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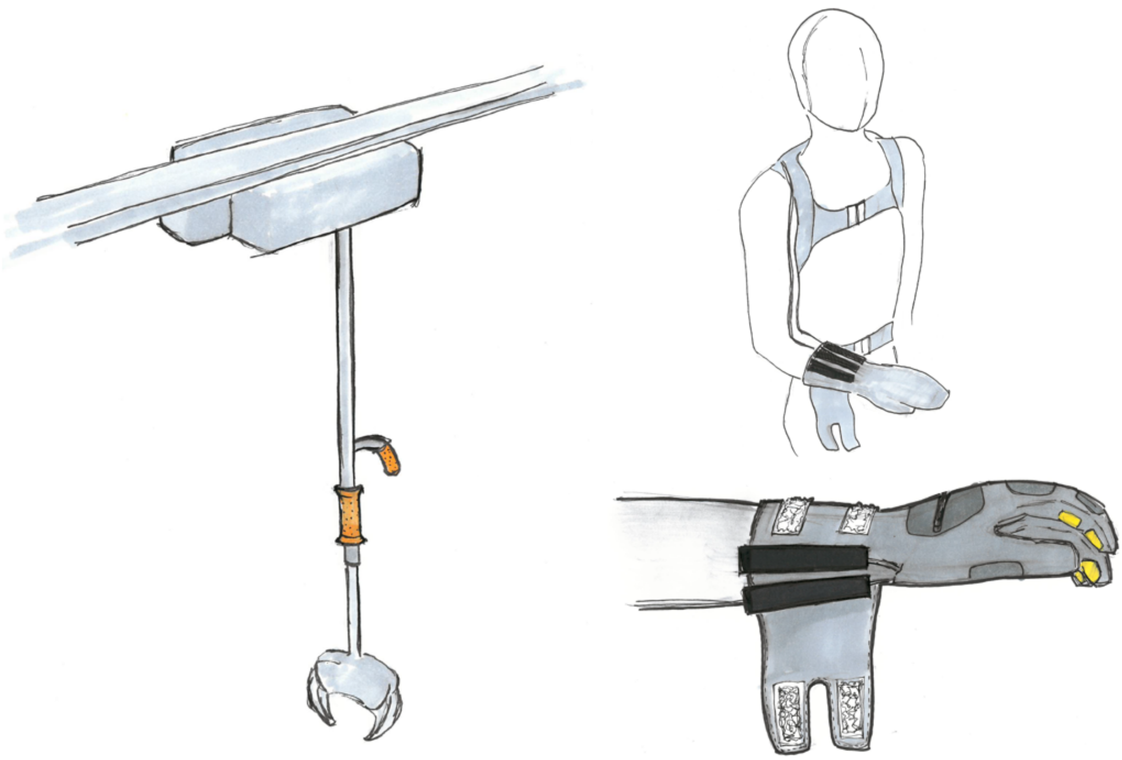

Intelligent Device Concepts for Medium Weight Lifting in Assembly Plant

Generating, studying and evaluating concepts for a new lifting assist in final assembly plant

Master's thesis in Systems, Control and Mechatronics

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Gothenburg, Sweden 2019

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Cover: Collage of sketches of final concepts generated during the thesis work.

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Abstract

This project has developed two concepts for a new type of lifting assist for a certain type of work station at the Volvo Cars Final Assembly plant in Torslanda. These stations are for medium weight material handling pre-assembly line. The initial issue that was presented was that the operators did not use the provided lifting assists and interest had been expressed for developing new assisting devices for the task. First, the reasons behind the issue were identified by thorough investigations from all available points of view. After establishing this, a requirement specification was formed after which novel concepts on how the problem could be solved were proposed. The concepts were evaluated and the list of potential concepts shortened using the requirement specification as well as discussing the ideas with Volvo Cars. The two final concepts were further developed in more detail as well as a technical analysis has been performed to form a basis for further development. Lastly all aspects of the two concepts were discussed and compared.

Keywords: Automation, Intelligent assist, Actuated glove, Overhead crane

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Samuel McHale Sjödin, Erik Pettersson, Gothenburg, June 2019

Definitions

Intelligent assist refers to a device equipped with sensors and a control system resulting in some level of awareness of the situation. The device is also helping the operator in a more active way using sensors and, for example, electrical motors to reduce the effort required to operate the device.

Process awareness refers to the ability to process information concerning a situation for example the tools current

Actuator is a controllable component providing motion which can be used to push, pull, rotate, extend, retract etc.

Duty Cycle is the portion of time during a period where a signal or system is active. The duty cycle is often expressed as a ratio or percentage where 100% means the signal is constantly active and 0% means it is never active. In the case of actuators, the term is used to describe the maximum amount of time an actuator can work. For example, 80% duty cycle means that the actuator has to be inactive for at leas 20% of the time.

Underactuation in robotics and control theory refers to a mechanical system which cannot be controlled to follow arbitrary trajectories. In this project underactuation takes the form of *trivial underactutation* meaning that a system has more degrees of freedom than controllable joints.

Quasi-static refers to a process that happens slow enough for it to remain in internal equilibrium. This means that calculations and modelling can be performed as if the system was in steady state.

Jib Crane is a crane which utilises a horizontal, or near horizontal beam (jib) to support the load clear of the main crane structure.

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Introduction

1.1 Background

Automation is a hot topic in the context of manufacturing and has seen much improvement in the last decades. Manufacturing has seen a transformation towards more automated processes. One example of this is the concept of Industry 4.0 which is currently being developed. A lot has been achieved in automation of factories and manufacturing systems and in many processes machines have relieved human workers of repetitive or physically demanding tasks. However, this is only true for certain processes, namely those which are appropriate to automate using methods currently available. One part of manufacturing that has not seen the same push towards automation is final assembly. Manual work is common in assembly plants across the EU and includes both assembly and lifting operations. According to a survey from 2017 conducted by the European Foundation for the Improvement of Living and Working Conditions, Eurofound, 62% of the EU workforce are exposed to repetitive tasks and 43% work in tiring or painful positions [1]. Comparing the two latest editions of the survey shows that the numbers for tiring or painful positions have remained largely the same from 1991 to 2015 and exposure to repetitive tasks has increased from 1995 to 2015 [2]. Figure 1.1 and Figure 1.2 show statistics for workers in the EU exposed to physical risks, including tiring and painful positions and repetitive movements.

The reason for these types of operations not being automated is believed to be that the type of work performed in assembly plants is much different from other parts of the process. An example is the Volvo Cars Torslanda factory where the final assembly plant is less automated than the welding or painting plants. Because of the more complex nature of the final assembly operations, traditional automation strategies are not as easily implemented resulting in most of the work still being done manually [3]. In an article by Fasth-Berglund and Stahre it is mentioned that in order to further automate this part of the manufacturing process, manufacturers must look in to new types of solutions for their production system. This should be done by incorporating both man and machine to create a new, flexible solution [4].

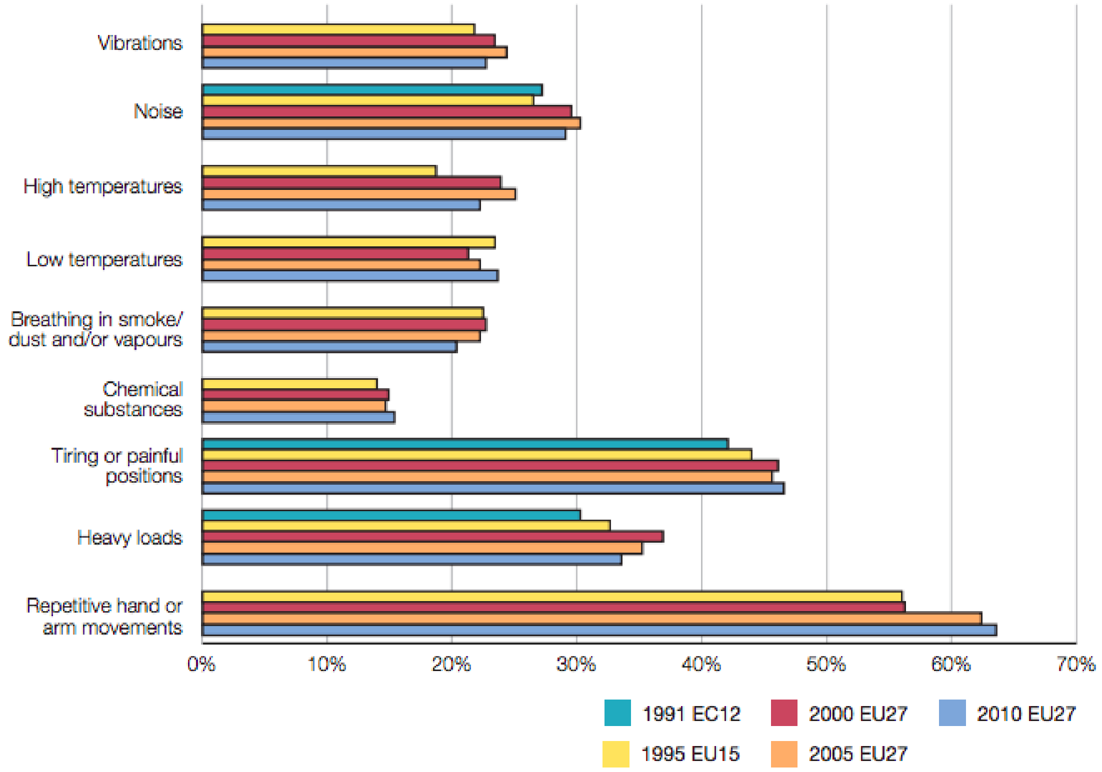


Figure 1.1: Exposure to physical risks over time (% exposed quarter of time or more) according to Fifth European Working Conditions Survey. From [2]

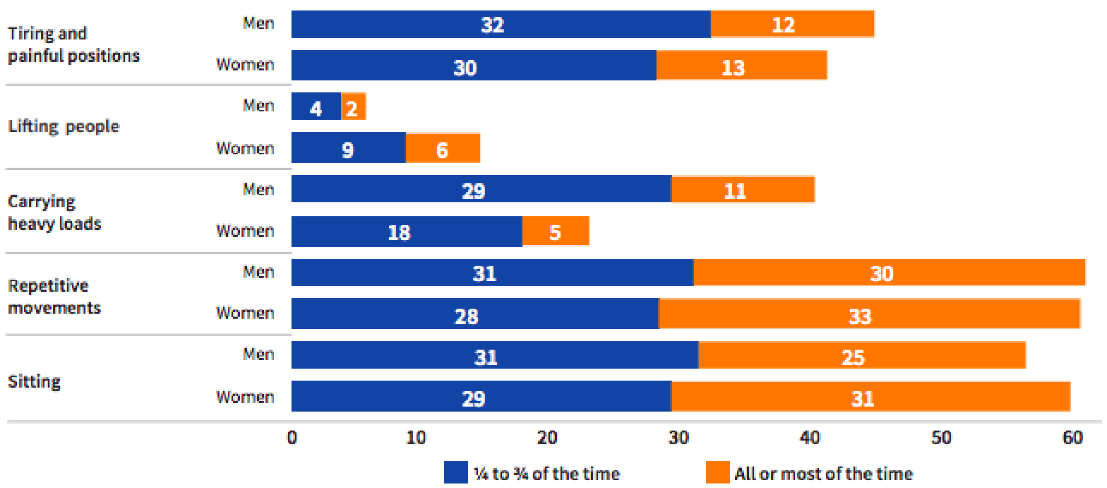


Figure 1.2: Exposure to different posture-related risks, by sex, EU28 (%) according to Sixth European Working Conditions Survey. From [1]

As established, traditional methods of automation that aim at replacing the human worker have proved to be difficult to implement for final assembly operations. Thus focus must be shifted to coming up with alternative ways to automate. The authors of this thesis believe the future lies in combining the different strengths of humans and machines and therefore also compensate for each others weaknesses. Machines excel at performing physically demanding and repetitive tasks, which human workers should avoid. On the other hand humans have great analytical and problem solving skills which is difficult to implement in a machine. If combined, humans could handle the cognitive aspect of a process while being relieved from physical strain by the machine.

In this thesis a specific work station in the Volvo Cars Torslanda final assembly plant has been investigated. At this station parts are sequenced, taking different car model parts from pallets and placing in a sequencing rack, in the order of cars arriving on the assembly line. The parts being handled at this station are of *medium weight*, ranging between 3-7 kg. Considering the weight of these objects and the high volume of parts, the operator is required to use a lifting assist due to ergonomic reasons. However managers at Volvo Cars have noticed that the lifting assist is rarely used by the operators and are now looking in to why and how the situation can be changed to ensure worker health and safety. One aspect that is being investigated is changing the lift assist. The current assist is in the form of a manually operated overhead crane that can grip the parts and assist lifting. The operator pulls the crane along by hand and lifts the parts by placing the crane over the part and enabling gripping with a simple button interface. The assist holding the part is then moved to the sequencing rack where a button is pressed to release the part. The reasons for operators not using the current lifting assist has not been thoroughly investigated. However it is believed to be because of it being easier and faster to lift the parts by hand instead of using the assist even though it is harmful in the long term. Figure 1.3 shows the posture when picking up an AC compressor from a half-full pallet by hand. Figure 1.4 shows one of the lifting assists studied lifting a link arm.

