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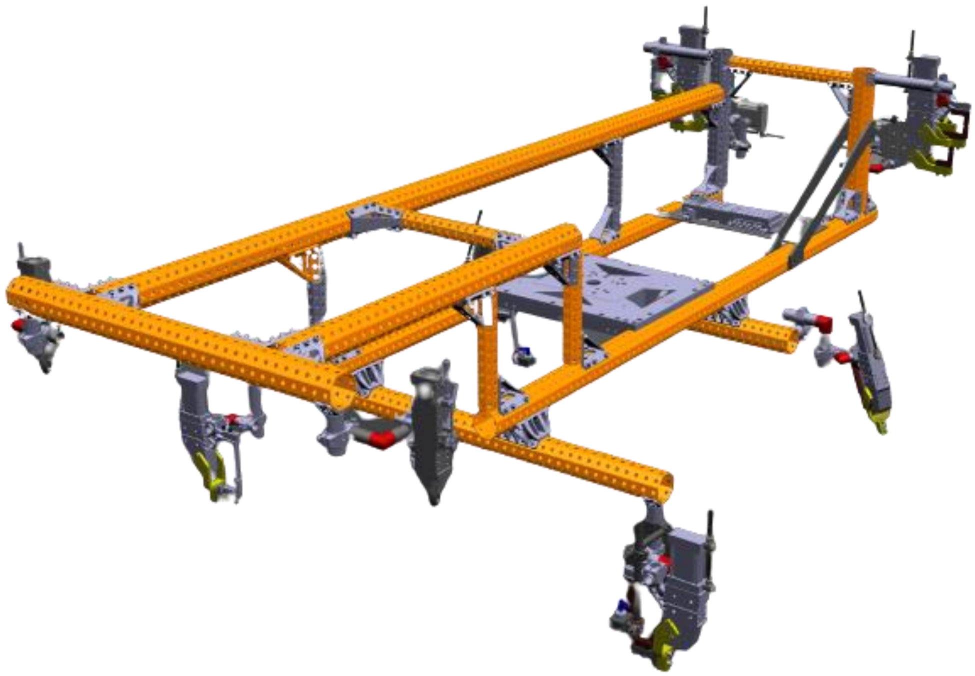

Modular robot gripper light weight concept

Master’s thesis in Product Development and Production Engineering

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Gothenburg, Sweden 2023
www.chalmers.se

MASTER'S THESIS 2023

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Abstract

Volvo Cars Corporation's (VCC) Technology development department is interested in investigating the feasibility study of a new gripper solution proposed by a supplier (ThyssenKrupp). The existing gripper profiles in VCC are made from Aluminum and welded Steel. VCC is facing a critical issue where the profiles get cracked or snapped under a crash. This disturbs the lead time within the production line and involves a lot of cost in replacing the damaged system.

Also, the weight of the grippers is increasing to handle new operations and requires adding new gripping components and subcomponents. This is in turn affecting the Motor load and causing performance issues with robots.

To solve these issues, ThyssenKrupp produced a new Gripper Profile concept made of Steel for implementing with all the robots. Considering the proposal and analyzing the challenges faced in existing techniques at VCC, this thesis aims to investigate the advantages and disadvantages of the new concept proposed by ThyssenKrupp and formulate conclusions about the proposed solution with respect to various aspects like Material, Mechanical properties, Weight, Energy consumption, Cost and Sustainability.

In this study, three grippers have been selected as sample data to study the system. The investigation will plot the effects on these selected grippers and differences between Aluminum gripper profile and steel gripper profile.

Keywords: Modular grippers, pre-galvanized steel, weight, energy consumption.

Acknowledgements

To begin with, we would like to express my gratitude to Daniel Thomson (Manufacturing Technology Development), Supervisor at VCC, Fredrik, Fredrik Någård (Manager - Project and Automation, Manufacturing Technology Development), at VCC and the entire Manufacturing team for their tremendous support during the thesis period. Furthermore, I would also like to thank Lars Lindkvist, Examiner at Chalmers University of Technology for the guidance and support offered for completion of the thesis and Kaub Tim from ThyssenKrupp, Arend Christian and entire ThyssenKrupp team for supporting us through the thesis.

We must also thank Gohil Parth (Equipment Engineer), Martin Krivy (Robotics Engineer), Nils Anderson (Robotics Engineer), Granberg Tobias (Business Analyst), Martin Karrin (Robotics Engineer), and Aguilar Gomez Raquel (Equipment Engineer) at VCC for their inputs, suggestions, and cooperation during the thesis work. We would also like to extend my gratitude to my previous employers as the learning from the experience did help us a lot in pursuing the thesis work.

Finally, but most importantly, a big thanks to our family and friends for their moral support and assisting us in whatever way possible.

Subramanian Lakshmanan. Suvyaktha Mohan, Gothenburg, June 2023

Contents

List of Acronyms

VCC – Volvo Cars Cooperation

CAD - Computer Aided Design

CAE - Computer Aided Engineering

ML - Machine Learning

SCARA - Selective Compliance Articulated Robot Arm

AGVs - Automatic guided vehicle system

EGT - Europe Gripper tooling

SEGT - Steel Europe Gripper Tooling

CNC - Computer numeric control

OEMs - Original equipment manufacturers

TOS - Tünkers One Screw

COG - Centre of Gravity

MOI – Moment of Inertia

Chapter 1 Introduction

1.1 Company Background:

1.1.1 VCC:

Volvo Group is a Swedish multinational enterprise, and VCC is its automotive division. It was founded in 1927 as a spin-off of SKF, a Swedish manufacturer of ball bearings. VCC has a long history of prioritizing security and innovation, which is why its vehicles are often regarded as among the safest on the market.

Over the years, VCC has developed a number of safety features that are now considered industry standards. Nils Bohlin, a Volvo engineer, invented the three-point seat belt in 1959, and it quickly became standard. This innovation significantly boosted car safety and is now widely implemented all over the world. In 2010, Zhejiang Geely Holding Group acquired VCC from Ford, ushering in a period of unprecedented growth and development for the company. After being purchased by Geely, the company recommitted itself to cutting-edge research and development, electric mobility, and ecological responsibility.

Cluster 60 is Volvo's assembly facility for their 60 series, while Cluster 90 is where their 90 series are put together. This allows for the production processes to be simplified accurately, improving the internal movement of parts. VCC has made significant progress in electrification since then, and the company has ambitious plans for the future. In 2019, Volvo introduced the Volvo XC40 Recharge, its first all-electric vehicle, as part of its plan to electrify its entire product line. VCC plans to produce only electric vehicles by 2030, with the aim of being the market leader in the premium electric vehicle class. VCC is always improving in terms of security, aesthetics, and environmentally friendly transportation. It's well-known for making reliable vehicles that successfully combine Scandinavian minimalism with state-of-the-art engineering and safety measures. All the company's sedans, SUVs, and electric automobiles are built with safety, performance, and environmental consciousness in mind.

1.1.2 ThyssenKrupp:

ThyssenKrupp is a major international manufacturer and provider of a wide range of goods and services across the world. ThyssenKrupp has been around since the 19th century, and in that time, it has become a powerhouse in many different markets, including the steel, automotive, materials, and industrial solutions sectors. ThyssenKrupp is well-known in the steel industry for its high-quality steel products, which include everything from flat carbon steel to specialized alloys for building, making cars, and making machines. Elevators, escalators, moving walkways, and passenger boarding bridges are all part of the company's suite of cutting-edge technology and solutions for efficient and environmentally friendly transportation. Construction, energy, and transportation are just a few of the many fields that benefit from ThyssenKrupp's extensive selection of materials, which also includes stainless steel, aluminum, and non-ferrous metals. ThyssenKrupp prioritizes environmental sustainability and operational excellence while always developing innovative products and technology to fulfill the ever-changing needs of its customers.

1.2 Project Background:

Lightweight modular aluminum grippers or steel welded grippers have been used for years in Volvo automobiles for handling car body parts. Geometry grippers, process grippers, and handling grippers are the three broad kinds of grippers. The advantages of the modular approach include reduced weight compared to a welded structure and an easier return to the original position after a collision.

In VCC automobile body manufacturing, process and handling grippers are employed for tasks that do not define geometry. Modular Grippers will be used from now on. Both process and handling grippers can benefit from the versatility of a modular gripper system. Together with fixed tools like welding guns or sealers, modular grippers perform a variety of tasks. Car body components handling is another popular use. Combining a modular gripper with, say, a robot mounted welding gun or sealing apparatus allows for robot-to-robot activities. Each new automobile project begins with a machine builder consulting with a VCC mechanical engineer on the design of a modular gripper.

1.3 Objectives:

The purpose of this thesis work is to find out if VCC can reduce weight by using an alternative material to casted aluminum for modular grippers without affecting robustness or material stiffness. To address this issue, ThyssenKrupp came up with a solution where steel can be used instead of aluminum for gripper profiles.

By implementing this, VCC could have following benefits:

- Improvement of robot energy consumption due to lighter weight.
- Lower investment cost due to enabling of usage of smaller robot sizes.
- Improvement of cyclical stresses by using another material than casted aluminum.
- Environmental benefits since casted aluminum have a big environmental footprint.

1.4 Limitations:

The modular grippers are used in both Cluster 60 and Cluster 90 at VCC, Torslanda which includes around 390 grippers. These modular grippers are mainly used in assembly and handling processes. Since, investigating all the modular grippers is not feasible in the thesis timeframe, three grippers in three different weight categories has been chosen for investigation. Also, concerning procedures and policies of VCC' on implementing this thesis, the thesis timeframe was mainly utilized to investigate and evaluate the selected grippers using digital tools like CAD/ CAE, ABB Robot Studio and Microsoft Excel. If the investigation is beneficial, VCC will consider the results derived from this thesis in the implementation phase. The thesis work is mainly focused on studying the effect of changing the profile in the gripper system.

1.5 Research Questions:

- What is a Robot Gripper and how does it connect to Robot Profile
- Is ThyssenKrupp's solution of adopting steel profile over aluminum for robot grippers better than the current system?
- What are the advantages and disadvantages of using the new grippers which are entirely made of steel from ThyssenKrupp over the current Aluminum grippers at VCC?

Chapter 2 Theory

2.1 Introduction to Industrial Robots

The robots that are utilized in manufacturing and other types of industrial situations are extremely complicated devices that are meant to carry out a variety of functions. Robots like this are frequently used to carry out labor that is either too difficult or too hazardous for people to handle on their own. They are an essential component in the process of increasing productivity, precision, and efficiency across a wide range of business sectors, including the automotive, electrical, pharmaceutical, and food processing arenas.

Industrial robots may be trained to do a wide variety of tasks, including but not limited to welding, painting, packing, material handling, inspection, and many more. Some examples of these tasks are assembling, welding, and painting. Due to the fact that they are designed with a mechanical arm that contains a number of joints, they are able to move and handle products. The end of the robot arm is designed to be compatible with a wide variety of tools and grippers, allowing it to carry out a broad spectrum of task

These robots often come equipped with a wide array of sensors and sometimes even cameras so that they can monitor their surroundings and react appropriately. They are particularly versatile and sensitive to new production demands since they can be programmed to either carry out static activities or to react to changing conditions. This makes it possible to carry out a wide variety of duties.

Industrial robots may be used for a variety of different applications. Automation has the ability to greatly boost output rates, product quality and consistency, waste and rework, and worker safety by removing the need for people to perform dangerous or repetitive operations. They are able to work constantly without experiencing fatigue, which results in cost savings for organizations and an increase in the productivity of their machinery.[6]

Industrial robots are available in a wide variety of forms and dimensions, each of which is tailored to perform a particular function. The most common types of robots include articulated robots, which have multiple rotary joints for maximum flexibility; SCARA robots, which are fantastic for jobs that call for quick and precise horizontal movements; delta robots, which are optimized for rapid pick-and-place operations; and collaborative robots, also known as cobots, which are able to work safely alongside humans because they have their own built-in safety features. [1]

Industrial robots continue to advance in terms of intelligence and sophistication in tandem with the development of processing power and software. The use of artificial intelligence (AI), machine learning (ML), and advanced technological sensors to improve perception and decision-making is on the rise. Because of this, individuals are able to do activities that were formerly considered impossible, adapt to new settings, and collaborate closely with people.

In general, the use of industrial robots is increasing the level of automation and efficiency within the production environment, which is assisting businesses in their efforts to adapt to the dynamic character of current markets. Their influence is predicted to increase as the boundaries of what can be achieved in industrial automation are pushed further and farther by robotics technology.

2.1.1 Industrial Robots in Automotive Sectors

Industrial robots have had a revolutionary effect on the automobile industry as a result of their ability to automate a broad variety of production processes, which has led to increases in output, precision, and efficiency. Industrial robots are employed often in the automobile sector for a variety of jobs, ranging from the relatively simple assembling and welding to the more complicated painting and inspection. [1]

Industrial robots are an important component of the production process on the assembly line in the automobile industry. The car industry relies heavily on robots because they facilitate increased precision, uniformity, and productivity throughout the assembly process of motor vehicles. Tasks such as installing doors and engine components, as well as installing interior components and tires, are all under their purview. Industrial robots carry out repetitive operations with higher accuracy and consistency, which results in an increase in overall production.

Industrial robots have been integrated into a variety of production processes at the well-known automobile manufacturer VCC. The incorporation of these robots into Volvo's production lines has led to significant improvements in the company's output, accuracy, and safety.

At VCC, industrial robots are put to work in a variety of different capacities, one of which is on the assembly line. Welding, painting, and assembling vehicle parts are all jobs that may be done by robots. For example, they may be responsible for the precise welding of vehicle bodywork in order to guarantee that the finished product satisfies the high-quality requirements set out by the corporation. In addition, the utilization of robots has significantly contributed to improvements in both the rate of completion and the precision of jobs such as the installation of windows and doors as well as seats.

At VCC, industrial robots are utilized for a variety of tasks, including material handling and logistics, in addition to the assembly line. Robots are used to carry heavy or unwieldy components throughout the plant, which reduces the requirement for human labor and the danger of injury connected with it. These robots are able to carry materials between workstations in an effective manner, which results in increased production and a reduction in downtime.

The assembly lines of VCC make use of collaborative robots, more commonly referred to as cobots for short. Cobots are designed to work alongside people in a manner that minimizes the hazards involved and optimizes the amount of work that can be accomplished. They are able to recognize the presence of humans and adjust their behavior appropriately because of the cutting-edge safety features that they are equipped with, which include force sensors and collision detection systems among other similar technologies. Cobots excel in conditions that require for an extraordinary level of precision. [4]

Industrial robots are utilized by VCC, and their application is not restricted to the manufacturing line. They are also employed in the field of research and development. During the testing and prototyping stages, robots are utilized to replicate and assess a broad variety of variables that have the potential to influence the overall performance, safety, and durability of a vehicle. These robots are able to carry out precise, repeated tasks, which contribute to the collection and processing of high-quality data.

The use of industrial robots into VCC' manufacturing processes has brought about a variety of advantageous outcomes. Because of the usage of these robots, the production times in the factory have been cut down, and the quality has become more constant. This has led to an improvement in the plant's overall productivity. They were able to raise the overall standard of the finished product by paying careful attention to detail during the welding and assembly operations. In addition, the presence of industrial robots in workplaces has increased employee safety by allowing people to delegate activities that are either too dangerous or too physically demanding. As automation and robotics continue to advance, VCC will surely give serious consideration to the possibility of further incorporating industrial robots into its production processes. As a result of this expansion, the firm should see increases in both its level of productivity and innovation, as well as its competitive advantage in the market.

2.1.2 Types of Industrial robots

There is a diverse selection of industrial robots on the market today; each model was developed to carry out a certain job function or collection of responsibilities. [3]

The mobility of human limbs is meant to be simulated by articulated robots, which are constructed with joints that are capable of rotation and are designed to mimic the creation of articulated robots. Because of their adaptability, they are able to adjust to new environments and take on a wide range of responsibilities. It is common practice to use articulated robots for a broad variety of tasks, including welding, the handling of materials, assembling, and even painting. This is because articulated robots can move in three dimensions.

Robots that assemble components by employing a device called the Selective Compliance Arm and Robotic Arm (SCARA) mechanism. Robots that have arms that are stiff are able to move in both the vertical and horizontal planes. Because pick-and-place operations, assembly work, and packaging all need quick and accurate motions, robots with stiff arms are a great choice for performing these tasks.

The structure of a Delta robot is easily identifiable since it has three limbs that are all linked to the same base. This gives the robot its characteristic appearance. Pick-and-place operations are used in many different industries, including the food processing industry, the electronics industry, and the pharmaceuticals industry, in part because of the high speeds at which they work.

