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1 Introduction

1.1 FESTO Background

Festo is a leading manufacturer in industrial automation based in Germany. It produces and sells pneumatic and electrical control systems and drives technology for factories and process automation. FESTO is exploring the integration of collaborative robots (cobots) within its cyber-physical production systems (CPPS). CPPS systems help with integrating digital and physical components together, which allow for real-time monitoring, control, and optimization of many different manufacturing processes.



Figure 1: Image showing the FESTO company logo.

1.2 Problem Statement

Automation plays a very crucial role in improving efficiency, precision, and reliability in modern cyber-physical production systems (CPPS). FESTO aims to improve its merchandise dispatch process by integrating a collaborative robot (cobot) to unload its fully assembled mobile phones from the production line to an autonomous guided vehicle (AGV) for transportation to inventory.

A key challenge in this process is the design of a suitable robotic gripper that can effectively and reliably take hold of the mobile phone without damage and misalignment. The gripper must operate mechanically and should not use pneumatic or hydraulic systems. It must also be able to handle high-volume manufacturing to make it cost effective, easy to assemble, and durable.

To ensure long-term reliability of the gripper it must incorporate design for manufacturing (DFM) and design for assembly (DFA) principles. DFM and DFA comprises of minimising part count, using standard components, and ensuring that there is ease of integration with the cobot.

This project aims to address these issues by designing a mechanically actuated gripper, optimizing it for manufacturability, efficiency, and durability. This project also aims to evaluate the grippers performance using 3D CAD modelling and digital simulations.

1.3 Project Objectives

The main objective of this project is to design and develop a mechanical robotic gripper that is optimized for FESTO's goods dispatch process in a cyber-physical production system (CPPS). The gripper should be able to fully unload the assembled phones from the output station onto an autonomous guided vehicle (AGV) with good precision and durability. Below is a list of all the project objectives:

- 1. Designing a gripper for high-volume production:**
 - Ensuring cost-effective production by applying design for manufacturing (DFM).
 - Optimizing the design for easy fabrication.
- 2. Designing a robust and durable gripper for automation:**
 - Selecting suitable materials to enhance reliability and longevity.
 - Making sure the gripper is manually actuated to be able to work without the need for pneumatic or hydraulic systems.
- 3. Integration of design for assembly (DFA):**
 - Using components that are standardized to lower production cost and to make repair easier.
 - Reducing the number of parts to make repair and assembly easier.
- 4. Creating detailed CAD models for the gripper:**
 - Creating CAD models to visualize and refine the design.
 - Perform kinematic and structural analysis to ensure the gripper functions correctly.
- 5. Evaluation and optimization of the gripper using digital simulations:**
 - Using finite element analysis (FEA) to test the designed grippers for structural integrity for industrial conditions.
 - Optimizing manufacturability and reliability using design for x (DFX) processes.
- 6. Integrating the gripper with the cobot and AGV:**
 - Ensuring gripper's compatibility with FESTO's cobot and dispatch station.

- Evaluation of the gripper's ability to handle the phones without misalignment or damage.

7. Recommendations for future improvements:

- Identifying and suggesting potential modifications and testing.

1.4 Project Scope

This section of the report will look at what the project will cover and what it will not cover.

The scope of the project will include:

1. Mechanical gripper design:

- Design and development of a mechanically actuated gripper. (This excludes pneumatic or hydraulic actuation).
- Selecting of appropriate materials and mechanical components for gripper durability and reliability.

2. Design for X (DFX) application:

- Ensuring cost-effective and high-volume production by using design for manufacturing (DFM).
- Simplifying assembly by reducing part count using design for assembly (DFA) tactics.
- Enhancement of the gripper's robustness using design for reliability (DFR) methods.

3. Development of CAD models and simulations:

- Creation of CAD models to visualise and refine the gripper's design.
- Use of finite element analysis (FEA) to assess the gripper's structural integrity and performance.
- Evaluation of gripping forces to ensure the mobile phones don't get damaged while being secure.

4. Compatibility and integration considerations:

- Making sure there is seamless integration with FESTO's cobot and AGV system.
- Monitoring the gripper's ability to handle the mobile phones without misalignment.

The project scope will not include:

1. Electronic and control system development for the gripper.
2. Software programming for cobot control.
3. Physical prototyping and industrial testing, as the project is limited to the digital modelling and simulation.

2 Literature review

2.1 Introduction

This literature review will explore concepts and principles relevant to the designing and development of a mechanically actuated robotic gripper for FESTO's cyber-physical production system (CPPS). This chapter looks at research on robotic gripper design, design for X (DFX) principles, and manufacturing concepts such as design for manufacturing (DFM), design for assembly (DFA), design for reliability (DFR), and design for maintenance (Ezpeleta *et al.*, 2019).

2.2 Robotic Grippers in Industrial Automation

Robotic grippers play a pivotal role in automated manufacturing as they allow for robots to interact with physical products to conduct monotonous tasks. There are many types of grippers used in manufacturing production lines such as:

1. **Mechanical fingered grippers** – These use mechanical fingers/jaws to grasp objects through geometric constraints.
2. **Vacuum grippers** – Use suction cups to hold objects. Vacuum grippers are commonly used on smooth and flat surfaces.
3. **Magnetic grippers** – Utilises magnets to lift ferrous materials such as cast iron.
4. **Soft robotic grippers** – Made of flexible materials to conform to the shape of the object its handling.