1.2 Purpose

The aim of this project is to determine why the current lifting assist at the workstation in question is not being used by the workers, evaluate possible changes or improvements and present a recommendation of changes that should be implemented. Presented will be a recommendation on how to implement a more intelligent solution that actively helps the worker.

Figure 1.3: Example of posture when picking up AC compressor

Figure 1.4: Lifting assist used for lifting link arm

1.2.1 Research Questions

To help guide the project in the desired direction, a number of research questions have been formulated. The questions the project will try to answer are:

- Why do the operators not use the current assist?
- What similar assisted lifting solutions exist?
- Can the current overhead crane be modified and improved?
- How can a solution be evaluated and improvements be measured and quantified?
- What safety and ergonomic requirements need to be considered?
- How can the chosen concept be implemented?

1.3 Limitations

The project will be limited to focusing on evaluating "intelligent" solutions, see *Intelligent Assist* in Definitions, that utilise automation and active assistance to some extent. This is because the thesis will be part of the Systems, Control and Mechatronics Master Program at Chalmers University of Technology.

Because of the time frame for the project, a finished product will not be developed nor implemented and the work will be limited to presenting a recommendation for continuing the work.

Depending on what solution is chosen the extent and type of testing will be limited. For example for some solutions physical testing might not be possible considering the scope of the project. The project will also focus solely on the lifting device and no other aspects of the process such as how the parts are packaged or how they are placed.

2

Context

This chapter presents the current situation at Volvo Cars and provides insight necessary for understanding the work presented in this report.

2.1 Current Situation

Three adjacent sequencing stations utilising similar devices for lifting have been studied in this report. All three were studied in order to identify individual problems with the specific devices, but also problems they might all have in common. As mentioned earlier, all three sequencing stations pick and place parts with a weight of 3-7 kg. More specifically, the three work stations studied pick and place link arms, AC compressors and generators.

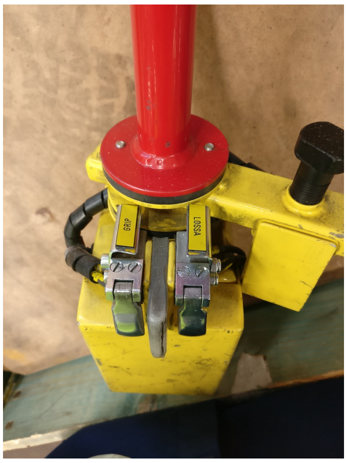
The device used for sorting of the link arms can be seen in Figure 2.1. The operator starts the tool by pulling a string hanging from the overhead crane of which the device is mounted on. The operator then has to reach down to the floor where the device is hanging and push the control lever to make the gripping device ascend. While the control lever is being pushed the device will continue to ascend until its maximum height is reached. If the control lever is "let go", the device will descend, returning to the floor. If the operator wishes to keep the tool at a specific height, the lever has to be held in a certain position. While using the lever shown in Figure 2.1 (a) the operator then pulls the device along to where the part is being picked from. The device is then lowered in to the pallet where the operator fits the gripper shown in Figure 2.2 (a) around the centre of the link arm. To pick the part up the button in Figure 2.2 (b) has to be pressed which extends the piston downwards and holds the part in place. Using the control lever, the device is raised and then pulled along to the sequencing rack where the part is guided in place before the release button is pressed, the gripper is then guided out from the placed part and the process can start again. Figure 2.2 (c) shows the device holding a part, note that the lever has to be held in position for the device to maintain its height.

(a) Link arm lifting device.

(b) Overhead rails with device attachment point.

Figure 2.1: Link arm lifting assist in its entirety, showing the device and movement system.

(a) Close up of gripping point.



(b) Buttons used for gripping and releasing.

(c) Picture showing device holding link arm.

Figure 2.2: Three images showing how the link arm lifting device grips parts.

As mentioned earlier the situation is largely the same for generators and AC compressors. The work process is the same, meaning a similar lifting device is used to pick parts from a pallet and place them in a sequencing rack. However some things about the lifting assists are different such as the grip, but also the interface.

In Figure 2.3 the devices for these two stations can be seen and one can see that the lever controlling the height looks different from the link arm lift assist. The behaviour of these assists are also slightly different. When the assist is started up and no control input is given to the height lever, the device ascends and the lever has to be pushed downwards to move the device down which is the opposite of how the link arm device behaves. Gripping the part is also slightly different, the parts are lifted from above with a claw like gripper which is triggered by a sensor in the claw shown in Figure 2.4 and Figure 2.5. Releasing the part works in the same way on all devices, by pressing a button. It is worth noting that all generators and some of the AC compressors are lifted in the belt pulley on the part. The pulley and generator/compressor can spin freely from each other causing the part to spin when lifted by the pulley. It is also worth mentioning that all three devices are currently operated using only pneumatics, including gripping, controls and triggers.

(a) Generator lifting device.

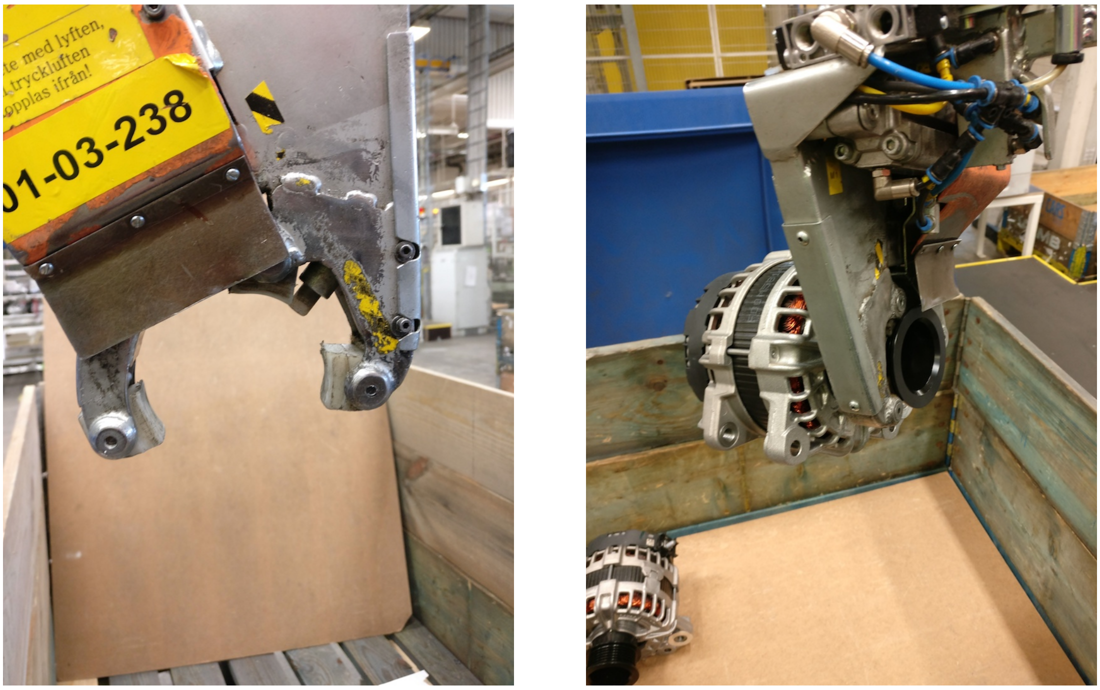
(b) AC compressor lifting device.

Figure 2.3: Overview of generator and AC compressor lift assists studied in this report.

(a) Gripper with sensor triggering grip function seen in top of gripper.

(b) AC compressor being lifted.

Figure 2.4: Close up of gripping system in AC compressor lifting assist.



(a) Gripper and sensor triggering grip function seen in top right of gripper.

(b) Generator being lifted.

Figure 2.5: Close up of gripping system in generator lifting assist.

Movement of the lifting assists is passive, meaning that they do not move using their own power. As shown in Figure 2.1 (b) and Figure 2.6 there is an overhead rail system in place for all three devices. Attached to two parallel rails is an orthogonal rail, allowing for the device to be moved in a two-dimensional space, which coupled with the up and down controls results in movement in three dimensions. The operator pulls the lifting assist along when moving between picking positions or when carrying a part. As can be seen, the generator and AC compressor work stations share a similar setup for attaching to the overhead rails where the flexible part of the assist extends only half way up to the ceiling. Unlike at the generator and AC compressor work stations, at the link arm work station the flexible part of the assist runs the entire length between the gripper and the overhead rails.

(a) Entire generator lifting device, showing overhead rails, attachment and gripping part.

(b) AC compressor assist overhead rails and attachment.

Figure 2.6: Overview of generator and AC compressor lift assists studied in this report.

2.2 Related Products and Possible Solutions

Manufacturing industry is moving towards active and intelligent solutions for assists and devices and there exists some products similar to the devices studied in this project. This section briefly describes some devices currently available as well as other technology which is of interest to the project. The aim of this section is to give the reader some more context on the current situation as well as to provide inspiration and ideas for the project.

Binar Quick-Lift

Figure 2.7: Binar Quick-Lift. From [8].

The Binar Quick-Lift is a lifting device which allows an operator to lift up to 300 kg with minimal effort while still retaining high precision and smooth movements. The lifting device features Binars ergonomic control handle which converts the operators hand movement into electrical signals for controlling movement up and down. The device also features auto self-balancing to adjust for different loads and display visual signals to the operator when it is safe to let go of the handle. The Binar Quick-Lift is equipped with a quick coupling mechanism allowing for fast and easy end effector changes and supports pneumatic, magnetic, mechanical and vacuum actuated end effectors. [9]

The Binar Quick-Lift does not have driven horizontal movement by itself, but can be combined with Binars driven rail system, the QLD-series, to assist operators further. The QLD-series utilises rope angle sensors which detects when the end effector deviates from the vertical line. Electrical signals are then sent to the rail systems motors accordingly which drives the lifting device in the desired direction. By combining the Binar Quick-Lift with the driven rail systems one can achieve driven assistance in 3D space. [10] The price of a Binar lifting assist ranges from 250 000 - 400 000 SEK according to Volvo Cars.

Mechlight Pro

The Mechlight Pro 50 from Movomech AB is an ergonomic and lightweight lifting device for loads up to 50 kg. The device comes in different versions that are balanced for one, two or a range of loads. The one and two load version of the device is calibrated to balance the weights while the varying load version uses a balancing regulator to automatically counter the weights. By simply counterbalancing the loads they effectively become weightless and the operator can easily move them around without having to operate controls. The Mechlight Pro 50 can be mounted on a rail system or a jib crane mounted on a wall or tower. [15]

Figure 2.8: Movomech Mechlight Pro 50. From [17].

With the Mechrail rail system Movomech offers powered drive for their lifting devices. The Mechrail comes in several different versions allowing for both powered horizontal linear drive and planar horizontal drive. The powered drive is controlled by the operator using a joystick. [16]

Gorbel

Figure 2.9: Gorbel G-Force lifting assist. From [11].

Another company that provides relevant solutions to the problem at hand is called Gorbel. Gorbel produces a few products in the ergonomic lifting category and two products of interest are the G-Force and Easy Arm [12]. The G-Force is an overhead mounted lifting assist that uses a servo to lift the parts vertically while horizontal movement is done manually, for example by mounting it to overhead rails. The G-Force can handle loads up to $\sim$ 600 kg and speeds of up to 1 meter per second and a photo sensor is used to determine when an operator is present. The higher end iQ model features custom input/output possibilities to allow for a wide range of applications.

The Easy Arm is an articulated jib crane coupled with servo controlled lifting using the same technology as the G-Force products. This combines the lifting assistance of the G-Force with controlled horizontal movement. The Easy Arm crane can be mounted as a freestanding crane like in Figure 2.10 or hanging from above, for example from the ceiling or on overhead rails. The Free Standing Easy Arm is stronger than the hanging arm and can handle speeds of 0.9 meters per second and loads of 300 kg. The Underhung Easy Arm can handle the same speed but only 75 kg of load.[14]

Figure 2.10: Gorbel Easy Arm. From [13].

