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ACHA5002 – Manufacturing Design & Technology

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Task 1 – Robot Gripper Redesign

1.1 Introduction

In the manufacturing application of automation and robotics, the ability to scale capabilities to meet market demand is crucial for success. In this task, a robotic tooling manufacturer aims to expand the production of one of their robotic gripper solutions. Until now, the gripper has been fabricated in limited quantities, tailored to niche applications and specific customer needs. However, with the surge in demand and the potential for widespread adoption, there is a need to transition from small-scale production to mass manufacturing.

1.2 Initial Boothroyd & Dewhurst (B&D) analysis

Conducting a Boothroyd & Dewhurst (B&D) analysis provides an efficient approach to evaluating the design efficiency of mechanical assemblies, focusing on minimising assembly costs and optimising the assembly process. This methodology assesses a product's design by examining the number of components, distinguishing between essential and non-essential parts, and their impact on assembly efficiency. The gripper assembly comprises 57 components—25 essential and 32 non-essential. The Boothroyd & Dewhurst analysis scrutinises each element to understand its necessity and contribution to the assembly. The distinction between essential and non-essential components is critical to the analysis. Fundamental components are integral to the assembly's functionality, structure, or compliance requirements. Non-essential components, while they may serve a purpose, often represent opportunities for design simplification and cost reduction. These could include parts added for aesthetic reasons, ease of assembly, or because of traditional design practices rather than functional necessity. Calculating the design efficiency involves a formula that considers the theoretical minimum number of parts (ideally, the number of essential components) against the actual number of parts. In this analysis, achieving an overall design efficiency of 43.86% signals a significant opportunity for improvement. The higher the design efficiency, the more streamlined the assembly process is, reducing production time, assembly costs, and potential error rates. After completing the Boothroyd & Dewhurst analysis, a detailed review of each component will be completed to evaluate its necessity. Design methods for the non-essential components can be eliminated, combined, or redesigned to enhance efficiency. This includes assessing if multiple parts can be integrated into single, multifunctional components or if certain non-essential elements can be removed without impacting the assembly's overall functionality or performance.

1.3 Further review of non-essential components

The largest area for improvement identified by the Boothroyd & Dewhurst analysis was 26 non-essential fasteners in the assembly process, which allows for a significant opportunity for design optimisation and efficiency improvement. Fasteners, while critical for the structural integrity and assembly of various components, can often be overused or misapplied, leading to unnecessary complexity, increased manufacturing costs, and extended assembly times. Eliminating these non-essential fasteners can have profound implications for the assembly process and the product's overall design efficiency. Eliminating the 26 non-essential fasteners simplifies the assembly process by reducing the

steps required to assemble the product. Each fastener eliminated also reduces the inventory of parts that need to be managed and stored, simplifying logistics and inventory management. This simplification can significantly reduce the direct cost of purchasing the fasteners and the labour costs associated with handling and assembly. The time saved by eliminating unnecessary fasteners is substantial. Each fastener requires time to align, place, and secure during assembly. By removing 26 non-essential fasteners, the cumulative time saved can significantly reduce the overall assembly time, increasing the throughput of the manufacturing process and enabling the production line to be more efficient and flexible. Rethinking the necessity of each fastener requires the consideration of alternative joining methods or design integrations that may offer superior performance or reliability. These alternatives can reduce the complexity and cost of assembly and improve the product's aesthetic appeal and functionality by eliminating protrusions or areas prone to loosening over time. Reducing the number of components in a product, including fasteners, also contributes to sustainability efforts. Fewer parts mean less material use and waste and reduced energy consumption during manufacturing. Additionally, products that are easier to disassemble at the end of their life cycle are more amenable to recycling, further supporting environmental sustainability. At the same time, these 26 fasteners make up the most significant amount of non-essential components; six components of the gripper frame that are also non-essential to the overall assembly can be reduced by consolidating them with the other frame components and being manufactured as one component.

1.4 Design improvements

When redesigning the components to reduce the number of parts, two different areas of the gripper were designed together. The first redesigned area was the gripper arms portion of the assembly. By joining the gripper claws to the arms that attach it to the frame and the servo motors, it eliminates the need for the two screws and nuts per side and reduces the number of components from 6 per side to 2 per side. Not only does this design reduce the number of components used, but it will also strengthen the gripper jaws as they will have increased stiffness and strength due to the reduction of joints.