Cartesian robots are distinguished by their three linear axes, each of which is capable of being controlled independently of the others. The axes in question are denoted by the notations X, Y, and Z. Because of the precision they provide to the material handling, assembly, and packaging processes, they find widespread application in the automotive and electronics sectors.

Collaborative robots, also known as Cobots, are machines that are designed to work safely alongside people to complete a variety of activities. They can execute their functions close to humans without extra safety barriers since they contain components such as force sensors and collision detectors. Cobots have a wide range of applications and may perform a number of jobs, including inspection, assembly, and the manipulation of tiny components. [6]

The wheels or tracks that are attached to the undercarriage of mobile robots allow these machines to freely investigate the areas in which they operate. The utilization of mobile robots is particularly advantageous to a wide variety of enterprises, including those whose primary focus is on the automation of warehouses, shipping, and the handling of materials.

The name "parallel robot" comes from the fact that all the parallel robot's limbs are connected to the same base. Their increased rigidity and precision are beneficial in a wide range of applications, some examples of which include high-speed assembly, packing, and machining. These are only some of the many possible uses.

Autonomous guided vehicles, also known as autonomous mobile robots, are driven forward by sensors, lasers, or magnetic tape. AGVs are also known by their other name, mobile robots. They perform a multitude of services that are connected to logistics, transportation, and storage in the context of commercial and industrial contexts. [2]

These are just a few examples of the many different sorts of industrial robots; due to the fact that the requirements of diverse industries are distinct, robots may be programmed to carry out a broad variety of different kinds of work. The design of the robot is dependent on a variety of elements, including the kind of work that is being done, its load capacity, reach, accuracy, and speed, and how quickly it can complete tasks.

2.2 Introduction to EGT modular robot grippers

This thesis involves investigating the structure of robot grippers which is called as "gripper profile." These gripper profiles play a vital role in making the robot grippers modular.

The term modular or modular robot gripper(here) means that the robot gripper should withstand significant loads of better threshold without crashing or getting snapped and it should easily return to its nominal form. Also, it should have ease of flexibility and freedom of interchangeability with its sub-components. [14]

Modular robot grippers: EGT (Euro-Gripper-Tooling) the beginning of modular gripper technology in the German automotive industry. TOS is a simple modular gripper system which does not require expensive special tools, can be quickly assembled and different profiles can be individually adapted to the respective task. TCR is Tünker's lightweight gripper system to counteract the ever-heavier components and thus also give older or smaller robots a chance. All systems can be purchased either as individual components or as fully pre-assembled and equipped grippers.

EGT modular robot grippers are state-of-the-art pieces of machinery that are utilized in the automotive sector. These grippers are designed to enhance the capabilities of industrial robots in the areas of component handling and manipulation. Material handling and vehicle assembly are only two of the applications where these grippers shine thanks to their versatility and effectiveness.

The grippers that are used by EGT robots have a modular architecture, which makes it possible to modify them so that they may be used with a broad variety of different components and applications. Because the fingers or jaws are modular, they may easily be modified to securely grab objects of varied shapes, sizes, and weights. The production line's flexibility enables it to undergo rapid reconfiguration or modification without interrupting the operation.

The car industry makes use of EGT modular robot grippers for a broad variety of tasks, some of which include part feeding, pick-and-place, assembly, and quality checking. [5] They have simple access to and control over a wide variety of components, including engine parts, electrical modules, sensor components, interior trim pieces, and more. During assembly, the consistent and firm grasp provided by the grippers makes it easier to achieve perfect placement and alignment.

A significant advantage is that the grippers on the EGT modular robot can securely manage elements of vehicles that are either fragile or perishable. A few of the high-tech components that have been incorporated into the design of the grippers are sensors that provide feedback on the amount of pressure that is being applied to the grip, variable force control, and soft or compliant fingers. Because of this, it is now able to handle fragile components with care, hence lowering the risk of causing damage such as scratches, dents, and other forms of general wear and tear.

In addition, EGT grippers usually incorporate innovative features and technologies, which further increase the grippers' overall performance. There is a possibility that some of these systems will integrate sensors or vision systems that provide real-time feedback on the position, orientation, and quality of the pieces. Because of this, the grippers can function dependably and accurately despite variations in the size or form of the component.

EGT modular robot grippers in the automotive sector have several improvements. They can handle components fast and correctly, which contributes to an increase in throughput and a decrease in cycle durations, which results in an increase in output. The fact that these grippers can easily adapt to different item designs or assembly techniques is one factor that adds to the assembly line's overall enhanced efficiency.

EGT modular robot grippers help create a more secure working environment for employees by automating tasks that would otherwise be laborious or hazardous. By taking over duties that need physical handling, they lessen the risk of accidents that are caused by heavy lifting or actions that are performed repeatedly. All workers in the production plant will benefit from the improved ergonomics and sense of safety brought by this outcome.

The EGT modular robot grippers have become an essential part of the car industry due to their flexibility, adaptability, and efficiency in the component handling and assembly activities. Because of their versatile design, soft handling capabilities, and smart features, they are suited for a wide variety of vehicle components, which contributes to an increase in productivity, quality, and worker safety in the automotive sector. [5]

2.2.1 Types of modular robot grippers

Modular robot grippers are versatile instruments that can complete a wide range of grasping activities. Modular robot grippers can accomplish a variety of grasping tasks. Because of the adaptability that they offer in terms of item handling, a broad variety of different kinds of modular grippers are currently in common use. [6]

- The first category of gripper is the mechanical gripper, which may seize objects with either its jaws or its fingers made of mechanical parts. It can be guaranteed that whatever the gripper is holding will not slide out of hands whether by using a parallel-jaw, angular, or three-finger gripper. This is the case regardless of which type of gripper is being used.

Figure 1: Mechanical gripper. [18]

- Vacuum grippers, which rely on suction to grasp items, come in at number two. Suction cups, which may be either flexible or rigid, maintain the vacuum seal that they form with the surface of the item they are attaching themselves to. Materials that are not porous and smooth, like glass or metal sheets, are the best candidates for vacuum grippers.

Figure 2: Vacuum gripper. [16]

- Magnets are utilized in magnetic grippers so that ferromagnetic objects may be grasped and held securely. Since they don't require any sort of physical contact or further processing, they are particularly useful for holding items that are metallic.

Figure 3: Magnetic gripper. [17]

- The term "adhesive grippers" refers to a specific type of gripper that adheres to objects through the use of adhesive materials or specialized tapes. They conform to the shape of whatever they are placed on, which makes them an excellent choice for items that are delicate or have an odd shape.

Figure 4: Adhesive gripper.[19]

- Electrostatic grippers rely on electrostatic forces in order to successfully grasp and hold things. As there is an electric field produced, which induces a temporary charge on the item's surface, the object can be held securely due to this. Electrostatic grippers are most frequently used for the manipulation of things that are low in weight or fragile. These grippers offer a mounting platform or base module on which other gripper modules can be mounted. These grippers are part of modular gripper systems. This flexible modular design enables quick switching out and easy customization to meet a variety of gripping requirements.

Figure 5: Electrostatic gripper.[20]

It is important to keep in mind that modular robot grippers may come in a wide range of forms and dimensions, depending not only on the manufacturer but also on the specific job at hand. As the field of robotics continues to grow and advance, new varieties of grippers that have enhanced capabilities for performing operations involving grasping and manipulation are continually being created. [6]

2.2.2 Properties of Modular Robot Grippers

It is important to know how grippers affect the entire profile. There are times and places when different gripper profiles for modular robots might provide the user distinct benefits. The following is a list of key properties of modular robot grippers which makes gripper profile modular:

- Dimensions: Modular grippers may be available in a range of dimensions and forms, which enables them to be utilized in many different contexts and settings. They range from being quite compact and lightweight to being enormous and robust in size.
- Gripping Force: The degree to which various types of grippers can securely hold onto objects is directly related to the amount of gripping force that they possess. There are grippers that have stronger grips for objects that are heavier or stiffer, and there are others that have grips with less force for things that are more delicate.
- The number of degrees of freedom that the gripper possesses places a restriction on the range of its opening and closing capabilities. They can handle items of varying sizes and shapes due to the versatility that they possess.
- The integration of sensors, depending on the gripper, these sensors may be located either internally or outside. The utilization of sensors that report on grip force, item position, or other data makes it feasible to achieve more precision and control over a system.
- The Actuation Mechanism Grippers can be activated via a variety of different systems, including pneumatic, electric, and hydraulic ones. When selecting an actuation mechanism, factors like speed, precision, and power are considered. This characteristic is widespread among modular grippers and refers to the ability to swap out the gripping modules or end-effectors. This makes it possible for the gripper to be quickly adjusted so that it may be used with a wide variety of items and gripping configurations without having to resort to a complete replacement.
- Grippers have a wide range of applications and may be utilized with a variety of materials, from metals and plastics to fabrics and other delicate items. To grab objects securely and efficiently, you need to use gripper materials that have characteristics, such as the ability to be rigid or flexible
- It is possible to use and program modular grippers in a few diverse ways, including manually, with the assistance of pre-programmed algorithms, or by integrating them into robotic control systems. These are just some of the options. The most recent generation of grippers may be able to carry out complex motion sequences and make use of flexible gripping techniques.
- It is possible to make grippers resistant to harsh environments, such as those present in cleanrooms, ovens, or underwater. It is possible that they were constructed to survive severe surroundings by including components such as resistance to dust and water.

- The maximum weight that a specific gripper can hold varies depending on the payload capacity of that gripper. Grippers that have a range of payload capacities make it feasible to grasp and manipulate objects of a wide range of sizes and weights.

The numerous characteristics of modular robot grippers are brought forth in these descriptions. To meet the requirements of a variety of business sectors, gripper manufacturers create products with a broad spectrum of capabilities and qualities to fit according to the gripper profile.

2.3 Manufacturing of Robot Gripper

Beginning with the design phase and continuing all the way through to the completed product, there are several steps involved in the production of a modular robot gripper. Most items are created in the following ways, in broad strokes:

- The stage of design and engineering comes at the very beginning of the process. The computer-aided design (CAD) tools are what engineers and designers use to produce an accurate three-dimensional model of the gripper. They think about the gripper's performance, as well as its dimensions, its construction, and its level of interoperability with robotic systems.
- The parameters of the gripper design guide the selection of materials to be used in its construction. There are several factors taken into consideration, including toughness, adaptability, portability, and weight. There are several varied materials that may be used, including metals, polymers, elastomers, and composites.
- Third, a test model of the gripper is manufactured to validate the conceptual design. As prototyping techniques, the use of 3D printing, CNC machining, and manual fabrication are all commonplace today. To guarantee that the gripper's shape, fit, and fundamental functionality satisfy expectations before mass production begins, prototypes may be put through rigorous testing and further developed.
- When choosing a manufacturing process, it is important to consider a few factors, including the complexity of the design, the required precision, the production volume, and the cost. Common manufacturing processes include computer numerical control machining, additive manufacturing (often known as 3D printing), injection molding, and hybrids of these processes.
- Producing Components of the Gripper: The gripper's components are produced using the procedures selected. To manufacture molds or fixtures, this needs the setting up of machinery, the preparation of materials, and the operation of equipment. The components are constructed such that they are accurate representations of the designs.
- The gripper module is constructed by piecing together the individual gripper components. It will be possible to attach fingers, jaws, actuators, sensors, and anything else that could be necessary. There are many diverse types of assembly procedures, some examples of which include mechanical fasteners, adhesives, and specific connectors.

- Testing and inspections for quality are carried out at several points during the production process. In this step, the gripper is checked to ensure that its dimensions are accurate, put through functional testing, and assessed in comparison to its target values. Any essential adjustments are made to ensure that the system will work at its absolute best.
- After the grippers have been examined for flaws and determined to be suitable for distribution, they are then meticulously packaged in preparation for dispatch. Labeling helps with identification and tracking, while protective packaging ensures that things remain intact during the transportation process.
- It is important to remember that the required manufacturing methods may vary depending on the gripper's design, the manufacturer's capacity, and the application requirements. It is likely that the production process might have some subtle modifications and optimizations performed by different manufacturers to better meet their expectations.

The extrusion of tubes made of aluminum alloy is a versatile technology that may produce tubes with intricate cross-sections, precise dimensions, and high-quality finishes. These tubes serve a wide variety of markets, some of which include the automobile industry, the aerospace industry, the construction industry, and the consumer products industry. [7]

2.3.1 Material used in EGT robot grippers

A diverse array of materials is used in the production of modular robot grippers so that they can achieve the appropriate mechanical characteristics and levels of use. The following kinds of materials are used to make some common profiles for grippers that may be found on modular robots:

Metals like Aluminum and steel are two of the most popular metals utilized in the production of grippers due to their high levels of strength and durability. The structural integrity of these materials and their resistance to high forces can be beneficial to load-bearing components such as gripper bodies, jaws, and other load-bearing components. [10]

Polymers, including thermoplastics and composites, are frequently used in the construction of grippers. Plastics are lightweight, resistant to corrosion, and can be molded into elaborate designs without compromising their strength or durability. In addition, plastics may be shaped into any desired shape. Grippers frequently have plastic components, including their fingers, housing, and protective coatings.

Elastomers such as rubber and silicone are two examples of materials that might be employed in the construction of grippers to enhance the flexibility and hold of the devices. Because of their extreme elasticity, elastomers are ideally suited for use in grippers, which may then shape themselves to conform to the specific shapes of whatever they are clutching. It is possible to improve the friction and reliability of grippers by either integrating elastomers into the fingers of the gripper or coating the jaws.

Composite materials such as carbon fibers or fiberglass encased in a polymer matrix are two examples of the types of materials that might be utilized to make grippers. The combination of composites' lightweight, stiffness, and durability makes them an excellent material choice. They are utilized to enhance the mechanical characteristics of the gripper components and reduce their overall weight.

Components for adhesive gripping materials Grippers designed specifically for this function may use a wide variety of sticky tapes and materials in their construction. These materials have a high coefficient of friction, which, combined with their stickiness, guarantees a secure hold on any surface they are put on. Sticky grippers prove to be an important tool if one is working with items that are fragile or have an unusual shape.

Grippers that are made from soft materials, such as soft polymers or elastomers, are more flexible and can adjust to the uneven shapes and surfaces of whatever they are gripping. The fact that soft grippers prevent things from being damaged or distorted while they are being handled makes them helpful in a wide variety of contexts.

When selecting an acceptable material for the gripper, it is important to consider the intended application of the modular robot, the required grasping capabilities, any weight restrictions, any environmental issues, and the available budget. When deciding the materials to use for the gripper, the manufacturer considers several factors, including how useful it will be, how long it will last, and how efficient it will be. [9]

Manufacturing with steel

The manufacturing process of steel tube for this gripper is explained below.

The cold rolling method is often utilized throughout the manufacturing process of pre-galvanized alloy steel tubing. [8]

To begin preparation of the materials, the pipes need to have the appropriate alloy steel chosen for them. Steel is one of the most used materials due to its long lifespan, high resistance to corrosion, and suitability for galvanizing. The selected alloy steel must first undergo hot rolling before it can be formed into considerable coils or billets. Hot rolling is the process that is used to shape steel into tubes or bars of a particular diameter and length. This method involves bringing the steel to a very high temperature and then passing it through a series of rolling mills. [15]

After hot rolling, a further process called cold rolling is done to remove the oxides and scales that were produced during the hot rolling process. After that, the material goes through cold rolling mills to undergo more refining. The process of cold rolling reduces the thickness of the steel while simultaneously refining its dimensions. This results in tighter tolerances and a better surface polish than would be feasible with any other method.

Pipes made of cold-rolled alloy steel can have their internal tensions relaxed by a process called annealing to improve their mechanical properties. Annealing is performed on pipes by first heating them to a specific temperature and then gently cooling them off.

After the alloy steel pipes have been cold rolled and annealed (if necessary), the galvanizing process can then commence. Pipes can be galvanized by having a coating of zinc applied to them to prevent corrosion. The pipes can either be electroplated or hot-dip galvanized, which involves placing them in a bath containing molten zinc and then galvanizing them.

After being galvanized, alloy steel pipes may go through additional processing, such as being cut to a certain length, having their threads threaded so that they may be connected, or having their surfaces treated to fulfill either esthetic or functional requirements.

At each stage of the cold rolling process, the quality of the pre-galvanized alloy steel pipes is subjected to close monitoring and control. Checks on measurements, assessments of the surface, and evaluations of the mechanical properties are some examples.

It is essential to keep in mind that the processes of cold rolling and galvanizing can be modified in accordance with the specifications of the pipe, the manufacturer, and the machinery that is available. [8]

Manufacturing with Aluminum

The manufacturing process of aluminum tubes for the gripper profile is explained here.