AIMCO Manufacturing

AIMCO Manufacturing offers a variety of lifting tools in the form of different types of jib cranes that can be coupled with different lift assists such as vacuum lifters or mechanical grippers. However, AIMCO also offers what they call *ergonomic controls*. These are fitted to the end effector of the lift assist and as the name suggests, these are designed to be as ergonomic as possible for the operator. The main idea of the ergonomic controls are to allow the operator to use the device interface from the same height at all times. One approach is to design the assist such that the vertical gripper of the lift assist moves independently from the interface, which stays at a proper ergonomic height throughout the operation. This can be done either by straight vertical translation of the gripper without moving the interface or by having an extension between the gripper and the interface which can be articulated. When the gripper is operating at a lower point, the interface is twisted upwards which coupled with the extension allows it to remain at the same height.[18]

Figure 2.11: Robo-Glove. From [19].

Human Grasp Assist by NASA

The Human Grasp Assist, or Robo-Glove, is shown in Figure 2.11 and is a product invented by NASA and GM to assist with grasping strength, for example when an astronaut is using a tool in space. Although it was developed for use in space, the technology has potential for use in many different areas where extra gripping strength is needed. The device is in the shape of a glove which the human wears. Fitted at the forearm are multiple electric actuators that pull on cords that run through the fingers of the glove which causes the grip to tighten. The actuators are powered by batteries that are worn around the waist. The glove is controlled by sensors integrated in the fingertips of the glove that allow the device to know when extra gripping strength is needed.[20]

Gripping assists by Bioservo

Figure 2.12: Carbonhand. From [23].

Bioservo is the Swedish company behind the Ironhand, Carbonhand and SEM glove gripping assists of which the Carbonhand can be seen in Figure 2.12. These assists are similar to the previously mentioned Robo-Glove by NASA and GM. Both the Robo-Glove and Bioservo's products utilise similar technology despite being developed for different applications initially. Bioservo provides gripping assists in the form of gloves marketed towards professional use such as carrying heavy objects in construction work but also for rehabilitation and assisting people with weak grip suffering from, for example, muscular dysfunctions. The assist devices from Bioservo work in the same way as the Robo-Glove with sensors triggering cords being pulled that contracts the hand which provides extra gripping strength for the user. The glove is powered by a battery worn around the waist as can be seen in Figure 2.12. For professional work applications Bioservo also offers a *soft exo-skeleton* that can be coupled with the glove to offer gripping and lifting strength. [24]

Figure 2.13: EksoVest. From [21].

EksoVest
The EksoVest from Ekso Bionics is an upper body exoskeleton that elevates and supports a worker's arms to assist them with tasks ranging from chest height to overhead. The EksoVest can be adjusted to provide 2-7 kg lift assistance to each arm and the vest itself only weighs 4 kg.

The support comes from spring actuators which can be adjusted to different weights and work heights. The vest is not designed to give super strength but rather to give extra endurance by reliving strain from the worker. By such, heavier objects than normally carried should not be carried even with the vest. [22]

Volvo Cars have bought a few exoskeletons for testing the feasibility of using these for various manufacturing tasks. The price for this type of exoskeleton ranges between 45 000 - 65 000 SEK.

3
Background

In this chapter the background regarding relevant methods used in the project is presented.

3.1 Ergonomics and Safety

In today's society people are in general living longer and healthier lives due to numerous advancements within science, medicine and health care. But this increase in lifespan comes with an added desire from employers to increase the retirement age and keep people working even at later years in their lives. This is both beneficial for the employers who can retain competence and experience within the organisation and for the employee who can work more to save up for a better pension. With this in mind ergonomics is a very important factor to consider when designing tools and work areas.

In order for workers to be able to extend their work capacity by several years it is critical that work related injuries are avoided by providing well designed tools and work tasks that are adapted to meet the needs of the operator. This includes providing tools to help lift heavy objects or increase strength where needed, but also to provide sufficient lighting and enable the worker to work in non straining work positions.

In Sweden *Arbetsmiljöverket*, the Swedish Work Environment Authority, governs and provides all acts regarding work environment and employment. The acts cover everything from working hours and parental leave to whistleblowing and dangerous substances. However in the regard of ergonomics there are very few laws and most of what is provided are policies and recommendations. Due to this Volvo Cars have made their own ergonomic and safety standard which incorporates all relevant acts from Arbetsmiljöverket as a bare minimum requirement. Moreover the Volvo Cars standard is more strict on nearly all aspects and only use local governing rules if they are more strict than the standard. This standard will be used as a baseline for formulating the ergonomic requirements for the list of specifications in this project and can be found in its entirety in Appendix A.

3.2 Designing Surveys

Surveys and questionnaires are a useful tool for gathering data and information from a population about a particular subject and can be conducted in many different ways. Before conducting a survey there are many things which first need to be considered and decided upon, including who the survey is intended for, how the survey is perceived, how the survey should be conducted and what type of questions that should be asked among other things. These design decisions are important since they will have a direct effect on the number of responses and the quality of the answers.

The book *Internet, Phone, Mail, and Mixed-Mode Surveys* Dillman *et al.* discusses at great length all the different parts and aspects to consider when formulating a survey [5]. In short it is important to try and minimise the time and effort required by the respondent to answer the survey. This includes making it possible for the respondent to conduct the survey in a way they are comfortable with and making sure the questions posed are well written and not too long or complicated. It is also very important to establish trust between the respondent and the surveyor by showing that the survey is of legitimate origin and for a legitimate purpose. The parts most relevant to this Master's thesis are summarised below.

3.2.1 Increasing Response Rates

A common problem when conducting surveys are low response rates and thus the first step in planning a survey is try to make people more inclined to respond. Here there are many aspects to consider such as how the survey is conducted, who the surveyor is, the length of the survey and how the survey will benefit the respondent.

For example when considering how the survey is to be conducted there is in general four main methods one can use; an online survey, a telephone interview, a paper survey and personal interviews. The advantages and disadvantages of each of the different ways to conduct a survey are discussed in Dillman *et al.* [5, pp. 19-55] What survey mode to use depends on who the respondent is where for example some people prefer answering a survey over telephone rather than online [5, pp. 35-36]. In general however Dillman *et al.* recommend to minimise the effort required to respond by the respondent and avoid forcing people to respond in ways they are not comfortable with.

Another important part affecting the response rate is how the surveyor is presented and perceived. This is especially important to consider when using web and paper based surveys since there is no human interaction and therefore harder to convey the legitimacy of the surveyor and the survey to the respondent. If the survey is perceived to be illegitimate it is hard for the respondent to establish trust and thus lower response rates can be expected. According to Dillman *et al.* to avoid this it is important to provide the respondents with means of contacting the surveyor if they have questions about the survey and its issuer. Moreover it is also recommend for paper and web based surveys to be presented together with the company logo or in other forms indicate the surveys origin. [5, pp. 39-41]

3.2.2 Crafting Survey Questions

Writing questions for a survey might seem as an easy task, but one must be careful since questions make up the main body of a survey and will decide what data can be obtained. Moreover the questions will also directly influence the respondents willingness and ability to answer and if poorly stated might result in confusing answers and mid survey termination by the respondent. Thus it is important to take some extra time to reflect on the questions and their formulations.

To formulate a good question there are several factors one needs to consider such as what information we are looking to obtain, if the question should be open or close ended and if the question is interesting or even relevant to the respondent. Furthermore what words are used when formulating the question also matters since complicated words might make it harder for the respondent to understand the question and vague questions often result in vague answers.

The length and level of detail of the question is also important to consider. Here one needs to balance the trade offs of having a very detailed question which will give detailed information, but at the same time make it harder to answer and more likely for the respondent to lose interest. Beyond this one should also make sure that only one question is asked at a time and avoid the use of so called "double barrelled" questions. [5, pp. 94-126]

3.3 Product Design

There are many different ways to design and come up with an entirely new product. Depending on the type of product and designer preference there is an array of engineered processes to choose from. All methods have advantages and disadvantages and it is up to the designer to choose a method that is believed to generate the best result for each step. From coming up with ideas to having a finished product requires many steps to be taken, however the two steps most applicable to this project is concept generation and evaluating the concepts.

3.3.1 Concept Generation

The first step in coming up with an entire new product is to generate different concepts. A concept is a short but concise description of a product and its attributes. This includes features such as the basic functions of the product and how these might be implemented. Generating concepts is an important part of the product design process and the quality of the different concepts can greatly affect the quality of the finished product [6]. Milton and Rodgers [6] split concept generation in to two different approaches: convergent thinking and divergent thinking. Convergent thinking is described as coming up with ideas and concepts using an analytic process as opposed to divergent thinking where the designer thinks more freely and in an exploring way. In order to come up with a good concept idea it is recommended to use a concept generation method, these are specific processes for the designer to follow to generate concepts in a more effective manner.

There are many different methods that can be used for concept generation, the ones used mainly in this project are briefly described as follows.

Brainstorming is a commonly method used when generating concepts. The main advantage of this method is that it allows for a wide variety and a large set of ideas to be generated. The basic concepts of brainstorming is to come up with as many ideas as possible and that there are no bad ideas and that all ideas are valid at this stage. No concept is rejected at this point, instead this is done solely in the evaluation and selection step. Brainstorming is most effective when done in a group. [6]

Another method is called *attribute listing* which aims at only finding concepts that fit the requirements of the finished product, as opposed to brainstorming where the focus is to come up with as many ideas as possible. This is done by listing all desired attributes of the product and combining solutions to all sub-problems to form different concepts. [6]

Analogical thinking is a method in which the designer looks at solutions for other problems and tries to apply them to the problem at hand. This can be done by modifying solutions to completely unrelated problems and applying existing technology to fit the current problem. Milton and Rodgers [6] suggests these four questions to be used as a baseline for the analogical thinking design method;

- What else is like this?
- What have others done?
- Where can I find an idea?
- What ideas can I modify to fit my problem?

3.3.2 Evaluating Concepts

The next part of designing a product is to narrow down the set of concepts generated in the previous step until only one idea can be selected. In [6] it is emphasised that evaluation and selection does not mean simply finding the best concept but a process of constantly decreasing the set of ideas and eliminating concepts not suitable.

When developing a new tool or assisting device at Volvo Cars, four different aspects of the concept are considered. These are ranked hierarchically where safety is most important, along with the functionality of the tool or device. These are followed by ergonomics and the least important aspect is the cost of implementation. This structure is common practice at Volvo Cars and a key method when evaluating concepts.

During this part of the process all project members should be involved, this is to prevent the risk of subconscious bias when eliminating and selecting ideas [6]. To make sure all possible perspectives are covered it is also recommended to involve different stakeholders, in this case the operators and other relevant personnel at Volvo Cars. As with the process of generating concepts, there are a variety of methods that can be used by the designer for evaluation and selection.

One way of evaluating concepts is by using a *Morphological chart* [7]. A morphological chart separates the problem into sub problems. These sub problems represent every part of the problem that needs to be solved and when all solutions are combined, they should form a possible solution to the entire problem. Focusing at only one aspect of the problem at a time allows for new, unexplored combinations to be evaluated as well as testing all possible ways of combining solutions to the sub problems. When all viable concepts for solving each problem have been listed, complete concepts are formed by choosing one solution from each category. If all sub concepts pose a viable solution to its sub problem, every possible combination should be a viable concept for the entire product.

4 Method

This chapter explains the method of the project in its entirety, thoroughly describing each part and listing them in chronological order.

4.1 Assessing the Current Situation

To be able to come up with a new and improved solution, it is absolutely necessary to have a deep understanding of the current situation and the problem. It is important to understand what needs to be improved and why. Therefore before starting any work on a future solution, the current one has to be studied extensively. This was done by meeting and talking to anyone that in some way works with the lifting assists in question, from operators to managers and specialists to ensure all aspects are considered.

Since the core purpose of the assist is to help the operators, their input about the current situation as well as what they would like to see changed is one of the most important aspects to consider. Because the input from the operators is so important, some time was spent studying and discussing the best way to formulate and conduct a survey that would yield valuable information to the project.

As discussed in chapter 2, one must consider how the surveying is conducted to make people more inclined to answer and provide information. The two different ways of conducting the survey that were considered are handing out a paper survey to all operators that work at the station, and interviewing some of the operators. Since the station is in an assembly plant and the work pace is high, there is very little time for the operators to step away from work and fill in a paper survey. Even if this was to be the case, it is likely the operators would only provide short and not very useful answers in order to get back to work as quickly as possible. Handing out the survey during a break was also ruled out because they might be less inclined to answer during their time off. Instead it was decided that some of the operators would be interviewed while working at the station. This method was chosen because it disrupts the work less and while the sample size was smaller, the quality of the answers was believed to be better.

During the day shift eight people work at the stations that were investigated in this report. These operators were all interviewed with the same questions as well as some follow up questions depending on their answers. The assists were then tested and investigated by the authors of this report. Three main questions were asked to all operators:

- How often do you use the assist?
- Why do you not use the assist?
- What would need to be changed to make you use the assist?

The interviews all revolved around these three questions and interviews were kept short as the operators were working simultaneously. Depending on the answers received, follow up questions were asked in order to get a deeper understanding to the operators experiences with the lifting assists. The follow up questions varied between the different interviews and depended entirely on the answers given and were asked to clarify or elaborate if the operator gave a vague answer.