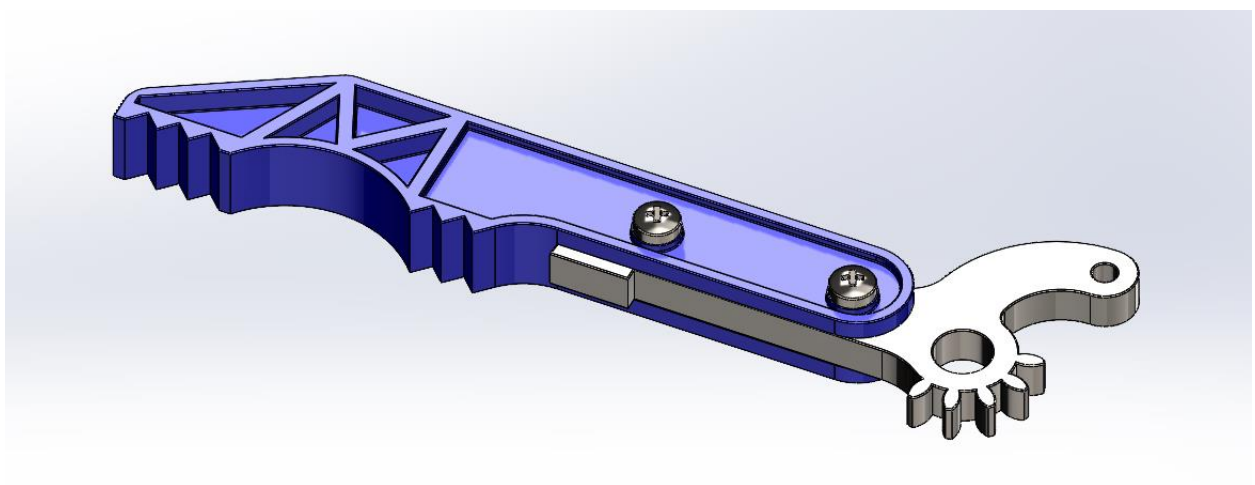


Figure 1 The original design for the gripper arm

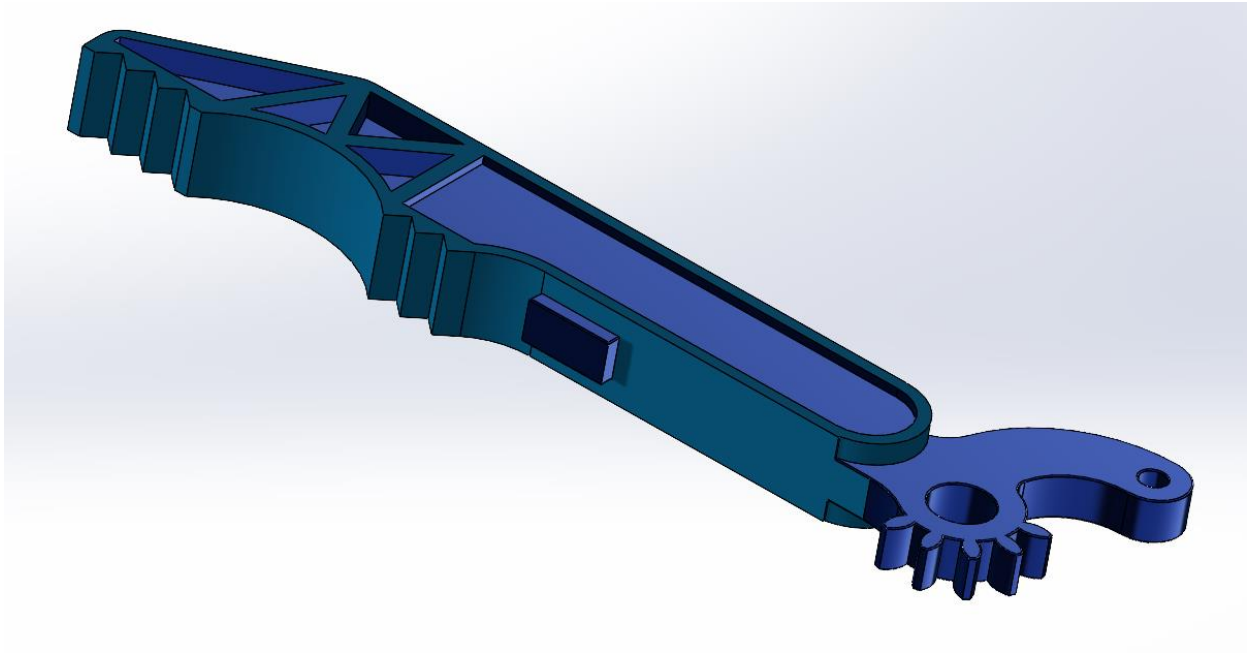


Figure 2 Redesigned gripper arm

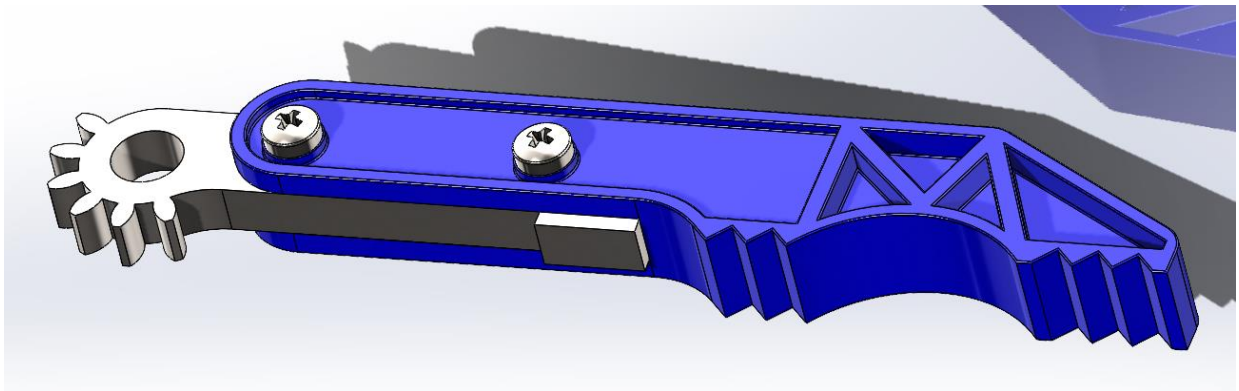


Figure 3 Original design for the alt grip arm

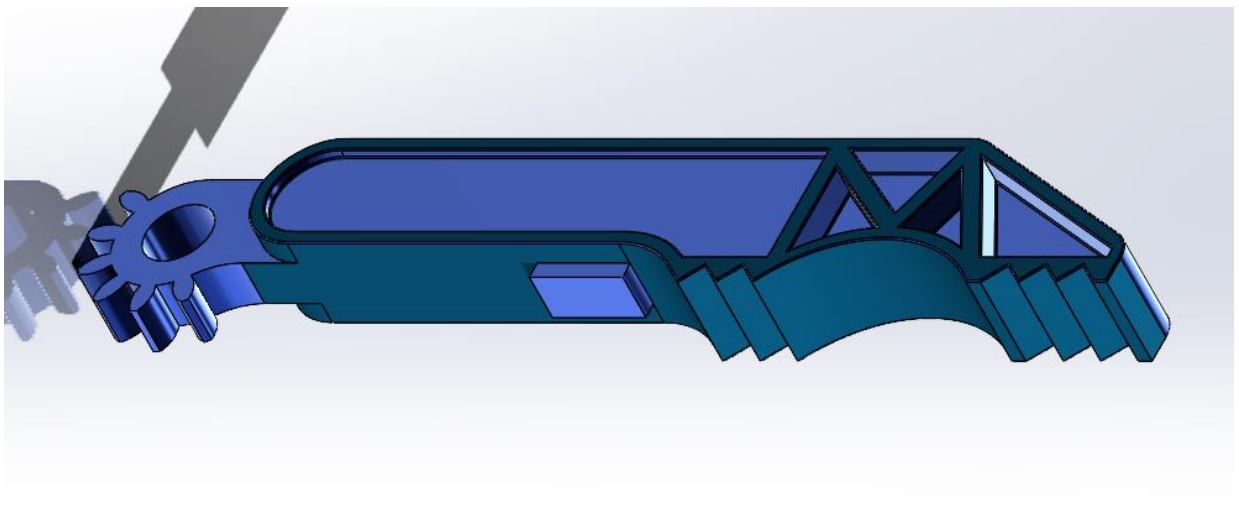


Figure 4 Redesigned alt gripper arm

The second part of the assembly that I redesigned, which eliminated the majority of the non-essential components, was the grippers frame, which connects all of the significant components, such as the gripper arms and the servo motor, and allows for the assembly to mount to the equipment at the other side. The design reduced the number of components and fasteners by combining the plates that make up the central mounting portion of the assembly, reducing the number of significant components into one main frame piece and, therefore, eliminating all of the fasteners needed to mount them together—threaded inserts. The only disadvantage of this gripper frame design is that due to the complexity of the design and its intricate geometry, traditional manufacturing methods would not be suitable for use. Therefore, different manufacturing techniques would have to be researched and implemented.