A typical step in the production process is the extrusion of aluminum alloys into tubes of a variety of shapes and dimensions. Aluminum tube production commonly makes use of the process of extrusion because of the process's effectiveness, malleability, and relatively low cost. A breakdown of the steps involved in the extrusion process for Aluminum Alloy tubes. [7]

To begin, a billet of aluminum, which is a bar of aluminum alloy in the shape of a cylinder, is prepared for the operation. Before beginning the process of extrusion, the billet is typically heated to a specified temperature to maximize the amount of flexibility it possesses.

The design of the extrusion die is determined, in part, by the contours and dimensions of the finished aluminum alloy tube. For the hot billet to adopt its final tube shape, the die has a precise cutout in it that it needs to go through.

To permit extrusion, the prepared billet must first be heated to the necessary temperature, which is often accomplished in a furnace. Temperatures might be different depending on the type of aluminum alloy used.

After that, the billet is moved to a chamber within the extrusion press so that it can be heated. A hydraulic ram is utilized to force the billet through the extrusion die. The tube is produced to the specified dimensions by squeezing the malleable metal through the opening in the die.

When the extruded aluminum tube emerges from the die, it immediately goes through the processes of straightening and cooling. It might be cooled by air, or it could be passed through a system that uses water. Following the completion of the cooling process, the tube can then be straightened to correct any defects that may have been caused when it was being extruded.

After the extruded aluminum tube has cooled and been straightened, the finishing and cutting processes may begin. To get the outcomes that you want, it is possible that additional finishing processes, such as deburring, surface treatment, or machining, may need to be applied.

To ensure that the completed aluminum alloy tubes will meet quality standards, the extrusion process includes several quality assurance tests at a variety of stages along the way. Checks on measurements, assessments of the surface, and evaluations of the mechanical properties are some examples.

2.3.1.1 Properties of modular robot Grippers

The utility and efficiency of modular robot grippers may be attributed to several properties of the grippers themselves. A few examples of these traits are as follows:

- The versatility of modular grippers to accommodate a wide range of tasks and objects is one of their most notable characteristics. They are versatile because of their modular design, which enables them to fit a wide variety of shapes, sizes, and weights. This gives them their adaptability.
- One of the modular grippers' defining characteristics is their ability to be assembled in a variety of configurations. A few examples of the interchangeable components that go into the construction of these robots are the fingers, jaws, and actuators. This enables simple customization to a wide variety of grasping demands with no downtime or additional costs incurred.
- The amount of force that modular grippers exert may be changed to accommodate a wide range of applications. They can adapt the force of their grasp, where it is located, or the shape it takes in accordance with the geometry or surface properties of the item. Because of its versatility, it can perform safe and efficient object grasping in a broad variety of contexts.
- Dexterity: Grippers who have a high level of dexterity can perform complex grasping movements and handle items with a high level of control. They can transition between different clutching positions, fit into restricted spaces, and manage complicated things because of their dexterity.
- Modular grippers share several similar characteristics, one of which is the ability to control the amount of force that is applied during a grab. This trait shines most brightly in circumstances that call for the cautious handling of things that have varying degrees of rigidity or fragility in their construction.
- There is the possibility of incorporating sensors into modular grippers to increase gripping control and feedback. The information gathered by sensors such as force sensors, tactile sensors, and proximity sensors may be used to infer several things, including the position of the object, the stability of the hold, and the applied forces. Because sensors have been incorporated into the design, gripping can now be done with more accuracy and adaptability.
- Grippers are constructed to withstand the rigorous conditions of industrial floors as well as frequent use. Because of their long lifespans and resistance to damage caused by normal usage, materials such as metals and robust polymers are frequently employed in their manufacture.

- Capacity for cooperation Modular grippers is designed to be compatible with a wide variety of robots as well as interfaces. They are compatible with a broad variety of robotic arms and automation systems, and they may be integrated without any noticeable disruption into already established processes or configurations.
- Grippers are capable of being instructed and programmed to perform a variety of different gripping sequences and approaches. To support sophisticated grasping methods or to adjust to changing situations, they can be operated by hand, by programmed routines, or by robotic control systems.
- Grippers can come equipped with safety measures, which are desirable since they can shield users, property, and machinery from damage. Examples of such qualities include the detection of collisions, the provision of gripping surfaces, and the installation of force-limiting devices. Since they have so many different functions that might come in handy, modular robot grippers are an essential component in a broad variety of manufacturing, industrial, and robotic applications.

2.3.1.2 Sustainability aspects of Modular robot grippers

Using modular robot grippers has a variety of advantages from a sustainability standpoint, including reduced waste and better utilization of the resources that are available. The following are some examples of these environmentally friendly features:

- Efficient Use of Resources: The use of replaceable pieces in modular grippers allows for the reduction of scrap during production. By using this approach, just the worn or damaged components of the gripper need to be replaced as opposed to the entire item; hence, this saves a significant number of important resources.
- As the grippers are built to withstand significant amounts of stress, modular grippers have a very long lifespan. Because of its robust construction and the ability to repair individual components modularly, it has a long service life. This reduces the frequency with which the grippers need to be replaced, which in turn diminishes the impact on the environment that is caused by the manufacturing and disposal of new grippers.
- Modular grippers are scalable and upgradeable, which means they can match your ever-changing requirements. This is an advantage over traditional grippers. Manufacturers are able to readily add or remove modules, improve functionalities, and integrate new technologies without having to replace the entire gripper. This not only extends the gripper's useful life but also cuts down on the amount of trash produced.
- The power demands of modular grippers may be maintained to a minimum by utilizing energy-saving design aspects such as efficient actuators, decreased friction, and improved motor control. This allows for power to be kept to a minimum. This leads to a reduced requirement for energy, which in turn reduces the amount of harm done to the natural environment.
- Because of the importance of recycling to the circular economy, modular grippers may be designed to be easily recyclable. During the production process, gripper manufacturers

could opt for or employ parts that are recyclable. The pieces of the gripper are made to be easily disassembled and recycled after they have reached the end of their useful life, which contributes to a circular economy and reduces the amount of trash produced.

- If a company uses modular grippers, there is a possibility that their influence on the environment will be reduced. Utilizing more resource-friendly materials, extending their useful lives, and increasing their adaptability are three ways in which manufacturers of grippers may cut down on waste, energy consumption, and emissions of greenhouse gases connected to gripper production, operation, and disposal.
- Since modular grippers are often manufactured to be compatible with a diverse selection of robotic systems and interfaces, it is possible for them to be included in systems that are already in existence. Because of this compatibility, the present robotic infrastructure may be utilized in the most effective manner possible, reducing the need for costly system upgrades.
- When making grippers, manufacturers also have the option of choosing materials that are friendly to the environment. Materials that can be recycled easily or that decompose naturally are two excellent examples of this type. Utilizing recycled or bio-based polymers, both of which have lower carbon footprints, is another viable option. It is a step in the right direction because the gripper's construction makes use of environmentally friendly materials.

The incorporation of these sustainability concerns into the design, production, and operation of modular robot grippers has the potential to make robotics a more environmentally friendly field of study.

2.4 Energy consumption in robots

The quantity of power that a robot requires in order to carry out its operations is referred to as its "energy consumption." Electricity, hydraulics, pneumatics, and even combustion engines are just some of the several types of energy that robots may get their power from, depending on their purpose and how they were designed. The actual amount of energy that a robot uses can be affected by a variety of factors, including its size, kind, level of sophistication, and the tasks that it does.

Electricity is required for the operation of virtually all robots, and electric motors are what move the joints and actuators on the robot's body. The amount of power that is needed to operate one of these robots is mostly dictated by the motors on the robot, the controls on the robot, and the weight that the robot is carrying. Energy consumption may be lowered by implementing power management systems, motor controllers, and designs for energy-efficient motors.

Robots cannot move or perform tasks such as picking up, moving, or manipulating objects without the assistance of an external power source. The amount of energy that is used is determined by a variety of factors, such as the weight of the robot, the distance it travels, the amount of force that is applied, and the level of precision that is required.

Robots are able to learn about their environments and respond appropriately by utilizing sensors such as cameras and proximity detectors to sense and perceive their surroundings. These sensors are unable to function or transmit data without the presence of energy. Utilizing algorithms for efficient sensing, methods for intelligent data processing, and sensor designs that are friendly to the environment are some ways to cut down on energy use.

To perform their jobs, evaluate sensor data in real time, and make decisions, robots need to be equipped with complicated processing and control systems. It's possible that the microcontrollers, central processing units, and memory that keep the robot running eat up a lot of power. Utilizing algorithms that are effective, coding that is simplified, and power management tactics are some of the ways that the amount of power required to run a system may be decreased.

To interface with other systems or humans, robots will commonly employ either wired or wireless channels. Energy is consumed whenever information is sent, particularly when it is done so through wireless networks. Utilizing effective communication protocols and technologies that conserve electricity can help reduce the amount of power that is consumed during the process of exchanging data.

There's the problem of standby and idle power consumption that occurs when robots aren't carrying out any tasks. Waiting for instructions and powering various components, such as displays and communication devices, both consume some of the available energy. During these periods, it may be possible to decrease energy waste by applying power management methods such as sleep modes or switching off procedures for components that are currently not in use.

The energy efficiency of robots is continuously being upgraded and enhanced. Hardware that is more efficient with energy use, complex control algorithms, motion plans that are more efficient with energy use, and the inclusion of renewable energy sources are all components of the solution. The use of energy-efficient robots not only helps businesses save money but also has a beneficial effect on the environment since it lowers the total amount of energy used by such firms. [2]

2.4.1 Methods of Calculation:

Estimating the amount of energy that a robot uses may be done in several different ways, each of which is determined by the design and power supply of the robot. The following is a list of several common approaches to calculating the amount of electricity used.

To begin, it is possible to monitor the precise quantity of power that is being utilized by the robot while it is at work by employing power meters or current sensors. Readings taken at various points in time can be combined to provide an estimate of overall energy use.

Second, an approach referred to as "component-level calculation" is utilized in order to derive an estimate of the amount of energy utilized by certain robot parts and systems. The minimum and maximum power inputs that are required for a manufacturer's motors, actuators, sensors, and control systems are often listed on the manufacturer's website. It is possible to obtain a rough estimate of the total energy usage by adding up the energy requirements of all these components.

When conducting an analysis of the duty cycle, it is important to take into consideration the length of time spent operating each individual system and component of the robot. It is possible to make an estimate of the total amount of energy consumed by taking into consideration both the duty cycles and the individual amounts of energy consumed by each component. This strategy is effective for systems that have components that have activity that is intermittent or power requirements that are intermittent.

The robot's tasks are taken into consideration in the fourth approach in order to ascertain the amount of energy it requires. The amount of effort required, the distance traveled, the amount of force exerted, and the amount of time spent doing the task are all factors that go into the equation when determining the amount of energy required for a particular activity. When the energy requirements of all activities are added together, you may receive an estimate of the total amount of energy consumed.

Simulation and modeling techniques are employed in the process of energy consumption estimation. Virtual models are created of the components, systems, and functions of the robot, as well as the tasks that it will do. An estimation of the amount of energy used may be obtained by simulating the operation of the robot with the help of energy models and algorithms.

However, these methods can only provide estimates, and the amount of energy that must be used will almost certainly change based on the circumstances. Nevertheless, these computational approaches shed light on the significance of energy requirements, which paves the way for the increase of robot efficiency and the optimization of energy use.

2.4.2 Impact of weight in robot energy consumption

The size and weight of a robot has a significant impact on the amount of energy it consumes. The following is a list of key aspects that address the association between the mass of the robot and its power consumption:

- To begin, a robot's energy requirements increase in direct proportion to its total mass. When it comes to moving, lifting objects, and overcoming inertia, heavier robots require a greater amount of energy than their lighter counterparts. The robot's motors and actuators must apply a greater amount of force and torque in order to raise the larger weight, which results in an increase in the amount of energy that the robot consumes.
- A robot's weight has a direct influence on how well it can move about its environment. Lighter robots have less resistance and friction while they are in motion, which results in a lower overall waste of energy. On the other side, heavier robots have a bigger influence on the environment because more energy is required to overcome resistance factors such as friction, inertia, and weight. This results in a greater amount of pollution.
- It takes a greater amount of work to speed up or slow down a robot that is heavier. Because of the additional load, maintaining the same level of effort while still moving about requires a greater quantity of energy. In applications that need frequent changes in velocity or

direction, the influence that weight has on the amount of energy that is used might be amplified.

- It may need more power to keep bigger robots steady and under control, especially if they are moving. Because the extra mass may create a shift in the location of the robot's center of gravity, it may need a greater amount of energy to maintain the robot's stability when it moves around or engages with the world around it. When items need to be placed precisely or manipulated in a certain way, this becomes an extremely important consideration.
- Energy Origins and Vaults of Supply It's possible that heavier robots may require more powerful and cumbersome batteries or other forms of power storage technology. Because of the incorporation of these energy storage components, the robot's movement and overall functionality will demand an increased amount of electricity.
- Gains in productivity have been associated with actions that reduce the workload carried by a robot. The use of lightweight materials, mechanisms, and components that are efficient, as well as efficient design and construction, may all contribute to the accomplishment of this aim. A lighter robot requires less power to perform the same duties as a heavier robot, which implies that it can go longer between recharges or consume less electricity overall. Robots benefit from being lighter because of this.

It is important to keep in mind that the amount of energy a robot requires to accomplish its work might vary depending on its design, the task it is assigned, and the operating circumstances. Therefore, it is essential to pay particular attention to the reduction of weight in order to bring about robot systems that are efficient in their use of energy.

Chapter 3 Investigation of problem statement

3.1 Existing grippers at VCC

3.1.1 Tünkers Gripper Solution

A selection of TÜNKERS grippers may be found in the inventory of Volvo's Gripper and Handling Technology business. The portfolio includes a number of modular system options that are based on either force- or form-closed closure. The body-in-white division is the principal user of these grippers, where they are put to use in a range of handling, process, and geometry-related situations. Tünkers contends that the versatility of the modular system makes it feasible to perform gripper duties such as crate palletizers in the realm of automation technology.

Tünkers has various product varieties in Gripper technology which is used by VCC [12]: Robot grippers, gripper systems, gripper arms, Euro-Gripper-Tooling (EGT), circular tube gripper, carbon gripper, one screw system, gripper profiles, modular gripper system, modular gripper design system, grippers, gripper technology, robots, modular design system, gripper station, Tünkers circular tube, Tünkers carbon gripper, carbon fibre, Tünkers One Screw, TOS, geometry, process, handling, gripper profiles, octagonal profiles, octagonal, flexible grippers.

3.1.2 Springer Gripper Solution

The components are manufactured, assembled, and integrated into Volvo's systems by Springer Company, which also utilizes the production facilities that are already in place. In short, it proposes an entirely individualized approach to the automation problem. Automation may be implemented using Springer's conventional gripping components as well as the company's bespoke gripping systems in a variety of sectors in addition to press plants and body shops. [13] The company designs and produces the components according to the precise specifications outlined by their customers.

Due to the wide range of available components and the ease with which they may be attached, there is no limit to the number of combinations that can be achieved. You can work with metal and plastic parts, including CFRP (carbon fiber-reinforced plastic), when you use the gripper systems offered by Springer in their body shops.

The results are as follows:

- It is feasible to keep the diversity of components while making use of flexible and multipurpose components.
- The capacity to recreate anything exactly paves the way for speedy modifications and recommissioning after a period of downtime brought on by a breakdown.
- The greatest combinability leads to the reduction of the number of pieces, which in turn leads to the reduction of the total volume [13]

These above two gripper solutions were used in VCC with all the robots.

3.2 Material study

It was found that the current material being used in grippers was Aluminum both by Tünkers as well as Springer and Aluminum had few disadvantages when it comes to using with grippers:

Since aluminum is a softer metal than steel, it is possible that aluminum profiles will not be able to support as much weight or withstand as much stress when used in the same circumstances. It is possible the robot's resilience and stability will suffer as a result.

Aluminum has a lesser stiffness than steel, robot profiles may be more readily caused to flex and bend when aluminum is used. It is possible the accuracy and precision of the robot's motions would suffer from this flex in particularly precise applications.

Aluminum will not last as long as other materials since it is not as durable as other materials. After extended exposure to mechanical stress, friction, and impact, the robot's aluminum profiles may get deformed or damaged, which may negatively affect its performance and longevity.

Also, the coefficient of thermal expansion of aluminum is greater than that of steel, the volume of heated aluminum increases more than that of steel. As a result, aluminum profiles are likely to undergo greater expansion or contraction than profiles made of other materials when the temperature is changed. Because of the robot's tendency to repeatedly expand and contract, the dimensional stability and accuracy of the device may be compromised.