After completing the interviews and the testing of the assists it was decided that sufficient information about the assists had been provided and focus was shifted to speaking with managers from different areas.

First a meeting was held with ergonomic experts from the departments of Process Engineering and Manufacturing Engineering. The purpose of this meeting was to establish what ergonomic issues need to be overcome when designing a lifting device for a picking and placing operation. This includes in what way the device must relieve the operator, but also the ergonomics of using the finished device. The most recent Volvo Cars ergonomic standard was presented and discussed during this meeting and was a very central part of the requirement specification later created.

The project was also discussed with tooling specialists from a tool development point of view such as what aspects of the development process are more important than others and what aspects can be compromised if need be. Similar solutions and implementation of different functions were also discussed along with safety requirements, providing valuable information for use in the requirement specification but also for concept generation and implementation later on in the project.

4.2 Requirement Specification

In order to evaluate the concepts and compare them, a requirement specification had to be formulated. The specification is divided into two parts, required and desired properties of the device. The requirements section lists all different things a concept must cover and any concept that did not satisfy every demand in this section was discarded. The second part of the specification contains desirable properties in a new solution and every concept should strive to cover as many items in this list as possible. However, not fulfilling an item in this list does not lead to automatic rejection. After gathering as much information as possible about the current situation, the requirement specification was created by carefully dividing all information in to either the required or desired aspects. In general, safety and ergonomics were added to the requirements list as these cannot be compromised along with some key functionality aspects. The desired section contains mainly functionality listings that are not as quantifiable and more difficult to measure, these would therefore be difficult to evaluate a concept against and determine whether the concepts satisfies the demand or not. By listing them as desired it is easier to evaluate if a concept strives towards fulfilling it.

Since the requirement specification was a central part in deciding what concepts are valid and ultimately choosing a concept, it was deemed very important that it accurately describes what a finished lifting assist should be like. Therefore, at this point in the project a meeting was held with all concerned parties at Volvo Cars in order to verify the requirement specification before continuing with the project.

4.3 Concept Generation

The three main methods for generating concepts that were used in this project are *Brainstorming, Attribute listing* and *Analogical thinking*. These methods are described in Chapter 3 and the different methods were used at different stages in this project.

Brainstorming was mainly utilised in the early stages of the project while gathering information of the situation at hand. Brainstorming came very naturally at this point in the project because it relies on having an open mind and not ruling out ideas. However, as more information was obtained about the problem and the list of requirements started taking shape, it became more obvious whether most ideas would be valid or not. Thus it became harder not to rule out concepts that were infeasible and the brainstorming gradually moved towards the method of attribute listing.

Attribute listing focuses on defining sub problems and finding concepts which solve these. Therefore it was easy to work according to this method when a requirement specification had been formulated and it was known what major obstacles needed to be overcome. At this point solutions to similar products were also being investigated and the method of analogical thinking was being incorporated alongside attribute listing. When researching similar problems and finding out what types of solutions were available on the market while at the same time discussing the current situation, it became quite clear what type of solution would suit Volvo Cars best.

As can be seen in Chapter 2, many solutions to similar problems that were investigated are based on some form of overhead lifting assist. This is also what the current situation at Volvo Cars looks like. It was therefore decided that an overhead lifting assist solution would suit the workstations well and some work should be focused on investigating this path. When this decision had been made a list of sub problems to solve for this type of concept, using attribute listing and a morphological chart was formed containing all aspects of a solution that needed to be decided. Using ideas generated earlier, the chart was filled with different concepts addressing every part of the problem.

As mentioned, an overhead crane solution would be very similar to what already exists on the market. It was therefore decided at this point that another concept would also be presented to Volvo Cars to choose between. This other concept should be more of a free thinking, completely new idea which has not been implemented in this way before. The reason for this is to come up with and provide Volvo Cars with a type of solution they have not previously considered instead of only trying to improve ideas that already exists. To find and list potential ideas for this second solution, all previously considered concepts from the initial brainstorming were considered again. These included many advanced, futuristic and free thinking ideas.

4.4 Concept Evaluation

When a larger amount of ideas and concepts had been generated, the process of concept generation was considered to be over and concept evaluation began. This means that the previously generated ideas were studied in more detail and in a critical manner. The aim of this part of the project was to gradually shorten the list of potential concepts in order to find a few ideas to proceed with.

During this part it was important to remember the general purpose of the project, which is to find the best possible solution to fit Volvo Cars' needs. Therefore a very important factor when making the decisions on whether to discard a concept or not was how attractive Volvo Cars might find this option. More precisely, what ideas fit the requirements but also allow for easy and simple implementation were common questions asked in this phase. It was concluded that a good solution fits what is required but is not over engineered. Additionally, it should also be possible to implement without having to, for example, rebuild the entire work station and instead utilise current infrastructure as much as possible.

With these thoughts in mind all ideas and concepts were discussed and some ideas could immediately be discarded for being unrealistic. The remaining concepts were then evaluated against the specification of requirements. Since the project aims to find a tailored solution for Volvo Cars, this step was done in close collaboration with the company. The input of Volvo Cars weighed heavily when evaluating ideas and was a big deciding factor. The process of evaluating and selecting concepts was then iterated, gradually shortening the list of potential solutions until only two concepts remained.

In conclusion all generated concepts were evaluated against each other which left two concepts that are very different. These two concepts were then studied and described in more detail, including specific solutions to sub problems.

4.5 Studying Technical Aspects

When all parties were satisfied with the general idea of the concepts, studying the technical aspects of these began. The goal was to present to Volvo Cars a guide to what components are needed for both proposed solutions, and the work these would require to be carried out. Effort was not spent on researching specific components since how the device might actually be implemented in the future and what components to use is ultimately up to Volvo Cars. Therefore it was concluded that referencing specifics for the parts such as make and model or even exact dimensions are of little value to the report since these decisions would be made by Volvo Cars either way. Instead it was investigated what general components would be needed for the concepts to work, how these should be used and also the general feasibility of implementation.

Some minimum performance requirements were decided for each part of the concepts and in order to prove feasibility, a quick investigation in to whether there exists components that meet these minimum requirements was carried out. This does not reveal whether a part is the best choice for the task and Volvo Cars is recommended to look into the exact dimensions at a later stage. However it does prove that the concepts are possible to implement and that the minimum requirements are not too ambitious.

First, a component flow chart was designed. This shows all the hardware components needed to control the device presented and how these are connected to each other, presented in a simple overview of the system.

After this the minimum requirements were formed. As described, these solely serve the purpose of loosely defining what performance is needed from the hardware components. The intention is not to use these values in the future if work is continued with a concept. In this case, very thorough calculations and collaboration with contract suppliers and such would be needed and carried out by Volvo Cars. Therefore these numbers were largely estimated based on reasoning and on simple calculations such as how much weight is lifted and how strong actuators and motors have to be to handle this weight.

When this had been done, work could be continued by searching for the desired type of component that fits the minimum requirements. Searching for these components was done mainly through large vendors in the category and simply investigating if there are parts available that meet the requirements. If suitable components for all parts of the concept can be found, the conclusion can be drawn that the proposed solution is possible to implement and the concept is therefore feasible.

5
Assessment and Concept Presentation

In this chapter the results from the interviews and meetings at Volvo Cars are presented along with descriptions of the generated concepts. This includes the requirement specification and technical analysis of the concepts.

5.1 Interviews

The interviews conducted were split and carried out separately for each of the three stations and the results from these are presented in this section.

5.1.1 Link arm

Out of all the interviewed workers only one said they used the lifting device and only did so because they were ordered to by the manager. The rest of the workers disregarded the managers orders and did not use the device. The workers stated that the reasons for why they do not use the device is largely due to three main problems; picking parts, placing parts and the general handling of the device.

The way the link arms are placed in the pallets when they arrive to the work station makes picking difficult and sometimes impossible without first lifting them by hand or adjusting their position. Moreover the picking is made further difficult due to the product variation. Small differences in the different link arms shape makes certain link arm models nearly impossible to pick with the current gripper even when they are properly placed in the pallet.

Many of the workers suggested that the gripper needs to be changed and be able to pick the parts directly from above. The suggestions included using a suction cup, a magnet, etc.

The problems when trying to place parts in the sequencing racks are also closely tied to the gripper and its design. According to the workers it is difficult for the gripper to release the parts properly when placed in the racks. Many stated that they need to fiddle with the device which often lead to the parts ending up misaligned in the rack or getting pushed out of position. This problem can mainly be accredited to the device's bulky design and that the racks are quite cramped. Most workers stated that they prefer to release the part into their hands and placing it manually instead of directly into the rack and having to manually adjust it after anyway.

For the general handling of the device almost all workers stated that it is much easier and faster to do the lifting by hand. Since the device is considerably slower to use the workers are almost guaranteed to fall behind schedule with stress and overburden. Some of the workers also stated that the device is heavy to handle and manoeuvre, especially with a part in the gripper.

In short the link arm lifting device can be summarised with the following quote from one of the interviewed workers

> "The lifting device inhibits work more than it enables" - Operator 1, Interview at Volvo Cars, March 6. 2019

5.1.2 Generator

About half of the workers stated that they use the lifting device for the generators but most of them also stated that it took some time getting used to and learning how to operate the device effectively. They also said that they would prefer to do the lifting by hand.

In general the workers found the generator lifting device to be much easier to use than the link arm device, but it still has a few problems. The biggest problem according to the workers is the "trigger" that is used to automatically grip a generator when the gripper is lowered onto it. This trigger is placed slightly to the side in the gripper and sometimes require fiddling with the device and pressing it against a part with an angle as shown in Figure 5.1 before it activates the gripper. To place a part in a rack there is a manual button to release the gripper, but it is common for the trigger to "get stuck" in an active position and thus the generator is not released when the button is pressed. This lead to even more fiddling from the workers which they say is both annoying and time consuming.

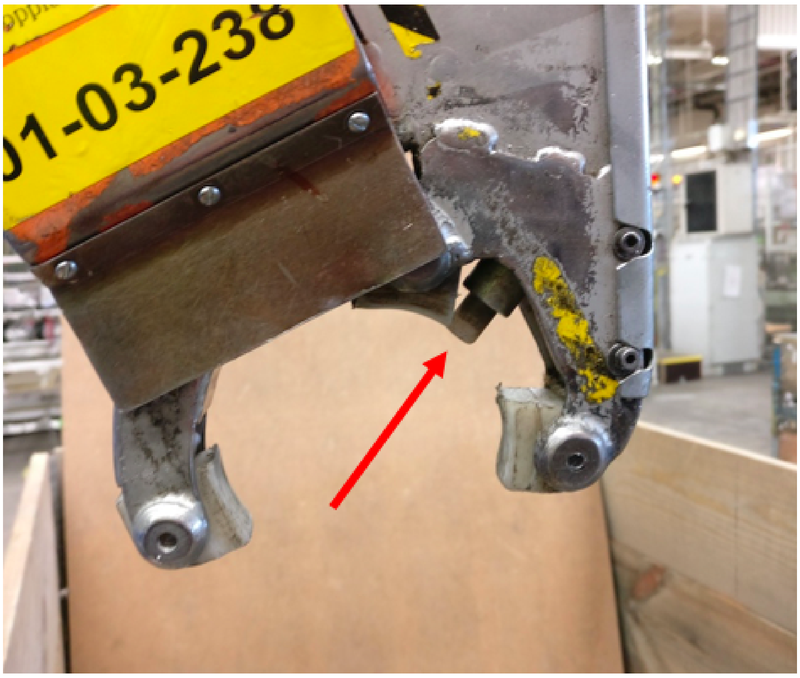


Figure 5.1: Trigger placement in generator lifting device and angle of which it has to be pressed.

Nearly all workers stated that they would prefer a manual button for both gripping and releasing parts since the trigger does not always work and they would like to have more control over the work process.

Besides the gripping and release issues the generator lifting device is also slower than doing the lifting by hand and is somewhat cumbersome to operate. One of the more annoying aspects of handling the device according to the workers is that it does not retain its height when loaded with a part. This means that the workers need to give constant input to the device in order for it to just stay level when moving it around. Most workers said they would prefer if the device could stay in the same position on its own without any input being needed.

5.1.3 AC-Compressor

For the final lifting device only one worker said they used it and thought the device was good enough to use. The remaining workers did not share this opinion however. According to them the biggest issue is that some of the compressor models are supposed to be picked up in the belt pulley. These models then start to rotate in the gripper when lifted and end up up-side-down. Thus when placed in the sequencing rack the compressors have to be manually adjusted to face the right way up.