This project will utilise a mechanically actuated gripper due to its simplicity, cost-effectiveness, and suitability for high-volume manufacturing.



Figure 2: Image showing a vacuum gripper.

2.3 Design For Manufacturing (DFM)

Design for manufacturing (DFM) is a method used in designing components in a way that simplifies production, reduces costs, and improves quality. The goal is to have components that are reliable and efficient to produce, while being able to achieve high performance. The items to be considered in the early stages of DFM to make it successful are materials, processing, and tolerances, as this will reduce potential problems during the manufacturing stage. (Ezpeleta *et al.*, 2019)

2.3.1 DFM Principles

There are several principles of DFM that can be applied to the mechanical gripper design to improve its level of manufacturability such as:

1. Minimizing number of parts:

- Lowers production costs.
- Easier assembly and maintenance.
- Reduces chances of failure, as more parts introduce more potential weak points.

Application to gripper design:

- The grippers' mechanism should be integrated into one part rather than assembled from a range of multiple components.
- Self-locking fasteners should be used rather than having multiple fasteners.

2. Standardised components:

Standardised components are cheaper, readily available, and are easier to maintain/replace when compared to custom made parts.

Application to gripper design:

- Use fasteners, bearings, and springs that are readily available off the shelf to reduce production cost and assembly time.
- Use a common motor or actuator.

3. Use of cost-effective materials:

Materials selected should have a balance between weight, strength, and cost while being easy to manufacture.

Application to gripper design:

- Use lightweight aluminium alloys or polymers to reduce weight.
- Avoid expensive finishes unless they are for corrosion protection.

4. Optimized manufacturing processes:

Manufacturing methods affect the complexity of the gripper. The gripper should be designed for processes that:

- Minimize waste such as CNC machining for metals.
- Reduces the amount of post processing steps.

Application to gripper design:

- CNC machining may be the preferred processing method for metal components.

5. Reduction of tight tolerances:

The inclusion of tight tolerances increases manufacturing complexity and cost. DFM practices usually recommend using loose tolerances, but without compromising the grippers functionality.

Application to gripper design:

- Use parts that can be interchanged to avoid the need for any custom-made components.
- Define tolerances based on the grippers functionality for example using tight tolerances only if it's very necessary.

6. Design for automation:

If the gripper is intended for high volume production, assembly should be automated whenever possible. (Ezpeleta *et al.*, 2019; Meeker)

Application to gripper design:

- Manufacture the gripper components in a simple direction. Top down is usually better for automation.
- Reduce the use of fasteners by using snap-fit connections to reduce the need for manual assembly.

2.3.2 Manufacturing Process Selection

The right manufacturing process helps in balancing cost, durability, and precision. Table 1 below shows some processes that may be used for constructing the gripper:

Component	Process	Reasoning
Gripper body	CNC Machining (aluminium) Injection Moulding (plastic)	CNC machining ensures precision and strength, while injection moulding can be cost effective for high volume production
Gripper fingers	3D printing or CNC Machining	CNC Machining ensures high durability, while 3D printing allows for custom grip designs.
Fasteners	Off the shelf fasteners	Standardised fasteners reduce the cost and makes future maintenance easier.
Actuation mechanism	Standardised mechanical components	Ensures that the cobot system merges well with it.

Table 1: Table showing the processes to be considered for the gripper.

2.3.3 Case Study: DFM In Gripper Design

A study conducted in 1994 by Boothroyd and Dewhurst showed that applying DFM principles to a robotic gripper yielded the following results:

- A reduction in the total number of parts by 74.5%.
- Simplifying manufacturing and logistics by a 66.7% due to having a reduction in different component types.

- A 77.6% reduction in total operations, helping to save costs and time.(Causey and Quinn)

By applying these principles this project can improve in terms of manufacturability and cost efficiency.

2.3.4 DFM Challenges and Considerations

Although DFM can improve manufacturability of the gripper, there are still a few challenges that need to be considered such as the following:

1. **Balance between cost and performance**

- High performance materials such as carbon fibre improve the components durability but increase costs.
- There must be a compromise made between the products cost, strength, and weight.

2. **Ensuring gripper is compatible with FESTO's CPPS**

- The grippers design must interface well with the cobot and AGV.
- The design must include standardised mounting points.

3. **Limitations in manufacturing process**

- CNC machining is precise but can be expensive for mass production.
- Injection moulding is less expensive but has a high initial tooling cost.

2.3.5 Summary

To guarantee cost-effectiveness, manufacturability, and efficiency, this section has examined how Design for Manufacturing (DFM) concepts might be used to the robotic gripper design. The finished design may be manufactured at scale with great reliability by reducing the number of parts, utilizing standard components, choosing suitable materials, and streamlining manufacturing procedures.(Meeker)

2.4 Desing For Assembly (DFA)

Design for assembly (DFA) is focused on simplifying a product for assembly, reducing production time, reducing cost, and reducing labour without minimizing the products reliability and functional efficiency. The main goals are to minimize the number of parts on

the vehicle and use standardised components to ensure that the automated production line runs smoothly and efficiently.(Ezpeleta *et al.*, 2019)

In line with the robotic gripper project DFA principles were applied to ensure fast and cost effective assembly particularly for high volume manufacturing(*BAE 682-Assembly Automation & Product Design*; Causey and Quinn). This allows for the gripper to be easy to assemble and maintain while keeping the grippers structural integrity.