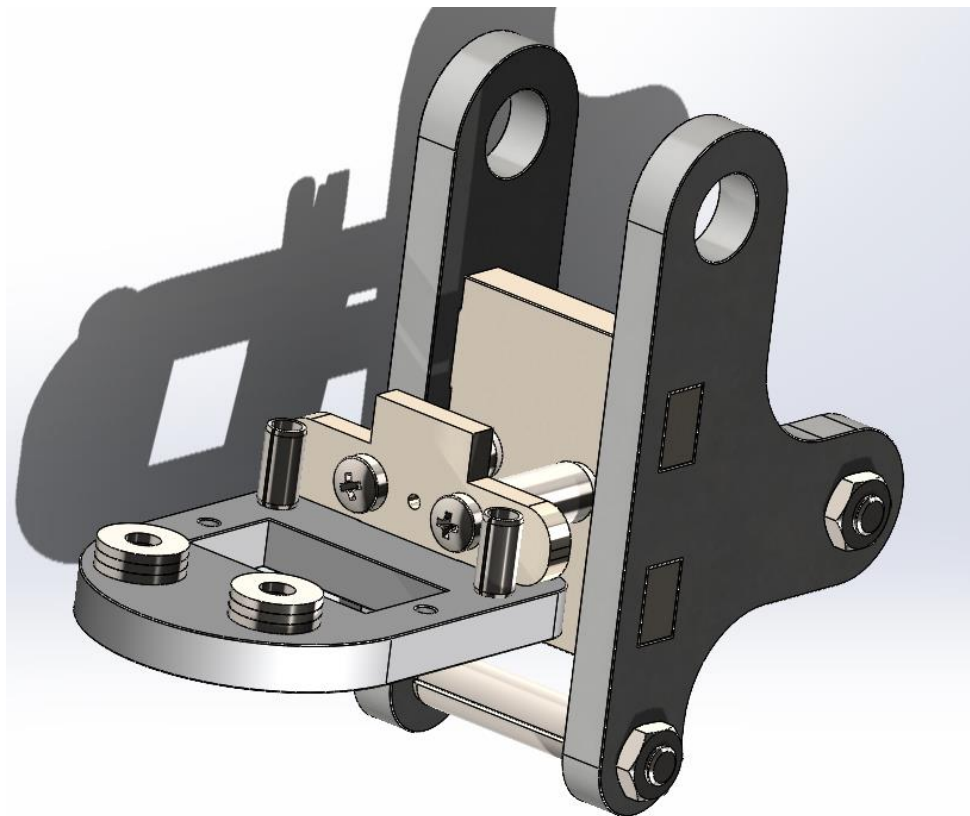


Figure 5 Original design gripper frame components

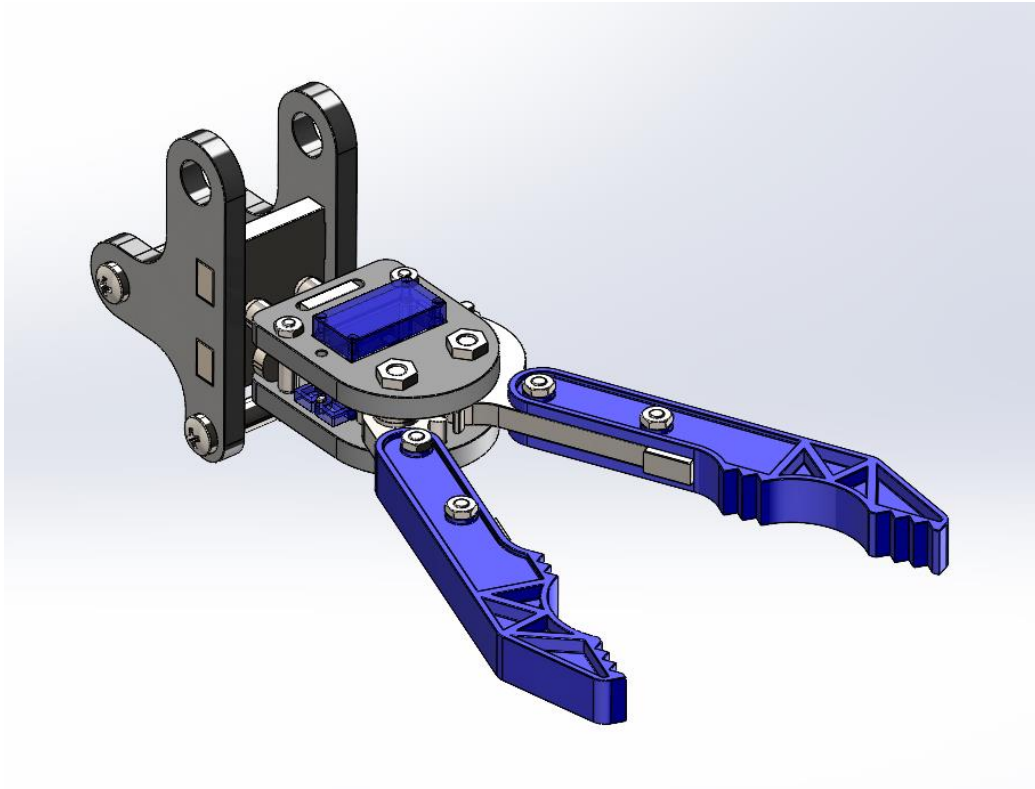


Figure 6 Original design of gripper frame with all of the components mounted

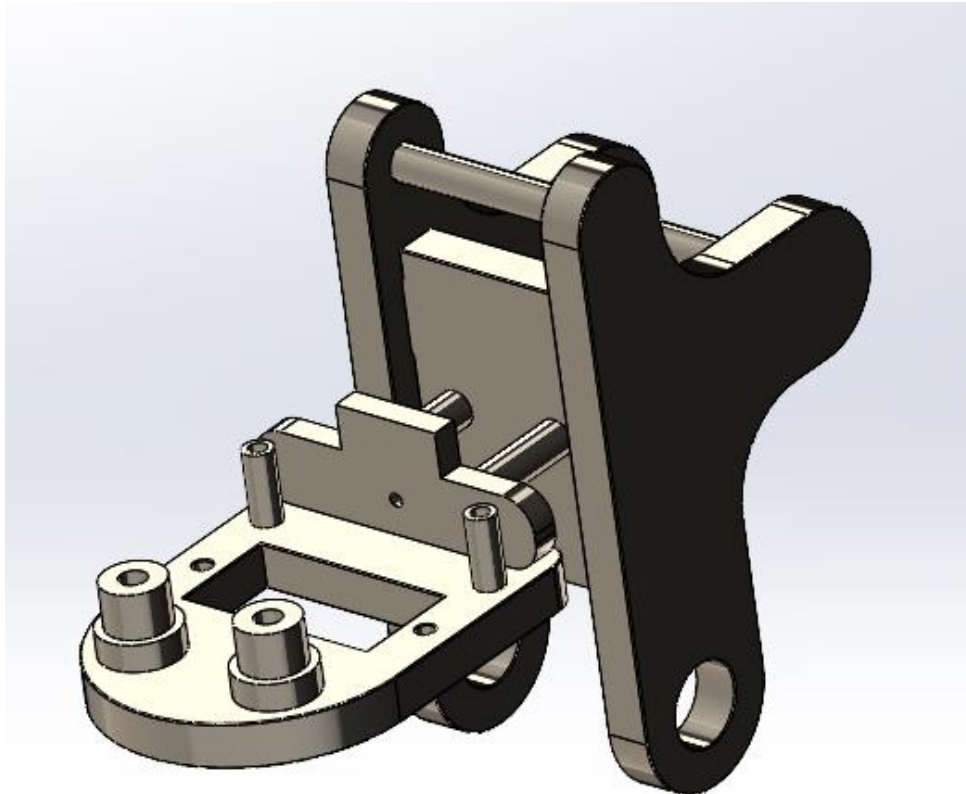


Figure 7 Redesigned gripper frame as one component

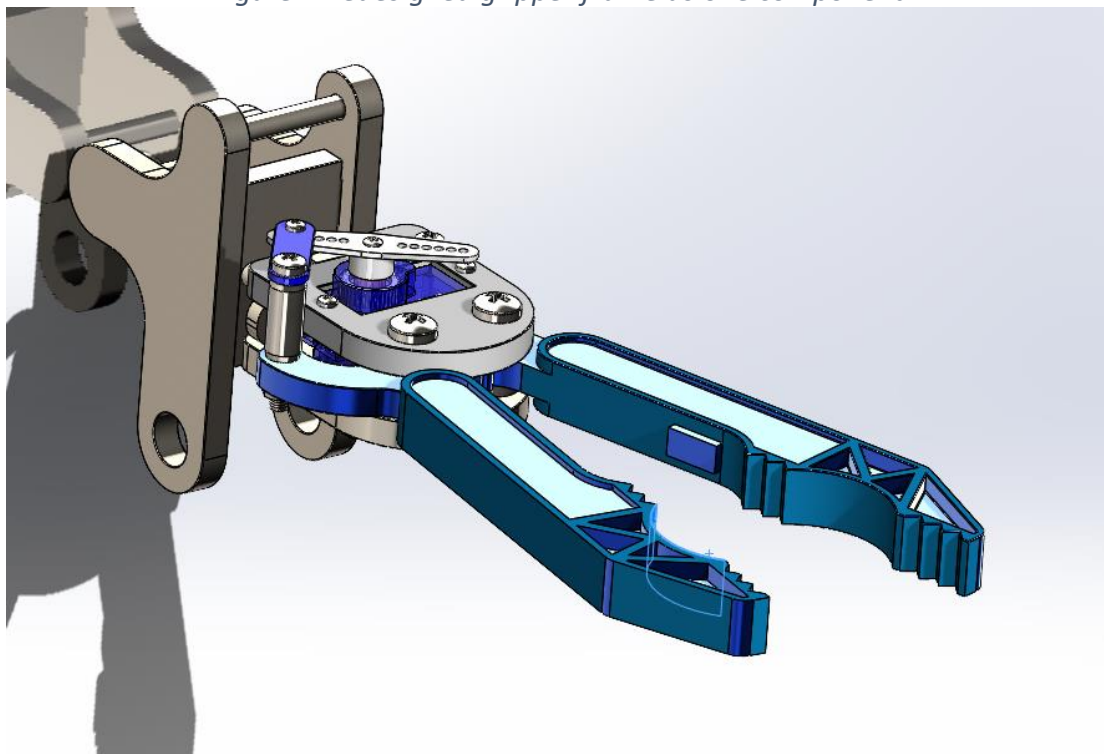


Figure 8 Redesigned gripper frame with all of the components mounted

1.5 Design for X

In redesigning the gripper, applying several "Design for X" (DfX) principles was critical in increasing the design efficiency. Of all the design for X principles, the ones most relevant to this project were:

1.5.1 Design for Assembly

Top-Down Assembly

Adopting a top-down assembly approach was a strategic choice in the gripper's redesign. This method allows each component to be slotted into place sequentially from above, minimising the complexity and time required for assembly. This vertical assembly technique can be particularly advantageous in environments with limited space, as it often requires less manoeuvrability from the assembly personnel or machinery. Top-down assembly typically enhances the visibility and accessibility of the assembly process, reducing the risk of incorrect assembly and improving ergonomic safety for workers.

Integration of Stand Offs and Spacers

Incorporating standoffs and spacers into a single-piece frame is an excellent application of DfA principles. This integration reduces the total number of parts in the assembly, which decreases the handling time and potential for assembly errors. Fewer parts mean fewer inventory items to track and store, simplifying the supply chain and storage requirements. It also contributes to a more robust design by eliminating joints that can become points of failure through wear or vibration.

Threaded Holes for Bolt Assembly

Modifying the design to include threaded holes where bolts are needed eliminates the requirement for separate nuts. This change streamlines the assembly process by reducing the steps in fastening components together. By threading the holes directly into the frame or other parts, the assembly becomes faster and requires less dexterity, as workers no longer need to align and secure nuts on the bolts. This can also reduce the weight of the final assembly and increase its strength by ensuring that bolts are more securely fastened directly into the material.

Standardisation of Fixtures

Standardising all remaining fixtures to the same size significantly improves the assembly process. This uniformity means that only one type of tool is necessary for the entire assembly, simplifying the tools and equipment required and reducing workers' time switching tools. This speeds up the assembly process and reduces training time for assembly workers, as they need to be familiar with fewer tools. Additionally, this reduces the likelihood of using the wrong tool, which can prevent damage to the components and tools alike.