Other than this the compressor lifting device is very similar to the generator lifting device in terms of handling speed and cumbersomeness. The compressor device also has a "trigger" which automatically grips the parts but the biggest issue here is that the gripper does not open properly when a part has been placed. This leads to some fiddling when trying to pick the next part which is time consuming. Like in the generator case the workers said they would prefer to have a button to manually grip and release parts to reduce the awkwardness of having to fiddle with the device just to be able to grip and release parts.

5.2 Personal Observations

Besides interviewing the operators the lifting devices were also tested by the authors of this report to help build a better understanding of the situation. In general much of what the operators said could be confirmed through testing and in this section comments and observations made during the testing of the devices are presented.

5.2.1 Link arm

The first observation made was how unintuitive the lifting device was designed since an explanation was needed in order to understand how to operate the device.

Regarding the handling it was noted that it was more or less necessary to use both hands to operate and move the device around due to two main reasons. Firstly it is difficult to move the device around since a constant input has to be given in order for the device to maintain its height. This means that one hand is needed to give the constant input while the other hand is used to move the device around. However it is very strenuous for the arm and hand to give this constant input because the muscles are constantly activated during the entire operation. The second reason why two hands are needed is the problem of picking and placing parts as described by the operators. From the observations made it was confirmed that gripping a link arm without first lifting it up slightly by hand is nearly impossible. Moreover the device has to be twisted and angled in order to be able to grip the parts which also is very strenuous for arms and hands. The placing of parts in the sequencing rack suffers from similar issues as picking parts and a placed part must almost always be manually adjusted afterwards.

For the handling speed of the device it was observed that the main reason for it being so slow is the picking and placing of the parts. These operations are extra time consuming since one has to manually adjust or lift parts in order to be able to pick them with the lifting device.

5.2.2 Generator

Similar to the link arm lifting device, the one used for the generators is also quite unintuitive and took some time to figure out how it works.

The generator lifting device is easier to handle than its link arm counterpart and is not as heavy. It does still require constant input to maintain its height but is easier to manoeuvre while doing so. The device can fairly easily be manoeuvred into position and pick parts using only one hand and both hands are only really needed when placing parts in the rack.

The biggest problem with this device are that the controls for lowering the device are somewhat clumsy and cumbersome and that it usually requires some fiddling when picking and placing parts. The fiddling is a side effect of the "trigger" which is placed in the gripper. This trigger sometimes fails to register that a part should be picked and does not activate the gripper. When placing parts the trigger also interferes and even though the release button is pressed the gripper does not open.

5.2.3 AC-Compressor

The compressor lifting device shares many similarities with the lifting device for the generator. The only real difference between the two is the placement of the "trigger" used to activate the gripper. For the compressor this "trigger" is located in the middle of the gripper instead of slightly to the side. This makes it easier to grip compressors than generators since less fiddling is needed.

The biggest problem with the compressor lifting device however is placing the parts in the rack. Certain compressor models are picked up by the belt pulley and rotates to an upside down position. When placed they then need to be manually adjusted. Also when released the gripper does not always open fully and thus new parts cannot be picked before the gripper has been opened properly by hand. Moreover the parts which are not picked by the belt pulley are instead difficult to pick from the pallets due to the way they are packaged. These compressors have cardboard supports surrounding them and thus the lifting device has to be angled and twisted in order for the gripper to reach around the part properly. This required manipulation is quite straining on both hands and arms.

5.3 Requirement Specification

After interviewing the operators and discussing with the ergonomic experts and the tooling department the requirement specification, shown in Figure 5.2, was formulated.

The requirement specification is divided into the three main subjects of Safety, Ergonomics and Function. The safety requirements were formulated using the conclusions from discussing with the tooling department and the ergonomic requirements mainly from the Volvo Cars Ergonomic Standard in Appendix A but also from the meetings with the ergonomic experts. The required functions refer to what features a possible proposed solution must fulfil and were generated from interviewing the operators as well as from the testing of the devices by the project members.

Requirement Specification
Intelligent lifting device for medium weight objects

Required	**Yes**	**No**
Safety		
Safety measure to avoid hand getting caught in device		
Ensure device can not move outside of station workspace by accident		
No possibility for operator to tamper with settings. (air pressure, speed, etc.)		
Speed and acceleration limited		
Emergency stop button		
Ergonomics		
Maximum force required for pushing/pulling overhead cranes: start <50 N, continously <40 N		
Maximum finger pressure force 15 N		
Maximum several fingers pressure force 30 N		
Maximum whole hand pressure force 50 N		
Maximum operating devices/control button pressure force 5 N		
Maximum hand-lever controls pressure force 20 N		
Pressure area large enough for a thumb, no sharp edges		
Button pressure direction in the longitudinal direction of arm		
Grip long enough to fit entire hand, >120mm		
Material on hand grip surfaces do not become slippery when wet or oily		
Height of interface and hand grip within "green" area according to VCS 8003,29 Fig. 1 & 3 (800-1200mm from floor)		
Good visibility of gripper and part at all times		
Maximum weight lifted by operator not to exceed values given in VCS8003,29 Table 1		
Device does not require fetching from "red" area according to VCS 8003,29 Fig. 1 (<800 or >1200mm from floor)		
Movement in at least 4 Degrees of Freedom (x,y,z and rotation around z-axis)		
Function		
Device compensates for entire weight of part held		
Device does not move if not ordered to		
Able to perform entire operation without requiring operator to manually lift part at any time		
Operator performs entire operation from control interface		
Gripping and placing parts is swift and easy		
Using the device is not much slower than performing operation by hand		
Device fits all product variations		
Controls are easy to understand and require minimal explanation and training		
Device is operable without having to change hand grip or hand position		
Device utilises some sort of intelligent control (eg. active control, force feedback, process awerness, etc)		

Desired	**Yes**	**No**
Safety		
Sensors for verifying functions (part gripped correctly, etc)		
Reduce risk for false signals from sensors		
Ergonomics		
Interface height adjustable		
Grip that fits different hand sizes		
Low vibrations		
Device is as light as possible		
Suitable for both left- and right-handed people		
Intuitive design of control interface		
Function		
Button used for controlling grip/release		
Operator understands all controls without any explanation		
Device utilises pneumatics as much as possible		
Feedback regarding if operation is performed correctly		
Grips all parts from above		
Minimise effort to move device		

Figure 5.2: Requirement specification for evaluating concepts.

5.4 Concept Generation and Evaluation

Figure 5.3 shows the Morphological Chart generated to help form different concepts of the overhead crane type. A number of different versions of this type of solution were generated consisting of different combinations of solutions in the chart. Furthermore, a selection of concepts ranging outside the general idea of an overhead crane where formed and after evaluating as described in Chapter 4, two main concepts remained. These concepts are described in more detail in Section 5.6.

Problems to be solved	Possible concepts of solution						
Positioning:							
Horizontal	"Feels" in what direction the operator wants the tool to move and actively helps with movement	Operator presses a button where they want the device to move to	Lifting assist has knowledge of the sequence and knows where it is supposed to be and moves there on its own	Motion tracking of operator and follows the operator on its own	Operator moves device manually		
Vertical	Balanced and stays in vertical position if let go, operator can push device up or down, "weghtless"	Balanced and stays in vertical position if let go, interface that lets operator control up or down motion	Automatic height control				
End effector manipulation	Flexibility in end effector manipulated manually by operator	Device automatically recognises how it should be positioned	Only manipulation possible is rotation around z-axis				
Gripping and placing parts:							
Controlling gripper	Button for toggling grip/release	Sensors trigger gripping function and senses when placed and triggers release	Sensors trigger gripping function, operator manually presses button for release	Automatic picking and placing by device			
How to grip	Suctioncup, above	Magnet, above	Piston, above	Claw, above	Hook, above	Expanding thing, above	Clamp, above

Figure 5.3: Morphological chart, listing different approaches to different parts of the problem. This chart has 1260 different combinations.

Here follows a brief description of a few select concepts that were evaluated but did not fulfil all of the requirements and were discarded. Although these concepts were rejected, they are included in the report since they were still considered feasible solutions up until the final stages of evaluation.

- **A.** Motorised Jib crane with force sensing handle for controlling planar and vertical powered movement. Extends downwards to pick part from above using custom gripper depending on part.
- **B.** Powered movement along overhead rails. Controlled by torque sensor in attachment point that senses when operator pushes lifting assist. This requires no interface for the horizontal movement. Up and down movement provided by powered telescopic rod that extends the gripper downwards. The operator controls this using buttons placed on the fixed part of the telescopic rod so that these always remain at the same height. The height can be controlled by holding the up or down buttons until desired height is reached. Another alternative is that the operator presses the down button once and the gripper measures the height in order to automatically position itself at the correct level.
- **C.** Overhead crane using powered movement and automatic positioning. Automatic positioning allows for multiple control methods such as: voice com-

mands, the operator orders the device to a position or that the device follows the operator, for example using a camera, and is therefore always easily accessible for the operator.

- **D.** Exoskeleton type solution, similar to Ekso-vest mentioned earlier. The operator wears the entire lift assist which works by enhancing the operators upper body strength and thus relieving the body of strain. The assist is powered by batteries also worn by the operator. One option is to combine with grip strengthening glove such as products by Bioservo.

5.5 Presentation of Final Concepts

All concepts generated through the morphological chart were evaluated and tested against the requirement specification and were subsequently eliminated if they did not meet the requirements. Besides this several concepts were deemed not feasible or too difficult to implement and were also eliminated. Following the eliminations only two main concepts remained and are presented in this section, one from using the morphological chart and in the form of an overhead crane, and another concept which is not based on this type of idea, in this case in the form of an actuated lifting glove. The concepts are described in their entirety with sketches showcasing the concepts and descriptions detailing how they work and can be implemented.

5.5.1 Force Feedback Overhead Crane

This concept is quite similar to existing lifting devices and combines features and elements from the Binar Quick-Lift (Fig. 2.7), Movomech Mechlight Pro (Fig. 2.8) and the Gorbel G-Force iQ (Fig. 2.9) systems. The key features of the concept is to be controlled using force feedback to help the operator position the device and to counterbalance its own weight and the weight of the picking parts to effectively render them weightless.

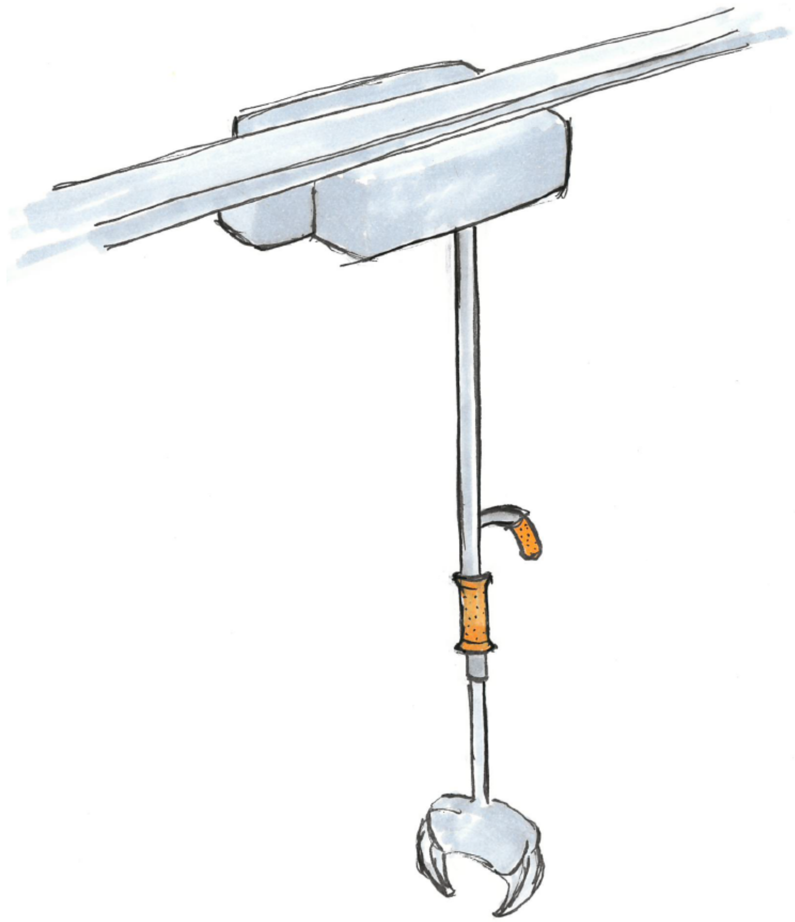


Figure 5.4: Overview sketch of the Force Feedback Overhead Crane Concept.

The overhead crane can be divided into three sections: top, middle and lower. The top section consists of the electrical power drive, rail attachment and house electrical connections, pneumatic pressure system and the control system. The middle section consists of a stiff metal tube acting as a telescopic housing for the lower end. Attached to the tube are the control handle and the support handle with a button for controlling the gripper. The entire middle section can rotate around the tubes z-axis to make picking parts easier. The lower section consists of a stiff metal rod which extends out from the telescopic housing in the middle section and at the end of the rod the gripper is located. The gripper is attached to the extending rod via a weight measurement system in order to counterbalance the parts being picked.