2.4.1 DFA principles

There are several principles of DFA that can be applied to the mechanical gripper design to improve its assembly efficiency such as(Causey and Quinn):

1. Minimize the number of parts

Reducing the number of parts leads to:

- Faster assembly by having fewer steps required.
- Lower costs as less materials will be used helping to reduce handling and storage.
- Improved reliability by eliminating potential failure points.

Application to gripper design:

- Integrate a number of functions into single components such as integrating gears with gripper claws.
- Eliminate unnecessary fasteners by using snap fits or press in joints.

2. Design for uni-directional assembly

Assembly should preferably take place from a top down position to simplify automated assembly.

Application to gripper design:

- All the grippers' components should be installed from the same direction to avoid manual intervention to change component orientation.

3. Use self-locating and self-fastening features

Self-aligning and self-locking parts reduce the need for having to manually adjust the components making assembly faster and reducing errors.

Application to gripper design:

- Include alignment features such as tapered edges and dimples to ensure a square fit.

- Use interlocking tabs to eliminate the need for screws.

4. **Standardise components and fasteners**

Use common of the shelf fasteners and components to reduce design complexity and production cost.

Application to gripper design:

- Use standardised screws, nuts, and actuators to make sourcing components and maintenance easy.
- Avoid variation in screw sizes.

2.4.2 Assembly Methods Comparison

Different assembly methods impact the components and assembly's cost, efficiency, and reliability(Causey and Quinn). Table 2 below shows a comparison of three assembly methods that can be applied to the robotic gripper design:

Assembly Methods	Advantages	Disadvantages	App To Gripper
Screws & Fasteners	Strong and secure	Slow assembly and requires tools	Used only where high load bearing is necessary
Snap-Fit Connections	Fast assembly and no tools required	May weaken over time	Used for non-loaded bearing joints
Press-Fit Joints	Simple and secure	Requires precise tolerancing	Used for joining lightweight components

Table 2: Table showing a comparison of assembly methods.

Using the right assembly method will mean that the gripper can be designed for faster production and easy maintenance.

2.4.3 Case study: DFA In Robotics

A study that was conducted by Boothroyd and Dewhurst in 1994 applied DFA principles to an industrial robotic gripper, which resulted in the following results(Causey and Quinn):

- A 56% reduction in assembly time.
- 42% reduction in in parts due to integrating components.

- A 30% reduction in in cost from reducing the number of fasteners and unnecessary parts.(BAE 682-Assembly Automation & Product Design)

An application of these principles to the FESTO gripper design can significantly improve the assembly time and cost effectiveness.

2.4.4 DFA Challenges and Considerations

Although DFA can improve the grippers assembly efficiency, some challenge can be considered such as the ones below:

1. **Assembly simplicity VS strength**

- A reduction of fasteners can compromise the grippers structural integrity.
- A solution could be to use snap fit joints where possible but keep screws for areas with high stress.

2. **Compatibility with FESTO's CPPS**

- The gripper must be modular to fit various cobot configurations.
- Design a universal mount that is compatible with the cobot's interfaces.

3. **Manufacturing limitations**

- Some snap fits and press fits require precise machining/moulding.
- Using standardised tolerances may help manufacturability.

Minimizing parts, using standard components, and reducing fasteners can make it faster and easier to assemble the gripper without compromising its performance.

3 Concept Development

This chapter will explore the concept development process for designing the robotic gripper suitable for FESTO's cyber physical production system (CPPS). The aim of this chapter is to evaluate the different gripping mechanisms, actuation methods, and structural designs that can be implemented to the gripper to find the best possible solution. The main considerations that will go into the design for the gripper include Design for Manufacturing (DFM) and Design for Assembly (DFA).

3.1 Concept Generation

3.1.1 Types of Robotic Grippers

Robotic grippers can be classified into different categories based on their working principles.

Table 3 below shows the different categories of robotic grippers, their characteristics, and their advantages and disadvantages:

Gripper Type	Mechanism	Advantages	Disadvantages
Mechanical Gripper	Uses fingers or jaws to grip objects	Strong grip and high precision	Requires complex mechanisms for adaptability
Vacuum Gripper	Uses suction force to pick objects	Works well for flat surfaces	Ineffective on porous and irregular objects
Magnetic Gripper	Uses electromagnets to lift ferrous materials	Fast and simple	Only works with magnetic materials
Soft Gripper	Uses flexible materials to wrap around objects	Safe for delicate objects	Lower gripping force

Table 3: Table showing a comparison of gripper categories.

Based on FESTO's need for versatility and precision, a mechanical gripper with adaptable finger designs is the most appropriate choice.

3.1.2 Actuation

The gripper's movement can be achieved using different actuation methods such as shown in Table 4 below:

Actuation Method	Mechanism	Advantages	Disadvantages
Stepper Motor	Rotational motor controlling gripper jaws	Precise control and programable	Requires power
Pneumatic Actuator	Uses compressed air to drive movement	Fast and high output force	Requires air supply system
Hydraulic Actuator	Uses pressurised fluid for movement	High force	Harder to maintain

Table 4: Table showing a comparison of actuation methods.

A stepper motor or pneumatic actuator is more ideal for FESTO's CPPS, due to precision, reliability, and ease of integration.