Although aluminum may be welded, the only methods that work well with it are those that use specialized aluminum wire, such as tungsten inert gas welding or metal inert gas welding. In comparison to welding steel, the processes described here may be more difficult and needed for employees with specific training.

These disadvantages were the reasons for causing various performance issues where the profiles get cracked or snapped under a crash. This disturbed the lead time within the production line and involved a lot of cost in replacing the damaged system.

3.3 Design

The Tünkers One Screw (TOS) gripper system claims it is at the forefront of modular gripper technology. This system's primary frame, which is located at Level 1, is based on an octagonal profile that has a pattern of bore holes. After the joints have been form-fixed and form-closed, the primary frame profiles are form-fixed to them. Although a form-closed build-up is the only choice for standard employment of the gripper arms (Level 2), a force-closed build-up is required for Geo applications. There is no requirement for any additional hardware or means of attaching, including blind rivets. All module-to-frame connections use screws of the same size, which are standardized across the industry. Because of its distinctive dual profile, this gripper is ideally suited for the most difficult of applications. [12]

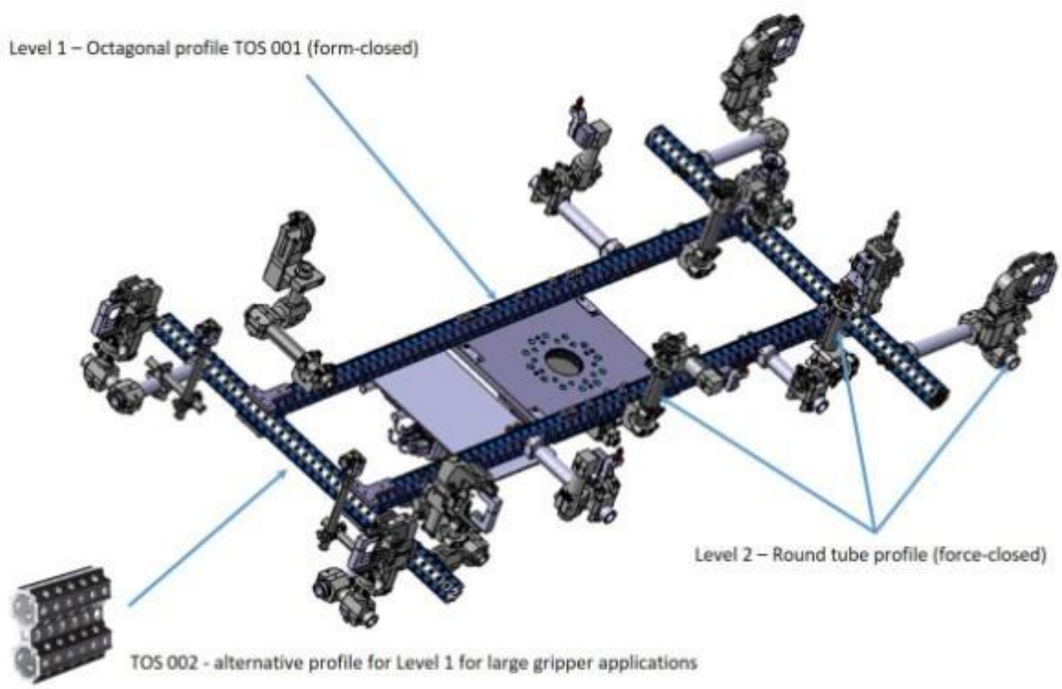

Figure 6: Profile detail

Even with meticulous preparation of the modular components, there is no way to ensure that the underlying system would function faultlessly. The stiffness, weight, and placement precision of a modular system are mostly determined by the design and construction of the system itself. Some applications may be limited by faults, such as when inappropriate placement or collision happens due to an inadequate mix of components or mass distribution. This type of problem can be caused by a lack of acceptable mass distribution or component mixing. Because of this, the gripper's design process needs to consider the features of acceleration, mobility, the environment, and external stress. [12]

3.4 Scope for new solution

ThyssenKrupp produced a new profile design which the company claims to be more economical with high mechanical properties compared to the aluminum profile.

With the new solution, there are potential improvement areas available which can be investigated in order to fulfill the objectives of this work. There was a noticeable change in weight which was the main key factor in proceeding with further investigation and analyzing its impact is critical. Also, there was scope for investigation in cost savings and energy consumption since weight reduction has an impact on these factors.

With these factors taken into consideration, capabilities and stability of grippers, gripping force, adaptability to various object shapes and sizes should also be considered to ensure there is no compromise in performance and efficiency

Chapter 4 Investigation and discussion of solution

The investigation begins by selecting three sample grippers in the existing production line at VCC.

4.1 Gripper selection and classification

The importance of selecting three sample grippers out of a vast pool of options based on load capacity lies in the need to ensure optimal performance and efficiency in the production line. By carefully selecting three grippers with different load capacities, the investigation aims to evaluate their suitability for specific tasks within the production line.

Table 1. Selected Grippers

S. No	Robot/Manipulator model	Gripper Size	Gripper ID	Cluster
1	IRB 7600-500/2.55	Large	TA-138010R07	60
2	ABB IRB6700-270/2.70	Medium	TA-136050R09	60
3	IRB 6640-235/2,55	Small	17-31-010R02 80-02-000	90

4.2 Material and weight analysis

Analyzing the qualities and attributes of materials and determining their mass or weight is what material and weight analysis is all about.

It was found out that there is difference in weight and material in the grippers from ThyssenKrupp to the existing ones at Volvo.

ThyssenKrupp has SEGT steel as their material for gripper profile whereas it was aluminum in existing Volvo grippers. Also, there was weight difference which ThyssenKrupp claimed that their profile would be lesser in weight. Hence, an analysis was conducted to verify the differences between SEGT steel and aluminum using grippers from Springer as well as ThyssenKrupp in ANSYS [3] and weight differences were calculated to check the values in CATIA. [25]

Analysis of mechanical characteristics and mass in relation to structural strength and performance may be thought of as mechanical material and weight analysis. Here are some particulars to be considered:

- Ensure the material can bear loads and pressures by calculating its tensile strength, compression strength, yield strength, and fatigue strength.
- To determine how rigid a material is, we may calculate its Young's modulus or modulus of elasticity.
- Consider the material's ductility, which is measured by its ability to undergo plastic deformation in the presence of stress without cracking.

- Toughness refers to a material's capacity to withstand impacts and other forms of abrupt stress without cracking.
- Examine how well the material holds up against erosion and wear when contacted with various surfaces and particles.
- Test the material's ability to withstand fatigue by subjecting it to cyclic loading or repetitive stress.

By considering the importance of material and weight, analysis was performed in Ansys software. Details of which are as shown:

Boundary Conditions - Geometry

- All variants have a length of L= 898mm.
- Note on the EGT001 – profile with direct thread from Springer:

To produce the thread, thread forming was chosen, for which the core hole is pre-drilled with 7.4 mm. An average value of 7.56 mm (about 0.3 in) is selected to calculate the mass and rigidity.

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Table 2. Mechanical properties

Boundary conditions - loads

EGT001	Material	E [GPa]	v	ρ [kg/m³]	R_m [MPa]	$R_{p0.2/e}$ [MPa]	A [%]	$\sigma_{W,zd}$ [7] [MPa]	$\sigma_{W,II,zd}$ [7] [MPa]
Original	EN AW-6063 T6	69.5[1]	0.33[1]	2700[2]	215[3]	170[3]	8[3]	64.5	47
Springer	EN AW-6082 T6	70[1]	0.33[1]	2700[2]	310[3]	260[3]	10[3]	93	68
Thyssen	E355 +SR	212[4]	0.285[4]	7833[4]	580[5]	450[5]	10[5]	261	261
	HC260LA				350[6]	260[6]	26[6]	157.5	157.5

E	Modulus of elasticity
v	Poisson's ratio
ρ	Density
R_m	Tensile strength
$R_{p0.2/e}$	Yield point at
R_e	Stretch limit
A	Elongation at break
$\sigma_{w,zd}$	Tensile compression strength
$\sigma_{w,II,zd}$	Tensile compression strength (n=10^8)

The Profiles are examined with the following boundary conditions:

- Fixed Support on the face behind the profile-
- Load Step 1: 500 N force on the front side of the profile
- Load Step 2: 125 Nm torque on the front side of the profile
- Load Step 1&2: 9806 mm/s² acceleration to take account of the dead weight

HC260LA micro alloyed steel [23] has a good bending recovery to EN AW-6082 T6 aluminum and thus the deformation is quick. [22] The aluminum profiles are always weaker in resisting deformation as they get cracked or snapped easily under certain loads but are stronger and stiff enough in terms of withstanding its bending capacity. Steel is a more flexible and forgivable material under loads.

4.3 Design study

After analyzing the current design of grippers from VCC as well as from ThyssenKrupp, it was found out that there are differences in the profile which is shown below.

For the Springer Gripper, it was 50 mm (center to center) between the holes. The holes are also alternating on the other surfaces, so it is 25 mm between successive holes.

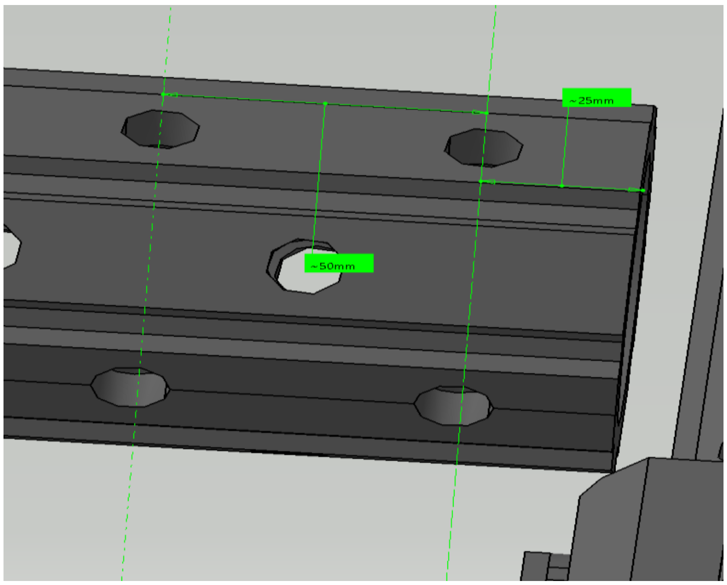


Figure 7: Springer profile

Similarly, it was also found out that for TOS gripper system the distance between the holes is 50mm (center to center) and 30 mm between successive holes.

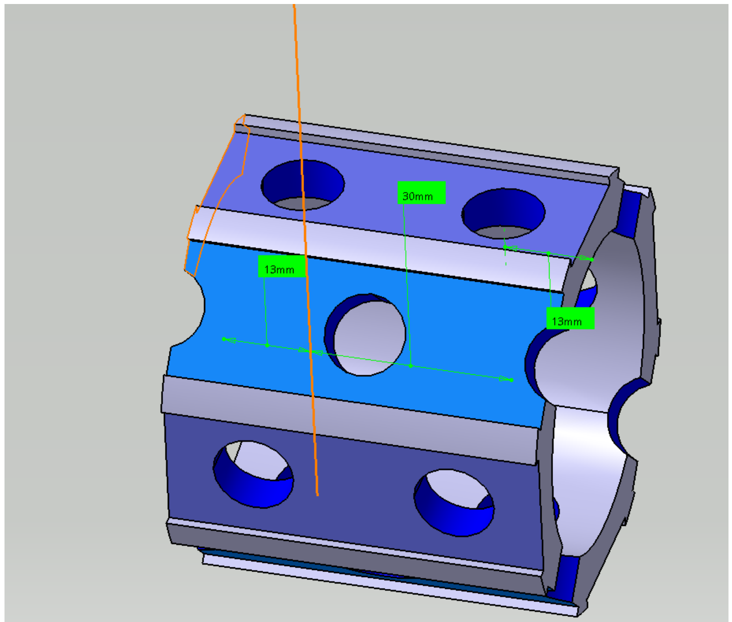


Figure 8: Tünkers profile

The first hole starts at 13 mm from the end. This is why a Springer and Tünkers TOS-gripper never can be interchangeable

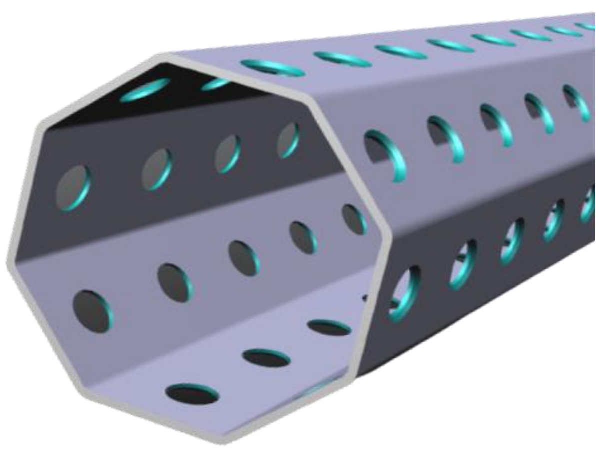


Figure 9: ThyssenKrupp profile

ThyssenKrupp had a distance between holes of 30mm (center to center), but holes were not alternating. Also, here the first hole started at 14 mm from the end.

The hole patterns can be sorted out, to get a one-to-one relation between the profiles. For example, TOS and ThyssenKrupp or Springer and ThyssenKrupp.

But, in that case, the companies need to decide what center to center distance they want to go for. Also, it was speculated that the hole pattern should be aligned with Springer since most of the grippers which are currently in use at VCC are from Springer and the three grippers which were selected also have Springer profile. Otherwise, the result of the gripper would be that it will look a little bit different. It will be a little bit bigger, since the center-to-center distance is going from 50 for Springer to 60 for ThyssenKrupp. Also, if the holes are not alternating, the gripper would look vastly different.

It is also important to note the benefits of ThyssenKrupp SEGT's profile design. From Picture 3, it is obvious that the profile has constant holes unlike the alternating holes in existing profiles. An exact plan is required for mounting in the alternating holes whereas linear pattern eases the mounting process. Also, the connections are performed using long screws through the profile in the existing design. ThyssenKrupp's design allows the connection using nuts. Usually, screws are required in aluminum profiles since they are threaded inside the holes which also adds up to the cost.

4.4 Economical review

After comparing the profile of ThyssenKrupp with that of Volvo, the major difference concerned the costs was in the material which was used in grippers. ThyssenKrupp used steel whereas existing grippers at Volvo are made from Aluminum. It was found that steel had various advantages and benefits over aluminum.

For large-scale construction projects, steel is typically the more cost-effective material. Steel may have a greater cost per unit of material initially, but its strength and longevity might lead to fewer repairs and fewer replacements over time. Thanks to the thinnest hexagonal design (2 mm thickness) making the production process simple and economical. Steel is an extensively traded commodity across the world, and the dynamics of its commerce are affected by variables including trade regulations, taxes, and differences in regional demand.

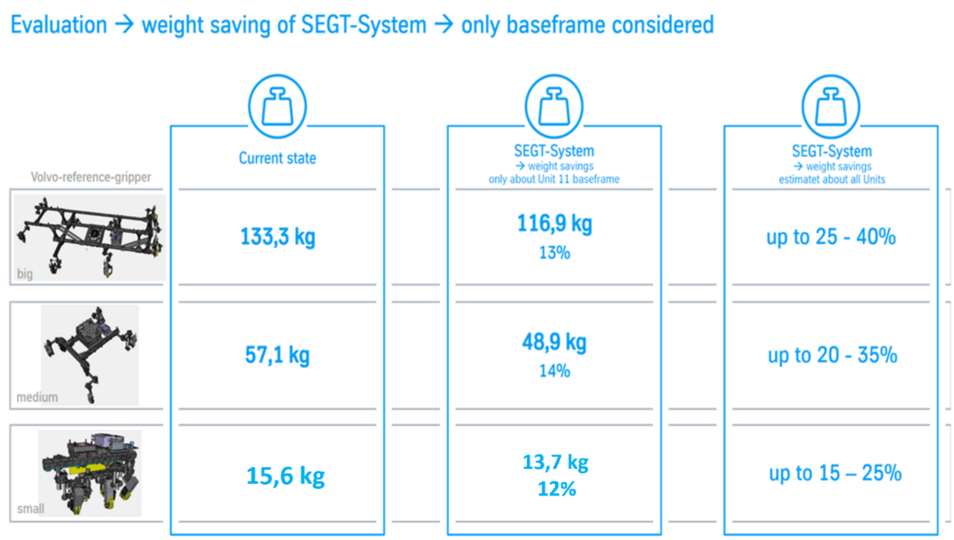
There was a detailed study performed regarding the cost factor including various calculations which were performed to compare in depth the cost distribution, and it was certain that ThyssenKrupp profile costs less compared to the existing ones. Due to the NDA issue, the details cannot be presented in this report.