1.5.2 Design for reliability

Enhanced Safety through Structural Integrity

The fewer the components, such as bolts, nuts, and washers, the fewer the weak points within the structure of the gripper. Reducing potential failure points directly translates to improved machine and operator safety. There is a reduced risk of components coming loose and causing operational disruptions or accidents, which is particularly critical in high-speed or high-load environments where the integrity of every component is vital. Thus, the reliability of the gripper is directly tied to its safety, ensuring that it can be operated confidently in its mechanical integrity.

Improved Maintenance and Inspection

Conducting maintenance and inspections becomes more straightforward and efficient with fewer fixtures. Visual inspections, a standard preventative maintenance method, become quicker and more effective when fewer components are examined. This ease of inspection ensures that potential issues can be identified and addressed before they lead to failure, thus preventing downtime and expensive repairs. It also means that maintenance personnel can be more thorough in their inspections without the need for extensive disassembly, which further increases the reliability of the gripper by ensuring that it remains in optimal working condition.

Streamlined Design for Longevity

A design with fewer components naturally requires less maintenance and is less susceptible to cumulative wear and tear. This streamlined approach improves the gripper's operational reliability and extends its lifespan. By focusing on a more straightforward, more robust design, the gripper will likely retain its functionality and structural integrity over a more extended period, a key objective in DfR.

However, while the previous two principles improved the robotic gripper's design, the change in design also adversely affected the component's manufacturability.

1.5.3 Design for Manufacturing

Increased Manufacturing Complexity

The introduction of more complex component geometries typically means more intricate production processes. Traditional manufacturing methods like machining or injection moulding might need help to produce these designs accurately or economically. Complex geometries often require advanced manufacturing techniques, such as additive manufacturing (3d printing), which can handle intricate details without complex tooling or assembly processes. However, these methods can vary regarding material choice, strength, and cost-efficiency.

