AALBORG UNIVERSITY

MASTER THESIS

Redesigning of a mechanical subsystem to ensure manufacturing compatibility with injection molding

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A thesis submitted in fulfillment of the requirements for the degree of Master's in Manufacturing Technology, Mechanical Engineering

from the

Aalborg University
Department of Materials and Production

May 31, 2023

Declaration of Authorship

I, Mayuresh SHRIKRISHNAN, declare that this thesis titled, "Redesigning of a mechanical subsystem to ensure manufacturing compatibility with injection molding" and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
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Signed: Mayuresh Shrikrishnan

Date: 31/05/2023

“To achieve great things, two things are needed: a plan and not quite enough time.”

- Leonard Bernstein

AALBORG UNIVERSITY

Abstract

Faculty Name
Department of Materials and Production

Master's in Manufacturing Technology, Mechanical Engineering

Redesigning of a mechanical subsystem to ensure manufacturing compatibility with injection molding

by Mayuresh SHRIKRISHNAN

Food for consumption must go through a series of processes before it can be sold to consumers. These processes, when done manually, are labor and cost intensive. Additionally, the level of reliability and accuracy of manually performing these processes are low. In the past few decades, companies have incorporated technological advancements into food processing equipment resulting in reliable, accurate, automated and cost-effective methods of performing these processes.

While there is no doubt about the benefits it offers, since the equipment is a combination of various mechanical, electrical and computer systems working together, it has an expensive cost price. Hence, companies that manufacture and supply these advanced food processing systems are always on the lookout for effective ways to optimize the cost of their already created machines or the ones to be developed. Marel is one such company that manufactures food processing systems and is working on cost optimizing their products. This thesis will focus on cost optimizing one of Marel's products or machines by looking into design for manufacturing methods.

Acknowledgements

I would like to express my deepest gratitude and appreciation to Casper Schou for his supervision throughout my master's program spanning three semesters. Casper has played a pivotal role in shaping my academic journey, and his guidance during the development of this thesis and the writing process has been truly invaluable.

I would like to express my heartfelt thanks to Peter Thisted Svoldgaard, my external supervisor from Marel, the company with which I collaborated for this thesis. Peter has been an exceptional mentor, providing guidance and support throughout the entire thesis process, from the mechanical design development to prototype creation and testing. I am grateful for his mentorship and for providing me with the necessary resources to successfully undertake this research.

Furthermore, I would like to acknowledge the contributions of the Mechanical Design Team at Marel. Their close collaboration, insightful discussions, and constructive feedback have greatly enriched this thesis. I am grateful to Dimitra Alexouli, Rasmus Andersen, Agnar Ferchland, Thomas Lanzky, Preben Nielsen, Mads Dahl, and Christian Hansen for their willingness to work alongside me and for their openness and support in addressing my questions and inquiries. A special acknowledgment goes to Christian Hansen for his efforts in contacting and arranging meetings with external stakeholders, enabling me to receive expert consultancy on the thesis work.

I am deeply thankful to Casper Schou, Peter Thisted Svoldgaard, and the Mechanical Design Team at Marel for their significant contributions to the completion of this thesis, which would not have been possible without their guidance, support, and collaboration.

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List of Abbreviations

DFM	**D**esign **F**or **M**anufacturing
IM	**I**njection **M**olding
TSA	**T**otal **S**urface **A**rea
ROI	**R**eturn **O**n **I**nvestment
POM	**P**oly**O**xy **M**ethylene
IDA	**I**ngeniørforeningen i **Da**nmark

Chapter 1

Introduction

The subject of this thesis is to perform cost optimization on one of the machines (Salmon Deheader) manufactured and sold commercially by Marel Fish. Marel Fish is a sub-branch of the company Marel that focuses on the development and production of fish processing equipment. Cost optimization is a recent area of focus that the company has been working on and the motivation behind it is to create savings on the manufacturing costs of their products.

Cost optimization, in this case, will be performed by focusing on Design for Manufacturing (DFM). Many of the sub-systems in the Salmon Deheader are presently being manufactured by expensive methods like milling. Thereby, contributing to an expensive final product. The thesis will investigate relatively cheaper alternatives to design the sub-systems. After identifying the suitable option, the thesis will perform a DFM case which will include redesigning of specific sub-systems to manufacture them with the proposed alternate method followed by their testing in the main system i.e., the Salmon Deheader machine.

1.1 About Marel

Marel is a machinery manufacturing company specializing in developing advanced processing systems for poultry, meat, and fish. The company was founded in Iceland in 1983 by a group of young engineers who were focused on developing systems to improve and automate fish food processing. (Stefán Tómas Franklín (2020))

FIGURE 1.1: Marel

Initially, the company used to produce and sell equipment solely for fish processing but eventually, expanded to selling equipment for meat and poultry industries as well. Marel's manufactured equipment or machines are capable of performing a range of processes necessary for the conversion of raw meat into a consumable and marketable product. The processes, namely, are weighing, cleaning, trimming, cutting, packaging, labelling. The company also makes revenue by providing aftermarket servicing of their products. Furthermore, the company offers software solutions for tracking and managing all operations in a production plant.

The company, as of February 2023, has over 7000 employees and has a global presence with offices in over 30 countries, Marel (2023). In the past two decades, the company has acquired multiple companies. The acquisitions have either been of rival companies to increase Marel's market share or of companies from other markets that Marel intends to be part of.

1.2 Marel's Operations

The company's operations are segmented into three main departments – Marel Fish, Marel Meat and Marel Poultry, Stefán Tómas Franklín (2020). The products created by Marel mainly service these three industries with the aim of providing maximum efficiency and productivity in food processing to their customers.

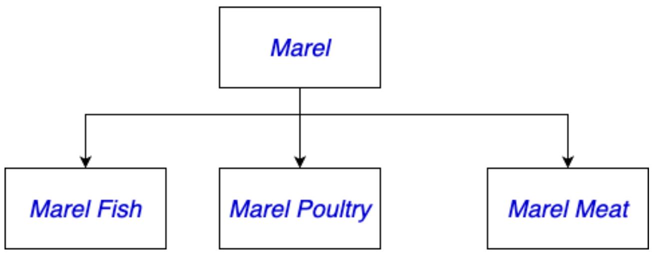


FIGURE 1.2: Marel's different departments

The products and services Marel offer to these industries can range from individual machines for specific processes like scales (for weighing) and cutters (for cutting) to complete processing lines. The complete processing lines cover the whole processing of the animals, from primary processes like slaughtering to secondary processes like filleting or portioning to tertiary processes like packaging or labelling. a comprehensive explanation of primary, secondary, and tertiary processes, Marel (2023). A comprehensive explanation of primary, secondary, and tertiary processes has been provided in the next section. Marel also provides aftermarket care to its customers which involves services, spare parts, maintenance and training for their staff.

1.3 Marel Fish

The Marel Fish segment deals with developing and selling processing systems for various types of fish. The machines are mainly made for whitefish and salmon. Marel's office in Støvring, DK is where the teams responsible for Marel Fish are situated. The goal of Marel Fish is to create and sell machines for all the processes involved in fish food processing from depalletizing boxes of frozen fish to packaging deliverable fish.

The company caters for low-end as well as high-end food processing solutions. The processing solutions are essentially standard machines that automate the various processes involved in raw fish meat processing. There are three types of processes - primary, secondary and tertiary - and for each of the processes in these types, Marel aims to offer an automated solution. Primary processes consists of processes like weighing, grading, batching, etc. Secondary processes covers processes like deheading, trimming, desliming, portioning, etc. Tertiary processes refer to value adding processes like spicing and marinating, slicing (as per customer's size and shape specifications), forming, etc.

Marel currently has standardised machines for these processes but is always looking for adding new solutions by automating more such processes. The entire line of products or machines of Marel' Fish division for salmon fish has been shown in Figure 1.3.

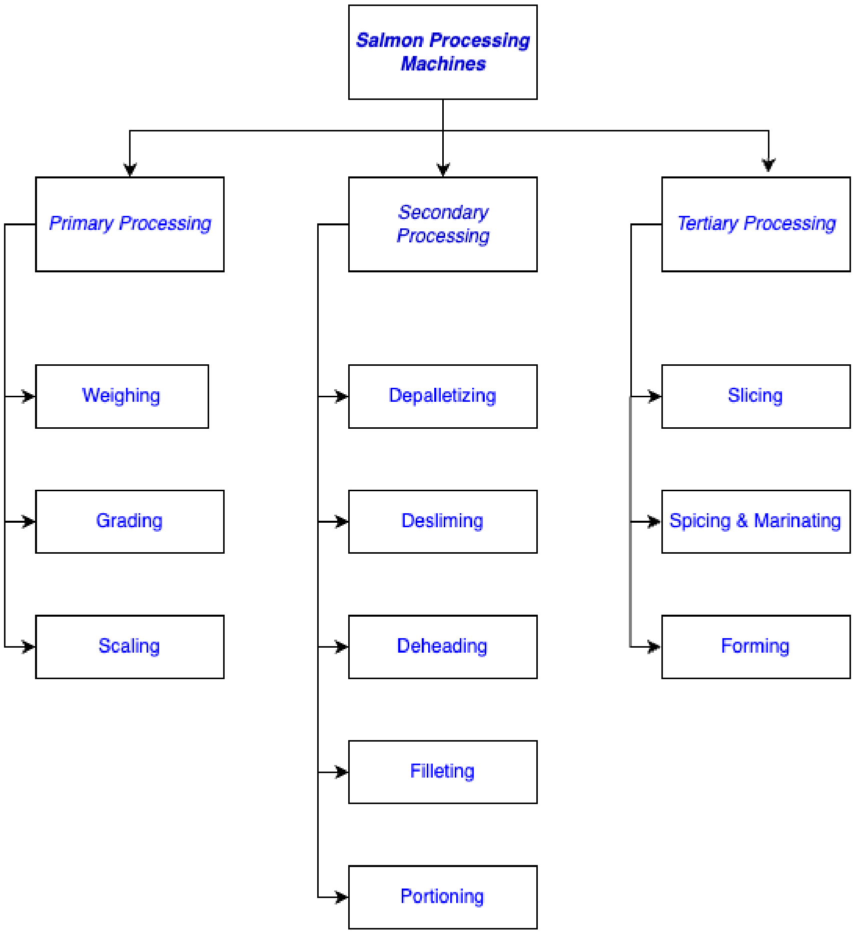


FIGURE 1.3: Marel's salmon processing machines

Some of the high-end machines currently manufactured are quite expensive to build, for example, the Salmon Deheader MS2721 V. Hence, it is of prime importance to the team to find effective ways to cut down the manufacturing costs of the machines to reduce the overall price. This challenge serves as the motivation for the thesis – cost optimization of the Salmon Deheader MS2721 V.

1.4 Objective

The main objective of the thesis, as mentioned above, is to cost optimize the Salmon Deheader machine. As identified by Marel, one of the integral mechanical subsystems of the Deheader has shown potential for cost savings if its manufacturing method could be changed from milling to injection molding (IM). This project will dive into that and be based on the principles of DFM. It will revolve around creating a new design of the subsystem such that it is compatible for IM.

The objective is stated below.

"The project aims to redesign a mechanical subsystem to ensure manufacturing compatibility with injection molding, employing Design for Manufacturing (DFM) principles."

1.5 Methodology

The following approach will be taken to achieve the above-mentioned objectives -

- Thorough study or analysis of the current subsystem in terms of performed functions and manufacturing cost.
- Creating a business case stating the investment, savings and Return on Investment (ROI) of having an injection molded subsystem. This would be done in association with the purchasing team at Marel and a few mold suppliers to get exact mold and material prices. A positive business case will serve as a motivation to the project and to carry out the next steps.
- Defining the design specifications for injection molding as well as other product specifications from Marel.
- Conceptualising various designs that conform to the previously defined design specifications.
- Selecting the most suitable design and designing its 3D model on Solidworks. This will be done in close association with the mechanical design team of Marel.
- Creating a physical prototype of the designed subsystem, after approval of the design, and testing it. The testing would be done by integrating the prototype into the main machine and its performance would be observed and studied.
- Making iterations in the design according to the test results, if needed, and testing the new prototype until satisfactory performance results are achieved.

1.6 Report Layout

This thesis report will document the complete work done in the thesis and will follow the same pattern as the methodology.

- The first chapter introduces the thesis along with its objectives and mission statement.

- The second chapter introduces Marel as a company and provides an in-depth study of the Salmon Deheader machine, its functioning and its subsystems that concern this project.
- Chapter three starts with introducing the various concepts and tools that will be utilized for this project like IM and Solidworks. Later, it defines design specifications for different domains like DFM, design for hygiene, design for modularity and design for wear and tear.
- The fourth chapter presents the designs that were looked into and the one that was selected as the main design concept. It further delves into discussing the creation of this selected design and explains the process followed to create it in a step-by-step manner which is influenced by the previously defined design considerations.
- Chapter five discusses the process of consulting with Marel's design team and external IM suppliers regarding the design and making changes based on their valuable insights.
- Chapter six states the aim, setup, method and expected results of the testing phase.
- Finally, chapter seven concludes the entire project and provides a brief summary along with key takeaways from the project.

Chapter 2

Analysis

2.1 Salmon Deheader MS2721 V

The MS2721 V is an equipment designed for the primary purpose of cutting and removing the heads of salmon fish, a process commonly known as "deheading." This is a crucial step in the processing of salmon, as (i) the head is typically considered an undesirable part of the fish for consumption; (ii) by removing the head, the fish can be filleted and portioned more easily, and the resulting product is of higher quality. Due to its importance in the fish processing industry, the MS2721 V deheading machine is considered a critical component of any modern fish processing line.

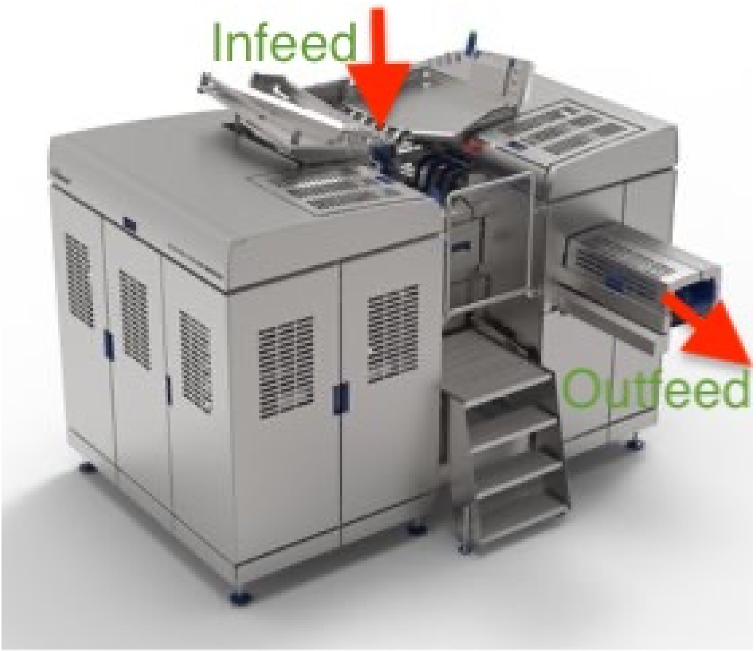


FIGURE 2.1: Deheader machine

Machine specifications -

- Can process 25 fishes per minute.
- Removes the head and tail of the fish.
- Removes the shoulder bone of the fish.
- Has an estimated cost price of DKK 4.5M.

2.1.1 Function

The deheader is primarily designed to remove the head and tail of a fish. To accomplish this task, it undergoes a four-step cutting process that involves cutting the neck, shoulder, and tail bones of the fish. Figure 2.2 gives an overview of the main processes involved in the deheader.

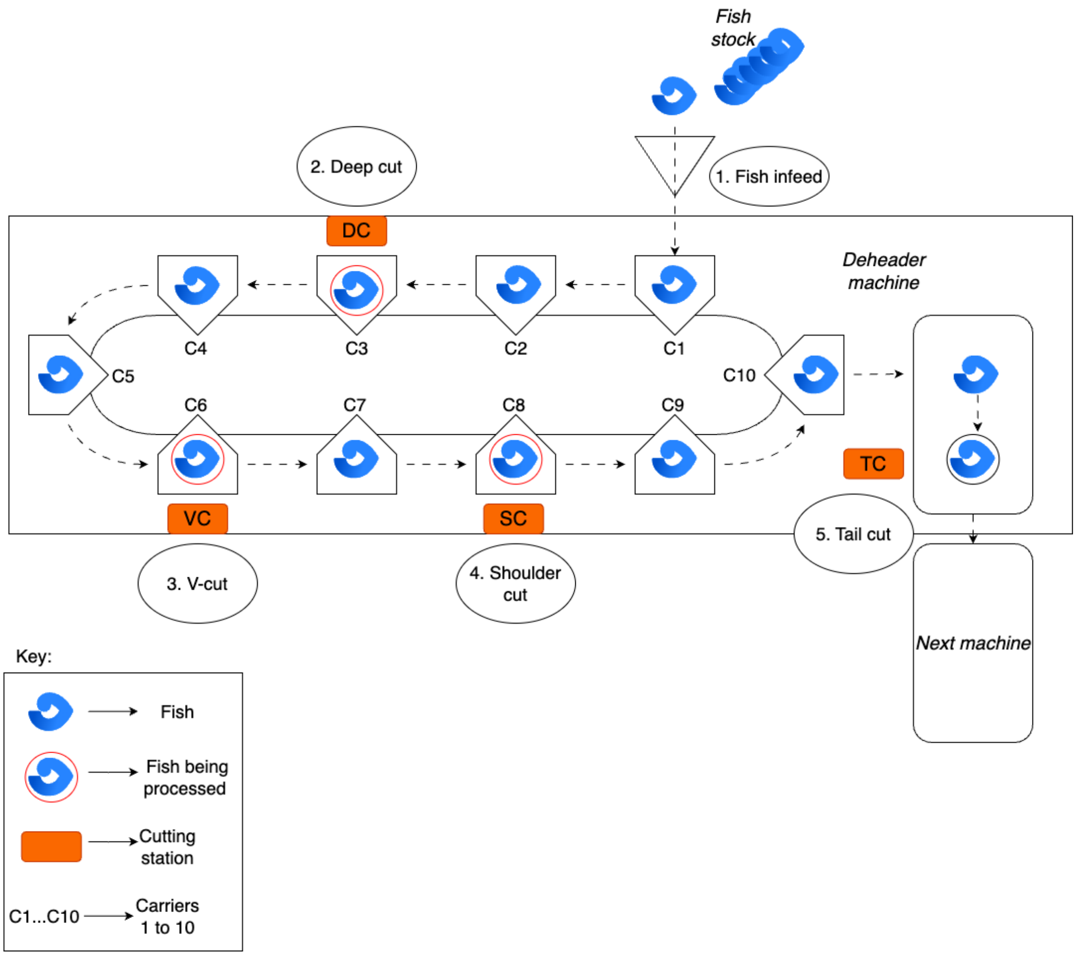


FIGURE 2.2: First deep cut made at the top side of the fish's head

The operational sequence commences with the operator placing the fish into the machine in a carrier, followed by the subsequent stages outlined as follows:

- The fish is grasped by one of the 10 carrier systems which are fixed to an elliptical conveyor belt and rolls around it starting from carrier location C1. The description of a carrier system is provided later in sub-section 2.1.2.
- There are cutting stations placed by some of the carrier locations.
- At the location of the third carrier position (C3), the first cutting station is present which is for the deep cut.
- At the location of the sixth carrier position (C6), the next cutting station is fixed which is for the V-cut.
- At the eighth carrier location (C8), the third cutting station is placed which accounts for the shoulder cut.

- Finally, when the fish is rolled to the tenth carrier location (C10), the fish is drawn out of the conveyor system and is placed on another flat conveyor system where the tail cutting station is present.
- At each cutting station, the cuts are performed and the final output after the tail cut station is a fish with its head and tail removed.

Subsequent sub-sections elaborate on each cut in detail, while also providing in-depth explanations of the carrier system, including its claws, mechanism, and structure.