Chapter 5 Results

5.1 Weight savings

Table 3, shows the current state of the weight (only frames are considered), followed by the change in weight after replacing the current system with SEGT profiles. The last column of the table shows the theoretical values (not proved) of potential weight reduction if VCC agrees to change the design of gripper system itself. This scope will be discussed in detail in Chapter 6.

Table 3. Weight Comparison



Evaluation → weight saving of SEGT-System → only baseframe considered

Volvo-reference-gripper	Current state	SEGT-System → weight savings only about Unit 11 baseframe	SEGT-System → weight savings estimatet about all Units
big	133,3 kg	116,9 kg 13%	up to 25 - 40%
medium	57,1 kg	48,9 kg 14%	up to 20 - 35%
small	15,6 kg	13,7 kg 12%	up to 15 – 25%

5.2 Cost savings - Robots

With the potential saving in terms of weight, by replacing aluminum profile with steel profile, VCC can not only save cost in grippers but also in the robots. During the investigation, an additional benefit for VCC was unlocked by considering the robot payload capacity. As mentioned in Chapter 5.1, on average 13% of weight can be saved in the gripper profiles which has equal impact in the entire gripper system. This serves as an opportunity to study the payload capacity of the corresponding robots.

The investigation started by collecting data which includes the list of existing manipulators at VCC, Torslanda and the recommended list of robots that VCC is interested in purchasing for future applications (Appendix). Then the weight range (minimum and maximum loads including the tool and part) of all the manipulators was extracted. This investigation provided surprising information on how many manipulators are working by exceeding its payload capacity.

The theoretical amount of weight is reduced in the current load (13%), thanks to SEGT profile. This paved a way for downsizing the maximum loads for individual manipulators ensuring it does not exceed the capacity in certain cases. As the payload decreases, it was also possible to reconsider the payload capacity of each manipulator. In some cases, it was concluded that manipulators that are required way beyond its actual payload can be replaced with low payload capacity manipulators. This will in turn reduce the cost of purchasing high payload manipulators.

It is also important to note that manipulators with high reachability or extended arm robots are costlier than high payload manipulators. [27]

5.3 Differences in mechanical properties

ThyssenKrupp's E355+SR pre-galvanized steel has been compared with Tünkers' EN AW-6063-T6 and Springer's EN-AW-6082-T6 aluminum alloy and the HC260LA low alloy steel. The analysis derived in Chapter 4.2 is inspired to perform a technical comparison. The table below is the summary of the comparison made. A quick decision on abstract level can be observed by evaluating the table.

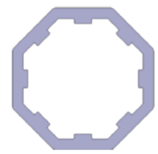
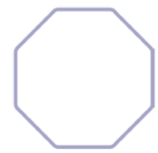
Tünkers' Original material is considered as a base for comparing the Springer's and ThyssenKrupp's solution. It is also important to consider the convention alloy steel in the comparison for better conclusion.

Observation of the pictures attached in the table, gives an understanding of how the density of each profile varies with design and so the weight. The weight is calculated in kilograms every meter. As expected SEGT had the lowest weight compared to aluminum alloys. Around 28% of weight can be saved for every kilogram of gripper profile by simply switching to SEGT.

The torsional analysis shows that an extremely high force is required to twist one unit length of SEGT by unit radian. Whereas the aluminum profiles can be twisted easily under low forces. The SEGT can withstand torsional deformation three times when compared to aluminum profiles. The torsional analysis provides a conclusion that SEGT profile is more ductile and can withstand cracks around 20% higher to aluminum profiles.

The bending stiffness of SEGT profile highlighted in red is taken as high priority. The investigation ensured to conclude that, the selected material for execution should outperform in all aspects. A possible solution for this problem is addressed in Chapter 6.

Table 4. Profile properties comparison

EGT 001	Original	Springer	Thyssen	
				
Material	EN AW-6063-T6	EN AW-6082-T6	E355+SR	HC260LA
Mass in kg/m	4.98	4.38	3.59	
Weight	100 %	88.08 %	**72.12 %**	
Bending Stiffness		**105.08 %**	96.61 %	
Torsional Stiffness		**128.71 %**	122.02 %	
Flexural Strength		127.27 %	**150.00 %**	90.32 %
Torsional Strength		**193.33 %**	**193.33 %**	120.83 %

5.4 Energy consumption

The energy consumption was evaluated using Robot Studio, a dedicated software from ABB. It will be easy to understand that heaviest (Large) gripper which is operated by a large robot manipulator will have a significant impact in weight reduction and thus the energy consumption. So, the large manipulator was chosen for studying energy consumption. Figure 21 and 22 illustrates one complete cycle of the robot operation before and after switching the profiles which were connected to Robot Studio. It can be observed from Figure 21. (Load graph with Aluminum Profile) and Figure 22. (Load graph with SEGT Profile), the impact of total motor energy is very minimal, and thus has a minor change in power consumption. [26]

It is important to highlight that the robot's COG should be considered and ensured if it is within the threshold whenever the payload is changed. Figures 23 to 38 describe the designs for the selected manipulators and the corresponding load graph with aluminum and SEGT profile individually.

The change in MOI with respect to weight is neglected for calculating the COG due to time limit.

Table 5. Energy Consumption Comparison

	Aluminum Profile	SEGT Profile	Reduction in Power Consumption
Total Motor Energy	38179.8 J	37708.7 J	474.4 J (1.24%)

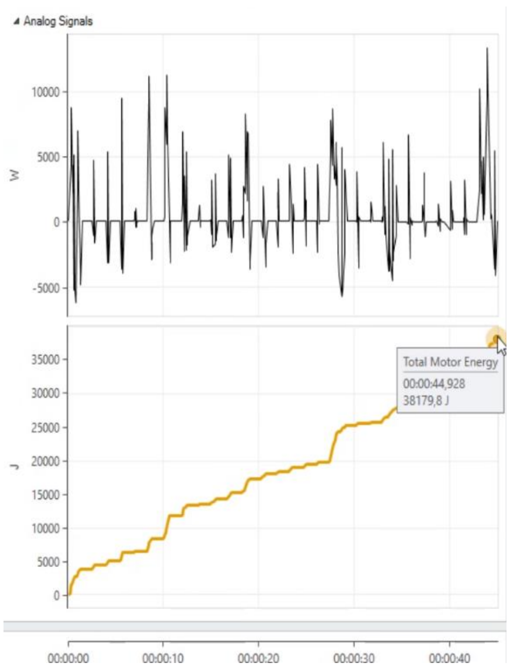


Figure 21: Motor Energy with Alu profile

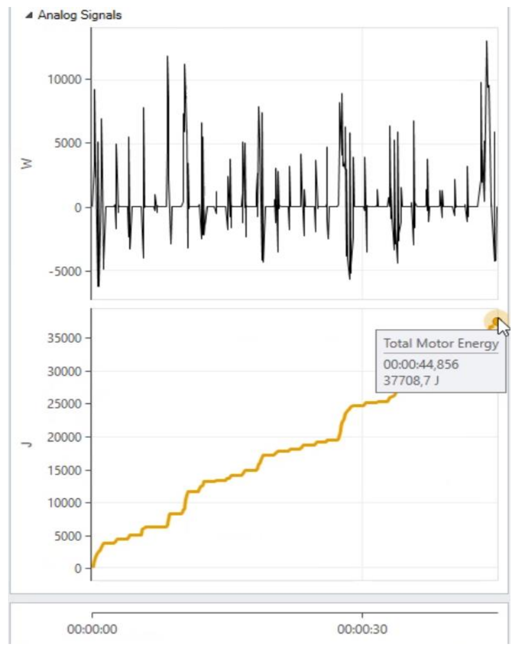


Figure 22: Motor energy with Steel profile

5.5 Sustainability aspects

It should be noted that for producing 1 kg of SEGT profile (ThyssenKrupp), 1.85 kg of CO2e is emitted, while for 1 kg of aluminum profile (Springer), almost thirteen times that amount of CO2e is generated. Taking the ideal case for example, if VCC can save 13% of weight in the gripper system, VCC can save 1.24% with the robot energy consumption and 24.05 kg of CO2e is saved. [21]

5.5.1 Reuse / Retool

The history of VCC in reusing or retooling the gripper profiles clarifies that these profiles are not reused or retooled for any new car project or car platform. The reason is the design of the gripper itself. As each gripper is designed and is well connected to product requirements. This means that the gripper profile is cut to correct lengths for each gripper. Adding to that, the process of disassembling the gripper and preparing it for a new project is an extremely complicated process which involves more time. Hence, it is a smarter approach to scrap and design a new gripper for every new application. This scenario can be avoided if the application is similar in specifications, for example, adding more clamps to handle bigger parts. However, the SEGT grippers are more sustainable compared to casted aluminum grippers.

5.6 Maintenance

Concerning the design differences, it is observed that ThyssenKrupp's SEGT profile will be more or less the most suitable profile at VCC.

In conclusion TOS is not fully compatible with Springer and ThyssenKrupp. Anyhow, ThyssenKrupp and Springer can be mixed to a certain limit.

One problem is, for example, the repositioning in case of a crash. With alternating holes (Chapter 4.3), an exact plan is required for mounting the profile.

ThyssenKrupp's profile has its own advantages. Each hole is threaded in Springer profile which is an extra work that leads to added cost. Whereas the ThyssenKrupp profile uses nuts for connecting subcomponents. However, the modular solutions are the same. The potential advantage in ThyssenKrupp profile is that steel can be a more forgiving material even for a bad design. Steel profiles bend under crashes and can be fixed with re-bending or welding operations with minimal effort. Unlike the aluminum profiles, which get snapped or cracked under crashes that leads to scrapping out the entire gripper. This is a major issue overserved in VCC production plants.

5.6.1 Standard components

Referring to Chapter 4.3, SEGT grippers are 100% not compatible with Tünkers' grippers. On the other hand, in SEGT grippers, the critical components like clamps can be interchanged with Springer's grippers. ThyssenKrupp and VCC's design engineers prefer to isolate the grippers in terms of interchangeability, concerning the challenges in purchasing spare parts and maintenance.

Chapter 6

Recommendations for further work

VCC will find a station in one of the production units where the SEGT gripper system can be tested. A Design Guideline needs to be created internally and ThyssenKrupp knows how to design the SEGT system according to VCC's demands. CAD data is to be published according to VCC's specifications which will be handed over and aligned with ThyssenKrupp. VCC requires dedicated resources to go for SEGT. It is also important for VCC to consider the maintenance and cost aspects and various challenges that may arise during the process of implementation. The data set in VCC must be updated with a new SEGT profile to avoid data collapse.

There is also an opportunity to reduce weight apart from the solutions which were discussed in the report. One of the main examples is:

Optimizing the topology of the gripper components to reduce the weight furthermore as shown in picture

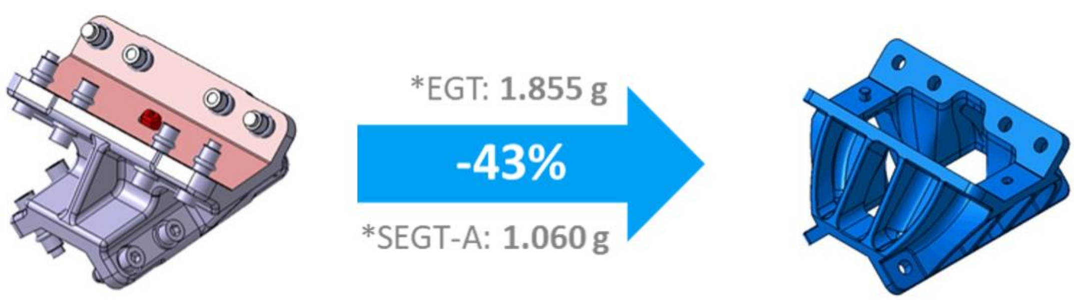


Figure 10: Topology optimization in connectors

If VCC agrees to optimize the design of the gripper system itself despite the challenges like time and cost, Optimization in Design of the gripper system will have a huge impact in saving the weight even more. This will in turn require thorough investigation of robot payloads, which might help VCC to replace the heavy-duty manipulators with lighter ones once VCC decides to deploy SEGT profiles in action. This has a vital role in saving thousands of euros on every new manipulator purchase.

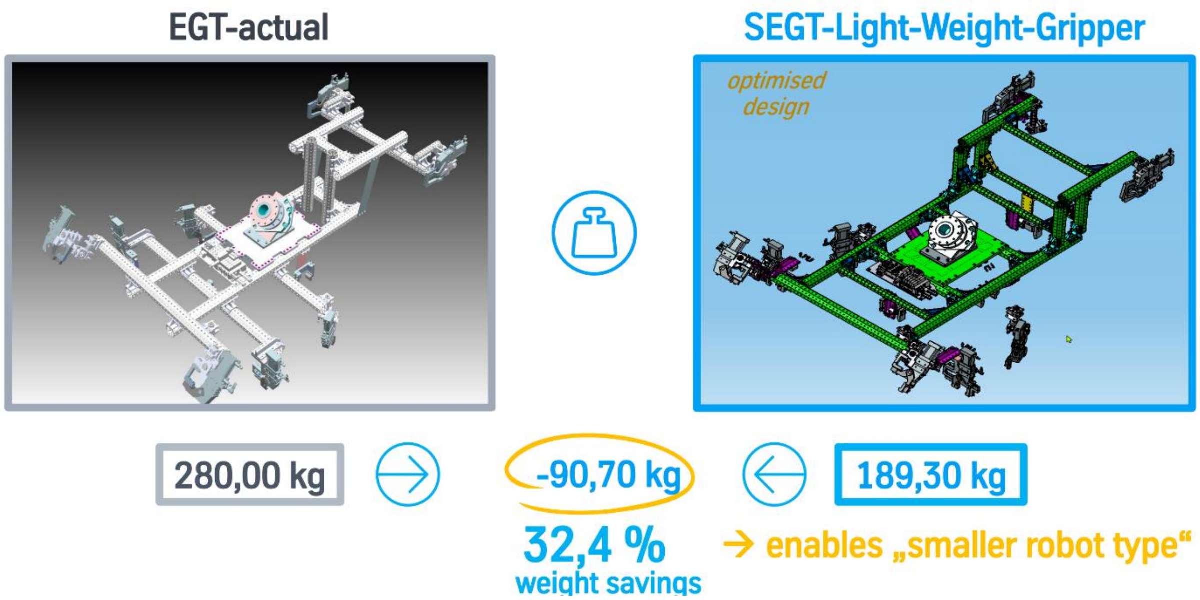


Figure 11: Weight saving with optimization of gripper design

Referring to table 5.3, the bending stiffness can be made stronger by increasing the thickness. It can be presumed that increasing the thickness from 2mm to 2.5mm doesn't affect the cost much. But this might have an opportunity for ThyssenKrupp in motivating the potential advantages and changes in the mechanical properties with respect to change in thickness. Despite the increase in weight, the design change will contribute a lot to mechanical analysis thereby proving the material to be stronger in every aspect.

To add an extra gripper, supplier requires a lot of internal hours from VCC as well.
During periods when VCC is compelled to decrease its overall workforce, it necessitates the utmost dedication and cooperation from its suppliers. One potential danger in the given scenario is the possibility of the supplier exhibiting insufficient effort, which could result in a contentious situation arising between an irate line builder and ThyssenKrupp.