Need for Advanced Manufacturing Technologies

With complex geometries, manufacturers may need to invest in new technologies or upgrade existing equipment. Processes like selective laser sintering (SLS), stereolithography (SLA), or metal 3D printing might become necessary. These technologies can efficiently handle complex designs but often come with higher operational costs and require specialised knowledge for operation and maintenance. Transitioning to such advanced manufacturing techniques involves training personnel, adjusting supply chains, and potentially higher per-unit costs.

Impact on Production Costs

Complex geometries can significantly affect production costs. Advanced manufacturing methods generally involve higher material costs, increased energy consumption, and potentially slower production speeds than traditional manufacturing. The initial setup or transition costs to new manufacturing processes can also be substantial. While unit costs may decrease as production scales and efficiencies improve, the initial investment and ongoing operation costs must be carefully considered.

1.6 Poke Yoke

Poka-yoke, a Japanese term meaning "mistake-proofing," is an essential concept in manufacturing and engineering that aims to eliminate errors by designing processes, equipment, or tools to prevent them from occurring. Applying poka-yoke in redesigning a robotic gripper provides an excellent example of how this principle can be integrated into equipment design to enhance functionality and reliability. In the case of redesigning a robotic gripper, the poka-yoke approach can be applied by ensuring that parts of the gripper can only be assembled in one correct orientation. The advantages of implementing the poka-yoke ideology include;

- **Unambiguous Assembly:** Designing the components to fit together in one way minimises the chance of incorrect assembly. This can involve unique geometric features, such as asymmetrical shapes, standoffs, tabs, and slots that only align in the correct configuration.
- **One significant advantage of using poka-yoke to redesign a robotic gripper is reduced training and inspection time.** The simplified assembly process means less time is spent training workers, and the need for inspection and testing is significantly reduced. This not only leads to faster production times but also translates into cost savings, making the use of poka-yoke a win-win situation.
- **Increased Reliability:** With parts that only fit together correctly, the likelihood of mechanical failure due to improper assembly is significantly reduced. This reliability is crucial in robotic applications where precision and durability are essential.
- **Ease of Maintenance:** Maintenance becomes more straightforward because parts are designed to be replaced or serviced in only one correct manner. This design reduces errors during maintenance, which can extend the gripper's lifespan and maintain its efficiency.

- Error Detection: In some poka-yoke implementations, if an error does occur during assembly, the design itself may prevent the assembly from proceeding or provide immediate feedback that something is wrong. This instant feedback allows for quick correction and prevents further downstream errors.

Task 2 – Design for additive manufacturing (DfAM)

2.1 Introduction

The surge in adopting Additive Manufacturing (AM) processes in the dynamic manufacturing realm marks a significant technological and strategic shift. This transformation is characterised by the ability to create parts with unprecedented complexity and precision, fundamentally challenging and expanding the boundaries of what can be achieved in design and production. Additive Manufacturing, through its capacity to layer materials into precise configurations, offers a robust solution to the constraints inherent in traditional manufacturing techniques, such as subtractive or formative methods. This leap in manufacturing capability opens up a new frontier of design freedom, allowing for the incorporation of intricate design features and complex geometries that enhance product performance and functionality. Because of this, the Design for Additive Manufacturing (DfAM) concept has gained prominence, encouraging designers and engineers to think beyond conventional design rules and fully exploit the unique opportunities presented by additive technologies. DfAM is not just about adapting existing designs to AM processes; it is about reimagining products from the ground up to leverage the full spectrum of benefits these technologies offer, including material efficiency, customisation, and the integration of advanced functionalities. The component that will be redesigned in this task is the car wheel, looking at all the advantages that producing them using additive manufacturing brings. I have chosen not to perform any CAD or CAE design due to the broad nature of car wheel design, instead focusing on discussing why I believe car wheels are a components that's manufacturing methodology could be greatly improved and advanced by integrating additive manufacturing.

2.2 Traditional wheel production methods

Car wheels, a critical component in automotive engineering, are produced through various manufacturing processes, each chosen based on the desired properties of the wheel, such as strength, weight, cost, and aesthetics. The production of car wheels involves complex engineering considerations and is primarily centred around two main types of wheels: steel wheels and alloy wheels (including aluminium and magnesium alloys). The manufacturing processes for each type of wheel differ significantly.

Steel Wheels

Stamping and Welding

- Stamping: Steel wheels are typically made through stamping, in which steel sheets are cut and shaped into the wheel's profile using high-pressure machinery. The process involves several pressing stages to form the wheel's basic shape, including the centre (where the hub attaches) and the rim.

- Welding: After stamping, the separate pieces (the rim and the centre) are welded together to form the complete wheel structure. The welding must be precisely controlled to ensure the wheel's integrity and strength.

Alloy Wheels

Casting

- Gravity Casting is the most basic method of casting aluminium wheels. Molten aluminium is poured into a mould and allowed to solidify under gravity's influence. While more straightforward and less expensive, gravity casting can produce heavier and less dense wheels.
- Low-Pressure Casting: A preferred method for producing alloy wheels, low-pressure casting involves injecting molten aluminium into the mould under low pressure. This method balances production cost and wheel strength, making it suitable for various applications.
- High-Pressure Die Casting: High-pressure die casting is used for wheels requiring intricate designs and superior strength. In this process, molten metal is injected at high pressure into steel moulds. This method produces wheels with high precision and good surface finish but can be more expensive due to the higher quality of the mould and the machining required after casting.