5.5.1.1 Movement

The 3D space movement of the device can be divided into two parts; planar and longitudinal both of which are controlled via the main handle of the device.

To achieve planar movement the device moves along a rail system suspended from the ceiling, like the situation today. The device has electrical motors which drive

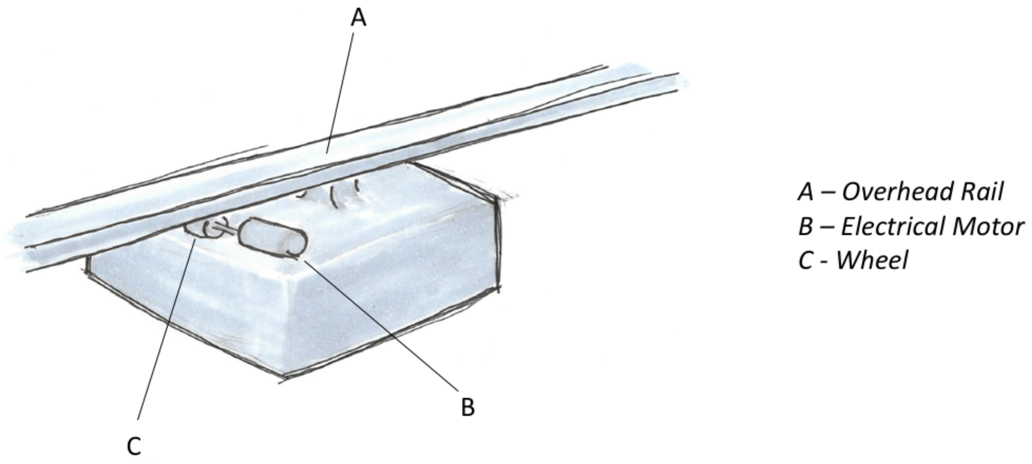


Figure 5.5: Sketch of device suspended from overhead rail with electrical motor providing powered movement along the direction of the rail.

small wheels which in turn move the device along the rails. The motors are placed so that one motor controls the x-direction and one controls the y-direction, creating a two-dimensional operating space. To move the device the operator has to grip the main handle and push it in the desired direction. This sends a signal, which is compensated for the orientation of the device, to the electrical motors which moves the device in the desired direction. The general idea for the device rail suspension and electrical motor placement can be seen in Figure 5.5.

The longitudinal movement is controlled via the same handle as the planar movement. Having one handle to control all movement was considered a big advantage when evaluating the concept since it was believed to be a more natural way of controlling the assist. Moving the handle up or down will extend or retract the gripper from the telescopic housing respectively using an electric drive or a pneumatic pressure system. Since only the lower part of the device extends and the handle is placed on the centre piece, the handle will always remain in the same position. This allows operators to pick parts without having to bend down into pallets and keep the controls within the green areas according to the Volvo Cars ergonomic standard in Appendix A, Figure 1.

5.5.1.2 Controlling the Device

To control the gripper a simple button interface is used for toggling the grip. There are two buttons placed on either side of the support handle and can be pressed with the thumb. Since the device can rotate around its z-axis this allows for operators to utilise the device using their preferred hand, whether they be right or left handed.

One desired feature in the specification of requirements in Fig.5.2 states that all parts should be gripped from above. This is possible with the grippers present at Volvo today for the generators and ac-compressors but not for the link arms. Thus a new gripper for the link arms would need to be designed. This has been intentionally left out of the project since it might require redesigning the link arm parts or do a thorough investigation on how it can be lifted, both of which are outside the scope of the project.

To make sure there is no risk of the operators hand being in the way when gripping, a so called dead mans switch is also placed on the movement control handle. This switch needs to be held for the assist to work including when gripping. By incorporating this function, the operator has to have both hands on the control interface when gripping and by such there is no risk of the operators hand getting caught in the gripper.

Another part of the device that needs to be controlled is the horizontal movement. The movement in the planar and longitudinal directions is controlled through a handle with force sensors, illustrated in Figure 5.6.

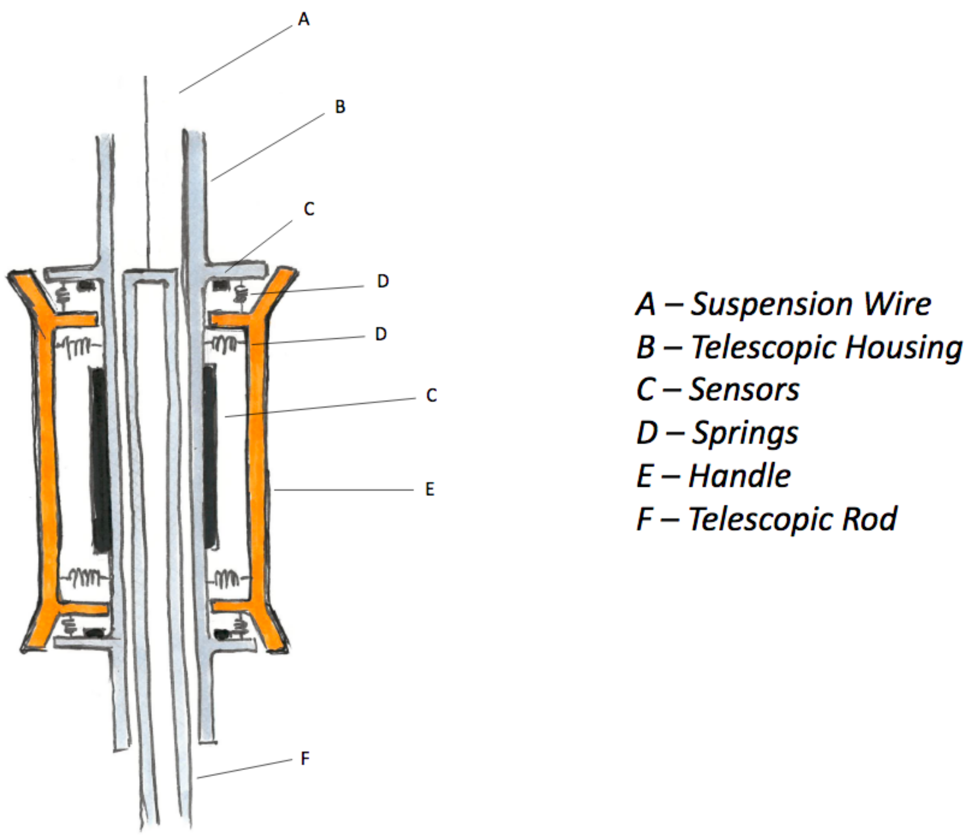


Figure 5.6: Cross section view of control handle.

The sensors are placed on the inside of the handle surrounding the telescopic housing and when triggered, the signal is converted to motor signals which control the motors mounted on the rail system. Since the entire device can rotate, angle sensors are placed in the top section to keep track of the orientation in order to move the device in the desired direction. In more detail the device should move in the direction it is actually being pushed regardless of which sensors are triggered. There are also force sensors in the top and bottom of the handle to control the longitudinal movement by controlling the pneumatic pressure in the device. The handle is also fitted with springs to reset the handle to its neutral position if "let go".

5.5.1.3 Counter Balancing of Different Weights

A key feature of this concept is the assist's ability to handle different weights and to provide "weightlessness" of the parts by compensating for the weight being held. Both of these specifications require that the lifted part be weighed in order to determine the force needed to suspend the part and the gripper itself. One solution to this is to use a so called *load cell*. More specifically, proposed for this application is a *strain gauge load cell*. The basic concept of this type of load measurement device is that strain gauges are placed on a surface that purposely deforms slightly which creates a strain when a pushing or pulling force is exerted on the material [27]. By placing the strain gauge in a circuit, the resistance in the gauge can be measured. The resistance encountered in the gauge is proportional to the strain, which comes from the material deformation.

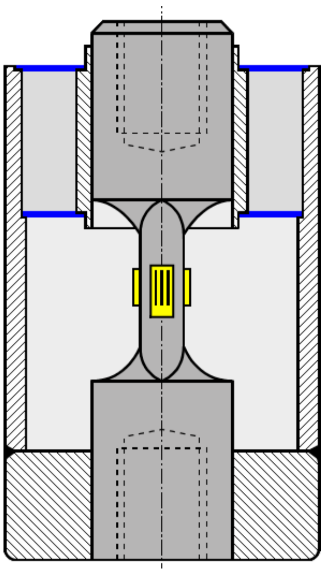


Figure 5.7: Intersection of a strain gauge load cell. The yellow parts represent gauges that measure strain in the material from the top and bottom being pushed or pulled. From [28]. CC BY-SA 2.5

The load cell can then be placed at the bottom of the telescopic rod, between the rod and the gripper as shown in Figure 5.8. This allows for measuring of the weight held by the gripper as well as the gripper itself. When no input is given to the vertical control sensors in the handle, the control system continuously measures the resistance in the strain gauge to determine the weight which needs to be compensated. This information is used in a controller to control the telescopic rod. It is also necessary at this point to calculate how the force created depends on the pneumatic pressure as this is how the telescopic rod is controlled. Ultimately this allows for the device to gain knowledge about the weight that needs to be compensated and how the pressure should be controlled to achieve this.

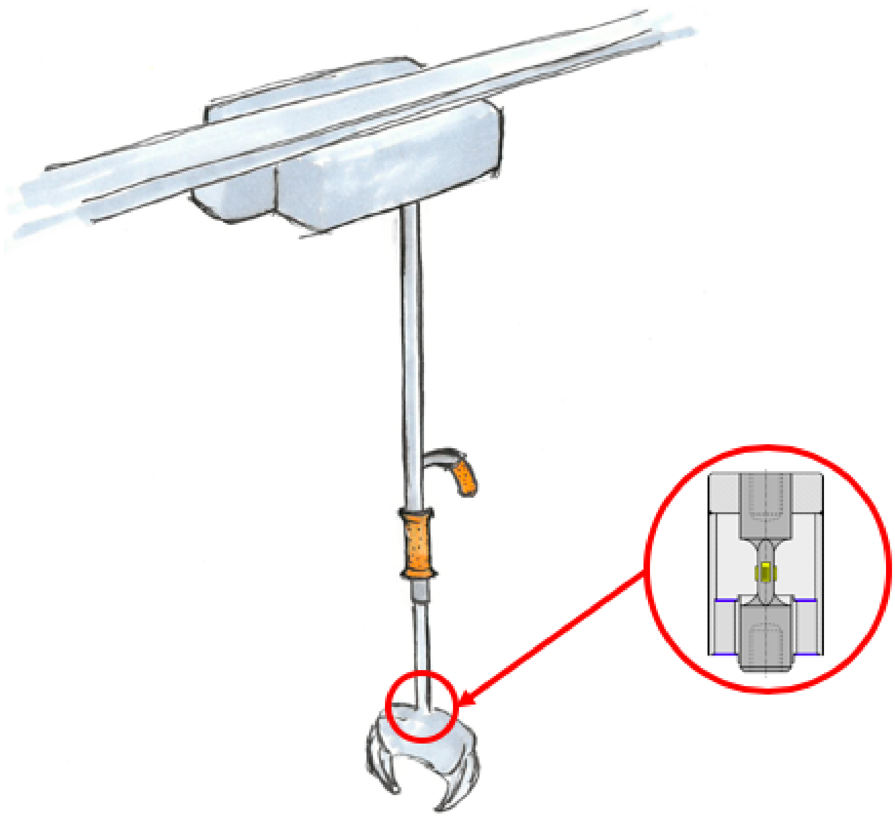


Figure 5.8: Placement of load cell

5.5.1.4 Evaluation Against Requirement Specification

As mentioned, the requirement specification was an important part when evaluating a concept. Figure 5.9 shows the specification previously presented in Figure 5.2 but filled in according to the Force Feedback Overhead Crane concept. Because the requirement specification is designed to be as general as possible to allow for evaluation of many different solutions, not all items are necessarily applicable for every concept. When the concepts were being evaluated it was found that in order to be able to check some items, slight additions or alterations to the concept had to be made, these have been included in the concept description above.