Neck cut: Deep cut and V-cut

For the neck cut, there are two cuts involved. The first is a deep neck cut made on the top profile of the fish, and the cutting station located at the third carrier location (C3) as shown in Figure 2.2. The cut nearly separates the head from the body and is accomplished through the use of a motor-driven blade. The blade rotates at a set speed and rotates 360 degrees. The rotational speed, blade sharpness, and blade length all contribute to the creation of a deep cut in the fish. A visual representation of the blade used for this cut and the cut made on the top side of the fish is depicted in Figure 2.3.

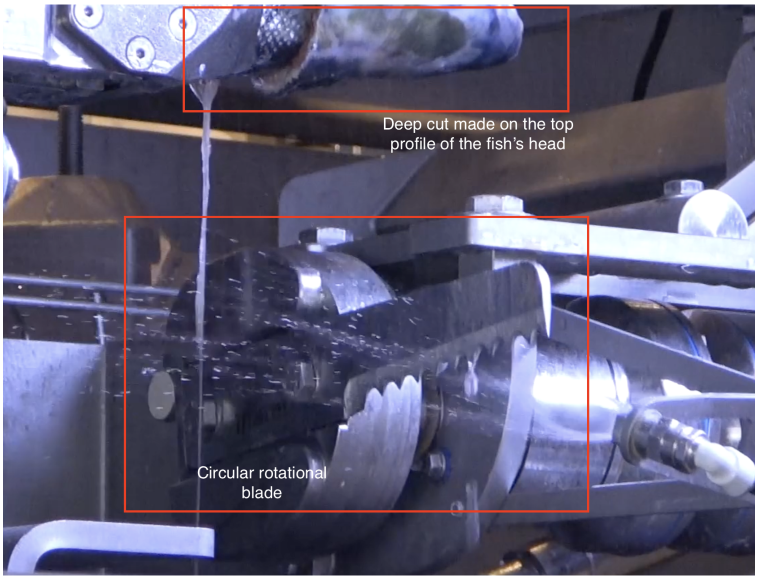


FIGURE 2.3: First deep cut made at the top side of the fish's head

The second is a V-cut that cuts the fish from its sides, shown in the Figure 2.4 and is located at the sixth carrier location (C6) as can be seen in Figure 2.2. The cut is performed by two circular rotational blades which are angled in a manner where the two blades create a 'V' cutting path. The blades are motor-driven. The cut completely splits the head off. To make sure the head does not fall off randomly, there is a plucking system that works alongside the V-cut blades. It plucks out the head after the cut and drops it at a destined area. Figure 2.4 shows the circular blades, positioned on either side of the fish, that perform the V-cut.

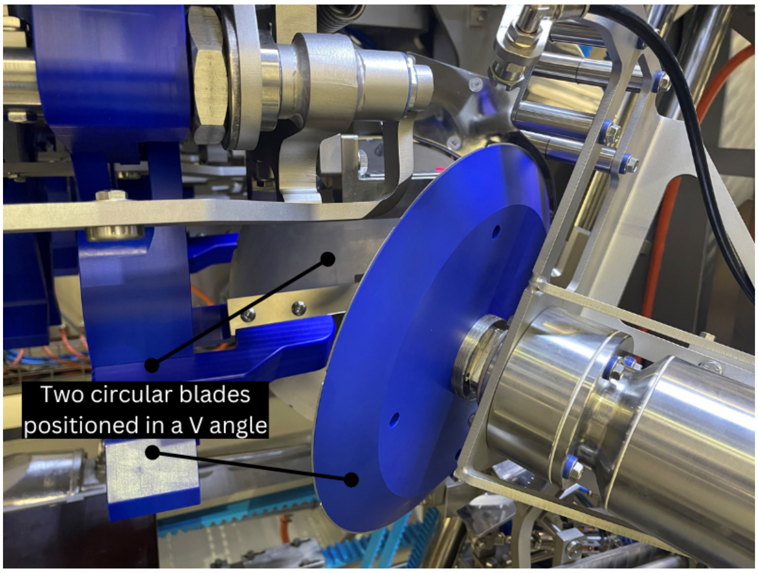


FIGURE 2.4: V-cut circular blades on both sides

Shoulder cut

The shoulder cut removes the shoulder bone which does not come off from the neck cut. It is a small piece of bone located at the front-top portion of the fish and must be removed before the next processes can be performed like filleting, slicing, portioning. The cut is an angled cut from the top of the fish. The angle is optimally set to get the maximum yield.

FIGURE 2.5: Two shoulder cut circular blades on each side of the fish

Tail cut

After the cuts, the fish is gently drawn out of the carrier with a mechanical system which looks similar to a tractor's claw. It moves in to the carrier at the tenth carrier location (C10 from Figure 2.2), draws the fish out onto a conveyor belt and sends it to the tail cutting station. At the station, a circular rotating blade performs the cut.

The next section will discuss the carrier and its functions.

2.1.2 Carrier system

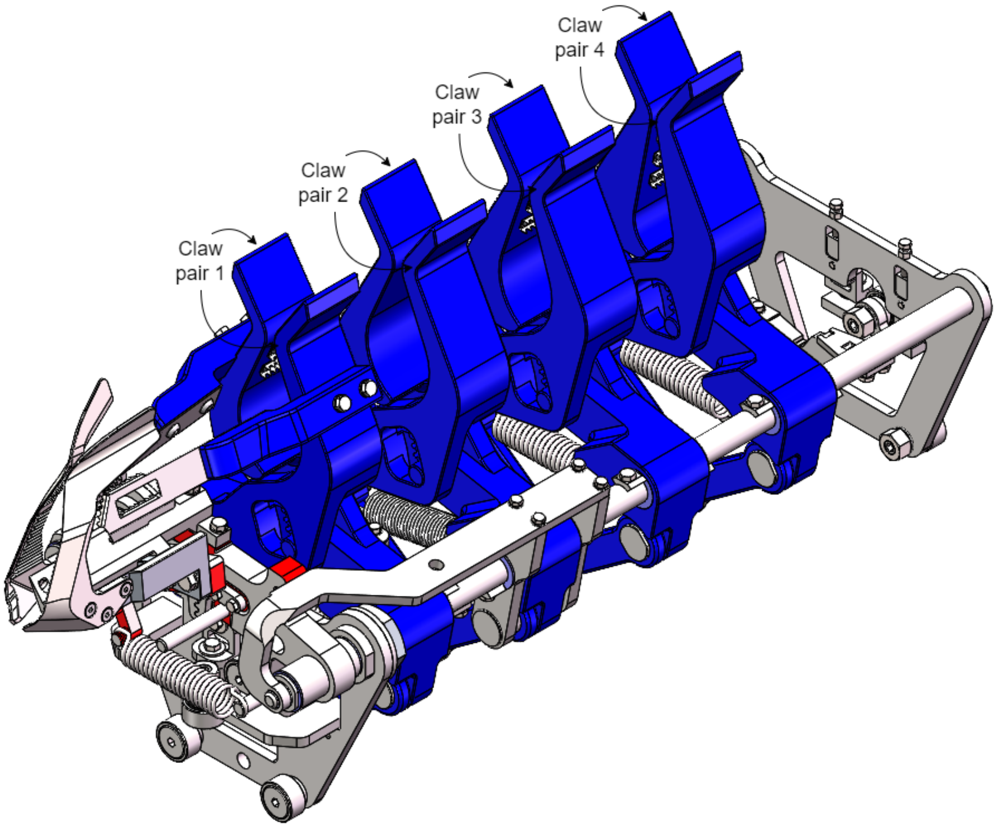


FIGURE 2.6: A single carrier unit with 4 pairs of claws

The carrier is essentially a mechanical system, consisting of a set of plastic (POM) claws, fixed on two parallely placed cylindrical rods, which has the sole function of holding the fish in a fixed position while it is being moved to different cutting stations. There are 4 pairs of claws in each carrier as illustrated in 2.6. The claws in pairs are positioned opposite each other.

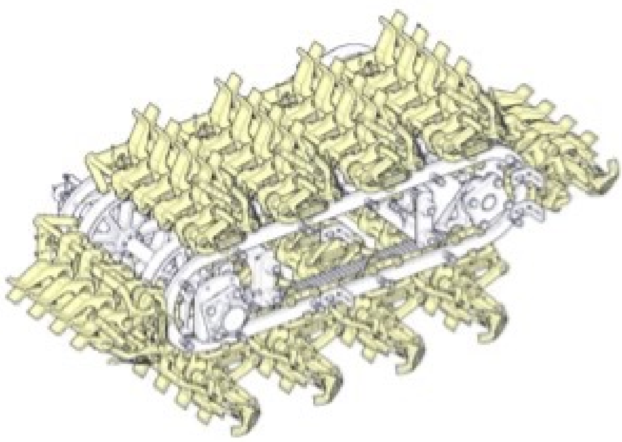


FIGURE 2.7: 10 set of carriers present in the machine

A single machine consists of 10 carriers, as depicted in 2.7, which facilitates the processing of up to 10 fishes at any time. These carriers are affixed to a conveyor belt, and the various cutting stations are fixed around the belt in a particular sequence - the neck (deep) cutting station, the V-cutting station, the shoulder cutting station and the tail cutting station as illustrated in Figure 2.8.

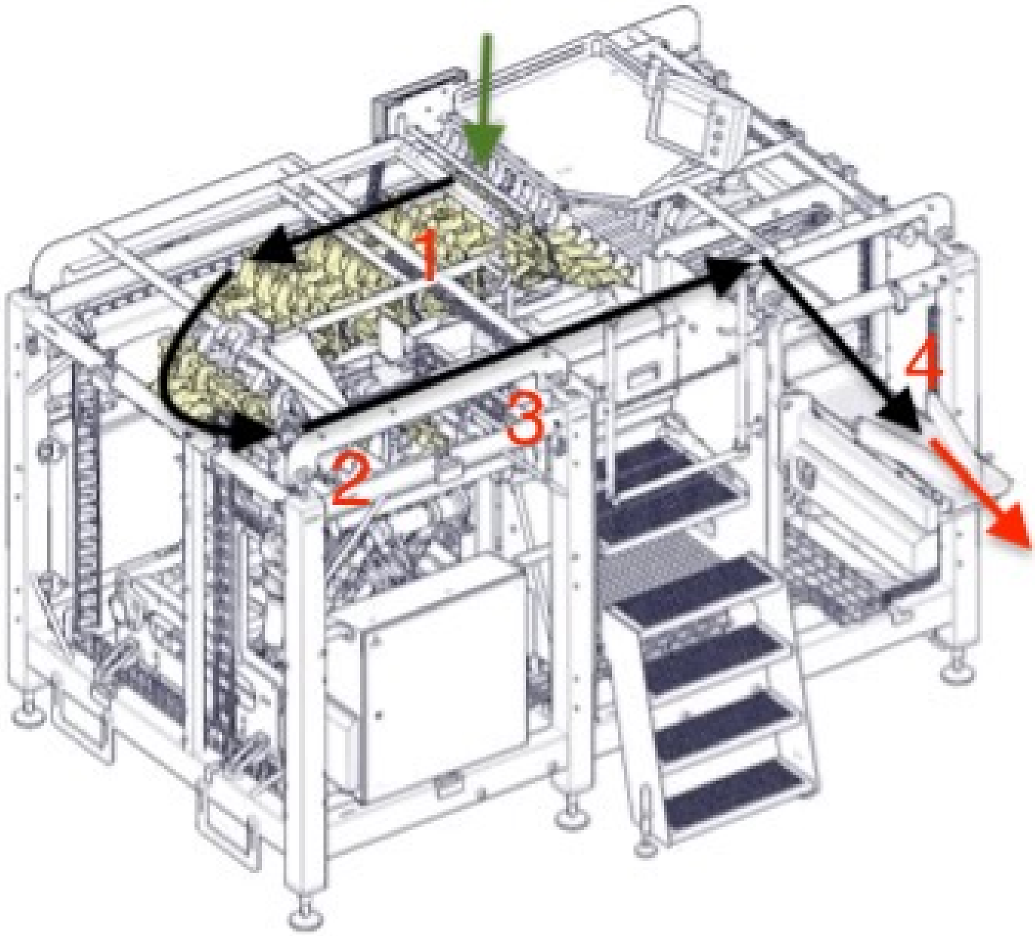


FIGURE 2.8: The process flow of the deheader machine: 1-Deep neck cut, 2-V cut, 3-Shoulder cut, 4-Tail cut

Claw mechanism

The mechanism of each claw pair is facilitated by a tension/extension spring, which allows for the opening and closing of the claws when subjected to external forces. It employs a spring-loaded mechanism. Under normal conditions, the default state of the claw pair is to remain closed as shown in Figure 2.9, owing to the normally compressed state of the spring. However, when a force is applied on the spring, it extends, thereby opening the two opposite claws, as seen in Figure 2.10.

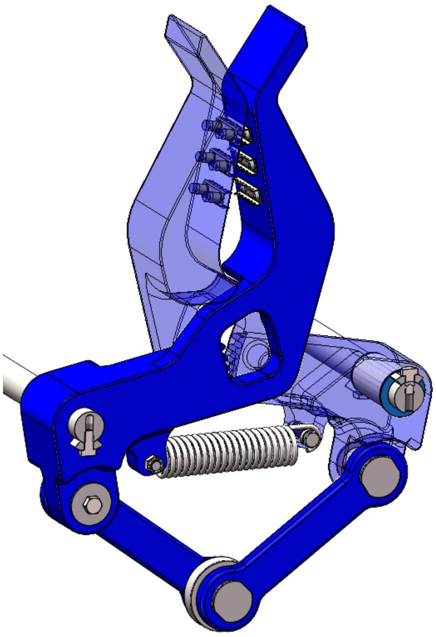


FIGURE 2.9: Claws in closed state

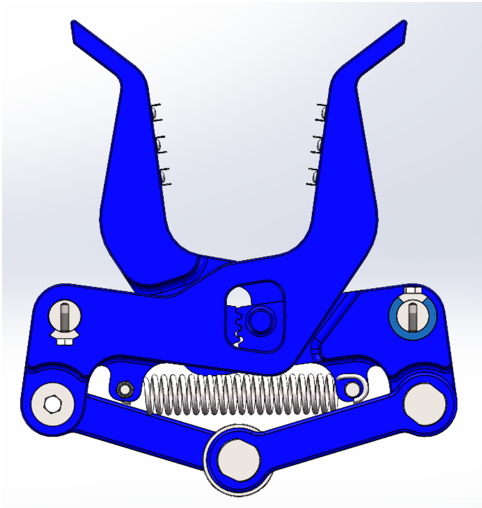


FIGURE 2.10: Claws in opened state

Conversely, it is also possible to indirectly extend the spring by applying force on the claws instead. This occurs with one of the claw pairs (second claw pair from Figure 2.6) where an operator feeds the fish into the machine by manually pushing and placing it onto the carrier situated at the in-feed station as shown in Figure 2.11. The claw, as a result, opens during the period of force application and subsequently closes when the operator ceases the force exertion. Notably, the spring in this specific claw pair possesses a comparatively lower strength value compared to the remaining three pairs. This deliberate design choice aims to minimize the force exerted by the operator when opening the claw pair to accommodate the fish. The primary function of this claw pair is to prevent any tilting of the fish when positioned within a carrier with all the claws fully open.

FIGURE 2.11: Operator placing the fish inside the carrier

The remaining three pairs open by a cam situated underneath the in-feed station. The cam is simply a solid curved structure positioned below the first carrier location (C1). It is placed such that it comes in contact with the circular end part of the claw system, termed as follower. The followers are shown in Figure 2.12. The figure also shows that there are only three followers in the four claw pairs as one of them (second claw pair) does not open by the cam-follower mechanism but through the operator's manual pushing of the fish.

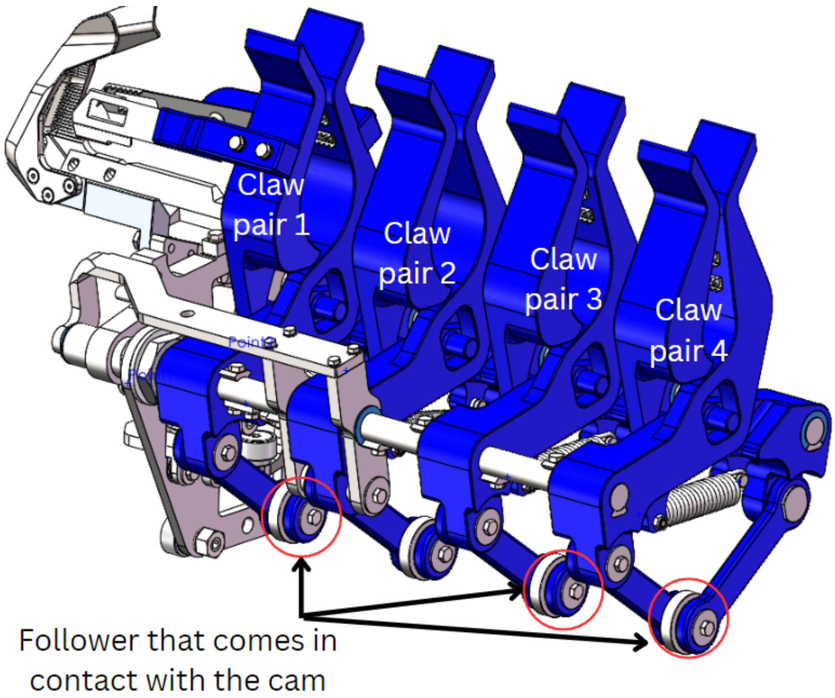


FIGURE 2.12: The three pairs subject to the cam-follower mechanism

When the carrier reaches the in-feed station (C1), it is subject to the action of the cam mechanism, which presses the follower upward because of its shape and opens the three pairs of claws, enabling the fish to be placed within the carrier. Once the fish has been inserted, the carrier is rolled forward, and the cam mechanism then retracts, resulting in the closure of the claws to secure the fish in place. This mechanism of claw activation and deactivation plays a pivotal role in the smooth functioning of the machine and ensures that the fish is securely held in place throughout the processing phase. A sketch diagram of the cam-follower mechanism has been shown in Figure 2.13.

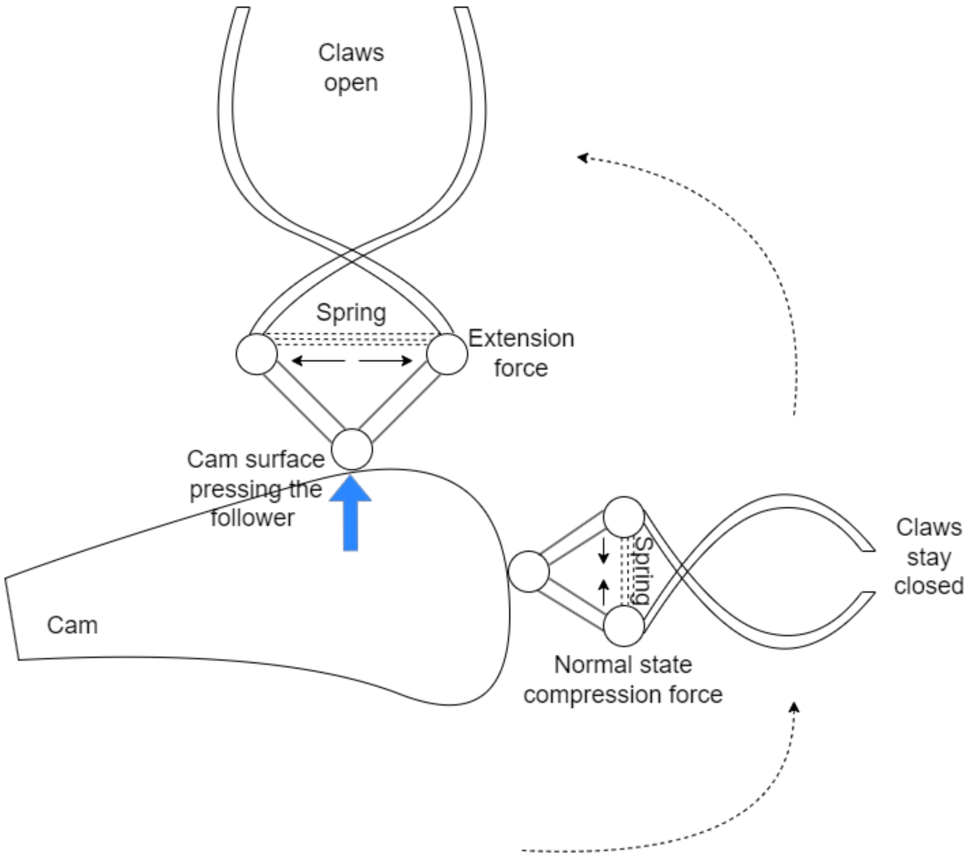


FIGURE 2.13: Functioning of the cam-follower mechanism

The functioning of the entire machine along with the claws's mechanism can be seen on: Deheader video.