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Appendices

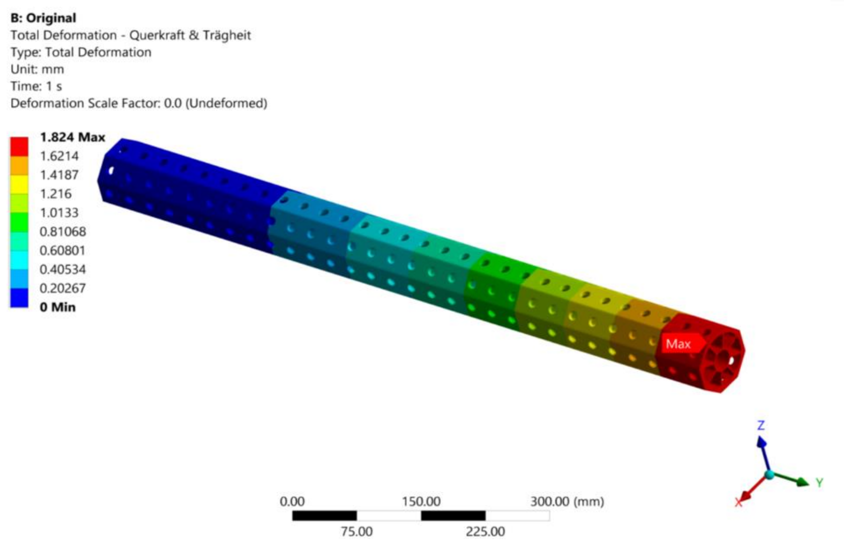

Figure 12: Total deformation – Bending – EGT

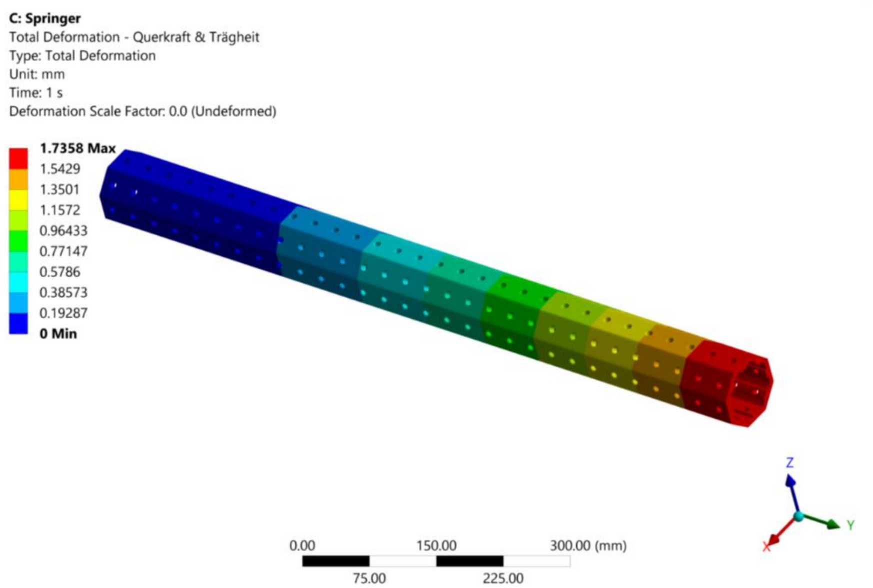

Figure 13: Total deformation – Bending – Springer

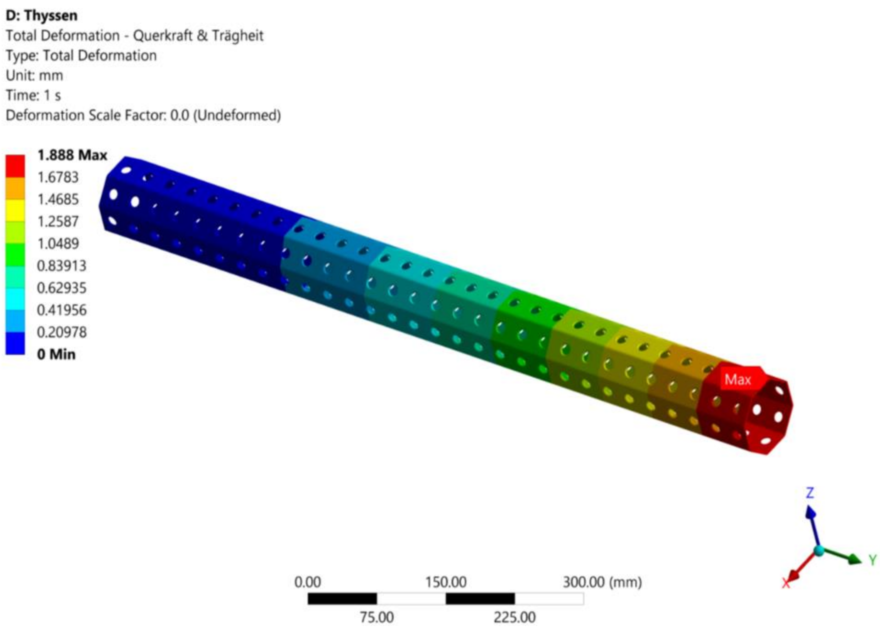

Figure 14: Total deformation – Bending – SEGT

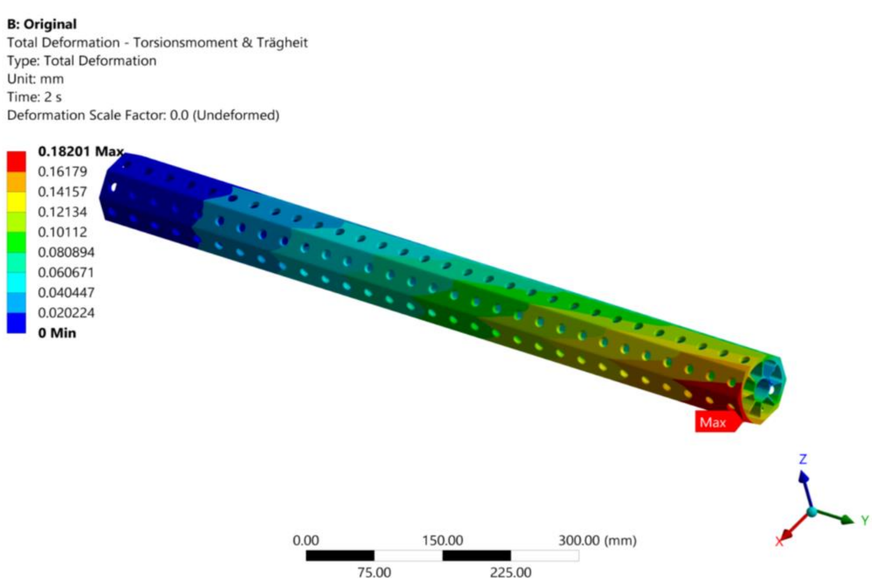

Figure 15: Total deformation – Torsion – EGT

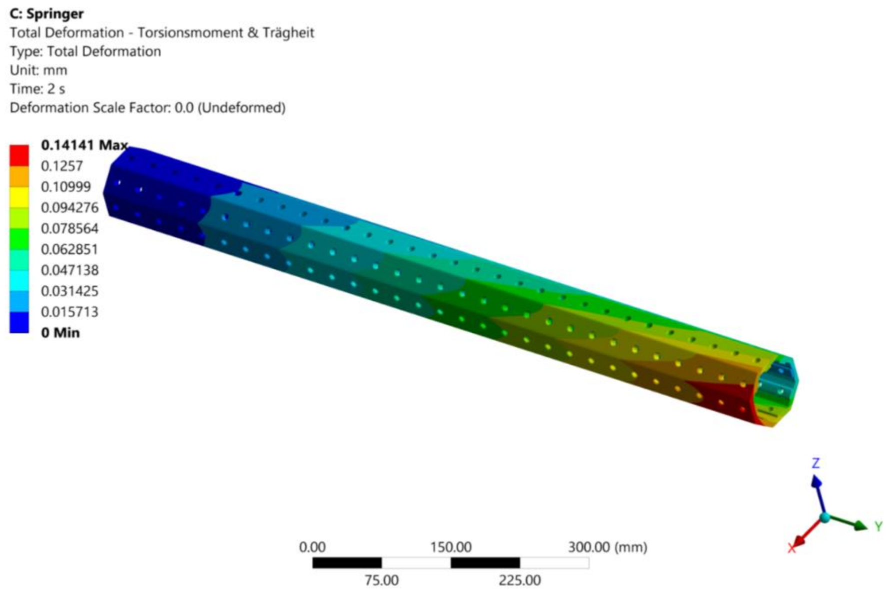

Figure 16: Total deformation –Torsion– Springer

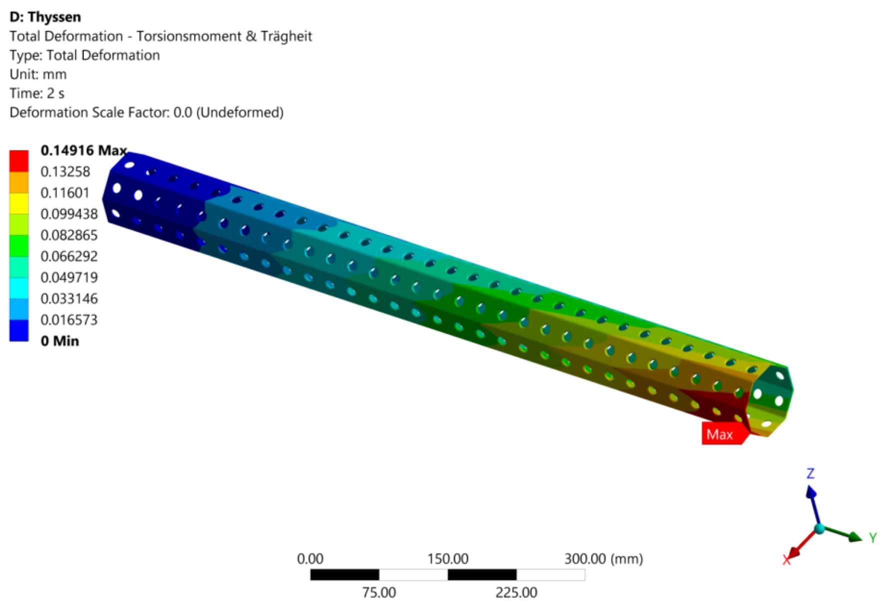

Figure 17: Total deformation –Torsion– ThyssenKrupp

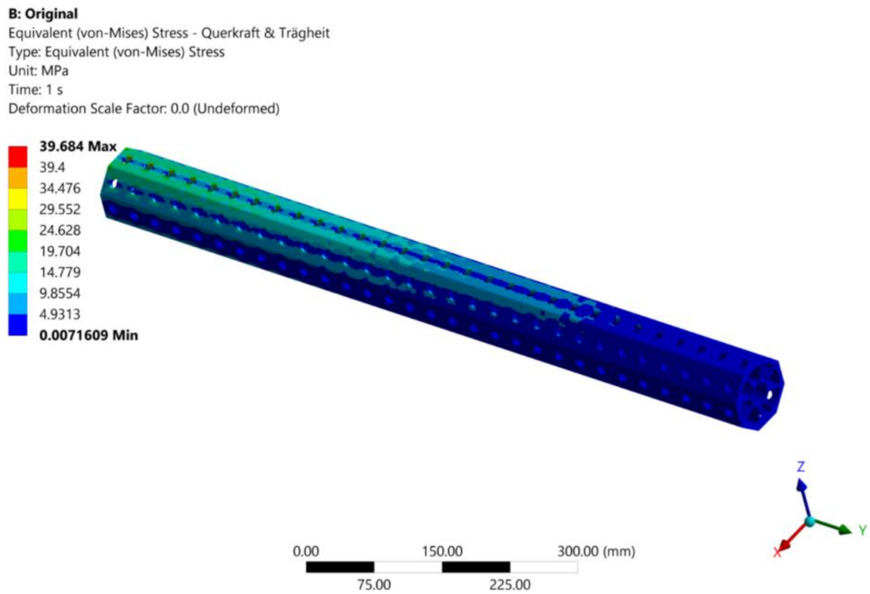

Figure 18: Equivalent stress – Bending – EGT

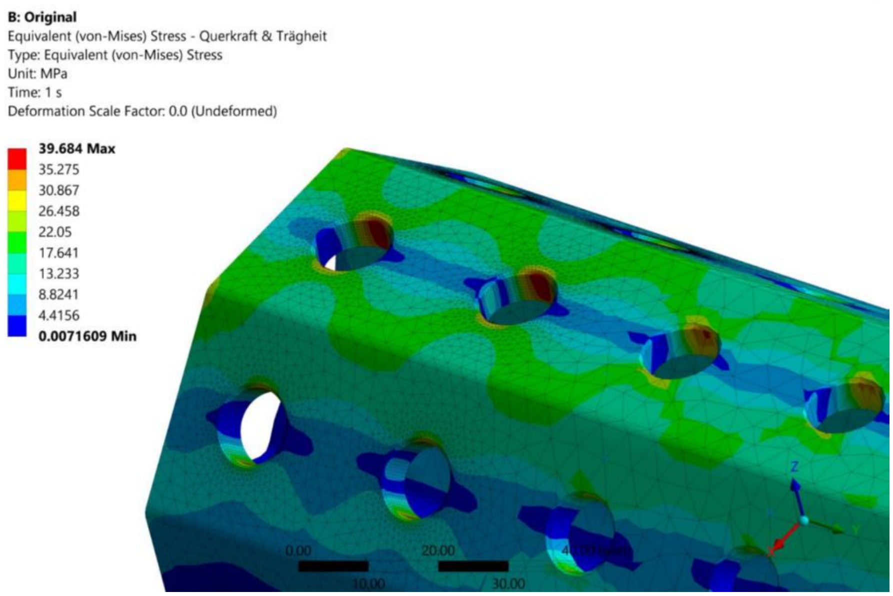

Figure 19: Equivalent stress – Bending – EGT (Detailed)

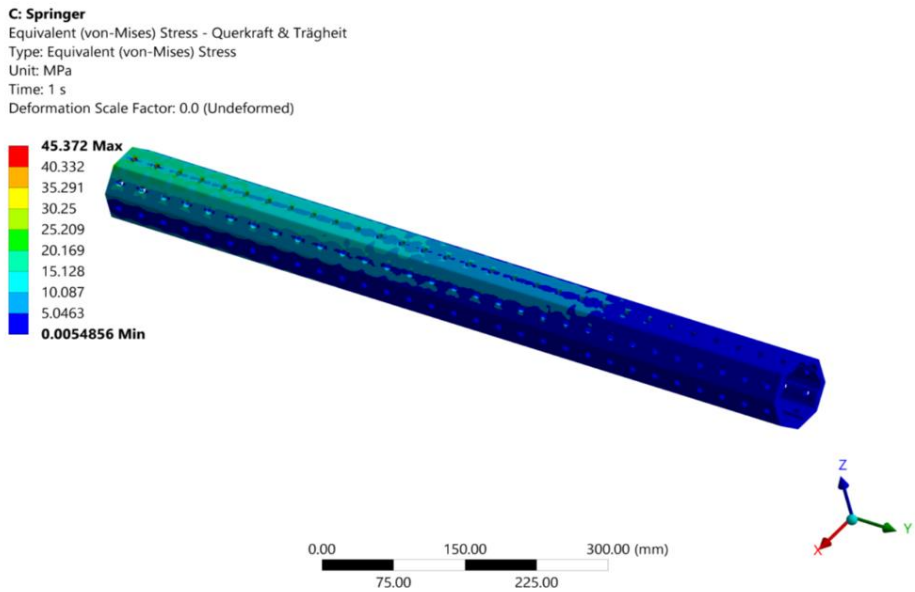

Figure 20: Equivalent stress – Bending – Springer

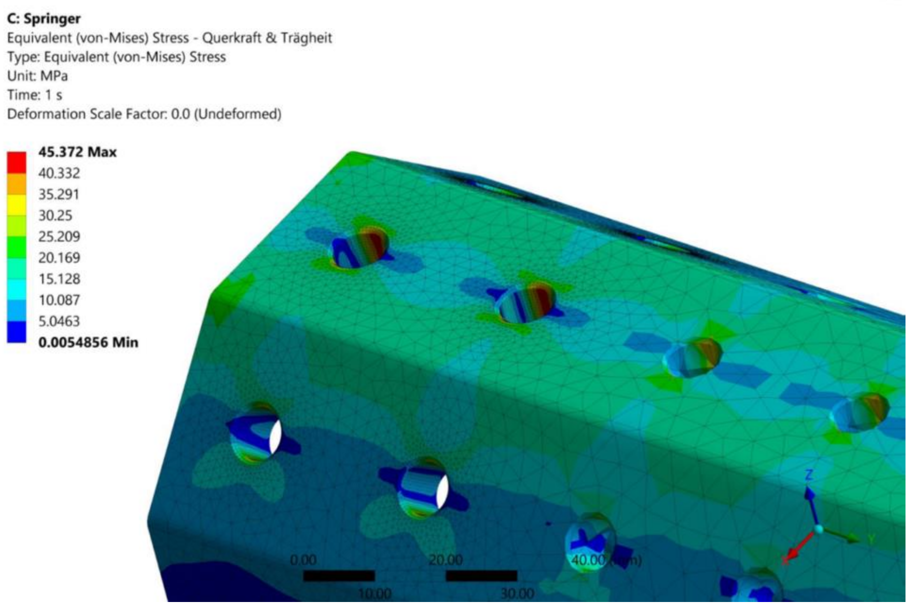

Figure 21: Equivalent stress – Bending – Springer (Detailed)