Requirement Specification
Intelligent lifting device for medium weight objects

Required	**Yes**	**No**
Safety		
Safety measure to avoid hand getting caught in device	✓	
Ensure device can not move outside of station workspace by accident	✓	
No possibility for operator to tamper with settings. (air pressure, speed, etc.)	✓	
Speed and acceleration limited	✓	
Emergency stop button	✓	
Ergonomics		
Maximum force required for pushing/pulling overhead cranes: start <50 N, continously <40 N	✓	
Maximum finger pressure force 15 N	✓	
Maximum several fingers pressure force 30 N	✓	
Maximum whole hand pressure force 50 N	✓	
Maximum operating devices/control button pressure force 5 N	✓	
Maximum hand-lever controls pressure force 20 N	✓	
Pressure area large enough for a thumb, no sharp edges	✓	
Button pressure direction in the longitudinal direction of arm	✓	
Grip long enough to fit entire hand, >120mm	✓	
Material on hand grip surfaces do not become slippery when wet or oily	✓	
Height of interface and hand grip within "green" area according to VCS 8003,29 Fig. 1 & 3 (800-1200mm from floor)	✓	
Good visibility of gripper and part at all times	✓	
Maximum weight lifted by operator not to exceed values given in VCS8003,29 Table 1	✓	
Device does not require fetching from "red" area according to VCS 8003,29 Fig. 1 (<800 or >1200mm from floor)	✓	
Movement in at least 4 Degrees of Freedom (x,y,z and rotation around z-axis)	✓	
Function		
Device compensates for entire weight of part held	✓	
Device does not move if not ordered to	✓	
Able to perform entire operation without requiring operator to manually lift part at any time	✓	
Operator performs entire operation from control interface	✓	
Gripping and placing parts is swift and easy	✓	
Using the device is not much slower than performing operation by hand	✓	
Device fits all product variations	✓	
Controls are easy to understand and require minimal explanation and training	✓	
Device is operable without having to change hand grip or hand position	✓	
Device utilises some sort of intelligent control (eg. active control, force feedback, process awerness, etc)	✓	
Desired	**Yes**	**No**
Safety		
Sensors for verifying functions (part gripped correctly, etc)		x
Reduce risk for false signals from sensors		x
Ergonomics		
Interface height adjustable		x
Grip that fits different hand sizes	✓	
Low vibrations	✓	
Device is as light as possible	✓	
Suitable for both left- and right-handed people	✓	
Intuitive design of control interface	✓	
Function		
Button used for controlling grip/release	✓	
Operator understands all controls without any explanation		x
Device utilises pneumatics as much as possible	✓	
Feedback regarding if operation is performed correctly		x
Grips all parts from above	✓	
Minimise effort to move device	✓	

Figure 5.9: Evaluation of the Overhead Crane against the requirement specification

5.5.2 Actuated Lifting Glove

This concept draws heavy inspiration from the Robo-Glove by NASA and GM (Fig. 2.11) and the SEM-Glove from Bioservo (Fig. 2.12) and is within this application quite different from anything available on the market today. The concept utilises a glove fitted with actuators which give extra grip strength to reduce the strain on the operators hands. The glove itself is suspended from a winch which is attached to the rail system currently in place at Volvo Cars. Sensors placed in the palm of the hand and on the finger tips allows the operator to control the grip strength support and the lift support from the winch. By combining an actuator fitted glove with a winch one can achieve a concept which combines the dexterity and cognitive ability of the human hand with the strength of machines. An important problem to consider with this concept is the height at which the operator performs the work, as previously mentioned and according to the Volvo Cars ergonomic standard in Appendix A. This concept does not by itself allow the operator to work solely in this "green" area shown in Appendix A, Figure 1. As such, looking into height adjustable packing options or some other change in how material is presented might be required if Volvo Cars proceeds with this concept.

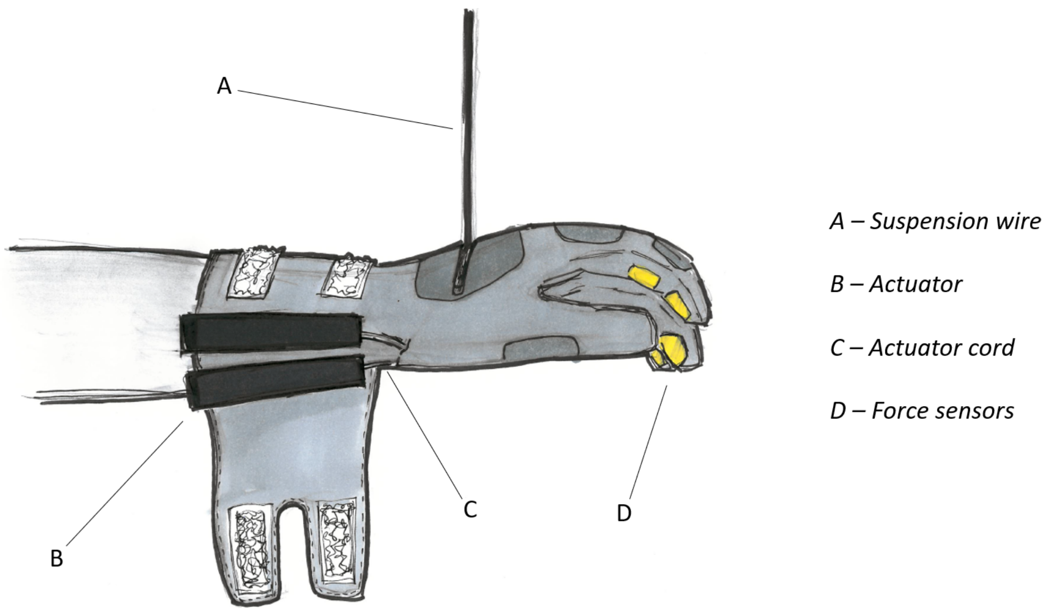


Figure 5.10: Overview sketch of the concept

5.5.2.1 Gripping and Actuator Control

Gripping is controlled by sensors and actuators and is inspired by the way the Robo-Glove and the Bioservo products work. Cords run along the fingers and palm of the glove and are connected to actuators as shown in Figure 5.11. When the actuators pull on the cords, the fingers contract and the grip is tightened, allowing the operator to grasp an object.

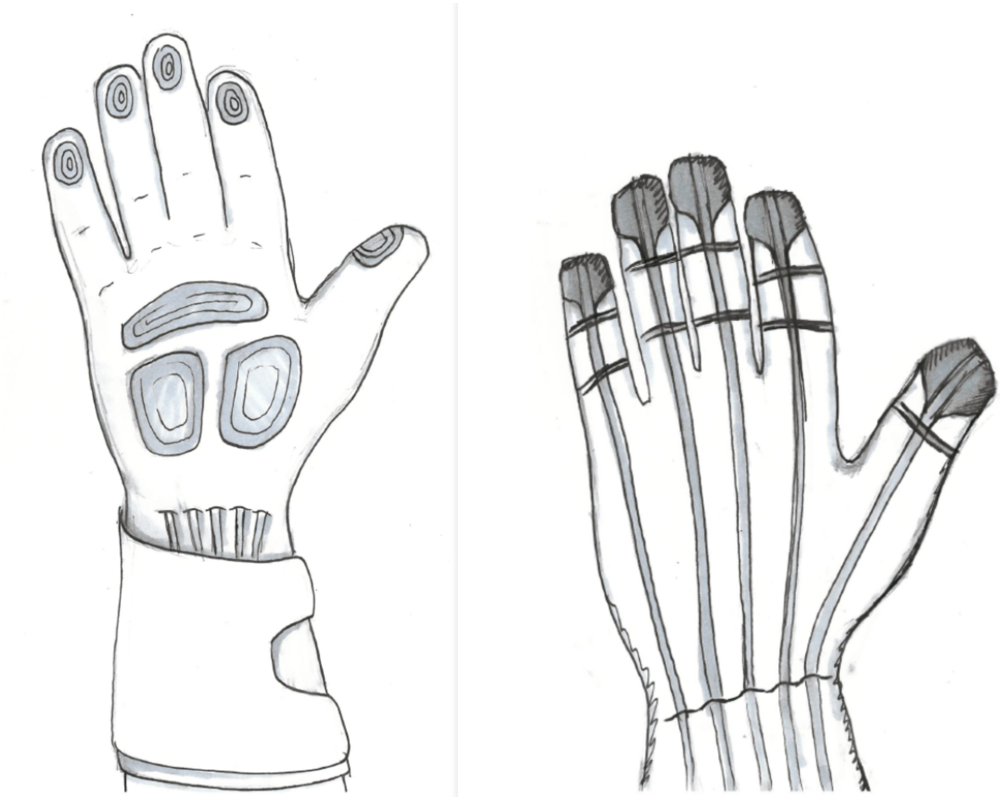


Figure 5.11: Sketch showing palm of glove and x-ray showing cords lining the fingers and palm, running between the fingertips and actuators

To control the actuators there are force sensors placed in the finger tips and the palm of the glove. The actuators are activated when the sensors exceed a certain force threshold. This means that the operator has to grip the part before the actuators will activate and help reduce the strength required to grip. To deactivate the actuators the operator just has to relax their grip slightly to get the sensors below the threshold, resulting in the operator controlling the assist and not the other way round.

The actuators give power based on a linear scale and is decided by how much force is registered in the sensors. If the operator has to grip the object tightly, more force will be registered in the sensors, causing the actuators to pull harder than if the part only has to be gripped lightly. Thus the gripping assist can be considered as an *extension* of the operators grip, making the operator stronger and amplifying the gripping strength. This part was considered to be of great importance for this concept since it is important that the assist feels natural to use and like an extension of the body instead of a cumbersome device that one has to actively control.

5.5.2.2 Movement

It was decided that the movement for this solution would work best by utilising an overhead rail system similar to the one that exists today. This gives a good operating space without obstructing workers or forklifts and such.

If the actuators used for gripping are kept lightweight and small, a big advantage of this concept is that most hardware can be placed on the glove worn by the operator. This means that the weight at the overhead attachment point becomes lower compared to other concepts which in turn means a smaller inertia to overcome when moving around. Having a smaller weight and thus a smaller inertia at the overhead rail means that the assist becomes more natural to operate for the operator since there is less "pulling" of the gripper from inertia. This also gives a more responsive feel and requires less effort by the operator instead of having to compensate for the moving mass. Of course this solution could also be coupled with a powered movement system controlled by, for example, a rope angle sensor as described earlier in order to even further reduce the inertia.

5.5.2.3 Winch Control and Weight Counter Balance

Another central part of this concept is how the weight should be compensated. As mentioned, the first idea was that this concept utilises an electrical winch. The winch is set to give a pre-determined torque to counter balance the parts being picked. The winch is activated through the same force sensors used to activate the actuators. For the winch to activate, all sensors must be in contact with the part being picked and triggered beyond a threshold. To deactivate the winch at least all sensors except one has to fall below the threshold which indicates a desire from the operator to let go and place a part.

To maintain as much of the wrist's natural flexibility and movement as possible without compromising lifting support a special solution for attaching the glove to the winch was developed. The main idea behind this is that the winch wire runs in a loop around the glove, allowing it to always lift from straight above while lifting the hand from straight below. The wire travels in a channel on the inside of the glove when the hand is rotated. Of course this solution does not allow for full 360° rotation, however this was not considered a problem since some angles of the wrist are unnatural and need no support. Thus the suspension system was placed in such a way that allows for support in the most important angles of the wrist. The attachment system was placed so that support can be provided from the back of the hand as well as towards the sides. One angle that is not covered by this is if the hand is rotated 180° meaning that the object is lifted from underneath and the palm is facing upwards. While this might be a desired lifting position for some objects, it would become difficult to implement using this solution since the wire might become tangled in the thumb as well as obstructed by the object being held.

As mentioned earlier, evaluating and formulating the specifics of the concepts was an iterative process and in a late stage of concept evaluation it became known that any form of attaching an operator to a fixed machine will not be allowed. Unfortunately this includes the proposed solution of attaching the glove to an electrical winch in the ceiling. At the same point however, positive feedback was received regarding the concept in general. By reinvestigating the issue of providing lift assist, this time with the new restriction, and discussing it with Volvo Cars, a conclusion was reached that technology similar to that of an exoskeleton should be utilised. It was also confirmed immediately that this type of technology would be an acceptable and allowed solution given that it is not attached to a fixed structure while in use. In short this means that it has to be battery operated and power cannot be supplied through a cord.

One idea that came up when discussing alternatives was to simply view the arm in the same way as a finger, but on a larger scale. By doing this, the same technique used for providing strength in the fingers could in theory be applied on the arm. The idea was therefore to attach another, more powerful, actuator to the shoulder or back of the operator and just like the fingers, run a cord along the arm. When the actuator pulls on the cord, the arm contracts which results in the operator being relieved of the weight in the arm. This also opens up for the possibility of having assists on both arms, providing even more flexibility and strength as well as the ability to lift larger objects. The entire device could be worn as sleeves that are attached to a backpack-like part so that the operator wears the actuators and batteries on the back. Straps can then be used to ensure tight fitting and that the weight of held parts is relocated to a stronger part of the body, just like how an exoskeleton works. This idea is shown in Figure 5.12.