Claw structure

In the present configuration, each carrier system is equipped with four pairs of claws, which exhibit distinct variations in cross-sectional thickness and functionality. The first two pairs are comparatively slender, whereas the last two pairs are thicker. The cross-sectional thickness disparity among the claws is illustrated in Table 2.1 and is also illustrated in Figure 2.14.

Component	Thickness (mm)
Claw pair 1	28.4
Claw pair 2	28.4
Claw pair 3	34.4
Claw pair 4	41.1

TABLE 2.1: Cross-sectional thickness of each claw pair

The variation in thickness among the claws is attributed to their respective responsibility in gripping specific cross-sectional sides of the fish. The thinner claws located at the front are designed to hold the relatively thicker portion of the fish, necessitating a larger open area between the two claws of a claw pair. Conversely, the claws positioned at the back are intended to secure the thinner back portion of the fish, requiring a smaller open area between the two claws. Consequently, these claws are fabricated with a thicker profile.

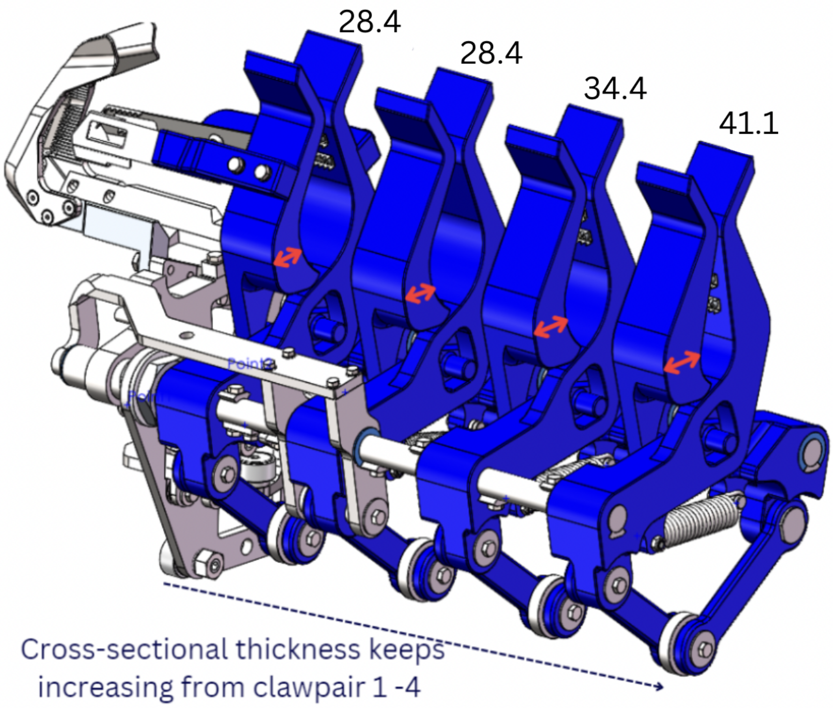


FIGURE 2.14: Cross-sectional thickness of each claw pair

Additionally, three of the claw pairs possess a tooth structure on their inner surface, serving as grippers to seize the fish. Figure 2.15 shows the design of the teeth gripper and Figure 2.16 depicts the teeth grippers fixed on the claws. The number of teeth mounted on a claw is dependent on the required degree of grip.

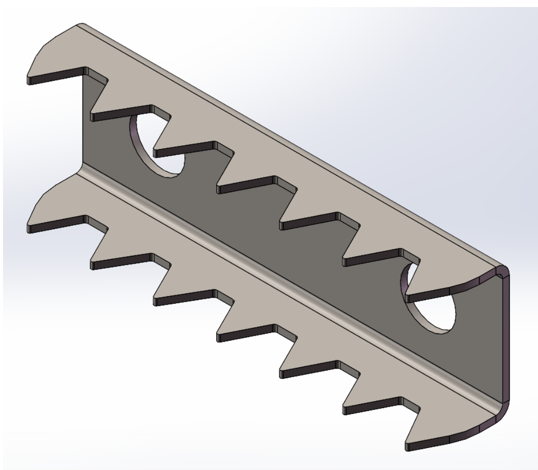


FIGURE 2.15: Teeth gripper

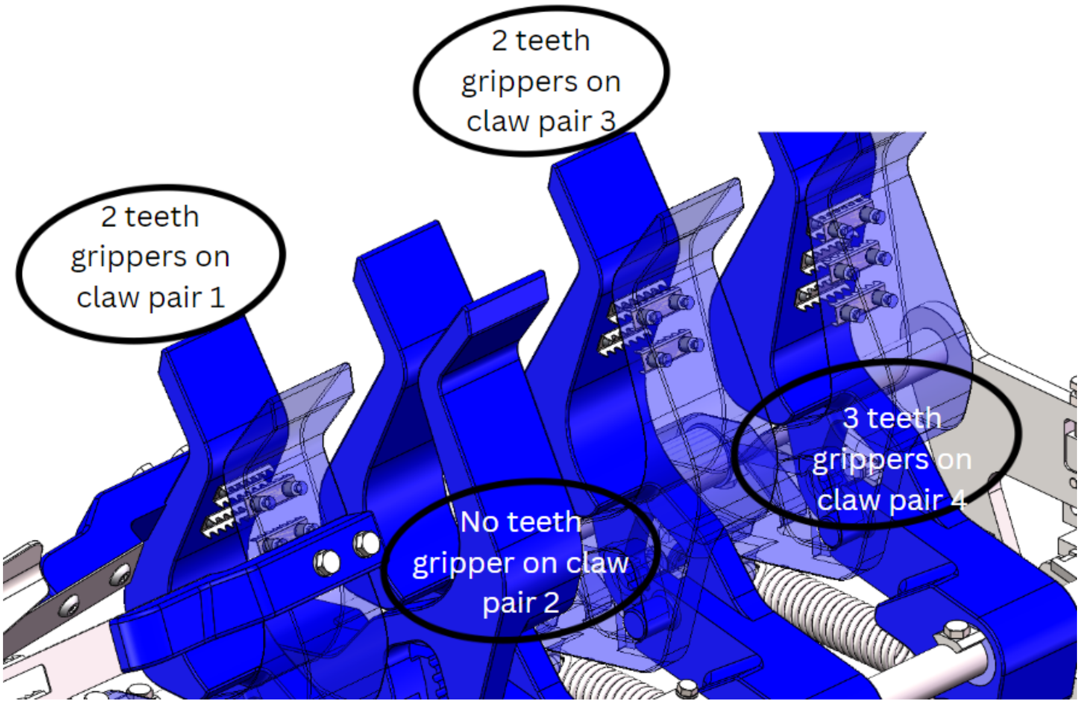


FIGURE 2.16: Teeth grippers on the claws

The first pair of claws is also outfitted with an externally mounted link (shown in Figure 2.17), which functions as a connector between the claw and the extended teeth gripper. It facilitates the movement of the extended teeth gripper according to the opening and closing of the claw pair. Both the teeth and the link are secured in place via bolts. The extended teeth gripper, as its name suggests, provides more grip on the fish.

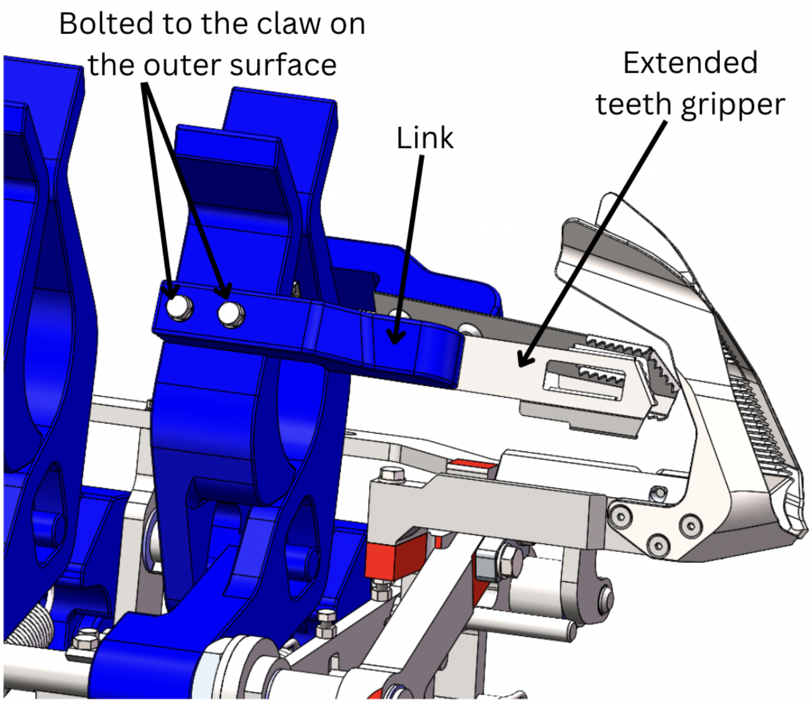


FIGURE 2.17: Extended teeth gripper attached to the claw pair 1

2.1.3 Process flow

Building upon the initial overview of the system's functionality and the detailed description of the carrier and claw mechanisms, the subsequent section outlines a concise step-by-step process flow as follows:

- The operator places the fish into the carrier positioned at the initial location (C1 in Figure 2.2). At this stage, three of the claw pairs (claw pair 1, 3, and 4 as depicted in Figure 2.12) are in an open position due to the influence of the cam-follower mechanism. The remaining claw pair (claw pair 2) opens upon direct force applied by the operator as they push the fish into the carrier.

- The purpose of keeping claw pair 2 closed when the fish is placed in the carrier is to ensure proper alignment, preventing tilting and maintaining an upright position of the fish at the center.

- Subsequently, the carrier advances from the first location (C1) to the second location (C2). As the carrier progresses, it disengages from the cam, resulting in the automatic closure of the three open claw pairs due to compression of the accompanying springs.

- As claw pair 2 lacks a cam mechanism, it briefly opens upon fish insertion by the operator, swiftly followed by closure.

- With all the claws closed, the carrier system proceeds to the third location (C3) where the first cutting station (deep cut) is present. After the cutting station executes the deep cut, the carrier is rolled forward.

- Advancing further, the carrier arrives at the sixth location (C6) where the V-cut is executed, removing the fish's head.

- Progressing to the eighth location (C8), the shoulder cutting station removes the shoulder bone from the fish.

- Ultimately, upon reaching the tenth location (C10), a claw withdraws the fish from the carrier, transferring it to a flat conveyor system, which subsequently transports the fish to the tail cutting station.

- At the tail cutting station, the fish's tail is sliced off, resulting in the final output or serving as input for subsequent processing machines such as a filleting machine.

- This iterative process is replicated for each fish placed in each of the ten carrier systems within the machine, enabling simultaneous processing of ten fishes at any given time.

2.1.4 Manufacturing method of the carrier subsystem

The manufacturing procedures of the carrier were found to be heterogeneous, with some mechanical parts being produced in-house and others being outsourced. Notably, most of the parts are manufactured in-house using primarily milling techniques. In addition, supplementary manufacturing techniques such as drilling and laser cutting are employed in the production of some parts.

The plastic (POM) claws, a constituent component of the subsystem, are also produced using milling techniques. It is noteworthy that the claws have been observed to be one of the most expensive parts of the carrier subsystem. Given this finding, the next section of this study will explore the pricing of the carrier subsystem to evaluate potential cost-saving opportunities.

2.2 Current manufacturing cost of the carrier

Table 2.2 provides a comprehensive overview of the carrier's components along with their corresponding manufacturing costs. It is apparent from the table that the claws are the most expensive component of the subsystem. The manufacture of a single claw incurs a cost of DKK 1,375. Each carrier comprises four pairs of claws, and a single machine contains 10 carriers, thus totaling to 80 claws per machine. This results in a significant cost of DKK 110,000 for the claws alone. Additionally, each claw necessitates a bushing set, which costs DKK 81.38 per set, translating to a total cost of DKK 6,670.4 for the required 80 sets. It is speculated by Marel that a different manufacturing method could significantly reduce the cost of claws.

Item	Price/unit (DKK)	Number of units/machine	Total price/machine (DKK)
Claws	1,375	80	110,000
Connector	125	80	10,000
Bushing	81.38	80	6,670.4
Spring	38.65	40	1,546

TABLE 2.2: Cost study of the carrier

Overall, the findings of this study highlight the substantial costs associated with the production of carrier claws in the machine. The potential cost savings that could be achieved through the implementation of alternative manufacturing methods warrant further investigation. The next section will provide a comprehensive analysis and elaboration on an alternative manufacturing method - plastic injection molding.

2.3 Proposed alternative - Injection Molding

During the course of exploring cost-effective methods for the manufacturing of claws, the injection molding process emerged as a viable option. It was also the first suggestion by Marel's team. Injection molding entails the utilization of plastic pellets that are subjected to high temperatures and injected into a mold, following which the molded part is cooled and ejected. The molds are opened for ejection and subsequently closed for the removal of the part, with the process being reiterated to produce parts that are identical in form. In Chapter 3, injection molding and its selection has been discussed in more detail.

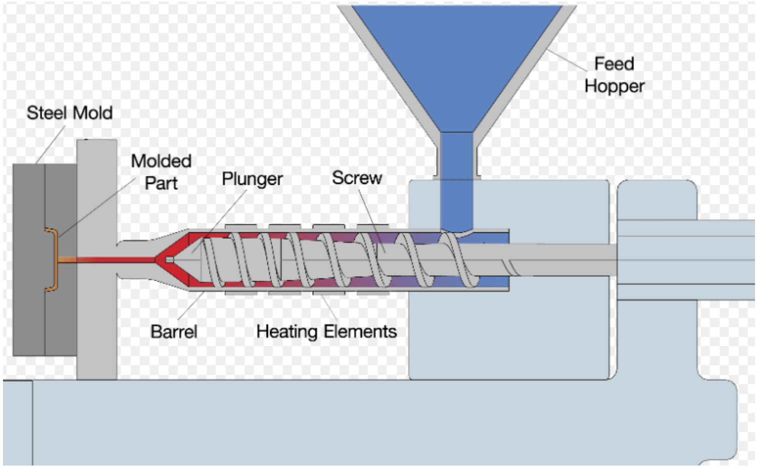


FIGURE 2.18: Basic illustration of the injection molding process

To adopt the injection molding method, Marel would need to invest in a mold and establish a partnership with an injection molding supplier who would keep the mold at their facility and use it to produce the claws as needed. Although the mold represents a significant portion of the investment, the production cost per unit can be reduced to as low as 40-50 DKK, rendering the investment financially feasible considering the projected sales volume of the machines in the future. An estimated cost of investment for the injection molding method is presented in the subsequent section.

2.4 Estimated cost of claws with injection molding

In the case of manufacturing claws using injection molding, there are several key areas where expenditures must be made. These include the purchase of the necessary molds, engineering cost to redesign the part, establishing a partnership with a supplier to produce the parts, and investing in any additional manufacturing processes required for claw production, such as drilling of holes in the claw. Since Marel owns resources for the additional manufacturing processes and does not have to outsource it, the cost is expected to be low.

To provide a comprehensive breakdown of the financial investments required for this project, Table 2.3 has been provided below. The table highlights the specific areas where expenditures will be necessary, along with the estimated costs associated with each.

Area of expenditure	Estimated expenditure (DKK)
Mold	75,000-100,000
Supplier's selling price per part	40-50
Additional rework	Cannot be determined yet
Engineering costs	approx. 144,0000

TABLE 2.3: Investment breakdown

From Table 2.3, it is evident that the total estimated investment required for the project of manufacturing claws using injection molding would be around 100,000 DKK, on the higher end, with additional expenses coming from supplier's selling price per part and additional rework. The prices were derived by guesstimates of Marel's mechanical design team based on their past experience and industry knowledge.

The estimation of engineering costs for the redesigning project can be calculated by multiplying the number of hours dedicated to the project with the hourly salary that Marel would typically allocate to its engineers. The project, equivalent to 30 ECTS credits, corresponds to a total of 825 hours, considering that 1 ECTS credit corresponds to 27.5 hours of work. Out of the total 825 hours, it can be assumed that 50% is allocated to report writing, consultancy with suppliers, collaboration with Marel's mechanical design team, research work, and other project-related tasks. The remaining 50% is attributed to design hours, which amounts to 412.5 hours.

Considering an approximate average pay rate of DKK 350 per hour for a mechanical engineer (estimated based on inputs from Marel's team and references to IDA guidelines), the total engineering cost would amount to approximately DKK 144,000. However, it is important to note that, in this case, the design work is being undertaken by a student, and according to Danish regulations, students cannot be remunerated for projects or internships. Therefore, the mentioned cost figure becomes irrelevant, as Marel is not obligated to provide payment in this context.

2.5 Financial Analysis

This section is intended to analyse the investment to be made and the potential savings that can be expected by switching to injection molding for manufacturing the claws. The analysis will answer the following four questions-

How much is the current manufacturing cost per claw?

From section 2.2, it is known that the current manufacturing cost per claw is DKK 1,375.

How much is the predicted cost with injection molding per claw?

From section 2.4, the predicted cost is a range between DKK 40-50.

How much is the required investment for injection molding?

As mentioned in Section 2.4, the estimated price range for the mold required for manufacturing the claws falls between DKK 75,000 and DKK 100,000. Additionally, there may be costs associated with potential additional rework on the part after injection molding, as well as modifications to other components if necessary to accommodate the new claws.

However, it is worth noting that the cost of potential additional rework and modifications to other parts is not expected to have a significant impact. Marel possesses the necessary resources and capabilities to handle such rework and adaptations internally. Therefore, rather than being a cost-related concern, it is more likely to involve logistical and operational adjustments within the organization.

Sr. No.	Parameters	Price (DKK)
1	Current manufacturing cost of one claw	1,375
2	Current manufacturing cost of 80 claws per machine	110,000
3	Expected manufacturing cost with injection molding for one claw	40-50
4	Expected manufacturing cost with injection molding for 80 claws	3,200-4,000
5	Investment for injection molding	100,000
6	Savings per machine after switching to injection molding	106,000
7	Number of machines to be sold to reach break even	1 machine

TABLE 2.4: Financial analysis

How long will it take to break-even?

The current manufacturing method of milling incurs a total cost of DKK 110,000 for producing 80 units of claws in a single machine, as mentioned earlier. However, by adopting the injection molding process, the total cost is expected to range between DKK 3,200 and DKK 4,000, considering the estimated price of a single claw ranging between DKK 40 and DKK 50. Consequently, this implies a potential cost saving of approximately DKK 106,000 per machine.

Considering an investment of approximately DKK 100,000, it is projected that the company would recover its investment by selling just one machine. Table 2.4 presents these metrics in a tabular format.

2.6 Conclusion: Decision to Proceed with the Project

Based on the conducted business case along with the financial analysis, the decision to invest in the redesign of the claws is a prudent one for Marel. This provides impetus to further explore the case of implementing design for manufacturing principles, which will be discussed in the subsequent chapter.

The following chapter will introduce the tools utilized in this project and establish the design specifications necessary for creating the design. These specifications encompass sections such as Design for Manufacturing (IM), Design for Hygiene, Design for Modularity, Design for Wear and Tear, and Design for Functionality. While the first four sections will be introduced for the first time in the report, Design for Functionality will be based on the constraints and functionality requirements previously stated in this chapter, including spatial constraints and the movement of the claws within the existing mechanisms, among others.