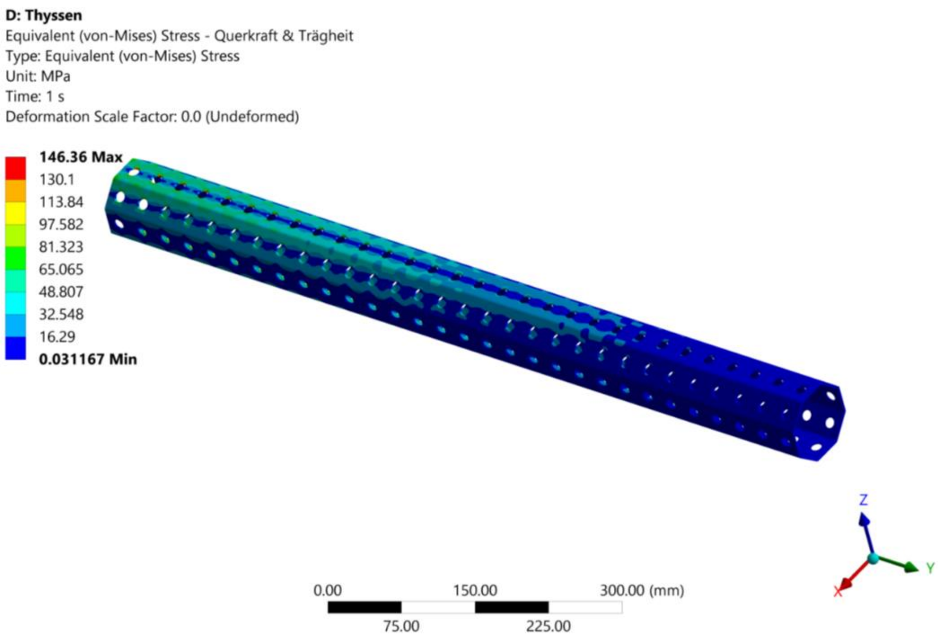

Figure 22: Equivalent stress – Bending – SEGT

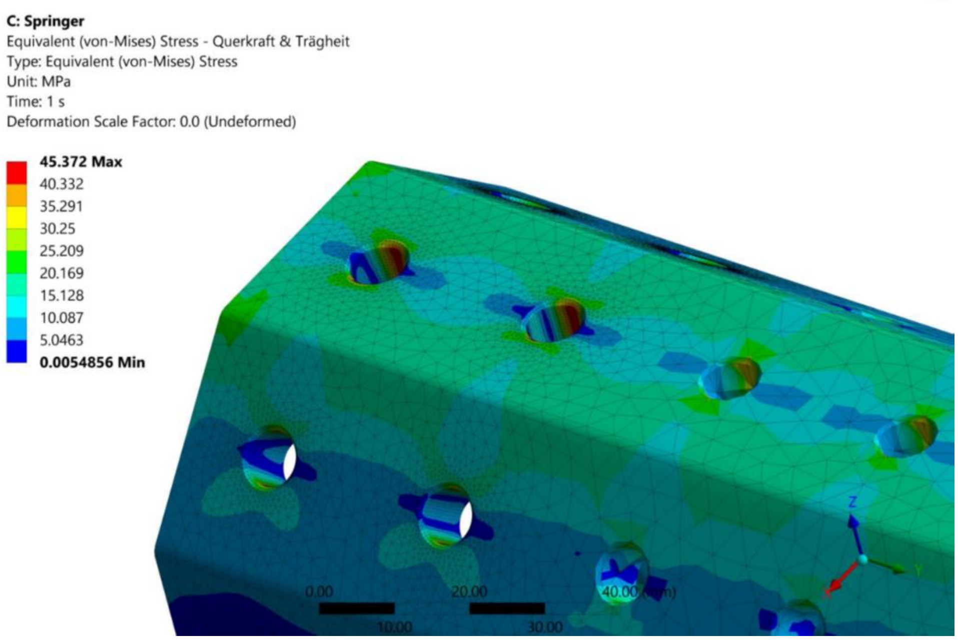

Figure 23: Equivalent stress – Bending – SEGT (Detailed)

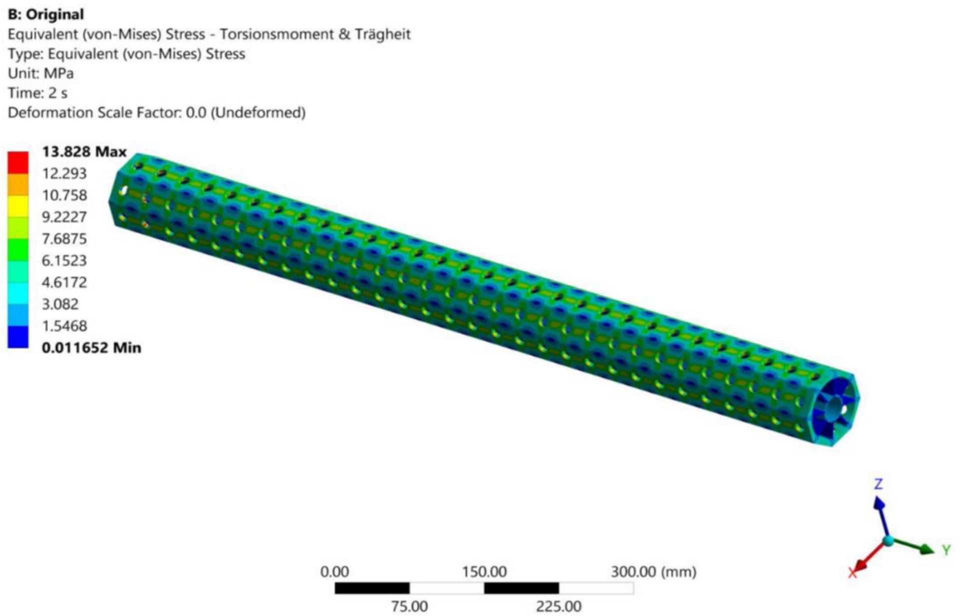

Figure 24: Equivalent stress – Torsion – EGT

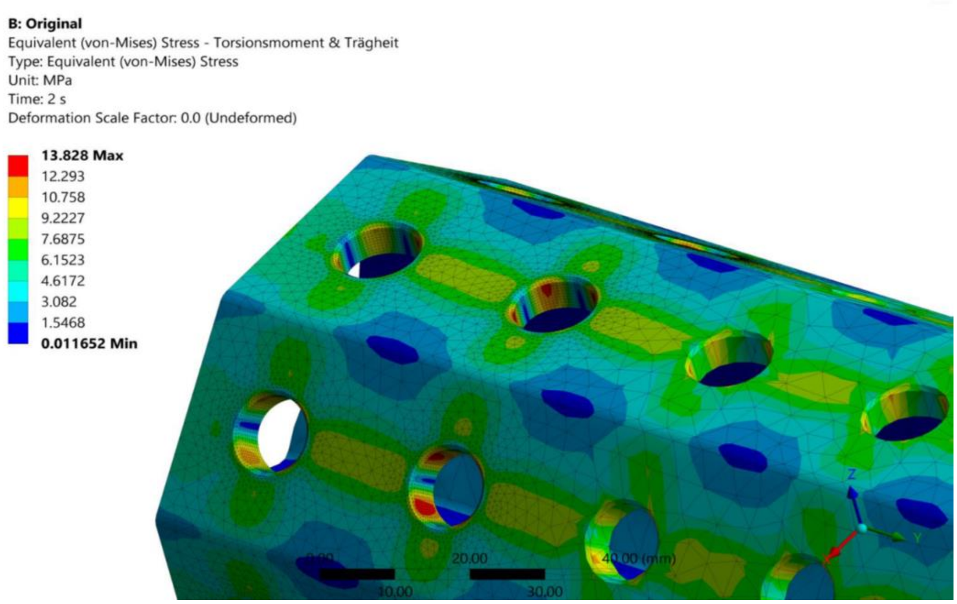

Figure 25: Equivalent stress – Torsion – EGT (Detailed)

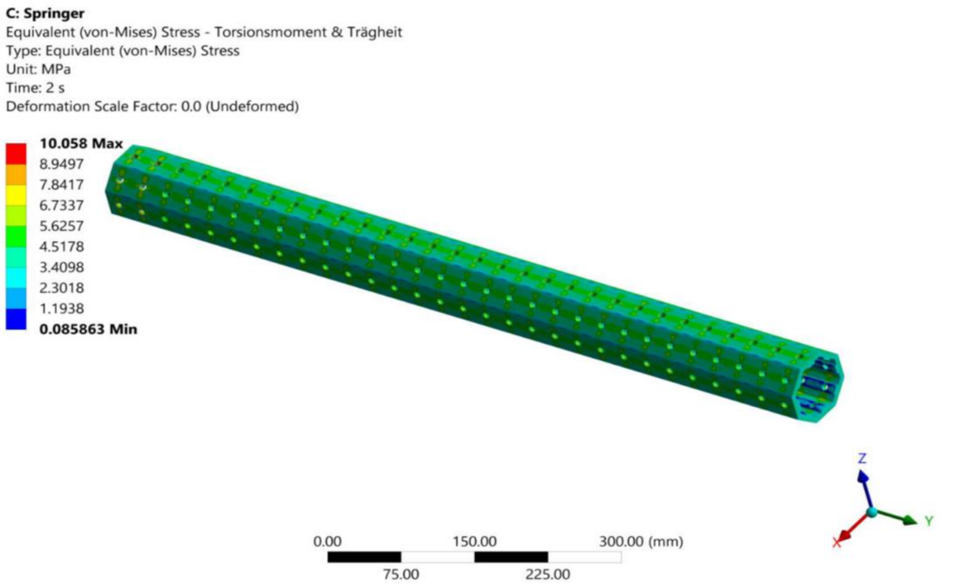

Figure 26: Equivalent stress – Torsion – Springer

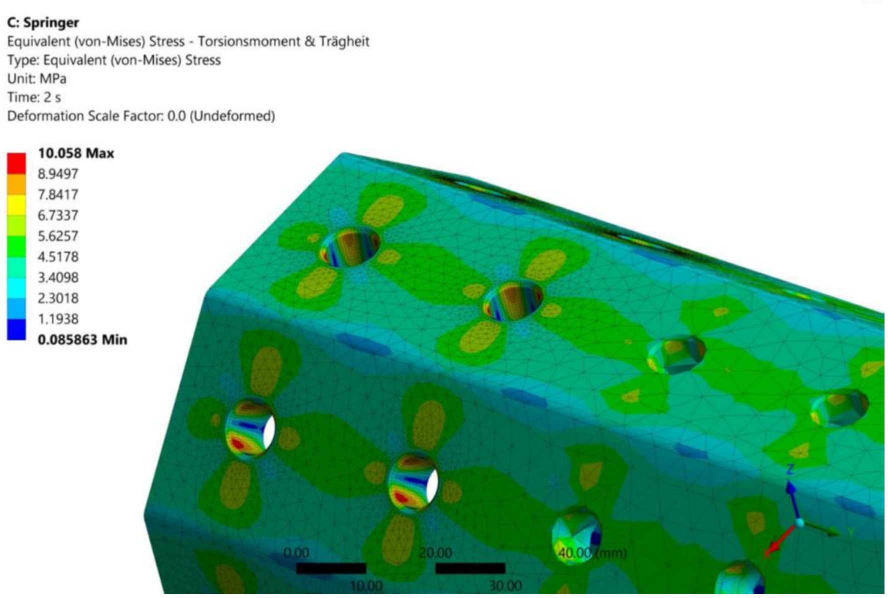

Figure 27: Equivalent stress – Torsion – Springer (Detailed)

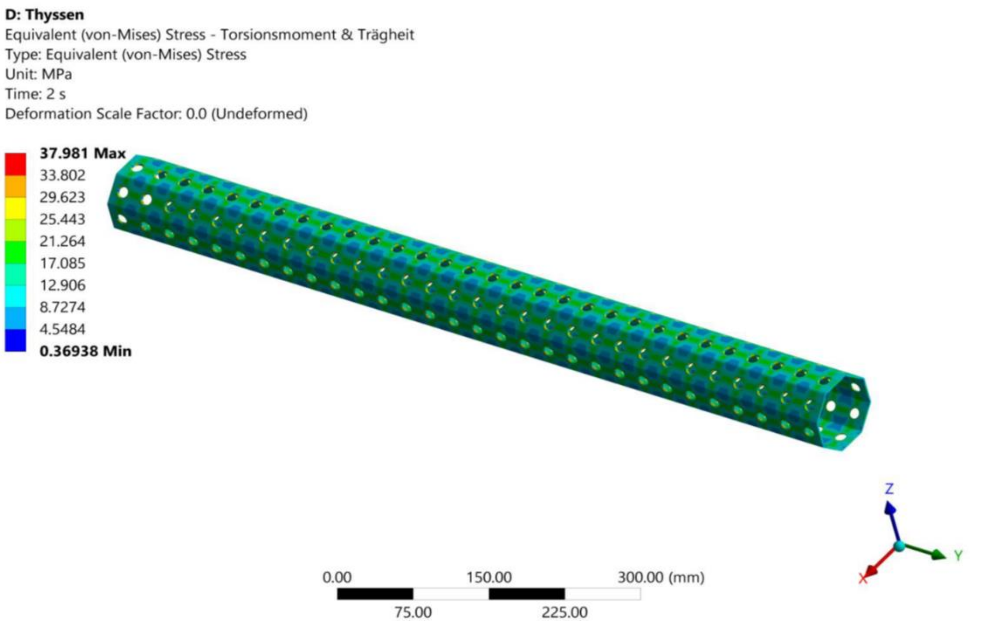

Figure 28: Equivalent stress – Torsion – SEGT

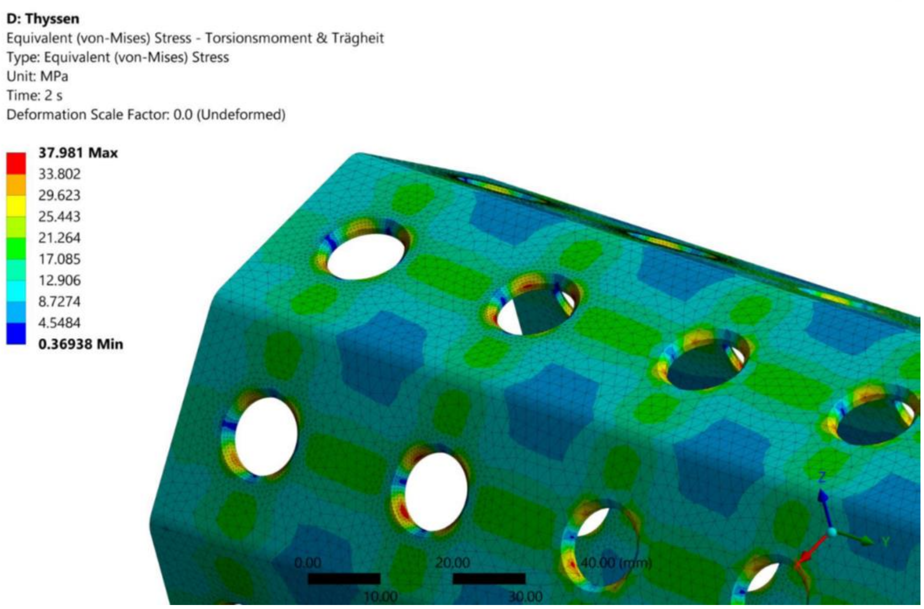

Figure 29: Equivalent stress – Torsion – SEGT (Detailed)