3.1.3 Finger Design Concepts

The gripping mechanism depends on the finger configuration. Table 5 below shows the different types of gripper finger configurations:

Finger Configuration	Description	Suitability
Parallel Gripper	Two fingers move symmetrically	Ideal for picking uniform objects
Three Finger Gripper	Three fingers provide better grip	Suitable for irregular shapes
Soft Gripper	Flexible fingers adjust to objects	Best for delicate materials

Table 5: Table showing a comparison of gripper finger configurations.

A parallel mechanical gripper offers the best balance between versatility and stability.

3.2 Evaluation and Selection

This section looks at the evaluation and selection methodology used to decide which of the finger gripping methods works best between the parallel gripper, three finger gripper, and soft finger gripper. The different concepts are evaluated based on the following criteria:

- Versatility – ability to grip the phones even when not positioned correctly.
- Manufacturability – ease of production using standard processes.
- Cost – production affordability.

- Integration – compatibility with FESTO’s CPPS.
- Durability – resistance to wear and tear.

3.2.1 Decision Matrix

A weighted decision matrix is used to rank concepts as shown in Table 6 below:

Criteria	Weight (%)	Parallel Gripper	Three Finger Gripper	Soft Gripper
Versatility	30	7	9	8
Manufacturability	25	9	6	6
Cost	15	8	6	6
Integration	15	9	9	8
Durability	15	9	8	7
Total Score	100	8.25	7.65	7.2

Table 6: Table showing a weighted decision matrix.

The parallel gripper is the optimal choice due to its high manufacturability, durability, and integration with the cobot.

3.3 Final Concept Selection

3.3.1 Chosen Concept

The selected concept is a stepper motor actuated parallel gripper, with the following features to make it function to the best of its ability:

- Parallel gripper
- Stepper motor actuation
- Lightweight, durable material (aluminium)
- Standardized mounting for collaborative robot (cobot)
- Two hooks to pick up the phone on the dispatch station

3.4 Summary

This chapter outlined the gripper’s development process, which led to the selection of a stepper motor actuated parallel mechanical gripper.

4 Detailed Design And CAD Modelling

This chapter presents the detailed design and modelling of the selected robotic gripper concept. It includes a breakdown of the mechanical structure, actuation system, material selection, and the use of CAD software to develop a 3D model. The design is driven by Design for Manufacturing (DFM) and Design for Assembly (DFA) principles to ensure that the gripper can be easily produced, assembled, and integrate with the collaborative robot (Cobot).

4.1 Design Objectives

The gripper design must:

- Securely grasp the phones without dropping or separating parts
- Interface smoothly with the cobot and AGV
- Be lightweight, compact, and easy to manufacture
- Use reliable actuation (stepper motor)
- Feature modular and symmetrical parts to ease assembly

4.2 Parts Modelling

SolidWorks was used to model each of the components for the gripper. It was also used to make a full assembly of the gripper. Each of the gripper's components were modelled with attention to material properties to help with simulation accuracy, parametric constraints to help with future editing, and tolerances and clearances to help with smooth movement and manufacturability. Below is a list of all the components featured in the gripper:

- Two gripping claws
- A 28BY-J-48 stepper motor to actuate the gripper, connected to one gear
- Base plate to connect the gripper to the COBOT
- Joints to make motion transfer from motor and gears to gripping claws

Figure 3 below shows the actuation mechanism which is a 28BY-J-48 stepper motor. It operated by rotating the driving gear, which transfers the rotational energy to linkages to open and close the gripping claws. The motor is suitable as it is small enough and has enough torque to move the claws and clamp the phone fast enough for the intended purpose.

Spindle that will be connected to the gear to allow the gear and motor to be one component. This will be a push fit requiring no fasteners.

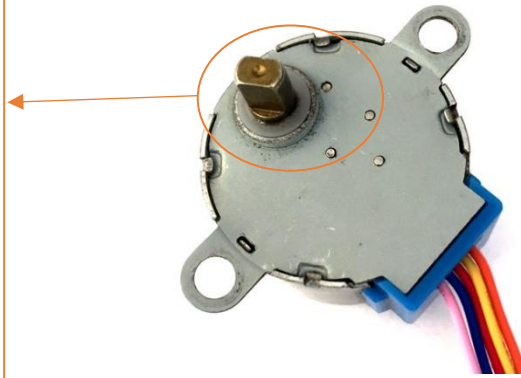


Figure 3: Image showing 28BY-J-48 stepper motor used.

Figure 4 below shows an isometric view of the designed gripper assembly:

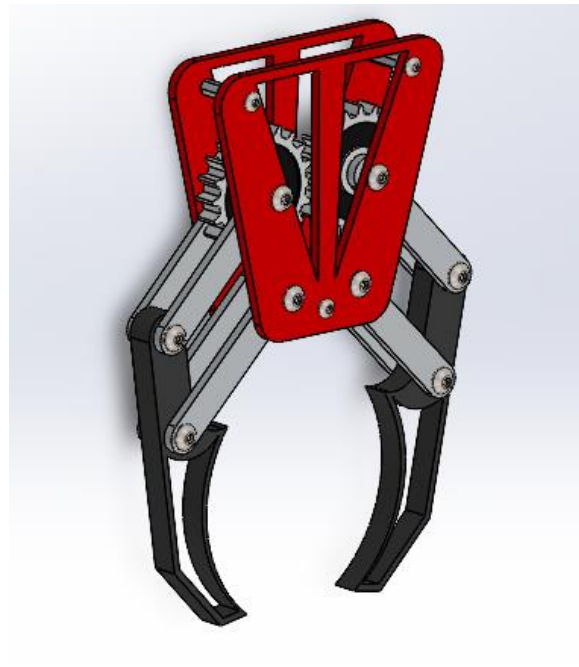
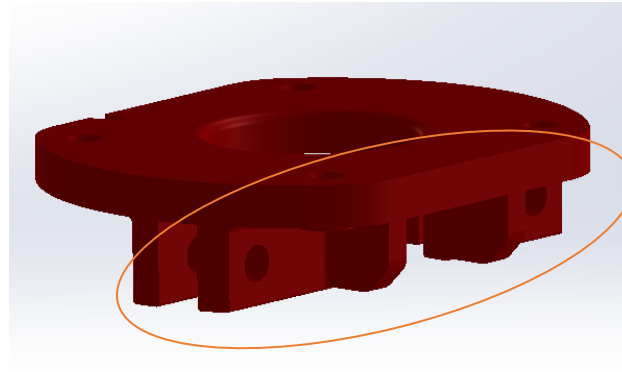


Figure 4: Image showing isometric view of the designed gripper.

Figure 5 below shows the base plate that will mount to the UR3 Cobot. This will allow for integration of the gripper and the COBOT. The cobot will mount to this plate using screws. This is shown by the circled areas.



The circled areas are the mounting areas for the gripper that will allow the gripper and the base plate

Figure 5: Image showing isometric view of the designed base plate.

Components Designed:

Component	Function
Gripper Claws	To securely grip the mobile phones.
Base Plate	To mount the gripper to the cobot.
Stepper Motor	To make claw open and close.
Linkage Arms	To transfer motion from motor to claws.
Cover Housing	To protect mechanical components.

Table 7: Table showing the designed components of the gripper design.



Figure 6: Image showing exploded view of the designed gripper.

Each of the components of the gripper were modelled with defined parameters such as, parametric dimensions to make it easy to scale and adjust and material assignment to accurately show in the stress simulations conducted.

4.2.1 Motion Study

The components of the gripper were assembled using some mechanical constrains such as concentric and gear mate. This allows for the motion study in SolidWorks to be possible. The motion study validated and checked for any collisions and the opening/closing ranges of the gripper claws as seen in Figure 7 below. These ranges confirm that the gripper is capable of gripping the mobile phones without putting any excessive force.

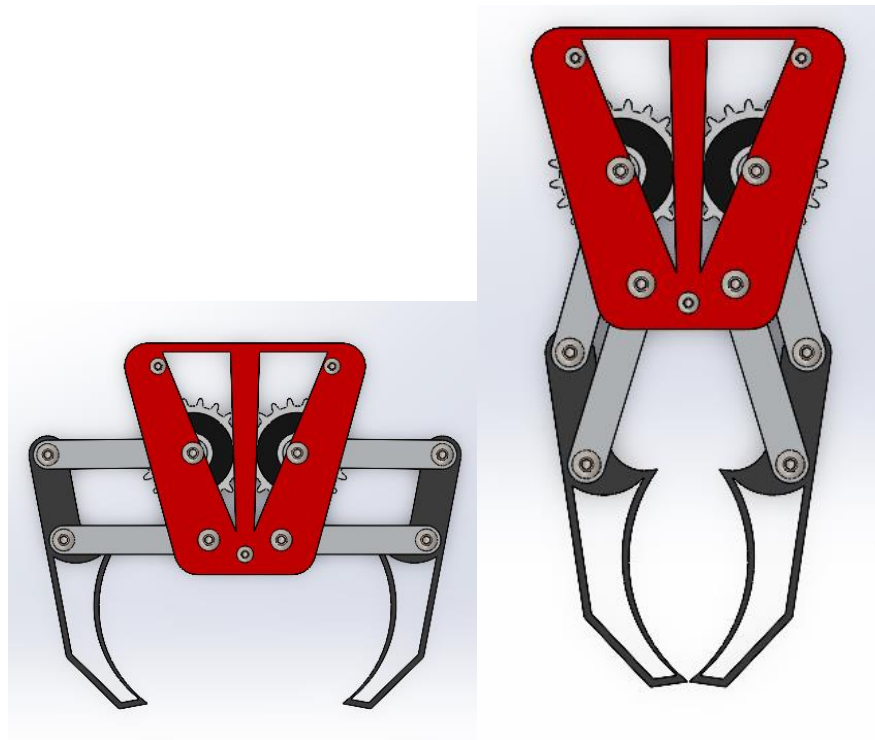


Figure 7: Image showing the grippers fully open and fully closed ranges.

4.3 Material Selection

Material selection is key for the durability and longevity of the gripper. It is also key in terms of easy manufacturability and cost effectiveness of manufacturing the gripper. Table 8 shows the components, their selected material, and the reasoning behind the choice of the material.

Component	Material	Reason
Gripper Claws	Aluminium 6061	Lightweight, strong, corrosion-resistant
Base Plate	Aluminium 6061	Lightweight, strong, corrosion-resistant
Linkages	Stainless Steel	High fatigue resistance and strength
Housing	Aluminium 6061	Tough, protective, good machinability

Table 8: Table showing the components chosen materials and reasoning.