Chapter 3

Tool box and Design considerations

The purpose of this chapter is to provide an overview of the factors to consider when designing a new iteration of the claws that are compatible for injection molding, as well as to outline the various tools and concepts that will be utilized in the design process. The chapter commences by giving a detailed account of injection molding, followed by a discussion of the design specifications to consider. Lastly, the chapter will focus upon the various tools that will be employed to facilitate the design process.

3.1 Injection Molding

According to Serope Kalpakjian and Steven R. Schmid, 2021, injection molding is a manufacturing process used to produce parts by injecting molten material, usually plastic, into a mold. The process involves melting the material in a barrel, and then using a screw or plunger to force it into a mold cavity. A schematic illustration of injection molding with a plunger and a reciprocating screw is shown in Figure 3.1. Once the material is in the mold, it is cooled and solidified to form the desired shape.

The molds used in injection molding can be made from a variety of materials, including steel, aluminum, and even ceramic. Figure 3.2 shows a two-plate mold and its various injection molding features. They are designed to produce parts with high precision and accuracy, with the ability to produce large quantities of identical parts in a relatively short amount of time. The process of injection molding involves several steps, including:

- Material preparation: The material is typically in the form of pellets or granules, which are loaded into the barrel of the injection molding machine.
- Melting: The material is heated and melted in the barrel, typically using an electric heater.
- Injection: The molten material is forced into the mold cavity using a screw or plunger.
- Cooling and solidification: The mold is cooled to allow the material to solidify and take the shape of the mold cavity.
- Ejection: The finished part is ejected from the mold, and the process repeats.

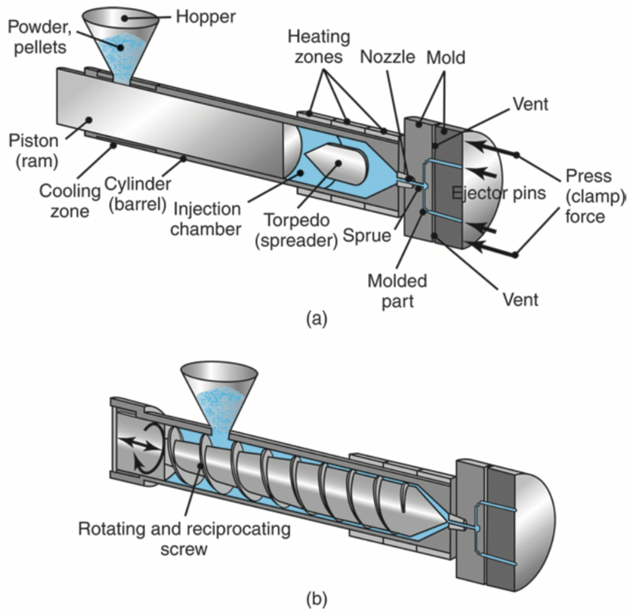


FIGURE 3.1: Schematic illustration of injection molding with (a) a plunger and (b) a reciprocating rotating screw
The picture is taken from Serope Kalpakjian and Steven R. Schmid, 2021

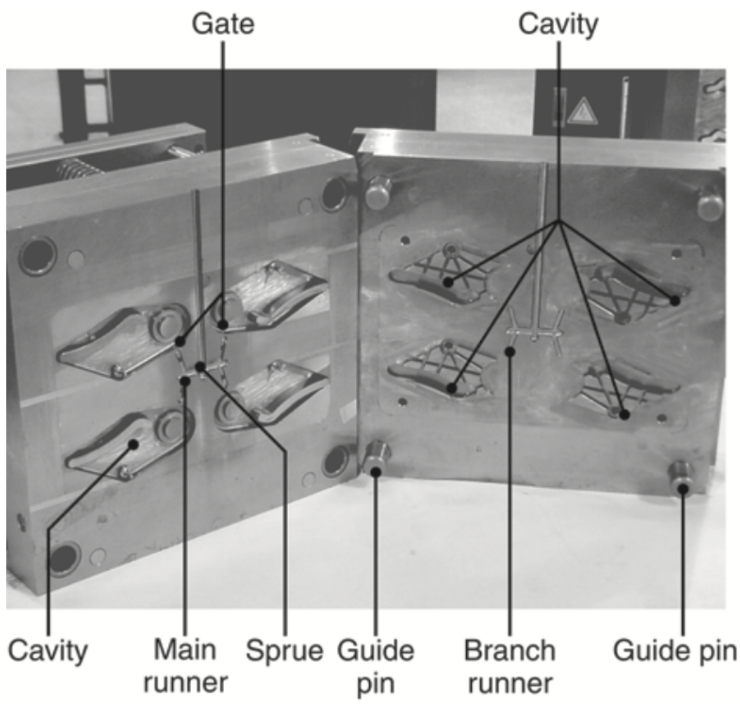


FIGURE 3.2: Two-plate mold with important mold features identified
The picture is taken from Serope Kalpakjian and Steven R. Schmid, 2021

Injection molding is widely used in the manufacturing of a wide range of products, including automotive parts, electronic components, medical devices, and consumer goods. The process is highly automated, making it ideal for producing large quantities of parts with high precision and consistency.

3.1.1 Selecting injection molding as the suitable manufacturing method

When seeking alternative manufacturing methods, a specific set of criteria was established in order to evaluate potential methods. These criteria included:

- the ability to produce complex shapes
- low tolerance
- high dimensional accuracy and precision with each part produced
- a positive ROI

Various methods surfaced as potential alternatives, including extrusion, injection molding, structural foam molding, blow molding, rotational molding, thermoforming, compression molding, transfer molding, and casting. These methods were presented in Serope Kalpakjian and Steven R. Schmid, 2021 which seemed as potential alternatives.

After consulting with the senior members of the Marel design team, injection molding was identified as a suitable option that met all established criteria. According to Serope Kalpakjian and Steven R. Schmid, 2021, the characteristics of injection molding were the closest match to the criteria. Furthermore, the earlier mentioned business case analysis indicated a promising ROI for this option.

Therefore, based on the evaluation and analysis conducted, the decision was made to select injection molding as the preferred alternative manufacturing method. Subsequently, a new design of the claws will be made aligned with the design considerations discussed in the next sections.

3.2 Design considerations

3.2.1 Design for Injection Molding

When designing a part for injection molding, several theoretical design considerations must be taken into account to ensure that the part is produced without errors. These considerations include:

- Wall Thickness: The thickness of the walls in the part must be uniform to avoid differential cooling and warping.
- Draft Angles: Draft angles must be provided to facilitate easy ejection of the part from the mold.
- Corner Radii: The corners of the part must be designed with a minimum radius to prevent stress concentration, warping, and sink marks.
- Gate Design: The gate location and design must be optimized to minimize part defects, such as weld lines, air traps, and knit lines.
- Sinking: The sinking of the part must be minimized to ensure dimensional accuracy and aesthetic appearance.

- Material Selection: The material selection must be optimized for part function, performance, and manufacturability.

After consulting with Marel's design team and conducting a brief research on injection molding design specifications, the following specifications were established for the design:

- Wall Thickness: 8mm.
- Draft Angles: 1.5 degrees.
- Corner Radii: 0.5mm.
- Gate Design: The gate should be located on the thickest section of the part and designed to minimize part defects.
- Material: POM or POM with addition of glass fiber material to improve stiffness characteristic.

3.2.2 Design for Hygiene

In the food industry, machines must be designed to minimize the risk of food contamination caused by bacteria, allergens, and other hazards. To meet the hygiene standards of the food industry, the following considerations should be taken into account during material selection and design:

- Material: The material used in machine design must be food-safe and meet the standards set by the food industry. For example, stainless steel is a common material used in the food industry due to its durability, corrosion resistance, and easy-to-clean surface.
- Color: The color of the machine parts should be selected to aid in the detection of any broken parts that may contaminate the food. Blue is a common color used for this purpose, as it contrasts with most food products and is easily detectable.
- Surface Contact: The machine design should avoid surface contact between two parts as much as possible. This is because surface contact can create spaces where bacteria can accumulate and grow, leading to food contamination. For this reason, machine designers should aim to minimize surface contact between machine parts and reduce the number of edges or gaps where bacteria can accumulate.
- Ease of Cleaning: Machine designers should consider the ease of cleaning when designing machines for the food industry. Easy-to-clean designs can help reduce the risk of food contamination caused by residual bacteria or debris. Smooth and unobstructed surfaces are easier to clean than textured or complicated surfaces.
- Filleted Edges: Filleted edges are another design consideration for machine designers in the food industry. Sharp edges can accumulate bacteria and be difficult to clean. Filleted edges can help prevent bacterial growth and make cleaning easier.

3.2.3 Design for Modularity

The incorporation of modularity as a key design consideration is motivated by the potential benefits of reusability of manufacturing resources and streamlining the manufacturing process. The key requirement in design for modularity is to:

- Design the two opposing claws as identical.
- Eliminate the need for two distinct molding tools.
- Minimize resource utilization and cost.

3.2.4 Design for Wear and Tear

During the design phase, it is crucial to assess the component's susceptibility to wear and tear during usage and take necessary steps to enhance its longevity and durability. This involves:

- Exploring wear mitigation strategies, such as:
  - Incorporating wear-resistant materials.
  - Implementing design modifications to reduce friction.
- Considering the feasibility of disassembling and replacing worn-out components. For example, in the current design, one of the claw's holes accommodates a connecting rod, and the component rotates along the rod's axis during operation. Prolonged use may cause wear and tear on the hole's surface, emphasizing the importance of implementing measures to minimize wear and extend the component's lifespan.

3.2.5 Design for Functionality

Design for functionality refers to the design constraints derived from the supporting parts surrounding the claws, as well as the expected and defined functionality of the claws. These constraints and functionality aspects have been thoroughly discussed throughout Chapter 2 and can be summarized as follows:

- Integration with existing mechanisms:
  TThe new design should seamlessly integrate and operate in conjunction with the current mechanisms, that is, the spring mechanism and the cam-follower mechanism.
- Expected function:
  The primary purpose of the claws and the carrier is to securely grip and hold the fish throughout the entire process cycle, allowing the cutting stations to carry out their respective tasks. The new design should effectively fulfill this function without any issues.
- Adapting to supporting parts:
  The current claws are accompanied by supporting components such as teeth grippers and carrier rods, which work in coordination with them. The new design should be capable of accommodating the teeth grippers and possess compatible hole dimensions to fit the carrier rods. While modifications to the design of the teeth grippers are possible, their presence and proper functionality should be maintained.

- Space constraints:
  The design must fit within the existing space allocated for the current claws. Failure to meet this requirement could introduce complexities in the functioning of the carrier and potentially hinder its intended operation.

3.3 Design plan and tools

To attain a newly designed claw that is compatible for injection molding, the following plan of action (refer to Figure 3.3) has been proposed:

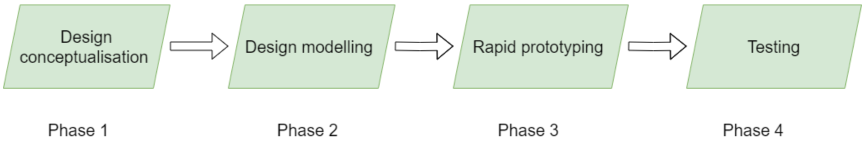


FIGURE 3.3: Design phases

3.3.1 Conceptualising a new design that aligns with the design specifications

The initial step involves conceptualizing potential design ideas or concepts that meet two primary requirements: alignment with the pre-established design specifications and proper integration with the carrier design. Subsequently, a thorough evaluation will be conducted to assess each concept's conformity to all specified criteria. The concept that fulfills all the criteria will be selected as the primary design and will proceed to the subsequent designing phase.

3.3.2 Designing a CAD model using Solidworks

The next step is to generate a computer-aided design (CAD) model of the chosen concept. This would also involve consulting with external injection molding suppliers and Marel's design team to obtain further insights into the creation of the design such that it is compatible with injection molding. The CAD model would be produced using the SolidWorks software, a widely-used program for 3D modeling and design.

FIGURE 3.4: Solidworks Logo

SOLIDWORKS is a computer-aided design (CAD) software developed by Dassault Systems. It is a popular 3D modeling software that allows engineers and designers to create and manipulate 3D models of parts, assemblies, and drawings. The software provides a comprehensive suite of tools and features for designing, testing, simulating, and producing products. With SOLIDWORKS, users can create 3D models and assemblies, perform simulations, and generate detailed 2D drawings. It is widely used in industries such as aerospace, automotive, architecture, consumer products, and manufacturing for product design and development.

3.3.3 Rapid prototyping using 3D printing

Upon completing the CAD design, the subsequent step would be to construct a physical model using 3D printing technology to facilitate testing and validation. Marel has an in-house 3D printing department dedicated to rapid prototyping and shall be leveraged to construct the 3D printed model in this instance.

The physical model would be fabricated utilizing the same material used for the current claw, i.e. POM, to ensure an accurate representation of the behavior and functionality of the new design in real-world scenarios. This would entail fitting a carrier featuring the new claws into the machine and assessing its performance against that of carriers fitted with the current claws.

3.3.4 Testing

The testing of the new claws involves replacing the existing claws in one of the ten carriers of the machine with the newly designed claws. Conducting this test with real fish being fed into the carriers would allow to observe and study the behavior and functioning of the carrier mounted with the new claws. This type of testing can also uncover any unanticipated behaviors, which can be rectified later.

It is important that the carrier with the new claws performs similarly to the carriers with the current claws in several areas and therefore the following evaluations shall be made:

- Firstly, the stiffness characteristic of the new claws will be evaluated to ensure that it is comparable to the existing claws.
- Secondly, the ability of the new claws to grip the fish should be assessed to ensure that they can hold the fish securely in the same way as the old claws.
- Finally, the new claws should integrate with the spring mechanism and perform the opening and closing movements properly, which is critical for the overall functioning of the machine.

The testing process of the new claws is crucial to ensuring that the machine's functionality remains consistent and reliable. By evaluating these areas, the effectiveness and efficiency of the new claws can be determined and any necessary adjustments can be made later to ensure they meet the required standards for performance and functionality.

3.3.5 Consulting with Marel's design team and injection moulding suppliers

It is agreed upon by Marel that the design team will actively contribute to the design by providing insights and evaluation during the making of the design. Furthermore, there will be talks conducted with injection moulding suppliers to check the design feasibility of whether it is compatible for injection moulding. With this constant feedback and review system, it will be more likely to come up with a workable design.

Chapter 4

Design models

Based on the specifications outlined in the previous chapter, two designs were conceptualised and one of them was finalized and 3D modelled on SolidWorks. The designs were inspired by existing mechanical concepts, input from Marel's design team, and integrating original ideas. The process involved starting with a design and, if it seemed impractical, discarding it and exploring a new idea. By following this iterative method, a feasible design was achieved in the second iteration. This chapter will describe both the designs, analyse their merits and drawbacks, and explain the reason behind either approving or discarding a design. Additionally, it will present and examine the design of the gripping tooth attached to the claws. Finally, the chapter will conclude with a brief description of the final design model incorporating both the claws and teeth.

4.1 Design 1

The first design focuses on creating smaller modular parts that interconnect to form a functional claw unit, as opposed to using a single solid body. This modular approach optimizes manufacturing costs by utilizing a single mold tool capable of accommodating all the smaller parts.

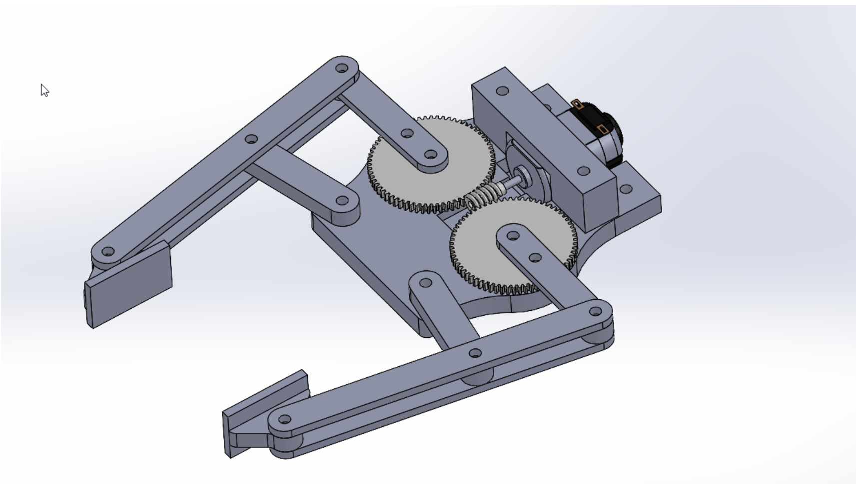


FIGURE 4.1: Inspiration for design 1 with modular parts

The smaller parts, shown in the accompanying Figure 4.1, play a crucial role in transmitting motion from the spur gears to the final link responsible for gripping the fish. Positioned between the two spur gears, a worm gear operates through a cylindrical rod. These parts are mounted on a back plate, serving as a platform for their attachment. While in the figure, the cylindrical rod of the worm gear is shown to rotate using a motor, in this design, it is planned to be connected to the underlying cam mechanism.

When the rod will engage with the cam, their interaction will cause an upward rotational movement. This upward movement of the rod, facilitated by gear meshing, will result in the rotation of the worm gear. As a result, the connected spur gears are set in motion, influencing the movement of the connecting links and leading to the opening of the claw.

Conversely, when the rod loses contact with the cam, it rotates in the opposite direction, moving downward. This downward movement is facilitated by the already existing spring mechanism designed to keep the claws closed.

4.1.1 Merits

The advantages of the design are as follows:

- Modular Design:
  The incorporation of a modular approach in the design necessitates the use of only one mold to produce all the diverse parts required for the design. This modular design not only simplifies the manufacturing process but also reduces costs associated with tooling and production setup.
- Cost-effectiveness:
  By utilizing a single mold for the production of various parts, the design achieves cost-effectiveness. This approach minimizes the need for multiple molds, resulting in reduced manufacturing expenses and increased overall efficiency.
- Functional Integration:
  The design concept seems to successfully integrates existing spring and cam mechanisms, enhancing its functionality. The presence of a spring mechanism ensures reliable closure of the claw, while the cam mechanism enables controlled movement and rotation of the interconnected parts. This integration enhances the overall performance and effectiveness of the design.

In summary, the modular design offers cost advantages by utilizing a single mold for all parts. Additionally, the functional integration of the spring and cam mechanisms enhances the design's reliability and effectiveness.

4.1.2 Drawbacks

The design exhibits certain limitations and drawbacks, which are as follows:

- Bacterial Accumulation:
  The introduction of additional parts in the modular design leads to an increase in the number of surfaces that come into contact with each other. Consequently, this creates additional areas where bacteria can accumulate, posing challenges for effective cleaning and sanitation.
- Precision Requirements:
  The functional feasibility of the design concept relies heavily on the precise dimensions of the worm gear meshes and spur gear teeth. Ensuring accurate alignment and proper meshing is crucial for the smooth operation of the

mechanism. Particularly, the wider mesh on the worm gear's rod introduces the possibility that the upward movement of the rod may not provide sufficient rotation to fully open the claw by properly engaging the spur gears. Achieving precise dimensions and tolerances adds complexity and demands meticulous attention during the design and manufacturing process.

- Spatial Constraints:
  The incorporation of the back plate and other modular parts poses challenges in terms of accommodating the entire assembly within the available space in the carrier. The limited spatial capacity within the carrier may restrict the size and arrangement of the modular components, potentially impacting the overall functionality and efficiency of the design.

- Usage of motor:
  While the design does not intend to work on the motor shown in Figure 4.1, in case the precision requirements are too tight to have a functional worm gear with the cam system, the motor will have to be utilized. However, having a motor in each claw pair will significantly increase costs making it economically infeasible.

Considering these drawbacks, it becomes evident that designing an accurate and functional implementation of the proposed concept would be complex and time consuming, involving meticulous attention to detail and potential modifications to address the spatial limitations and ensure optimal performance.