Forging

- Forging is a process in which solid aluminium is shaped under high pressure and temperature to form the wheel. Forged wheels are known for their superior strength, lighter weight, and increased durability compared to cast wheels. However, the forging process is more labour-intensive and costly, making forged wheels a premium option.

Machining and Finishing

- After casting or forging, wheels undergo various machining processes to achieve precise dimensions, including drilling for bolt holes and milling for decorative features.
- Finishing processes such as painting, polishing, or powder coating enhance the wheel's appearance and protect against corrosion.

2.3 method for producing additive manufacturing car wheels

Producing a car wheel using additive manufacturing involves a series of meticulously planned steps, leveraging the unique advantages of AM processes. This approach enables the creation of wheels with complex geometries, optimised structures for weight reduction without compromising strength, and potentially integrating features that traditional manufacturing methods cannot achieve. The process of producing a car wheel using 3D printing can be broken down into several key stages:

1. Design and Optimization
 - Initial Design: Use CAD (Computer-Aided Design) software to create the wheel's initial design. This stage is where creativity meets engineering, allowing for incorporating intricate patterns and structural optimisations that are only feasible with AM.

- Finite Element Analysis (FEA): Perform simulations to analyse the stress distribution, deformation, and other critical factors under various load conditions. This step is crucial for optimising the design for strength while minimising material use.
 - Design for Additive Manufacturing (DfAM): Adapt the design to suit additive manufacturing's capabilities and constraints, such as minimising supports, considering build orientation for structural integrity, and ensuring the design is optimised for layer-by-layer construction.
2. Material Selection
 - Choose a suitable material that meets the performance requirements of car wheels, such as aluminium or titanium alloys, known for their strength-to-weight ratio, corrosion resistance, and durability. The selection depends on the specific 3D printing technology being used.
 3. 3D Printing Process Selection
 - Direct Metal Laser Sintering (DMLS) / Selective Laser Melting (SLM): These powder bed fusion technologies are well-suited for producing high-detail and strength metal parts. They work by selectively melting metal powder layers using a laser.
 - Electron Beam Melting (EBM): Like SLM/DMLS, EBM uses an electron beam to melt the metal powder. This process can benefit certain alloys due to their high-energy density and faster build rates.
 4. Printing the Wheel
 - Preparation: Prepare the 3D printer by selecting the appropriate process parameters (e.g., laser power, scan speed) and loading the metal powder.
 - Printing: The wheel is printed layer by layer. Depending on its size and the specific AM process, this may take several hours to days.
 - Post-Processing: Remove the wheel from the build platform, then remove any supports. This stage may also involve stress relief heat treatment to reduce residual stresses and improve mechanical properties.
 5. Machining and Finishing
 - Machining: Conduct machining operations, such as drilling bolt holes and machining the hub interface, to ensure the wheel fits precisely onto the vehicle.
 - Surface Finishing: Apply surface finishing techniques, such as sandblasting, polishing, or coating, to enhance the wheel's aesthetic and functional properties, including corrosion resistance and surface smoothness.

2.4 Advantages of producing car wheels using AM

Producing car wheels using Additive Manufacturing brings many advantages over traditional manufacturing methods, such as casting and forging. These benefits stem from AM processes' inherent flexibility, precision, and efficiency, offering innovative pathways to design and produce car wheels. Here are some of the key advantages:

1. Complex Geometries and Customisation
 - Design Freedom: AM allows for creating complex, intricate designs that are difficult or impossible to achieve with traditional manufacturing methods. This enables designers to incorporate unique geometric features, such as lattice structures, for weight reduction without compromising strength.

- Customisation: AM processes' flexibility makes it feasible to produce customised or limited-run wheels for specific applications or aesthetic preferences, catering to niche markets or special editions of vehicles.
2. Optimised Performance
 - Lightweighting: Through topology optimisation and generative design algorithms, AM can produce structurally optimised wheels, reducing material usage and overall weight while maintaining or enhancing performance characteristics.
 - Improved Strength-to-Weight Ratio: Customised internal structures, such as honeycombs or gyroids, can be designed to increase the strength-to-weight ratio, leading to more efficient and performance-oriented wheels.
 3. Reduced Material Waste
 - Efficiency: AM is an additive process that builds parts layer by layer, significantly reducing material waste compared to subtractive manufacturing processes. This not only lowers material costs but also aligns with sustainability goals.
 - Recyclability: AM metal powders can often be recycled and reused, reducing material waste and environmental impact.
 4. Streamlined Production Process
 - Reduced Lead Times: The direct-from-digital-to-physical production process eliminates the need for complex tooling, moulds, or dies, considerably reducing the lead time from design to finished product.
 - On-demand Manufacturing: AM supports just-in-time production models, reducing inventory costs and enabling rapid response to market demands or design changes.
 5. Enhanced Product Quality
 - Precision: AM processes offer high precision and repeatability, ensuring that each wheel meets stringent quality and performance standards.
 - Material Properties: Advanced AM techniques can produce wheels with material properties comparable to or exceeding those made by traditional methods, including improved fatigue resistance and mechanical strength.
 6. Cost-Effective Prototyping and Testing
 - Rapid Prototyping: The ability to quickly produce prototypes allows for extensive testing and refinement of wheel designs without the high costs and time delays associated with traditional prototyping methods.
 - Iterative Design: Based on testing feedback, designers can iteratively improve the wheel design, optimising performance and manufacturability with minimal additional cost.
 7. Integration of Functions
 - Functional Integration: AM enables the integration of multiple functions within a single component, such as incorporating cooling channels or sensors directly into the wheel structure, enhancing functionality without increasing complexity.
 8. Supply Chain Simplification
 - Localised Production: AM technology can be deployed virtually anywhere, allowing for the localisation of wheel production closer to end-use points, simplifying logistics and reducing transportation costs.