4.3.1 Manufacturing Method

Due to all the materials of the components being either Aluminium 6061 or stainless steel, the manufacturing method of choice is CNC machining. This is because of its ease in manufacturing and its cost effectiveness.

4.4 Finite Element Analysis (FEA)

A stress analysis was performed on the fingers and the linkages to ensure that they could withstand the expected forces without excessive deformation of the mobile phone and the components that make up the gripper. The following parameters were set for the analysis:

- Load: 10N of force
- Material: ABS plastic
- Factor of safety: Above 2

4.5 DFM & DFA Applications

4.5.1 DFM Considerations

- Reduced part complexity to simplify the grippers production
- Standard hole sizes for used screws
- Modular design allows for easy changes without redesigning the whole gripper

4.5.2 DFA Considerations

- The symmetrical parts will reduce the number of errors had in assembly.
- Press fits were used to connect the motor to the gear.
- Top-down assembly was used to allow for easy manufacturing either manually or automated.

4.6 Mounting And Integration

Shown in Figure 8 below is how the base plate features universal mounting patterns that are compatible with the UR3 COBOT. The base plate will be fastened by fasteners to the COBOT to allow for a secure fix to it.

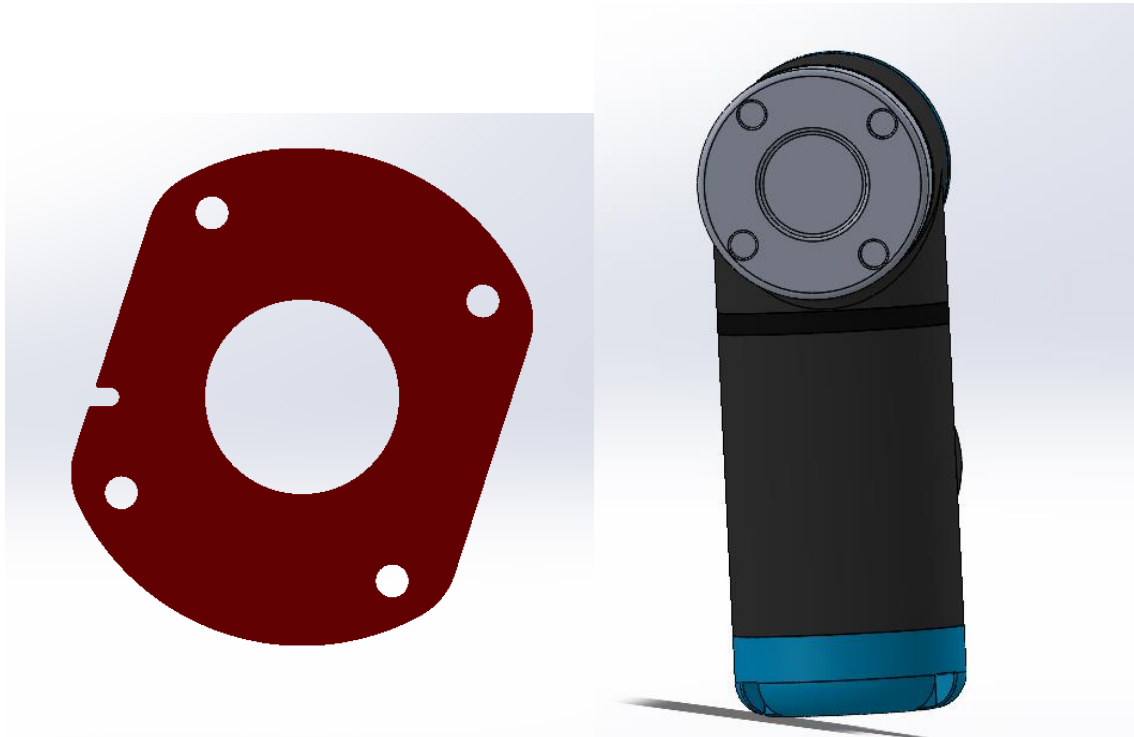


Figure 8: Image showing the integration hole design of the base plate and UR3 COBOT.

4.7 Summary

This chapter showed the full mechanical design, CAD modelling, material selection, and assembly plan for the robotic gripper. The design ensures that the system can be lightweight, reliable, manufacturable, and easy to integrate with the whole FESTO CPPS.

5 Prototyping And Testing

Chapter 5 will investigate the prototyping and testing of the designed robotic gripper. The prototyping stage enables the early validation of the gripper's performance against the specified requirements, while being able to test that the gripper design will operate reliably within FESTO's CPPS.

The digital prototyping and plans for physical prototyping are covered in this section. The testing will focus on the strength, mechanical function, movement, and gripping capability of the designed gripper.