4.1.3 Discard

Despite the advantages offered by the design in terms of modularity and cost savings, its drawbacks relating to bacterial accumulation, design complexity, and spatial constraints significantly undermine its overall appeal. The potential for bacterial accumulation on numerous contact surfaces poses challenges for thorough cleaning and sanitation. Additionally, the intricate nature of the design, necessitating precise dimensions and meshing of the gears, increases complexity and introduces the possibility of sub-optimal functionality. Moreover, the limited spatial capacity within the carrier restricts the accommodation of the modular components, potentially compromising the design's overall effectiveness.

Considering these shortcomings, the design was deemed unsuitable and therefore discarded. Subsequently, alternative design options were explored in order to identify a more viable solution that addressed the aforementioned concerns.

4.2 Design 2

The second design is based on one of the early prototypes that was created by Marel's team. The Figure 4.2 shows the prototype. While this design is functional, it has distinct spur gears on the opposing claws (right and left) which are designed to mesh into each other and synchronise the movement of the two claws. Due to this difference in the two claws, it will need two distinct molds for each claw which would make this project an expensive investment and also increase the time of ROI.

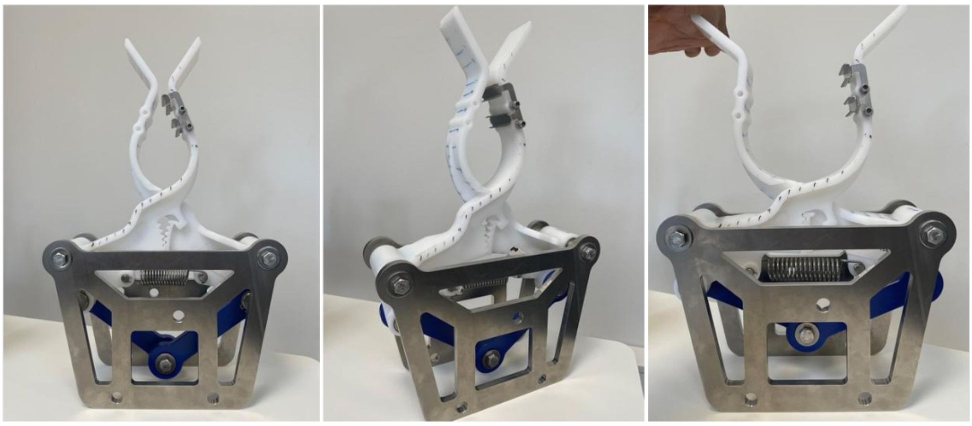


FIGURE 4.2: Marel's protoype claw - Front, Isometric and Open View

This design concept attempts to use the feature of interchangeable insert tools in the main mold. The idea is to have a single mold with two interchangeable inserts at the spur area of the mold. Each insert will accommodate the design of one of the two spur gear designs such that they can help produce either of the two spur designs for the opposing claws. With this approach, investment has to be made only on a single mold and the insert tools in the mold. While it would be costlier than a simpler single mold, it will still be cheaper than having two entirely distinct molds.

4.2.1 Merits

The design has the following benefits:

- Modular design:
  The design will only require a single main mold, adding modularity to the design. The two insert tools in the mold will be utilized according to which claw has to be created - the right claw or the left claw.

- Cost-effective:
  While the two insert tools in the mold will definitely make the mold complex and slightly expensive as well, it will still be cheaper than having two completely distinct molds. This makes the design a cost-effective one.

- Strong foundational design:
  With the design based on a previous prototype, there is already an agreement and approval by the team at Marel as it is understood that the design already factors in some of the important constraints like tolerances and dimensional accuracy. Hence, designing the new part on this platform makes it more convenient as well as the strong foundation has a higher chance of leading towards a workable design.

- Hygienic design:
  The claw design will be thinner than the current claw which infers that it will have a lesser overall surface area and hence, lesser area for bacteria accumulation. Additionally, with filleted edges to be a common feature in the design, cleaning of the parts would be easier and more efficient.

- Easier integration with the carrier structure:
  As the design is based on a previous prototype, it has the required dimensional accuracy and some important constraints already dealt with. This ensures that

the design will fit into the main carrier model, i.e, with the existing rods on the two sides of the carrier, the springs and most importantly the two opposing claws will synchronise with each other. Thus, it is also expected to function in the desired way.

4.2.2 Drawbacks

The drawbacks of the design are:

- Stiffness:
  Since the claws in this design (Figure 4.2) are comparatively thinner than the original claws (Figure 2.9 and 2.10), the stiffness of these claws is anticipated to be inferior than the original one's, provided it is made of the same material. The reason for the thin feature is to have a uniform thickness throughout the design for injection molding.

- Need for an alternative material with higher stiffness coefficient:
  Following from the previous point, to achieve the same level of stiffness from the new design, another material must be looked into which provides higher level of stiffness.

- Relatively higher mold cost:
  As mentioned earlier, with the insert tools, the cost of the mold will be higher than a simpler version mold. Hence, there is a certain possibility that the previously estimated price of the mold between DKK 75,000 - 100,000 will increase. The actual numbers will be known when IM suppliers are contacted.

4.2.3 Approval

With its positive points on modularity and cost-effectiveness, it aligns well with the previously defined business case from Chapter 2. It also conforms with the hygienic design specifications and has a solid foundation as it is based on a past prototype. While it has drawbacks in terms of its stiffness property and the need to look for a stiffer material, it is a problem that can and will be solved during the development process.

With the points made and an approval from Marel's team as well, it was finalised as the approved design. The next section will discuss the design process of how it was made.

4.2.4 Design process

The first task of the design process involved creating the base prototype using Solidworks, as Marel did not possess a Solidworks file for the part but instead had a STEP file. Due to its nature as an "Imported" body in Solidworks, derived from the STEP file, modifications to the design were not feasible. The absence of visible features and construction steps made it impossible to edit the design. Figure 4.3 illustrates the "Imported" feature in Solidworks, signifying that the part was imported as a single body and remained uneditable.

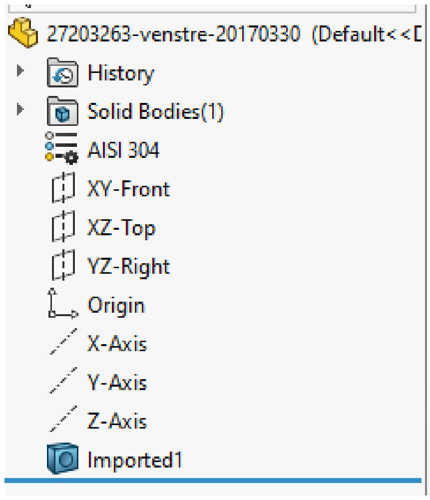


FIGURE 4.3: Imported feature on Solidworks' Tree which cannot be edited or modified

However, the STEP file proved useful when developing the design from scratch, providing accurate dimensions. Figure 4.4 showcases the newly designed prototype of both the right-sided and left-sided claws. Notably, the figure highlights the distinct design of the spur gears between the two claws, marked by a light blue line.

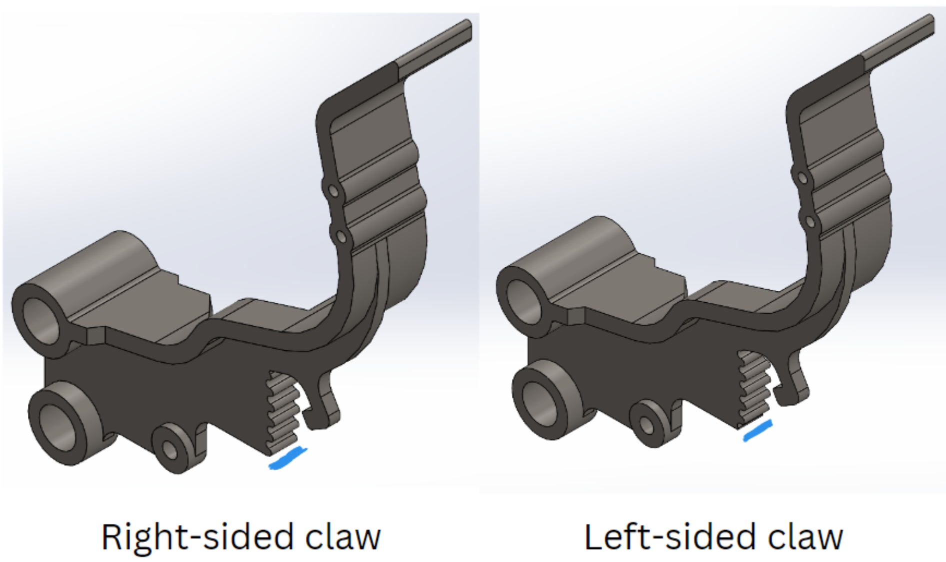


FIGURE 4.4: Design of right-sided claw and left-sided claw built from scratch on Solidworks

The second task was to make the design as per the concept for which the common part and the interchangeable insert tool (spur gear) of the design must be defined. Figures 4.5 and 4.6 shows the common part and the insert tool for both the claws. The dark gray shaded part is the common part and the blue shaded part is the insert tool.

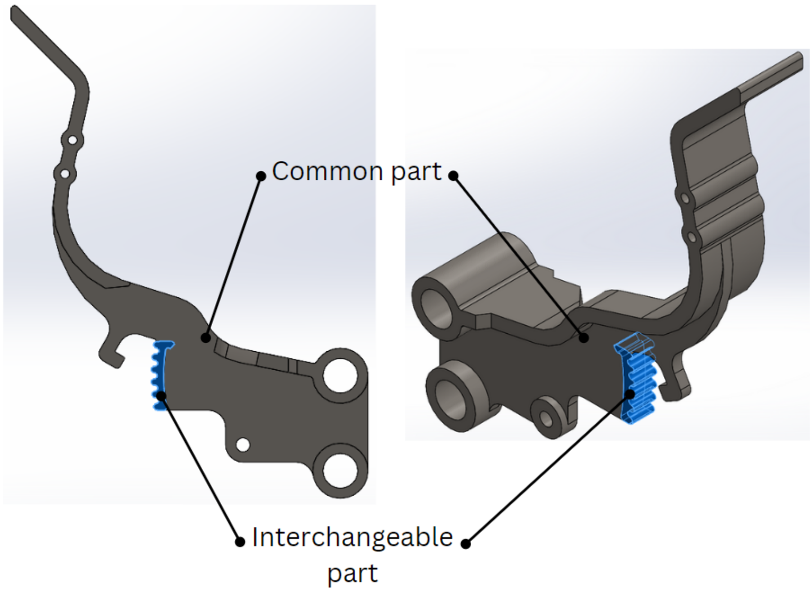


FIGURE 4.5: Right-sided claw - (i) front view and (ii) isometric view

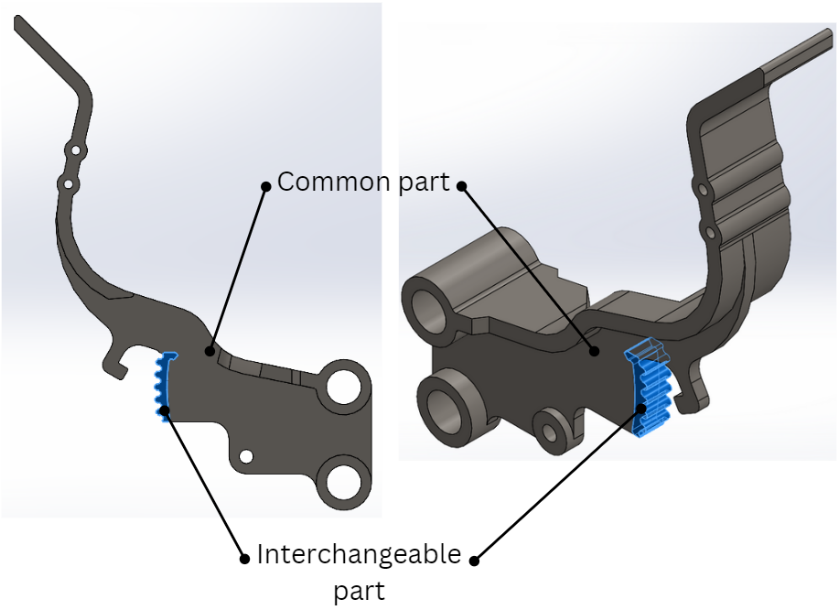
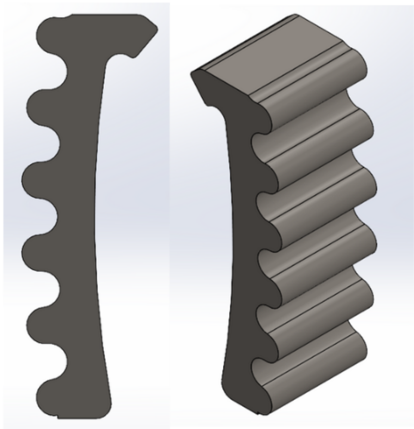
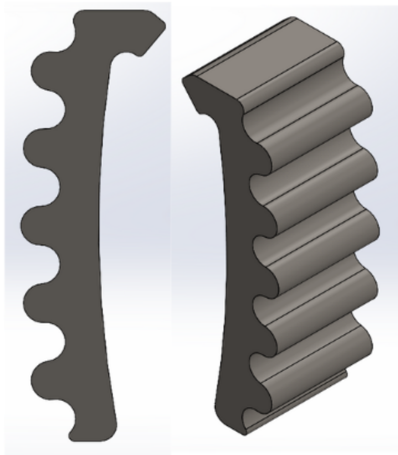


FIGURE 4.6: Left-sided claw - (i) front view and (ii) isometric view



(A) Right-sided claw's interchangeable insert tool



(B) Left-sided claw's interchangeable insert tool

FIGURE 4.7: Interchangeable insert tools of the claw

Figure 4.7 shows a close-up view of the distinct insert tools of both claws.

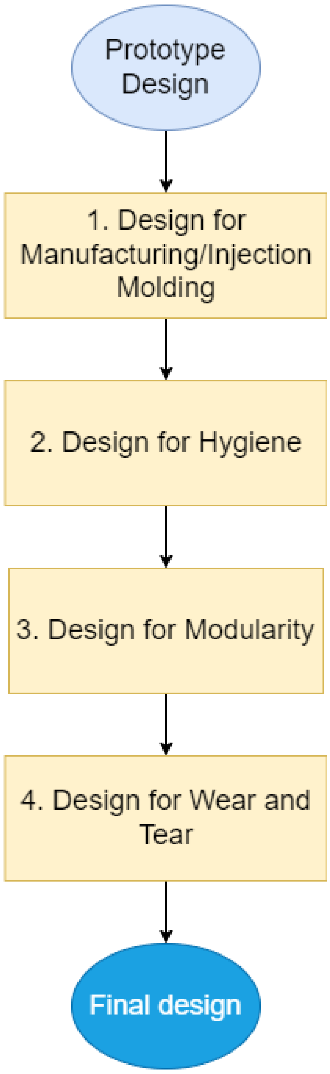


FIGURE 4.8: Sequential plan for design

The design process then adheres to the specifications outlined in the preceding section 3.2, encompassing considerations for manufacturing (injection molding), hygiene, modularity, and wear and tear, as depicted in Figure 4.8. Although the design plan was initially conceived as a sequential framework, it should be noted that certain situations necessitated an iterative approach. However, to maintain coherence in presentation and writing style, the design process is presented and discussed in a sequential manner.

Design for Manufacturing/Injection Molding (IM):

Considering that the design should be reworked to be compatible for injection molding, the following steps were taken:

- As the prototype design already had a uniform thickness of 8mm, as seen in Figure 4.9, it was decided to keep it that way as it is necessary to have uniform thickness throughout the design for IM. Furthermore, the thickness of the holes are 8mm which can not be changed as it would create spatial issues in the existing carrier design.

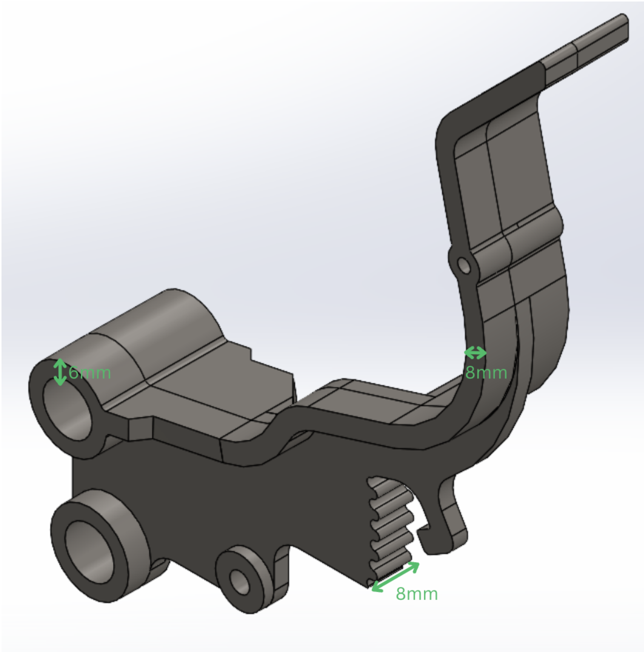


FIGURE 4.9: New design's thickness at various areas

- A parting line was created through a plane that divided the design into two distinct halves - green half and yellow half - as shown in Figure 4.10.

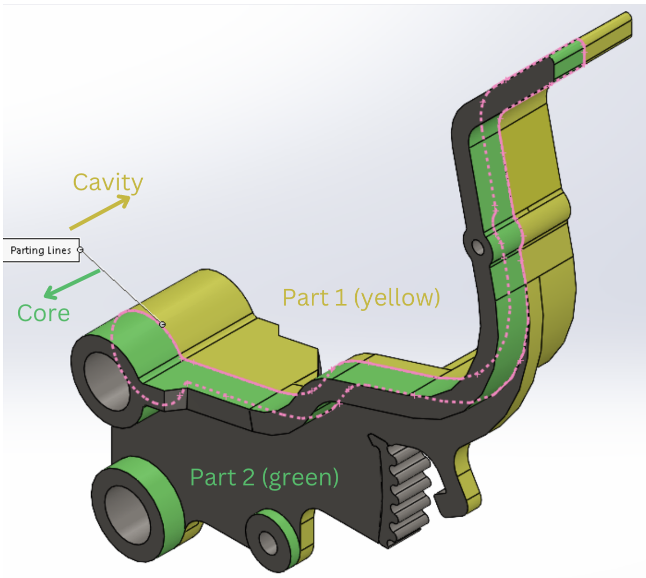


FIGURE 4.10: The design's parting line dividing it into two halves - green and yellow

- Both the cavity (yellow half) and core (green half) were given a draft angle of 1.5 degrees, illustrated in Figure 4.11.

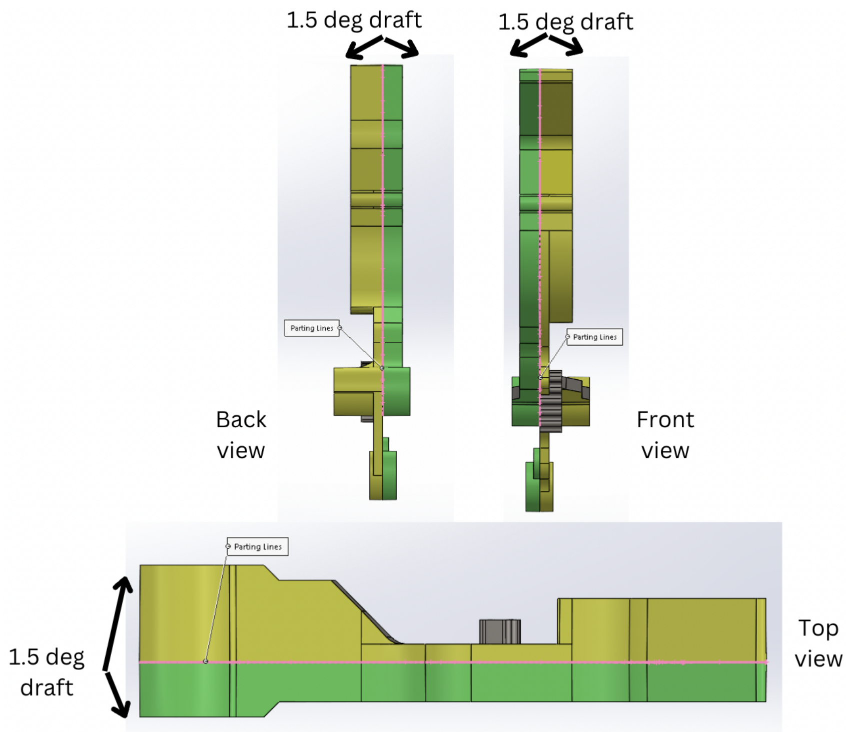


FIGURE 4.11: Draft angle of 1.5 degrees from the parting line to each side of the design shown from three different views

- With some holes in the design supposed to accommodate cylindrical rod or fasteners, it was essential to not have any draft on the inner surface of the hole. Figure 4.12 shows the areas in the design without any draft.
  Due to this, it was decided to add more ejector pins around this area to still be able to eject the mold with drafts only on the outer surface of the hole. The reason being it will be possible to eject the parts smoothly with more ejector pins around the area without draft. An illustration of the ejector pin locations has been shown in Figure 4.13.