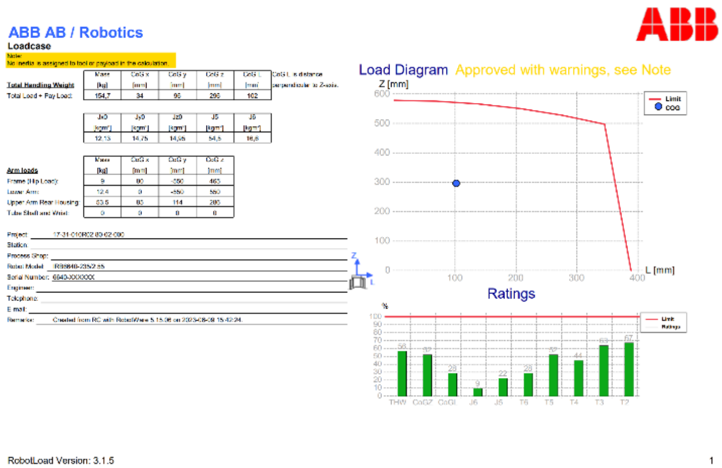

Figure 30: Load graph for small gripper with Alu profile

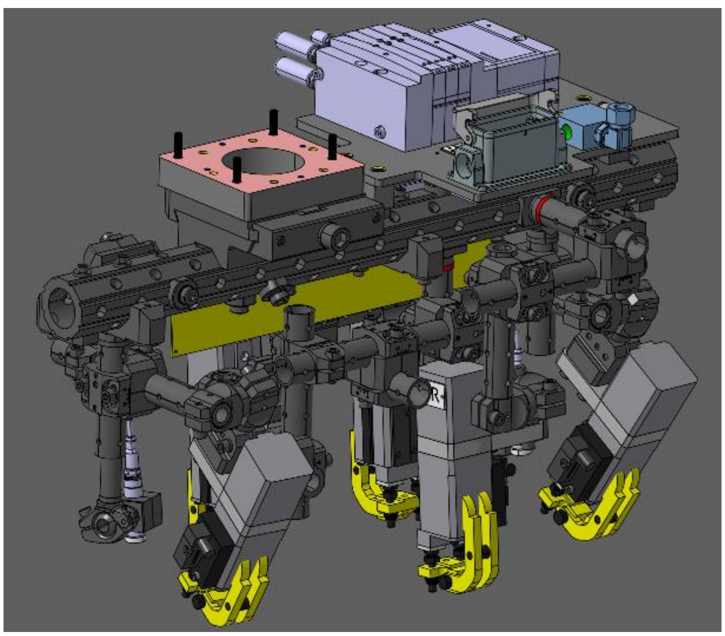

Figure 31: Small gripper with Alu profile

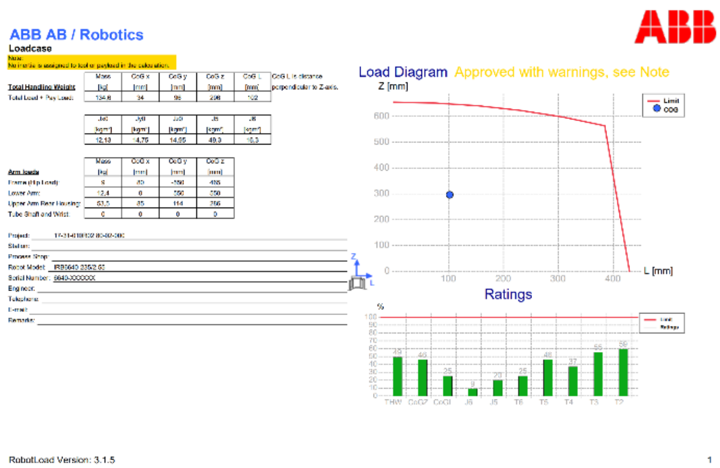

Figure 32: Load graph for small gripper with SEGT profile

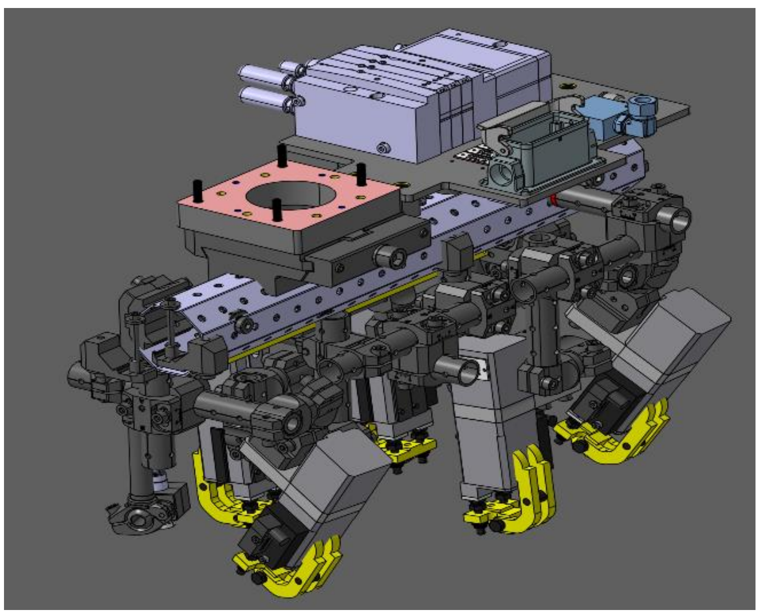

Figure 33: Small gripper with SEGT profile

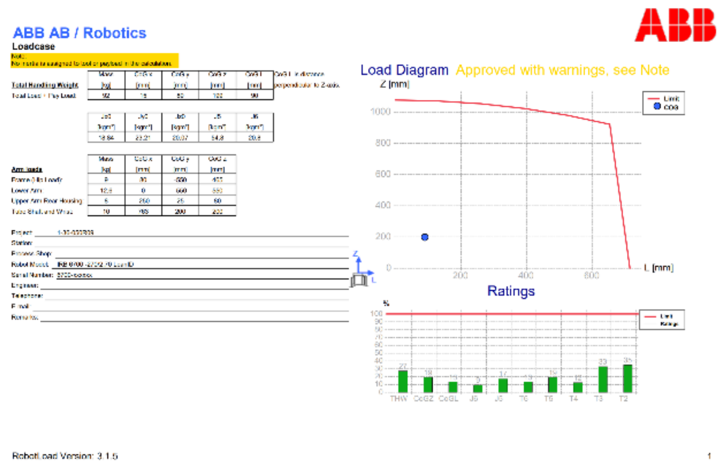

Figure 34: Load graph for medium gripper with Alu profile

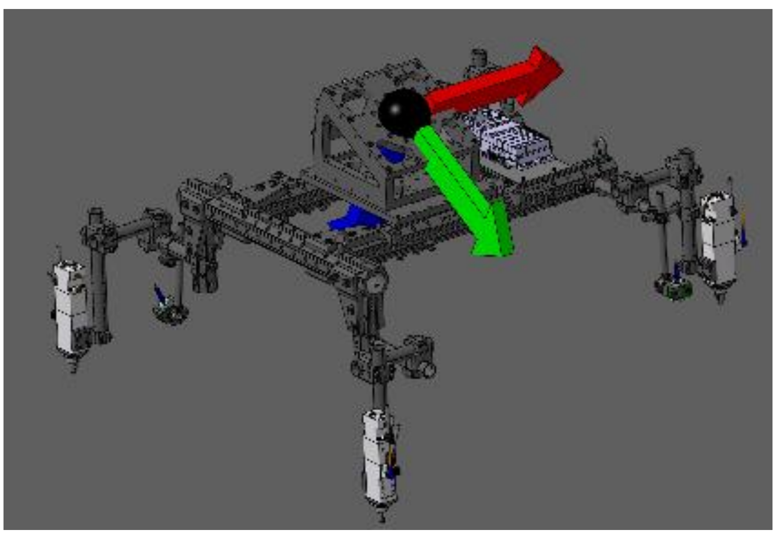

Figure 35: Medium gripper with Alu profile

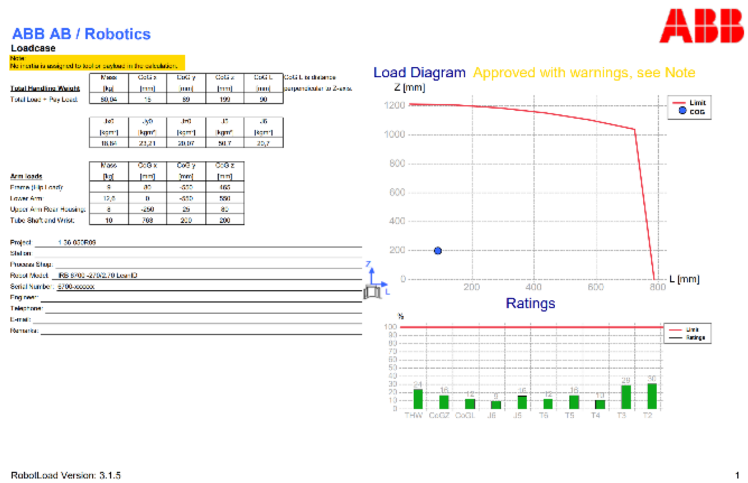

Figure 36: Load graph for medium gripper with SEGT profile

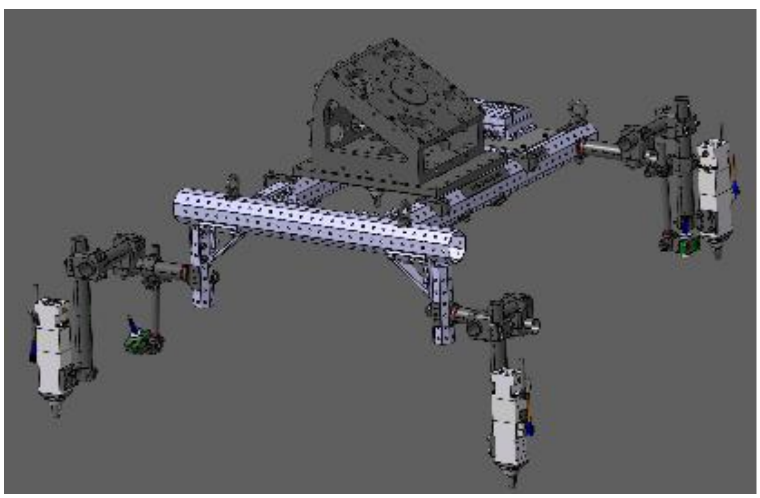

Figure 37: Medium gripper with SEGT profile

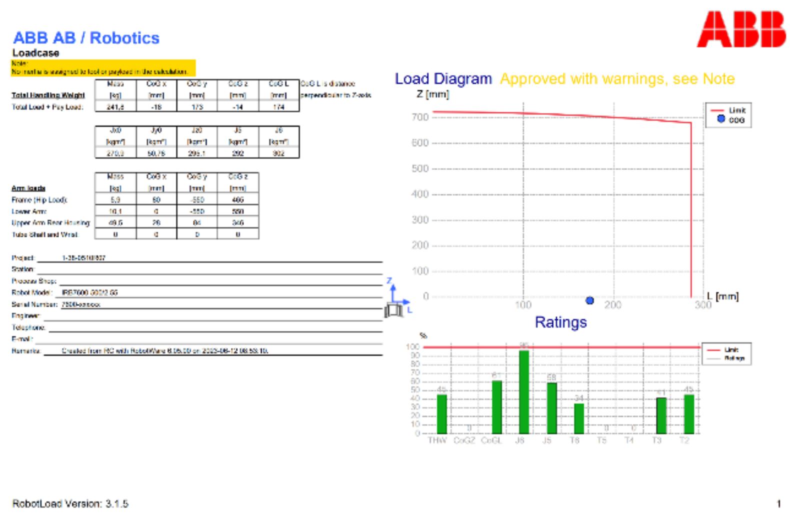

Figure 38: Load graph for large gripper with Alu profile

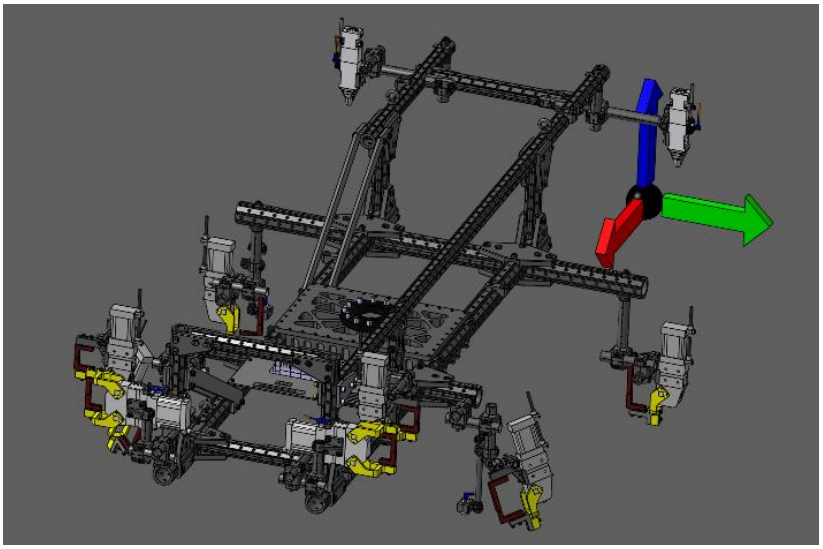

Figure 39: Large gripper with SEGT profile

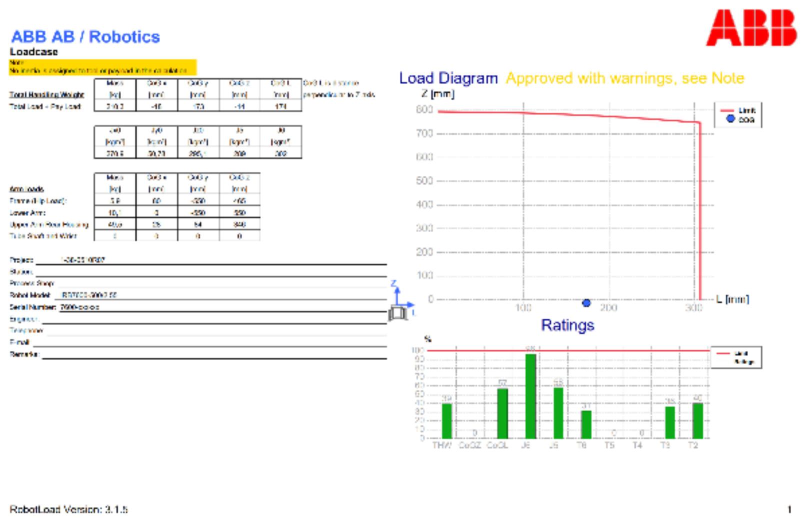

Figure 40: Load graph for large gripper with SEGT profile

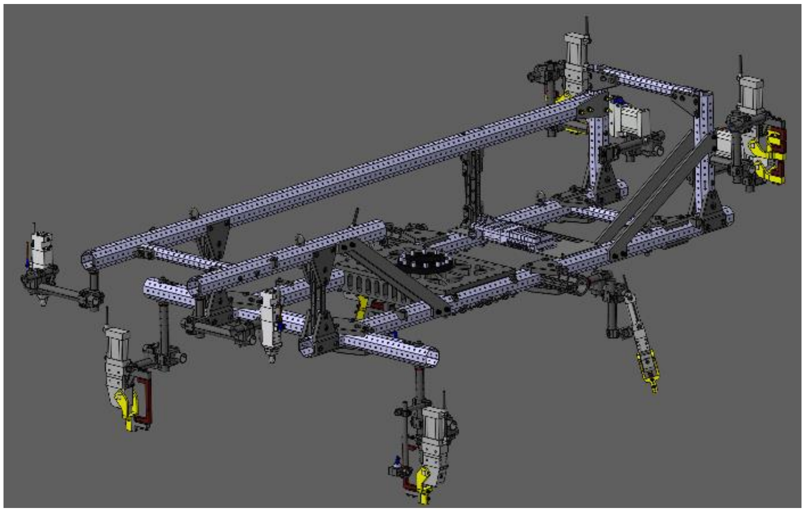

Figure 41: Large gripper with SEGT profile

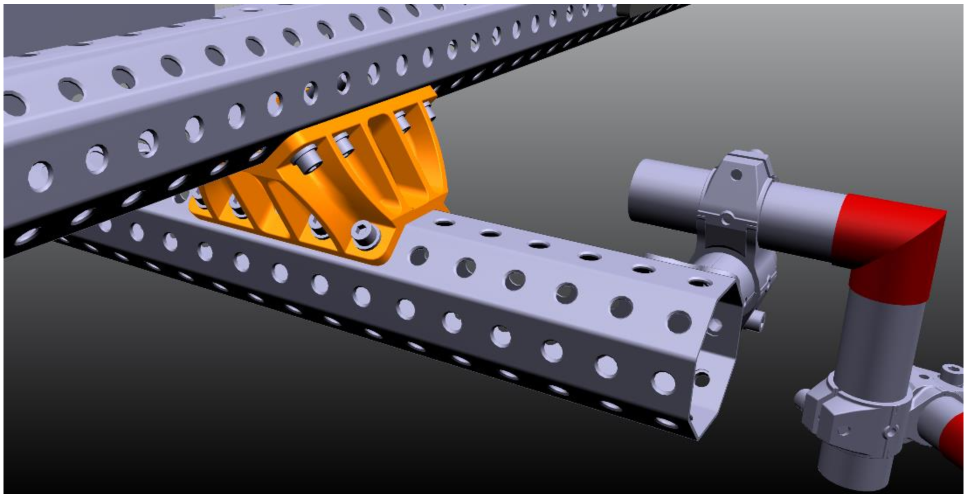

Figure 42: Topology optimized connector in SEGT profile

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MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
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