2.5 Further advantages in specific sectors of the automotive industry

Additive Manufacturing is revolutionising various automotive industry sectors by offering unprecedented flexibility in design and manufacturing. Using additive manufacturing to produce car wheels is particularly beneficial in two segments: performance applications and show cars. Both areas benefit distinctly from the capabilities of 3D printing, albeit for different reasons.

Performance Applications

Optimising every component towards maximum efficiency is critical in performance vehicles, including racing and high-performance sports cars. Here, the advantages of AM-produced wheels are particularly pronounced:

- **Lightweight yet Stiff:** AM allows for the creation of incredibly lightweight wheels without sacrificing stiffness or strength. This is crucial for performance vehicles where reduced weight contributes to better handling, faster acceleration, and improved fuel efficiency. The ability to use advanced materials and to create intricate internal structures that traditional manufacturing cannot achieve means wheels can be optimised for the specific stresses they will encounter, enhancing performance and safety.
- **Topology Optimisation:** This process uses algorithms to determine the "optimal" material layout within a given design space for a given set of loads, boundary conditions, and constraints to maximise performance while minimising weight. AM is ideally suited to realise these complex, optimised shapes, making it an ideal choice for performance wheels.
- **Aerodynamic Improvements:** AM's design freedom also allows for creating wheels with aerodynamically optimised shapes that can reduce drag and improve vehicle stability at high speeds.

Show Cars

For show cars, where aesthetics can be as important as or even more important than performance, AM offers unparalleled design possibilities:

- **Customisation and Complexity:** AM excels in producing highly customised, intricate designs that stand out. Show cars often feature wheels with unique patterns, shapes, and details that reflect the vehicle's theme or aesthetic vision. With AM, designers are not constrained by the limitations of traditional wheel manufacturing methods, enabling them to experiment with designs that would have been impractical or impossible otherwise.
- **Visual Impact:** In show cars, visual impact is paramount. AM-produced wheels can include fine details, textures, and elements that catch the eye, contributing to the overall allure and theme of the vehicle. Another advantage is directly integrating branding or unique identifiers into the wheel design.
- **Material and Finish Variability:** AM processes allow for diverse materials and finishes, offering a broad palette for customisation. From polished metal finishes that showcase the material's natural lustre to coatings and treatments that provide colour or special effects, AM wheels can be tailored to complement the show car's aesthetic perfectly.

2.6 HRE 3d printed wheel

HRE Wheels' venture into 3D-printed car wheels, showcased through their HRE3D+ project, represents where additive manufacturing is currently used in producing car wheels. This pioneering project underscores the practical applications of AM in the automotive sector and highlights the potential for innovation in wheel design and production.



Figure 9 HRE 3d printed wheel (Source: HRE wheels.,2018: online)

Background and Concept

HRE Wheels, a leader in designing and manufacturing wheels for racing, performance, and luxury cars, collaborated with GE Additive for the HRE3D+ project. The project explored the possibilities of using Electron Beam Melting (EBM) and Direct Metal Laser Melting (DMLM) technologies—two forms of additive manufacturing—to create a novel wheel design. The choice of these technologies was pivotal, allowing the team to work with high-strength titanium, a material well-regarded for its excellent strength-to-weight ratio and corrosion

resistance. The wheel that HRE has produced is a three-piece wheel, a wheel with three main components: the inner rim, located closest to the vehicle's axle, forms the interior section of the wheel where the tyre bead is seated, and the Outer Rim that forms the exterior edge of the wheel. It also helps hold the tyre in place and is often part of the most visible wheel, allowing for aesthetic customisations. And the face that connects the wheel to the vehicle's axle. It typically features a bolt pattern that matches the vehicle's specifications and can include aesthetic elements like the brand's logo. However, only the face of the wheel has been manufactured using additive manufacturing, with the other two components being manufactured using traditional methods. One of the most compelling aspects of the HRE3D+ project is its embrace of design freedom afforded by AM. The project team created a complex and visually striking wheel design that would be difficult, if not impossible, to replicate using traditional manufacturing methods. The design features intricate, aesthetically appealing lattice structures and is functionally optimised for strength and weight reduction. This approach to using geometric complexity for functional gains—such as improved airflow and reduced unsprung mass—exemplifies the core advantages of AM in automotive applications. The manufacturing process for the HRE3D+ wheels involved the layer-by-layer construction of the wheel's components using titanium powder. This process allows for a significant reduction in waste compared to traditional subtractive manufacturing methods. Moreover, the use of titanium not only ensures that the wheels are incredibly durable and lightweight but also showcases the versatility of AM in handling different materials. The decision to utilise EBM and DMLM technologies highlights a strategic approach to selecting the most appropriate AM technology based on the material properties and design requirements. While the HRE3D+ project illustrates AM's remarkable capabilities, it also highlights several inherent challenges. For instance, post-processing and finishing 3D-printed parts can be labour-intensive, requiring significant time and resources to achieve the desired surface finish and precision. HRE addressed these challenges through meticulous planning and execution, ensuring the final product met its high quality and performance standards. The success of the HRE3D+ project has profound implications for the automotive industry, particularly in the realms of performance and luxury vehicles. It demonstrates the feasibility of using AM for critical, high-value components like car wheels, opening new avenues for customisation and performance optimisation. Furthermore, it underscores the potential for reducing lead times and material waste, contributing to more sustainable manufacturing practices.

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