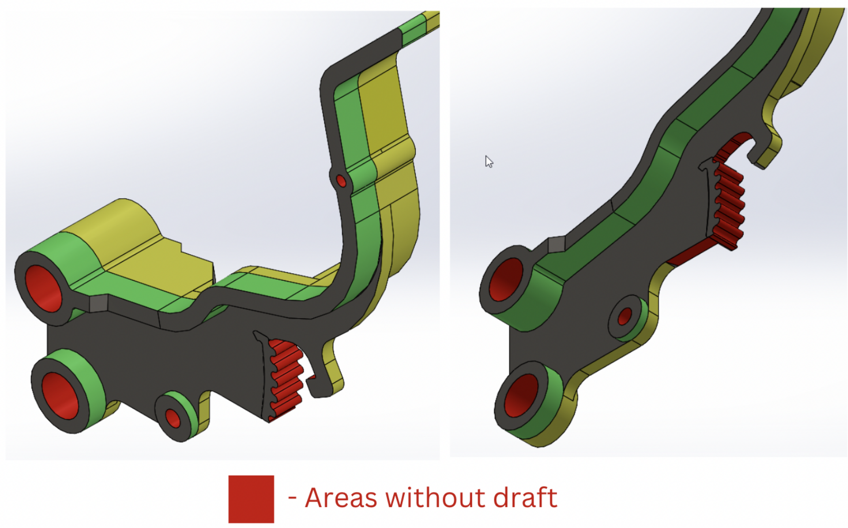


FIGURE 4.12: Areas in the design with no draft shown in red shade

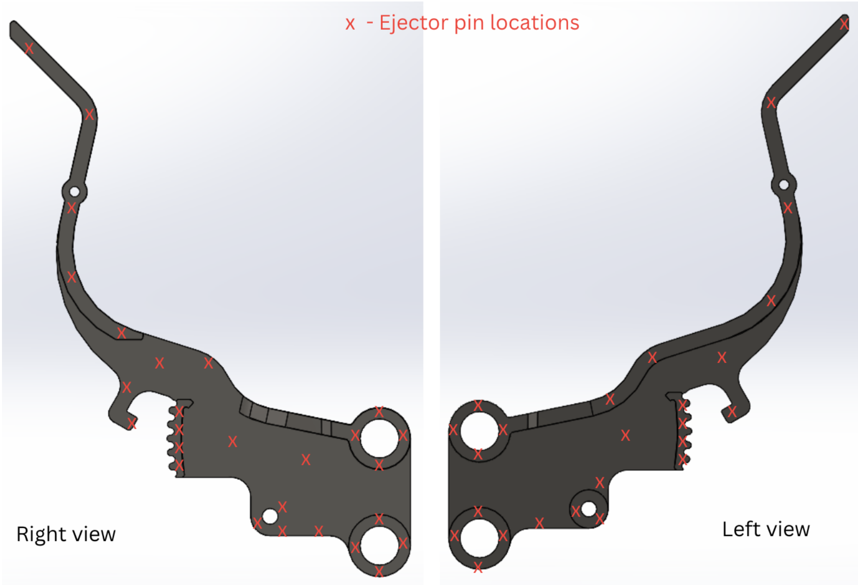


FIGURE 4.13: Ejector pin locations for both halves

- It was considered to create drafts on the inner surface of the holes and later perform some reworking to remove the draft material. However, since this would increase the manufacturing cost as well as more handling/logistics would be required, the idea was dropped.
- It was not possible to have drafts on the surface of the spur gears as well. Hence, it was again decided to add more ejector pins around that area in order to eject the part easily as shown in Figure 4.13.

Design for Hygiene:

After making the design compatible for IM, the design for hygiene specifications were considered and the following steps were taken:

- Filleting all the rough edges was attempted. Edges, particularly inside-edges, are an area where bacteria can accumulate and also makes it difficult to clean the part. Figure 4.14 shows the filleted-edges on the right-sided claw.

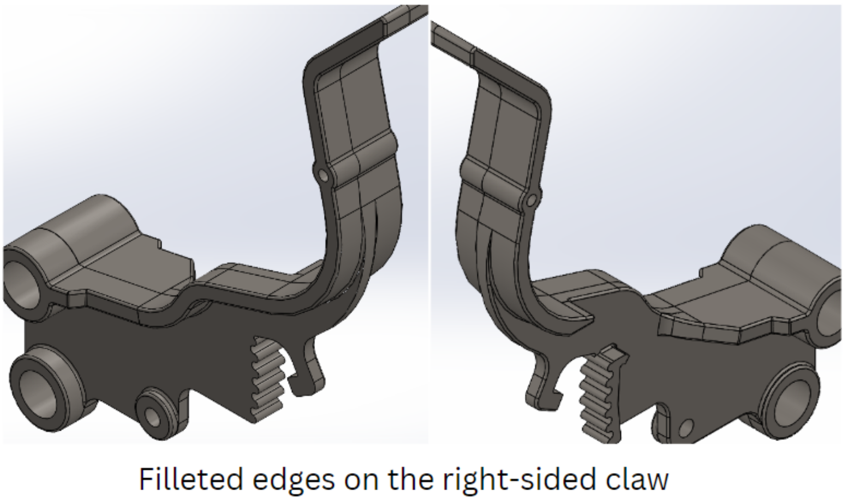


FIGURE 4.14: Fillet feature of 1mm added to all the possible edges in the right-sided claw, shown from two different angles

- Ways to reduce surface contact between the claw and other parts were looked into. One of the areas has been to not have the teeth structure bolted onto the claw's surface and rather a different design was considered with less surface contact. Figure 4.15 shows the reduced surfaced contact in the new design as compared to the current one.

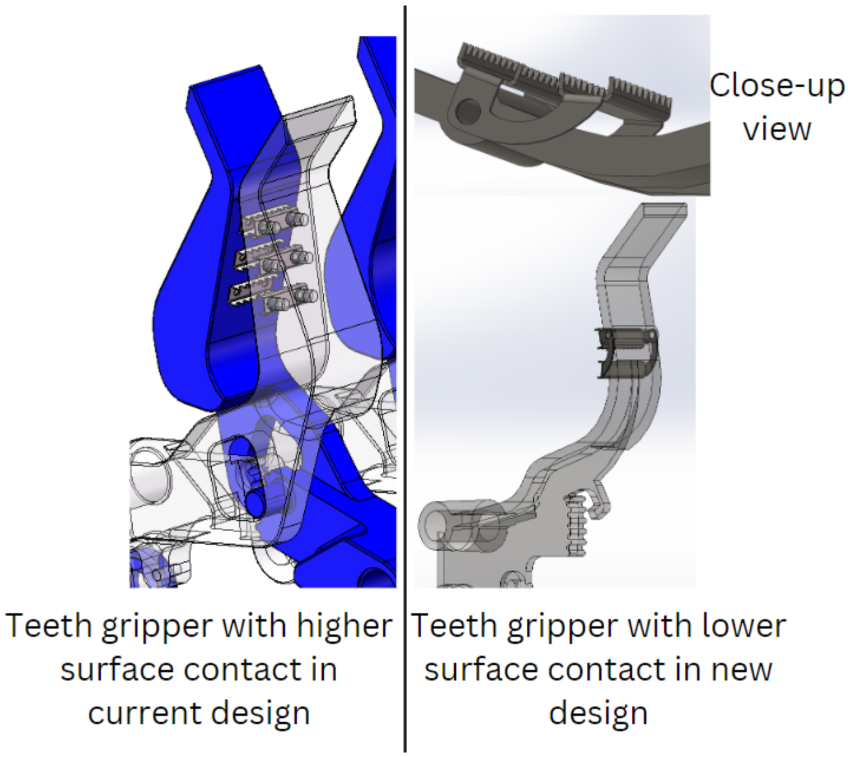


FIGURE 4.15: Lower surface contact in the new design

- The prototype design has two holes at the top section of the claw used to fix the teeth grippers. In the new design, it has been reduced to a single hole with a new design for the teeth grippers as shown in Figure 4.16. This has been done in order to reduce surface contacts where bacteria can be accumulated and to have a standard teeth gripper design which would only need a single fastener hole. The new teeth gripper design has been elaborately discussed in the upcoming sections.

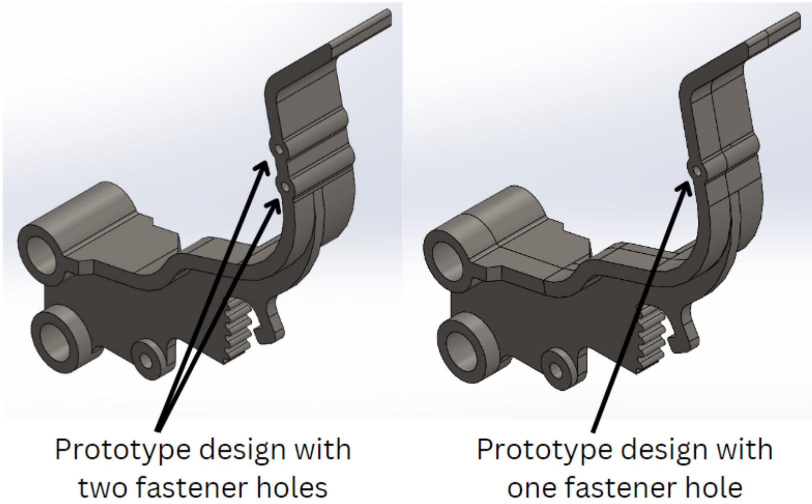


FIGURE 4.16: Reduced number of fastener holes

- The material has been defined as POM and the color of the model changed to blue to align with the food safety guidelines, as shown in Figure 4.17.

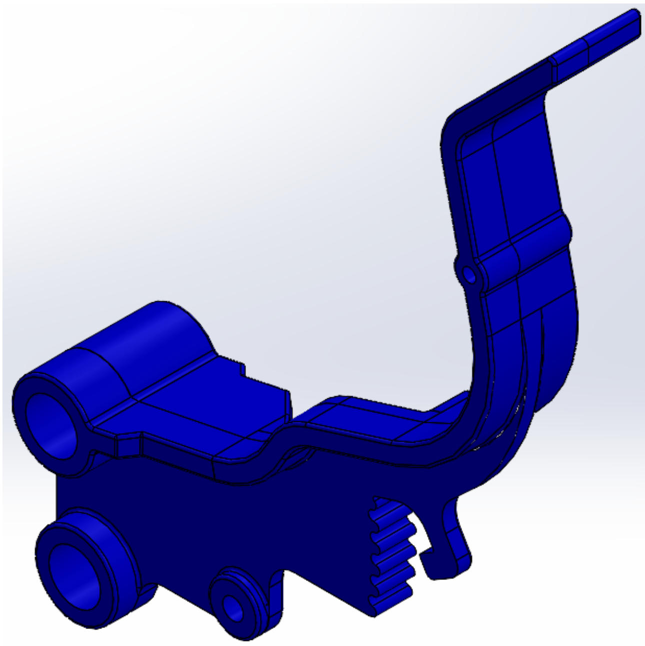


FIGURE 4.17: POM material claw with industry standard blue colored appearance

Design for Modularity:

As mentioned earlier, the interchangeable mold feature was utilized ensuring that there would be only one main mold required to produce the two opposing claws.

To achieve this, each claw (right and left) was split into two separate parts in SolidWorks as shown in Figures 4.5 and 4.6. The two parts, one from right-sided claw and one from left-sided claw, were then considered as the core inserts/interchangeable molds.

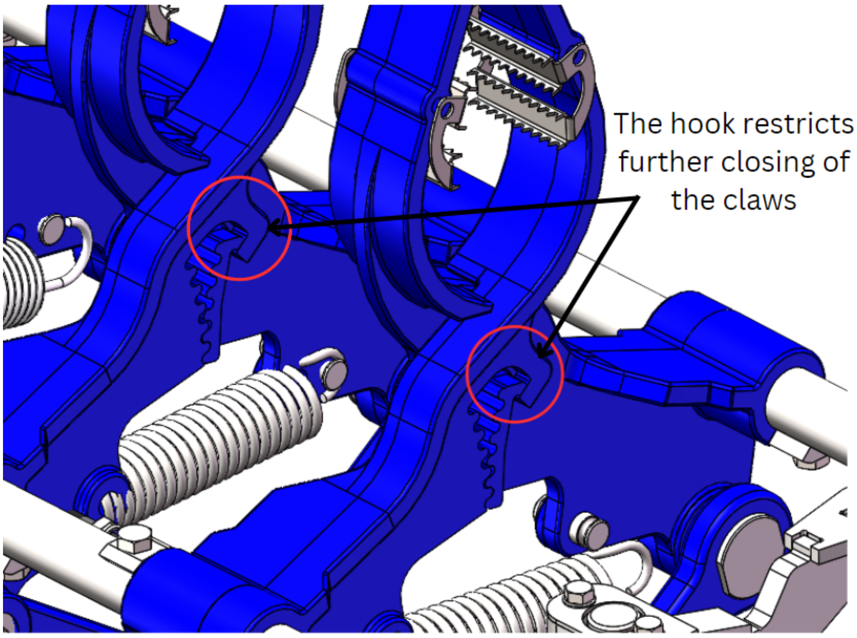


FIGURE 4.18: Hook structure on the claw to restrict movement

4.2.5 Working of the design

The new claw design aims to replicate the functionality of the original claw by incorporating the same spring mechanism, cam mechanism, and spur gear structure for synchronized movement. Similar to the original claw, the new design maintains a closed position through the compression of the spring. When the cam mechanism is activated, the spring extends, leading to the opening of the claws. To prevent excessive movement, a blocker is implemented.

Unlike the circular extruded block used in the original design, the new design features a hook-like structure. This hook interacts with the top end of the spur gear in the opposing claw, effectively restricting the movement of the claws beyond the required degree. Refer to Figure 4.18 for a visual representation of this configuration.

4.2.6 Main design differences: Current vs New

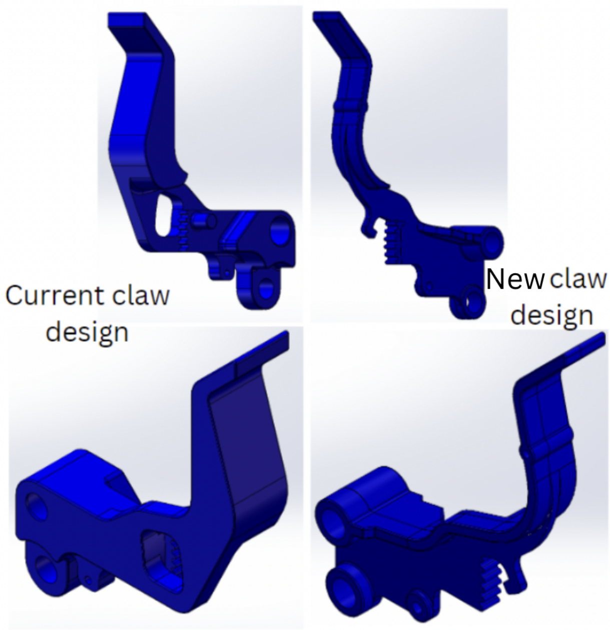


FIGURE 4.19: Current claw design and new claw design

Figure 4.19 shows both the newly designed claw and the current claw and Table 4.1 enlists the main differences between the two claws. The main differences in the two designs are:

- Thickness:
  The new design is significantly thinner than the current design. This reduction in thickness is a result of the requirement to maintain a uniform thickness throughout, with certain areas being constrained to a thickness range of 6-8mm. Consequently, an overall thickness of 8mm was adopted. While the new design presents a more slender profile, there are concerns about potential lower stiffness, which is an undesired quality. However, further investigations will be conducted during the testing phase to evaluate its performance.

- Spur gear design:
  The new spur gear design retains the functionality of the previous design while incorporating enhanced aesthetics and simplicity.

- Blocker design:
  The new design is much simpler and slender compared to the current design.

- Claw design:
  In the current design, the claws are generally bulkier, with varying thicknesses depending on their position. In contrast, the new design standardizes the claw size and significantly reduces its thickness compared to the current design.

- Bolting of the teeth grippers:
  Currently, the teeth grippers are bolted onto the surface of the claws, creating contact between two surfaces that are difficult to clean and prone to bacterial accumulation. In the new design, the teeth grippers are mounted to the sides

of the claw, eliminating direct contact between the gripper's main surface and the claw surface, resulting in a more hygienic design.

- Total surface area:
  Due to its overall thinner and more slender construction, the new design exhibits a reduced surface area compared to the current claw. This characteristic reduces the likelihood of bacteria accumulation and facilitates easier cleaning due to its improved hygienic design.

- Stiffness:
  With both designs using the same material, the new design is expected to have lower stiffness compared to the current design. As mentioned earlier, the stiffness will be confirmed during the testing phase. If the new design provides sufficient stiffness for gripping and holding the fish, no changes will be made. Otherwise, alternative materials or the possibility of increasing the claw thickness will be explored.

Sr. No.	**Parameter**	**Original Claw**	**New claw**
1	Thickness	Relatively a thick design	Significantly thinner
2	Spur gear design	Comparatively thicker	Sleeker
3	Blocker design	Is a circular extruding material that restricts the movement of the opposing spur gear	Is a thin extruding material from the spur gear structure that restricts the movement of the opposing spur gear
4	Claw design	Bulky	Sleek and aesthetically pleasing
5	Bolting of the teeth grippers	Teeth grippers are in contact to the claw surface	Teeth grippers are not in contact to the claw surface
6	Total surface area	Relatively more	Relatively less than the TSA of original claw
7	Stiffness	Stiff enough to function appropriately to grip the fish firmly	Anticipated to have a lower stiffness level due to the thin and sleek design

TABLE 4.1: Comparison of the original claw and the newly designed claw

4.3 Redesigning of the supporting parts

With the design of the claw finalised, the focus can be shifted towards the parts that are attached to the claw and work in tandem with it, i.e., (i) the teeth grippers on the surface of the claws and (ii) the extended teeth gripper attached to the first pair of claws.

4.3.1 Teeth gripper

Current design of the teeth gripper

The teeth gripper is a structure that is mounted on the inner surface of the claws and has teeth-like edges on it making it function to provide extra grip to the claws in gripping the fish by pressing onto the sides of the fish. Figure 4.20 shows the teeth gripper from the current design. A claw can have from no teeth gripper to three units attached to its surface. Figure 4.21 shows the current carrier design with each claw having none to three teeth grippers attached to them.