5.1 Digital Prototyping

Using SolidWorks the gripper was assembled and validated to check for the following things:

- Checking that all the mechanical mates are working
- Ensuring that there are no collisions during the opening and closing motions
- Validation of the claws motion ranges to ensure they meet the phones size and handling requirements

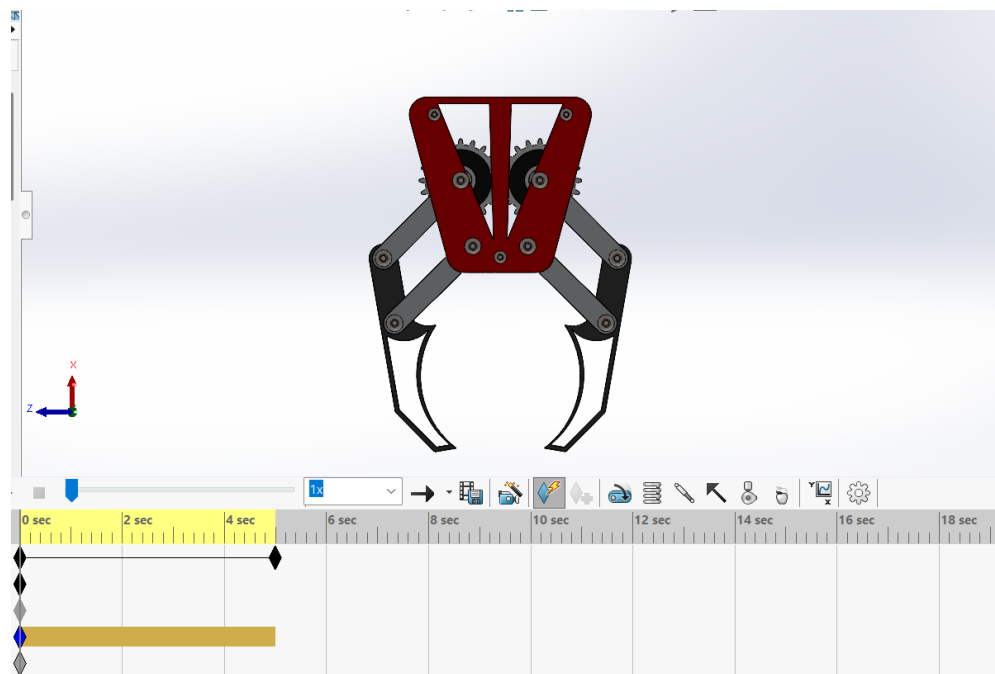


Figure 9: Image showing the motion study.

5.2 Motion Study

A motion study was carried out to simulate the actuation cycle:

- **Input:** 28BY-J-48 stepper motor applied to the driving gear.
- **Output:** Symmetrical and simultaneous movement of the 2 claws.

Results:

- Full gripping cycle was completed in under 8 seconds
- There was no interference or gear jamming observed during the movement

- The maximum claw opening span achieved was 115mm which is enough to grip the phone

5.3 Finite Element Analysis (FEA)

Finite Element Analysis was used to evaluate the structural strength of the CNC-machined aluminium gripper under gripping conditions. This ensures that the claws will not deform or fail during operation.

FEA Setup:

- **Material:** Aluminium 6061
- **Loading Conditions:** Simulated gripping force of 10N applied at the claws
- **Boundary Conditions:** Fixed mounting points at the base
- **Mesh Type:** Fine mesh was used for higher accuracy in critical areas such as screw joints

5.3.1 FEA Results

- Maximum Von Mises Stress: 90Mpa which is below the yield strength of Aluminium 6061 (275Mpa)
- Factor of Safety: Calculated as 3.06
- Deformation: Minimal, less than 0.18mm under full load.

Conclusion:

The gripper is structurally sound and capable of gripping the phones without risk of deformation or mechanical failure.

5.4 Manufacturing Plan

Although the gripper was not fabricated, a prototype manufacturing plan was developed as follows:

Claws: CNC machined from Aluminium 6061 stock material

Base plate and linkages: CNC machined and assembled using fasteners

Gears: CNC machined and assembled with pins and fasteners

Assembly: Parts assembled manually and tested with FESTO's cobot

5.5 Proposed Physical Testing Procedure

If physical testing is to be performed the tests in Table 9 below would be used:

Test	Purpose	Success Criteria
Grip Strength Test	Measure maximum load held without slipping	Hold the phone securely
Endurance Test	Cycle open/close 10,000 times	No visible wear, no mechanical failures
Object Compatibility Test	Handle different object sizes and shapes	No damage, good alignment, consistent grip
Speed Test	Measure time for full grip cycle	Complete cycle under 10sec
Safety Release Test	Test emergency stops and fail safe	Safe opening

Table 9: Table showing the proposed testing methods.

5.6 Conclusion

This chapter looked at the prototyping and testing of the designed robotic gripper. The CAD assembly and motion studies confirmed the mechanical compatibility and function, while the FEA analysis validated the structural strength of the gripper under the expected loads.

The results show that the design is fit for the intended purpose by meeting FESTO's requirements for a robust, precise, and manufacturable gripping mechanism. Further physical testing is required to fully validate performance under real world conditions.

6 Discussion And Evaluation

This chapter will look into the discussion and evaluation of the designed robotic gripper for FESTO's CPPS. It will assess the extent to which the design meets the original objectives and requirements, the outcomes of the digital prototyping and testing, and reflects on the strengths, weaknesses, and limitations of the design.

6.1 Evaluation Of Design Objectives

Objective	Achievement	Comment
Design a high-volume manufacturable gripper using DFM principles	✓ Achieved	The design minimizes part count, uses standard materials, and applies manufacturing methods.
Develop a robust and durable gripper for industrial use	✓ Achieved	FEA results showed low stress and deformation, with a FOS of 3.06.
Integrate Design for Assembly (DFA) principles	✓ Partial Achievement	Modular parts, symmetric claws, but no use of minimal fasteners.
Create 3D CAD models and validate the design	✓ Achieved	Full CAD assembly and motion studies completed with no collisions.
Evaluate the design through digital simulations	✓ Achieved	Motion studies and FEA stress analysis performed.
Plan for integration with FESTO's CPPS	✓ Achieved	Universal mounting plate designed for easy cobot attachment.

