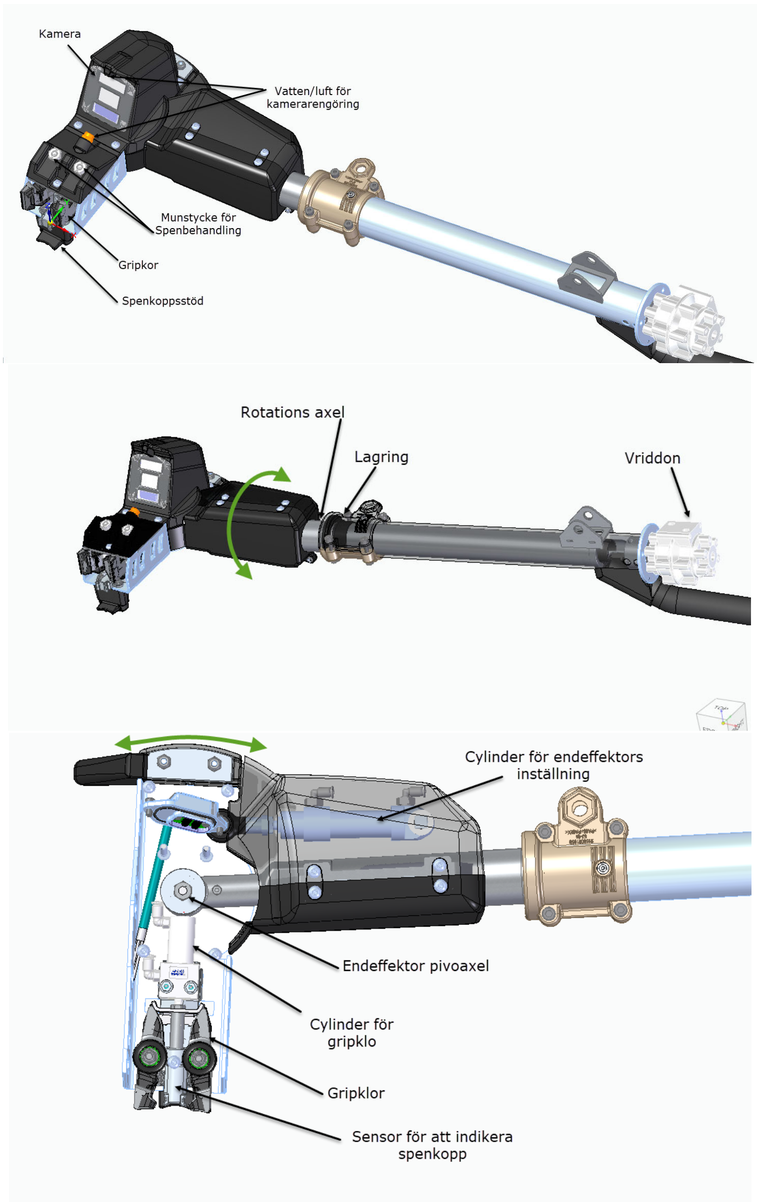

Figure 2: Current design of link 3

Mechanical interface between end effector and teat cup is a claw/handle.

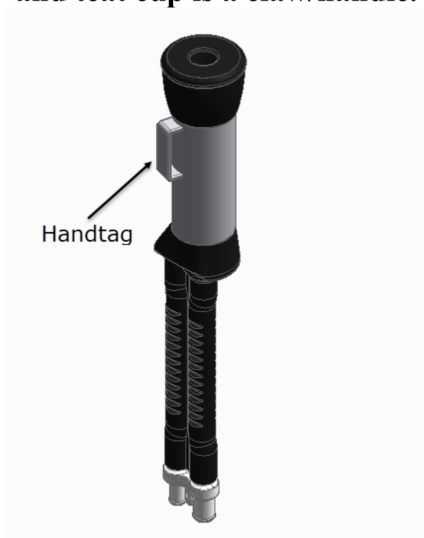

Figure 3: Teat cup

D. Concept sketches

The group produced a number of concept sketches for the yaw-joint actuation. These can be seen in Fig. D.1 and are namely showing the three concepts of introducing direct drive, bowden cables and a chain drive to the end-effector.

(a) Direct drive (b) Bowden cables (c) Chain drive

Figure D.1.: Concept designs for the yaw-joint

E. GANTT

For the work during the Fall semester in the HK project, a GANTT chart was created. The planned work is based on the course deliverables and deadlines and is mainly divided into work on the concept prototype, test rig, and report writing. For the prototype and test rig, an evaluation phase, concept design phase, and construction phase are planned individually.