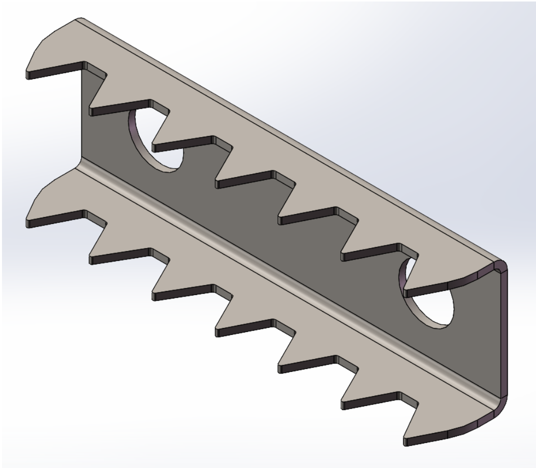


FIGURE 4.20: Teeth gripper from old design

The number of teeth grippers on a claw is determined by the position of the claw on the carrier and its specific function. In the case of the second positioned claw pair, its primary function is to provide stable alignment to the fish during the insertion process into the carrier by the operator.

When the fish is being inserted, it will slide through the closed inlet of the second claw pair. However, if teeth grippers were present on this claw pair, they could potentially tear through the fish's skin, causing damage to the flesh. To prevent this, the second claw pair is designed without any teeth grippers mounted on it.Figure 4.21 visually illustrates the appearance of the second claw pair without teeth grippers.

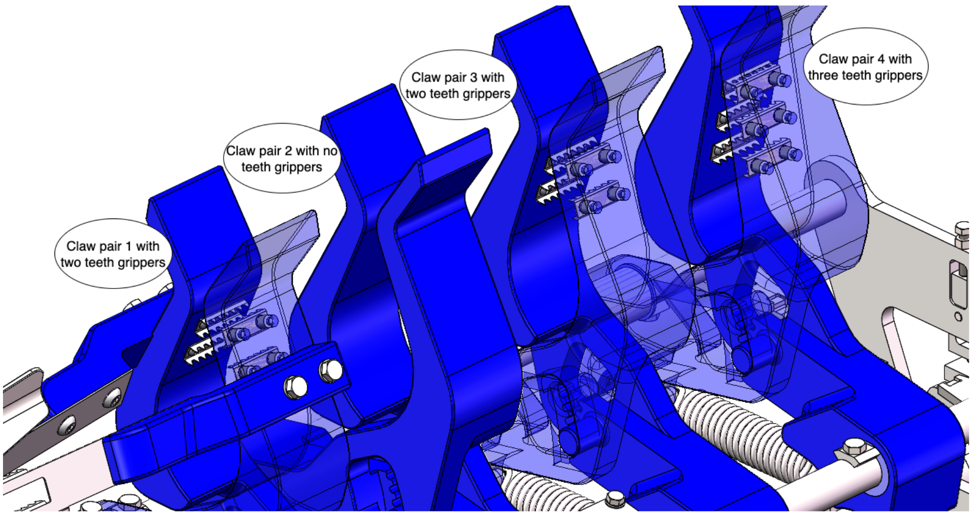


FIGURE 4.21: Teeth gripper attached to the surface of the claws in the old design

The remaining claw pairs, excluding the second positioned claw pair, are equipped with teeth grippers. These claws start in an open state due to the influence of the cam mechanism and close after the fish has been inserted into the carrier. This design ensures that the tearing or ripping of the fish's flesh does not occur.

In the current design, the number of teeth grippers on each of the remaining three claws depends on the thickness of the fish and the claw itself. For example, the first and third claw pairs, which grip the thicker and fatter side of the fish, were found to provide a strong grip with only two teeth grippers. Therefore, these claw pairs are equipped with two teeth grippers, as shown in Figure 4.21.

The claw pair positioned last has been given three teeth grippers. This is because it grips the thinner back side of the fish. To accommodate the thinner area, the claw itself has been made thicker compared to the other claws, resulting in a reduced open space between the two opposing claws. The Figure 4.21 shows the three teeth grippers on the last claw pair.

New design of the teeth gripper

In the new claw design (Design 2), a uniform thickness was adopted for all four claw pairs. Additionally, a different mounting approach for the teeth grippers was implemented to minimize surface contact. This required the development of a new design for the teeth gripper.

Instead of having a single modular design that can be attached in different numbers onto the claw, three distinct designs were created for the teeth grippers instead of a single modular design. The aim was to have a common assembly method while offering various functionalities.

The first design, depicted in Figure 4.22, features two teeth gripping structures integrated into a single body. It also includes two holes on the sides for fasteners to attach it to the claw.

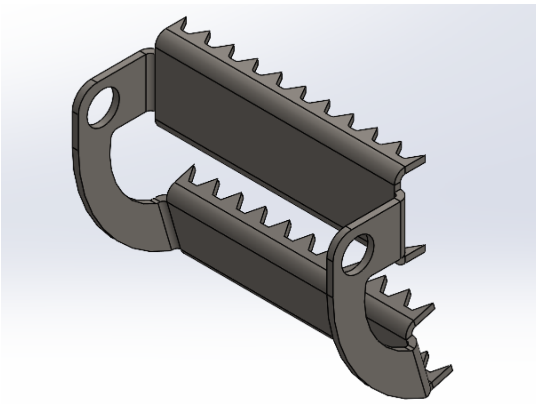


FIGURE 4.22: New teeth gripper design 1

The second design, shown in Figure 4.23, incorporates three teeth gripping structures within a single body. Like the first design, it includes two holes on the sides for attachment.

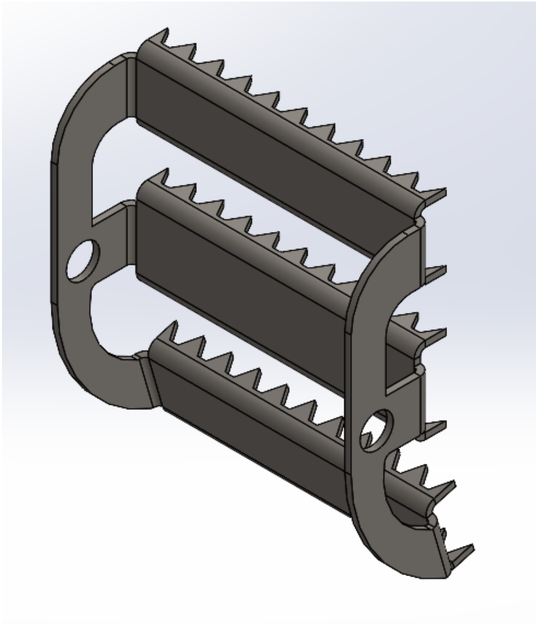


FIGURE 4.23: New teeth gripper design 2

The third design, illustrated in Figure 4.24, consists of two teeth gripping structures and an additional strap from the other side. This design is specifically intended for the first claw pair and will be further explained in the subsequent section.

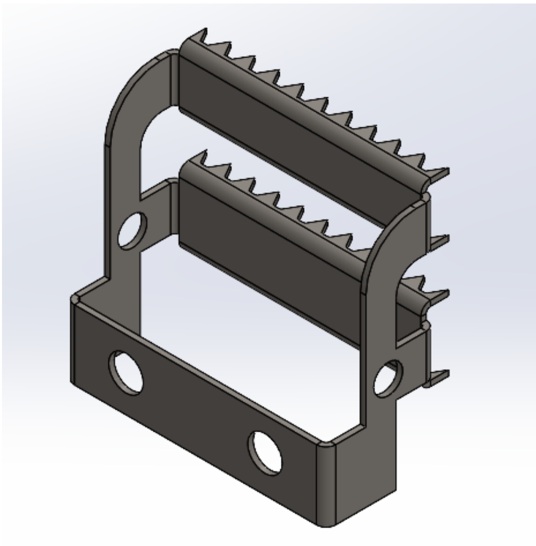


FIGURE 4.24: New teeth gripper design 3

The benefit of the design is the reduced level of surface contact between the teeth gripper and the claws, a factor critical in design for hygiene. The contact between surfaces will only occur in the areas between the fasteners, the teeth gripper and the claw which is significantly lesser than the surface to surface contact the previous teeth gripper had.

4.3.2 Extended teeth gripper

Current design of the extended teeth gripper

As mentioned in Sub-section 2.1.2, the extended teeth gripper is a structure present only in the first claw pair and is attached on the outer surface of the claws. Its function is to provide further grip near the front side of the fish.

In the current design, the extended teeth gripper is attached to a link which is attached directly to the front claws using fasteners. When the front claws open and close, so do the extended teeth grippers. With the claws being thicker in the original design, it was possible to drill holes on the outer surface of the claw to accommodate the fasteners and attach the link directly. Figure 2.17 shows the first claw pair of the original design with the link and extended teeth gripper.

New design of the extended teeth gripper

With the new claws, which are considerably thinner than the original ones, having the same method of attaching the link to the outer surface of the claw would not have been feasible as the claw is not thick enough to afford a deep hole for the fasteners. Hence, a special design of the teeth gripper was made that would have two teeth gripping structures on one side and a strap on the other side which would act as a plate on which the link would be attached to. Figure 4.24 shows the design. The strap has two holes on it and there is also a low depth hole on the claw's outer surface (Figure 4.25) for the fasteners.

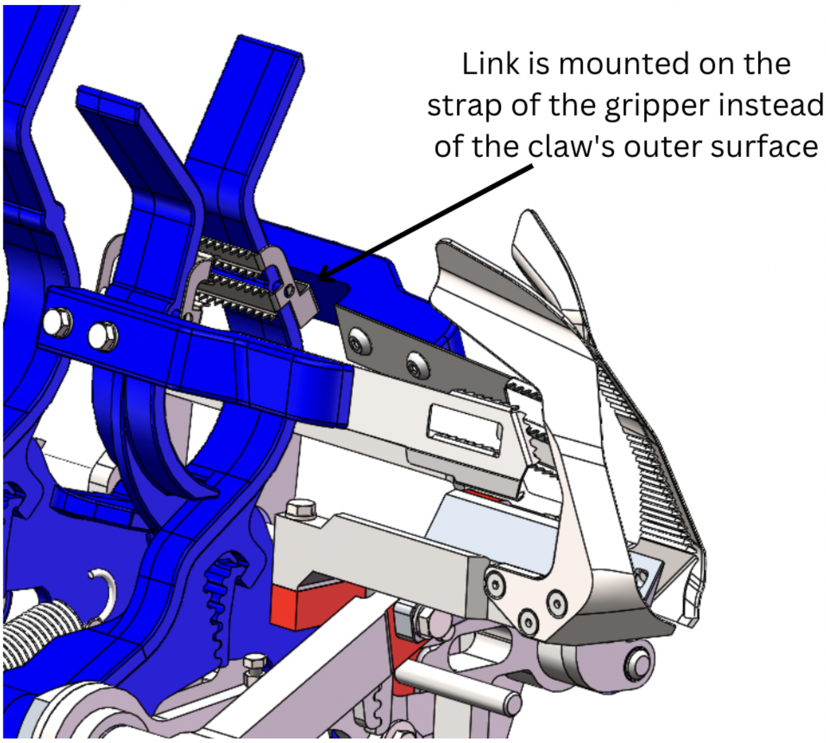


FIGURE 4.25: New design for the extended teeth gripper

While there is surface contact between the strap and the link in this design, it is similar to the surface contact existing in the previous design. Moreover it integrates well with the new teeth gripper design. The hole on the surface of the claw will only be created on the first claw pair as it is the only one that has this extended teeth gripper.

4.4 Final design

The final design of the claws, as shown in Figure 4.26, incorporates the selected second design idea and includes the different teeth gripper designs. The design consists of four claw pairs, similar to the original design, but with the distinguishing feature of having a uniform thickness throughout all the claws.

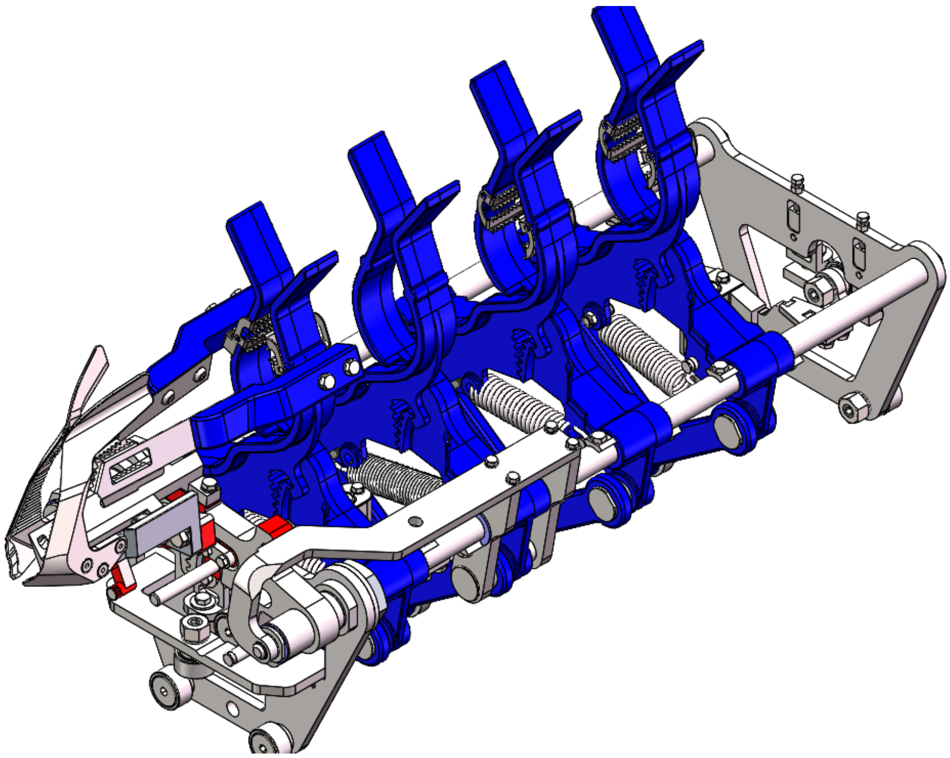


FIGURE 4.26: Final design model

In the first claw pair, there are two holes on the outer surface to accommodate the fasteners for attaching the external teeth gripper. The teeth gripper unit in the first claw pair consists of two teeth units, similar to the current design.

On the other hand, the second claw pair, which does not require a teeth gripper, does not have any holes for fasteners, as depicted in Figure 4.27.

The third and fourth claw pairs have the new two-unit teeth gripper design attached to them, providing improved gripping functionality.

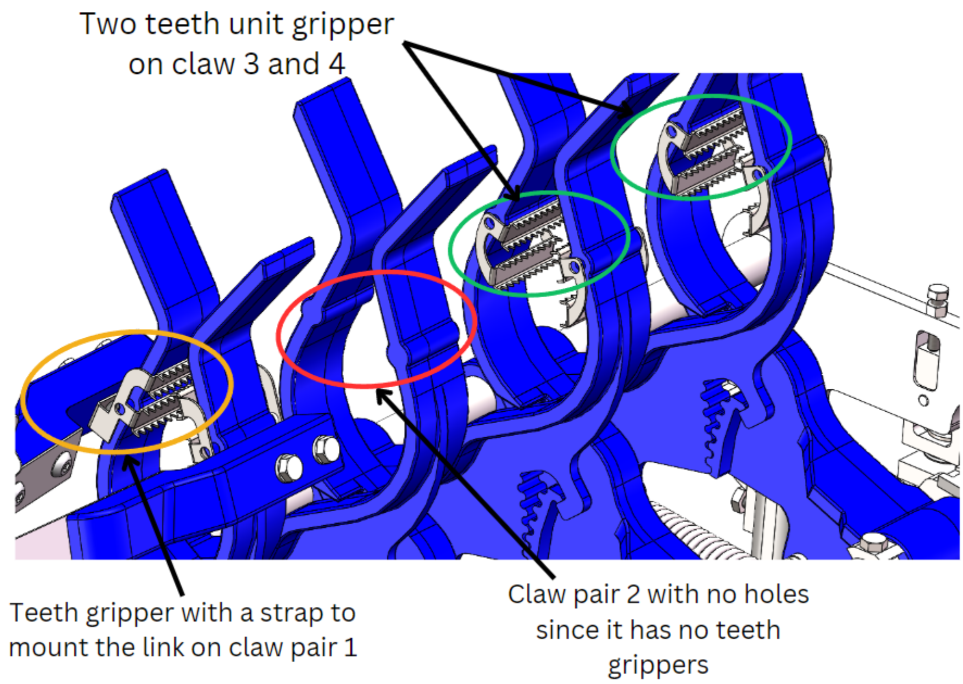


FIGURE 4.27: Close-up view with teeth gripper configuration

Overall, the final design incorporates the necessary modifications, ensuring proper functionality and compatibility with the existing carrier mechanism.

Chapter 5

Supplier Consultancy and Final Design Modifications

The design of the claws was sent to two external injection molding suppliers for further evaluation. Discussions were conducted with these suppliers to address two key aspects: pricing and design feasibility. The chapter will focus on the outcomes of these discussions and examine their implications for the business case and the design itself. It will explore potential updates or modifications that need to be made based on the information gathered during the supplier discussions.

About the suppliers
Two Danish injection molding suppliers, with a reputable background in the industry and experience working with renowned clients such as Lego, were contacted for this project. Meetings were arranged with the project managers responsible for handling new projects. The purpose of these meetings was to gather essential information related to the cost of the mold, pricing per part, and technical details including mold material, design considerations, and manufacturing feasibility. These discussions aimed to provide insights into the financial aspects and technical requirements of the injection molding process for the claws.

5.1 Pricing and Updated Business Case

Regarding the pricing, the two suppliers provided different quotations. One supplier proposed a price of 150,000 DKK for the mold, while the other supplier quoted 223,100 DKK. Detailed pricing quotations from both suppliers can be found in Table 5.1 and Table 5.2 respectively. These quotations outline the cost breakdown and provide a clear comparison of the pricing offered by each supplier.

Sr. No.	Parameters	Price (DKK)
1	Tool price	223100
2	Per unit peice for 800 pcs/year	31,10
3	Additional rework price	Not determined yet

TABLE 5.1: Price estimation from Supplier 1

Sr. No.	Parameters	Price (DKK)
1	Tool price	150000
2	Per unit peice for 800 pcs/year	31
3	Additional rework price	Not determined yet

TABLE 5.2: Price estimation from Supplier 2

With the updated pricing information from the suppliers, the previously made business case can now be updated with evidence-based data, adding credibility to it. Table 5.3 presents a comparison between the old and updated business metrics.

Based on the updated information, the investment on the tool will change to either 223,100 DKK (supplier 1) or 150,000 DKK (supplier 2). In the first case, the investment will break even after selling 2 machines, and from the third machine onwards, it will generate savings. In the second case, the investment will break even after selling 1.5 machines, and savings will start from the second machine.

Considering the expected product life cycle of 10-15 years and predicted sales of 4 machines per year, the updated business case remains valid and financially beneficial.

Parameters	**Old price (DKK)**	**Updated price as per supplier 1**	**Updated price as per supplier 2**
Tool price (Investment)	75,000-100,000	223,000	150,000
Per unit piece for 800 pcs/yr	50	31.10	31
Additional rework price	Not yet determined	-	-
Current manufacturing cost of 80 claws per machine	= 1375 x 80 = 110,000	110,000	110,000
Savings per machine after switching to injection molding	=110,000 - (80 x 50) =106,000	=110,000 - (80 x 31.10) =107,512	=110,000 - (80 x 31) =107,520
Number of machines to be sold to reach break even	=106,000/110,000 =0.94 1 machine	=223,100/107,512 =2.07 2 machines	=150,000/107,520 =1.39 Through the 2nd machine

TABLE 5.3: Updated business case analysis

5.2 Design feasibility

In regards to the design, there was some specific data required to confirm the feasibility of the design. This data was formulated in the form of questions which have been listed in Table 5.4.

Sr. No	**Questions**
1	Is the design compatible for IM?
2	Where should the gate location be?
3	Where should be the parting line?
4	What should be the optimum draft angle?
5	Where should the ejector pins be located?
6	What is the recommended material?

TABLE 5.4: Technical questions asked to the suppliers

While one of the suppliers has not responded to the questions, the other gave a comprehensive insight onto each question. The specific answers to all the questions have been mentioned below.

Q1: Design compatibility
The design was approved as compatible subject to a couple of changes. Firstly, the design of the interchangeable block or the sub-insert was asked to be changed as with the current design, the dimension of the sides of both the block are not the same. Hence, a design with the same side dimensions for both the blocks was recommended. Figure 5.1 shows the recommended design.