Table 9: Table showing the evaluation of the design objectives.

6.2 Analysis Of Prototyping And Testing

6.2.1 Motion Study

- The gripper successfully demonstrated smooth opening and closing
- The maximum opening span was enough to be able to grip the phone successfully.
- There was no interference or gear jamming observed.

6.2.2 Finite Element Analysis (FEA)

- Maximum Von Mises stress of 90Mpa
- Factor Of Safety of 3.06 which exceeds the targeted value of 2
- Maximum deformation of 0.18mm

This shows that the structural strength and mechanical performance of the design ensures reliable operation.

6.3 Design Strengths

- **Robust and durable:** a long life can be seen ahead of the gripper due to a high factor of safety and low deformation
- **Easy manufacturing:** design tailored for CNC machining and uses standard fasteners
- **Modular assembly:** is easy to disassemble making maintenance simple
- **Lightweight:** this helps as it does not put any extra strain on the COBOT arm.

6.4 Improvements

Although the gripper meets the requirements and performs well, some improvements can be made to the design. these improvements include adding rubber pads to the inside surface of the gripping claws to help enhance the gripping capability of the gripper as illustrated in Figure 9 below:

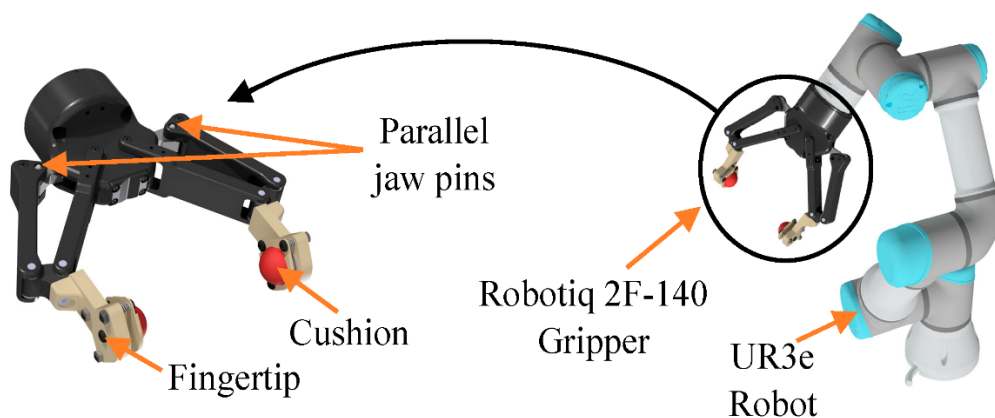


Figure 10: Image showing robotic gripper with rubber cushions.

The other improvement that could have been beneficial to the gripper design is the use of supports to support the phone when it is being gripped as there are tendencies for grippers to not fully support the phone. The supports are shown in Figure 10 below:

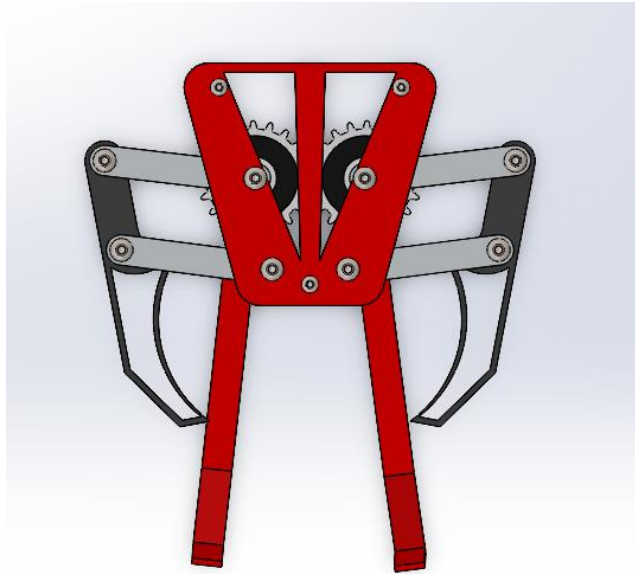


Figure 11: Image showing robotic gripper with phone supports.

In order to handle the phones for automated dispatch procedures, the main goal of this project was to design a mechanically operated robotic gripper that was optimized for usage within FESTO's Cyber-Physical Production System (CPPS).

Motion investigations were carried out to confirm seamless operation free from mechanical interference.

A high factor of safety (3.06) and little deformation (0.18 mm) under anticipated gripping loads were confirmed by Finite Element Analysis (FEA).

The design satisfies the integrative, mechanical, and functional specifications established at the start of the project.

Digital prototyping and simulation findings show that the gripper can operate dependably, be easily manufactured, and integrate seamlessly with FESTO's cobot system, even though physical prototyping was not finished within the project timeline.

The significance of implementing Design for X (DFX) principles throughout product development has been illustrated by this project. The gripper demonstrates that a methodical, organized engineering approach may provide creative and useful automation solutions because to its resilience, manufacturability, and simplicity. Moving toward

complete real-world application within FESTO's smart manufacturing operations, the project offers a strong foundation for subsequent development stages.

7 References

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