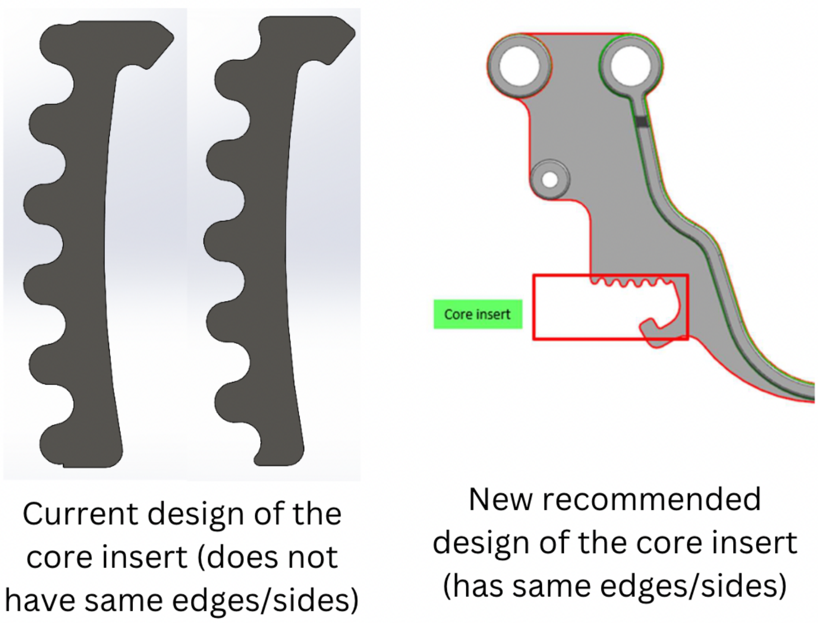


FIGURE 5.1: Updated insert block design

Secondly, the thickness at one of the sides was seen to be 9mm and the injection flow simulation, made by the IM supplier, showed it to be bad for the design, shown in Figure 5.2. The comment has been that there will be some shrinkage marks on that area. Since the shrinkage marks would only affect the aesthetics of the design and not the functionality, it can be safely ignored.

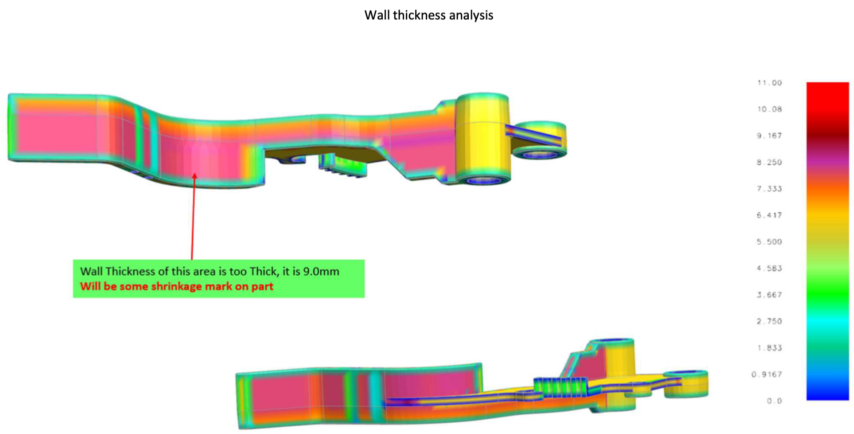


FIGURE 5.2: Sink mark problem with thickness

Q2: Gate location

The gate location was suggested to be made on the side shown in Figure 5.3.

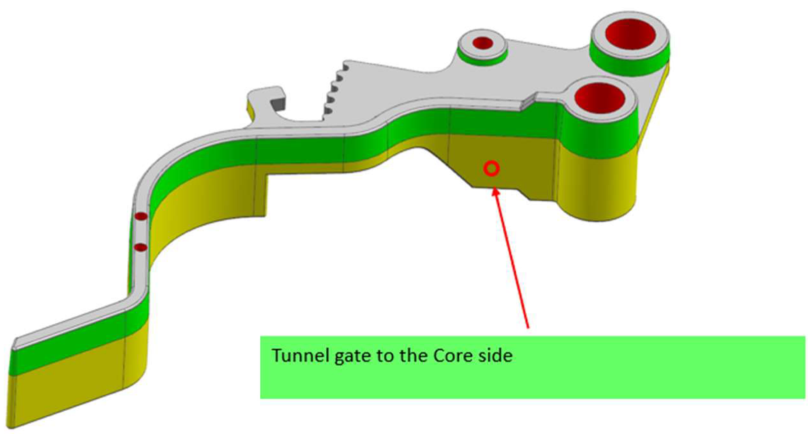


FIGURE 5.3: Suggested gate location

Q3: Parting line

The suggested parting line is the same as the initially set parting line, shown in Figure 5.4.

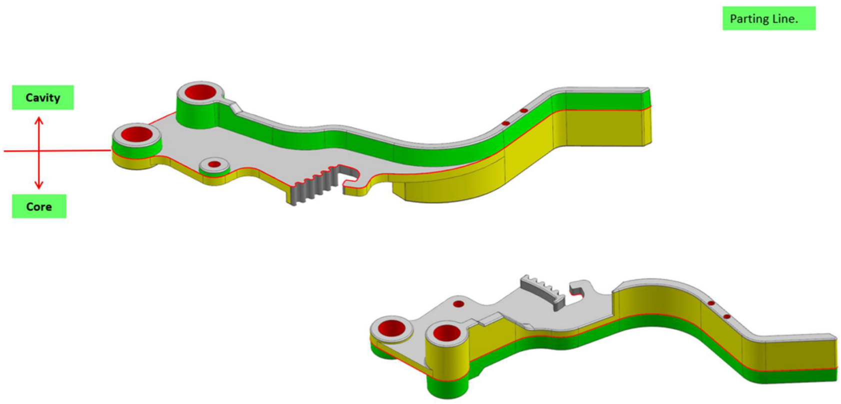


FIGURE 5.4: Suggested parting line

Q4: Optimum draft angle

The draft angle was informed to be maintained at 0.5 degrees, as shown in Figure 5.5. Initially, as mentioned earlier, it was set as 1.5 degrees but now, after the recommendation, has been changed to 0.5 degrees.

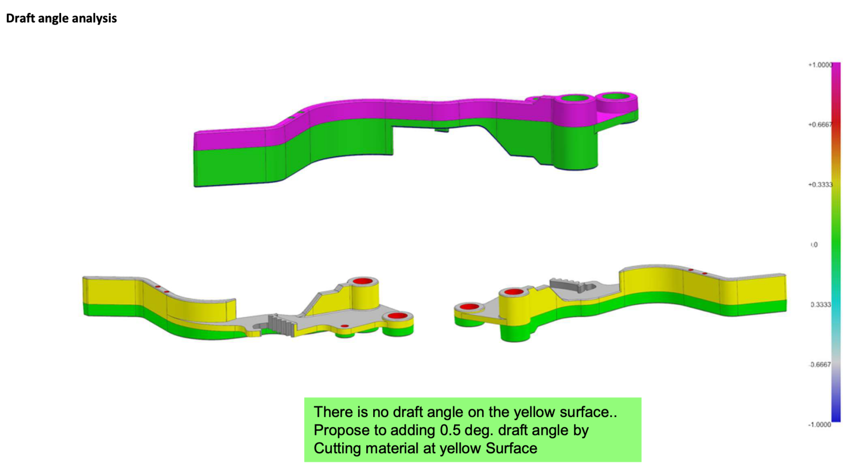


FIGURE 5.5: Draft angle suggestion

Q5: Ejector pin locations

Unlike the ejector pin locations made earlier shown in Figure 4.13, the supplier suggested the use of a combination of sleeve and round ejectors as shown in Figure 5.6.

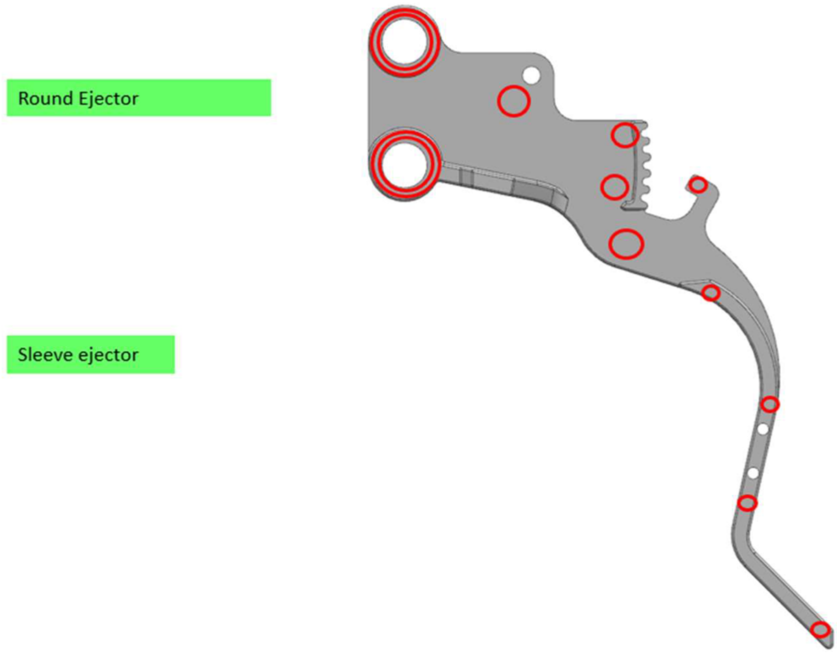


FIGURE 5.6: Round and sleeve ejector suggestion

Q6: Recommended material

It was informed that the current material of the part, POM, can be used in injection molding as well. However, due to the design being relatively thinner, it may be required to look into alternatives with higher stiffness coefficient.

5.2.1 Modified design

From the insights received, the design was accordingly modified and the design shown in Figure has been finalised. The updated claw design with the main changes has been summarised and shown in Figure 5.7.

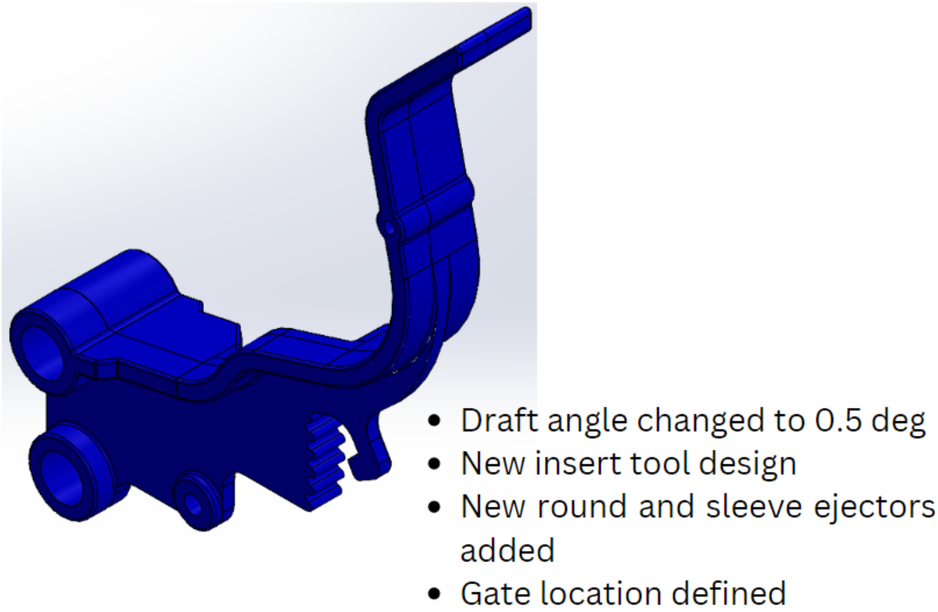


FIGURE 5.7: Updated and finalised claw design

Chapter 6

Rapid prototyping and testing

To ensure that the new design performs similarly to the current carrier model, rapid prototyping and testing will be conducted.

As mentioned in Kuang-Hua Chang (2015, Chapter 14), rapid prototyping is a set of techniques used to quickly create a physical prototype of a product or a concept from a CAD model. Usually, the techniques are additive layer manufacturing techniques like 3D printing. In the context of this project, rapid prototyping involves using the design made on CAD software, Solidworks, and to create its virtual 3D model using the 3D printing resources from Marel's Research and Development department.

6.1 Aim

The aim is to create a prototype of the new claw design and conduct testing to evaluate its performance and behavior. A specific focus is placed on assessing the ability of the claw's thickness in effectively fulfilling its intended function of gripping and holding fish. The findings from this evaluation will provide valuable insights to determine the need for any necessary modifications to optimize the design's functionality.

6.2 Method

To achieve the aforementioned aims, the following steps will be undertaken:

- 3D Printing of Claws:
  - Four pairs of the newly designed claws will be 3D printed, ensuring the use of the same material as the original claws (POM). If POM is unavailable, a material with similar mechanical properties will be selected.
  - The 3D printing process will be conducted at Marel's Research and Development department in Aarhus, utilizing their advanced 3D printing equipment. The estimated time for completion is two weeks.
- Creation of New Teeth Grippers:
  - The new teeth grippers will be fabricated using laser cutting techniques.
  - Marel's production facility in Støvring possesses the necessary resources, from raw materials to laser cutting equipment, to produce these components.

  - The estimated time required for this process is within one week, and it will be carried out concurrently with the creation of the claws.

- Claw and Teeth Gripper Assembly:
  - Following the completion of both the claws and teeth grippers, they will be assembled.
  - The dimensions of the teeth grippers will be adjusted, if necessary, to ensure proper fit with the claws. Redesigning the claws will not be feasible due to time constraints.

- Carrier Assembly:
  - The assembled teeth grippers will be affixed to their respective claws.
  - The set of claws will be inserted into one of the ten carriers within the machine, replacing the original claws.
  - However, the availability of the machine at Marel's production site in Støvring will determine the feasibility of this step.

- Testing Case 1:
  - If the machine is available, testing will be conducted by installing a carrier equipped with the newly designed claws and running the machine.
  - The performance of the machine and the carrier, specifically focusing on the new claws, will be observed and compared to the performance of carriers with the original claws.

- Testing Case 2:
  - In the event that the machine is unavailable, an alternative testing method will be employed.
  - The new claws will be integrated into a carrier set, and their mechanism will be individually evaluated.
  - Various aspects, such as the opening and closing mechanism, gripping of the fish, and integration with the carrier set, will be examined and assessed.

6.3 Testing timeline and delay note

he entire testing process is projected to span over one month. Initially planned to commence in May 2023 and conclude by the end of the month, unexpected delays in obtaining approval from the injection molders, as well as the extended time required for claw design, have resulted in a postponement of the testing phase. Regrettably, it will not be feasible to initiate and complete the testing before June 1st. Consequently, it has been discussed and agreed upon to extend the testing period until the final exam date of June 27th. It is anticipated that the testing will be concluded before this deadline, allowing for the presentation of the test procedure and outcomes during the examination.

6.4 Expected results

As of May 31st, 2023, the testing process has not yet been conducted, and therefore, no definitive results are available. However, based on the expected performance of the new claw design, the following anticipated outcomes can be outlined:

6.4.1 Case 1: Testing with the machine

In the scenario where the claws are tested within the machine, it is anticipated that they will integrate seamlessly with the spring mechanism and the cam-follower mechanism. The following expectations have been established:

- The three pairs of claws (first, third, and fourth) are expected to come into contact with the cam and open when they reach the infeed position (C1 location in Figure 2.2).
- Once the claws reach the next location (C2) and are no longer in contact with the cam, it is expected that the spring mechanism will close them. They should remain closed until they return to the C1 position.
- The second pair of claws is expected to remain closed at all times, except when the operator loads the fish. During this process, the claws should open in response to applied force and close once the force is removed.
- The teeth grippers are expected to effectively grip the fish by engaging with its flesh through the teeth structure. It is also anticipated that the teeth grippers will remain securely in their original position without tilting around their fasteners, even when subjected to direct force, such as when the claws close and the teeth gripper enters the fish's flesh.
- TThe claws should firmly hold the fish throughout the process without losing their grip due to their slim design.

6.4.2 Case 2: Testing without the machine

In the absence of the machine, the claws will be tested as part of a carrier set. It will be fitted into a carrier set and the following behavior will be expected:

- The integration of each claw pair with the springs will be observed, and it is anticipated that the claws will remain in the closed position when no external force is applied.
- When the claws will be manually tried to be opened, the spring should extend. The moment the manual force is removed, the claws should close. The manual operation is being done as the claws will not be subjected to the cam mechanism that is present in the machine in this case.

By manually operating the claws, the focus will be on evaluating their opening and closing mechanism, as well as their integration with the carrier set. This testing approach will provide insights into the functionality and behavior of the claws in a controlled environment, despite the absence of the complete machine setup.

6.5 Conclusion

In conclusion, this chapter discussed the process of creating a prototype for the new claw design and outlined the steps involved in testing its performance and behavior. The aim of the prototype and testing phase is to evaluate the functionality of the new claw design, specifically focusing on its gripping and holding capabilities for fish processing.

The testing process will involve 3D printing the claws and creating new teeth grippers, followed by the assembly of the claws and teeth grippers. The claws will be integrated into a carrier set, either in the machine or in a manual testing setup. The expected results include proper integration with the machine's mechanisms, reliable opening and closing of the claws, secure gripping of the fish by the teeth grippers, and overall effectiveness in holding the fish without losing grip.

Chapter 7

Conclusion

To conclude, the project has provided a good starting point for Marel to look into cost optimising the manufacturing of their products. Specifically, through this project, Marel can start identifying more components or parts that can be manufactured in an alternative manner to reduce costs, material wastage and to standardize the manufacturing of these parts. It has also provided Marel with insights on the potential benefits of using IM in their manufacturing operations. This chapter gives an overall conclusion of the entire project by discussing the project summary and its main takeaways.

7.1 Project Summary

The project started with creating a business case to determine whether it was sensible in the first place to look into injection molding to produce the claws as a cheaper alternative to milling. The inputs for the business case was taken by Marel's team and calculations were made on the investment, the savings, the ROI and the break-even point. The business case set a good platform and motivation to further explore this project as it showed convincing savings.

The next stage was to redesign the claws to make it compatible for injection molding. Hence, a set of specifications in the area of design for manufacturing/injection molding was defined along with design for hygiene, design for modularity and design for wear and tear. After defining these specifications, a couple of designs were looked into and one of them was considered and worked upon. It was made sure that the new design followed all the specifications previously defined.

The design was later presented to two injection molding suppliers along with some design related queries. The suppliers returned with some valuable insights on which further modifications to the design were made and finalised.

The design then enters the rapid prototyping and testing phase where it is planned to be 3D printed with the same material. After having the 3D model, it will be assembled into one of the carriers of the machine and depending on the availability of the machine at the site, it will be integrated into the machine and tested whether it runs the way the carriers with the original claws run.

Depending on the results, further changes could be made to the design if needed or it will be presented to Marel and a presentation case would be made about the savings Marel can benefit from if implemented.

7.2 Main takeaways

From this project, the discussions held with Marel's team and the injection molding suppliers, it can be certainly said that the case for injection molding will be an economically successful one if implemented. The predicted business case as well as the updated case after getting inputs from the suppliers showed significant savings of around 100,000 DKK per machine. Thus, it evidently has a very solid business plan.

Currently, it is an assumption that the new claws would work the same way as the current ones. It shall be confirmed after the testing phase and the results it will provide. However, with the positive feedback received by Marel's team and the injection molding suppliers along with the fact that the CAD model of the new design has shown assembly compatibility with the carrier, it is a safe assumption to make at this point of time that the new claws shall perform as expected.

There is still a concern about the thickness of the claws which might lead to changing the material and looking for an alternative material that has a higher stiffness coefficient. However, it can only be certain after the testing phase.

Overall, this project is deemed to be a successful one as it has laid a solid foundation for the cost optimisation process in Marel and specially for converting parts that are currently manufactured with expensive techniques into parts that become compatible for cheaper manufacturing methods.

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