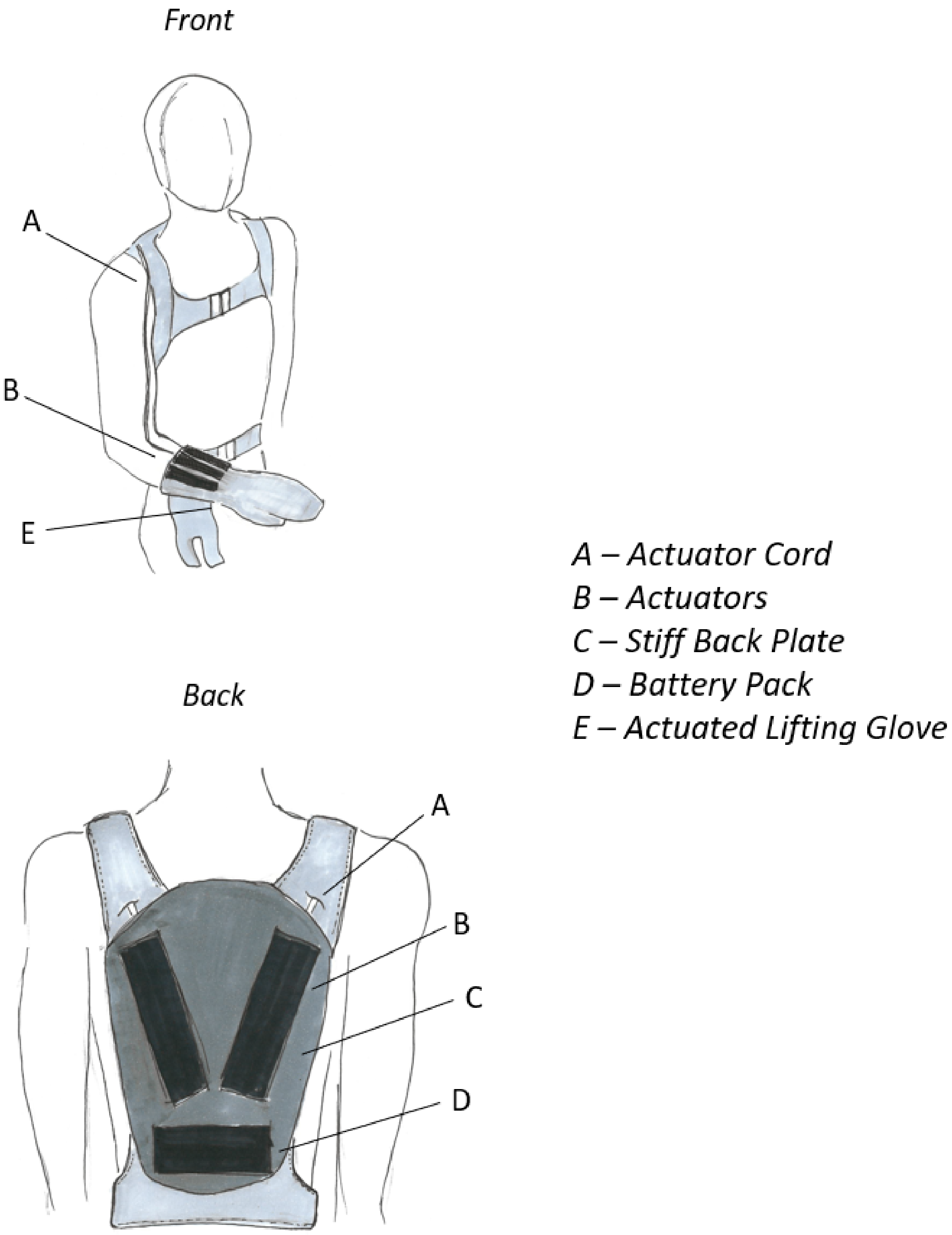


Figure 5.12: Overview of concept including lifting assist using actuated arm

5.5.2.4 Evaluation Against Requirement Specification

Figure 5.13 shows the requirement specification filled out according to the Actuated Lifting Glove concept.

Requirement Specification
Intelligent lifting device for medium weight objects

Required	Yes	No
Safety		
Safety measure to avoid hand getting caught in device	✓	
Ensure device can not move outside of station workspace by accident	✓	
No possibility for operator to tamper with settings. (air pressure, speed, etc.)	✓	
Speed and acceleration limited	✓	
Emergency stop button	✓	
Ergonomics		
Maximum force required for pushing/pulling overhead cranes: start <50 N, continously <40 N	✓	
Maximum finger pressure force 15 N	✓	
Maximum several fingers pressure force 30 N	✓	
Maximum whole hand pressure force 50 N	✓	
Maximum operating devices/control button pressure force 5 N	✓	
Maximum hand-lever controls pressure force 20 N	✓	
Pressure area large enough for a thumb, no sharp edges	✓	
Button pressure direction in the longitudinal direction of arm	✓	
Grip long enough to fit entire hand, >120mm	✓	
Material on hand grip surfaces do not become slippery when wet or oily	✓	
Height of interface and hand grip within "green" area according to VCS 8003,29 Fig. 1 & 3 (800-1200mm from floor)	✓	
Good visibility of gripper and part at all times	✓	
Maximum weight lifted by operator not to exceed values given in VCS8003,29 Table 1	✓	
Device does not require fetching from "red" area according to VCS 8003,29 Fig. 1 (<800 or >1200mm from floor)	✓	
Movement in at least 4 Degrees of Freedom (x,y,z and rotation around z-axis)	✓	
Function		
Device compensates for entire weight of part held	✓	
Device does not move if not ordered to	✓	
Able to perform entire operation without requiring operator to manually lift part at any time	✓	
Operator performs entire operation from control interface	✓	
Gripping and placing parts is swift and easy	✓	
Using the device is not much slower than performing operation by hand	✓	
Device fits all product variations	✓	
Controls are easy to understand and require minimal explanation and training	✓	
Device is operable without having to change hand grip or hand position	✓	
Device utilises some sort of intelligent control (eg. active control, force feedback, process awerness, etc)	✓	
Desired	**Yes**	**No**
Safety		
Sensors for verifying functions (part gripped correctly, etc)	✓	
Reduce risk for false signals from sensors		x
Ergonomics		
Interface height adjustable	✓	
Grip that fits different hand sizes		x
Low vibrations	✓	
Device is as light as possible	✓	
Suitable for both left- and right-handed people	✓	
Intuitive design of control interface	✓	
Function		
Button used for controlling grip/release		x
Operator understands all controls without any explanation		x
Device utilises pneumatics as much as possible		x
Feedback regarding if operation is performed correctly		x
Grips all parts from above		x
Minimise effort to move device	✓	

Figure 5.13: Evaluation of the Actuated Lifting Glove against the requirement specification

5.6 Technical Description

As a last step before being able to reach a total conclusion and presenting the suggestion to Volvo Cars, a technical description was formulated and feasibility of implementation of the concepts was studied. The technical description in this section covers what hardware components would be needed if the concepts were to be realised and what performance would be required from these.

5.6.1 Overhead Crane

The technical description of the Overhead Crane concept, split in to the different parts of the concept, is presented below. Figure 5.14 shows the general layout of the components needed.

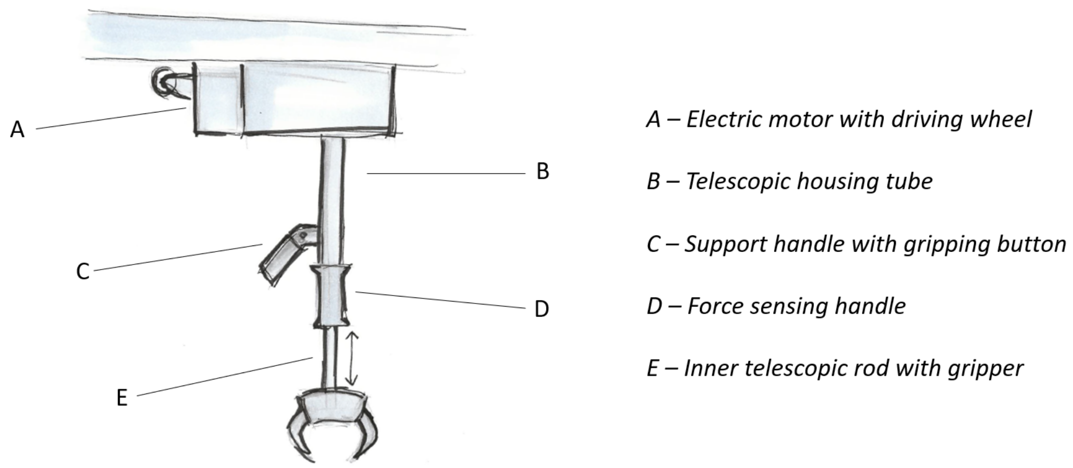


Figure 5.14: Overview of controllable parts

5.6.1.1 Control and Interface

The main part of the overhead crane concept that was interesting to study with regards to implementation was the presented control handle. This handle is considered to be the key function of this concept because of its potential to provide seamless translation from what the operator wants to do, to the lifting assist performing the action. It is therefore important that the handle be implemented in a way that allows it to function as well as the concept presupposes.

The first problem to address is recognising what input is given from the operator. Four force sensors are placed in the handle, spread evenly in a circle as shown in Figure 5.6 and 5.15. This gives sufficient information about the direction the handle is being pushed and by adding the force acted upon each sensor together, the system can determine the exact direction. The force sensors have to be able to register a linear force scale to allow for better movement precision and a maximum force of at least 50 N. The sensors also have to be small enough to fit four of them inside the control handle and be durable enough to withstand nearly constant use. The handle is placed around the pole and sensors, with springs placed in between so that the sensors are only triggered when the handle is pushed and the handle returns to its natural position when let go. The stiffness of these springs and force needed to push the handle have to comply with the Volvo Cars ergonomic standard of 50 N maximum at the start of a push and 40 N maximum for continuous pushing.

Using this configuration, the force sensor triggered when pushing the handle is on the opposite side of the desired direction. The system will register what forces are acted on what sensors as well as the angle from the sensor in the top of the device to calculate how fast and in what direction the device should move. This is then passed on to the motors and continuously updated according to how the forces in the handle change.

From Figure 5.15 depicting a top-view cross section of the handle and showing outer handle as well as the sensors placed on the inner tube, equations for the relationship between sensors and motors can be derived.

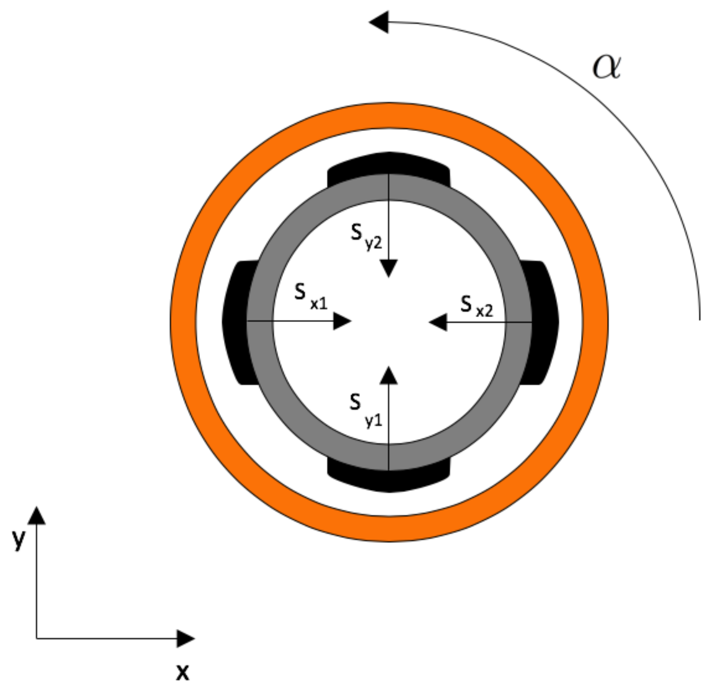


Figure 5.15: Cross section of control handle viewed from above

In Figure 5.15 α is the angle of how much the device is rotated as measured at the attachment point at the top and S_{ij}, where $i \in [x, y]$ and $j \in [1, 2]$, is the output given from each of the handle sensors. From the requirement specification it is known that the maximum continuous force that the operator should have to use to control the device is 40 N. This means that the sensor output should have a range of $S_{ij} \in [0, 40]$ (N) when "pushed" towards the centre of the handle. Because 40 N is the maximum continuous value the operator should have to apply to the handle and should relate to maximum speed, any output above 40 N from the sensors is in this case irrelevant and therefore capped to 40 N.

Since there are two electrical motors that control the planar movement, one for the x-direction and one for the y-direction, a two dimensional force vector is needed to translate the sensor data into motor signals. To obtain the two dimensional force vector the sensor values in each direction are added together

$$\vec{F}_s = \begin{bmatrix} S_x \\ S_y \end{bmatrix} = \begin{bmatrix} S_{x1} - S_{x2} \\ S_{y1} - S_{y2} \end{bmatrix} \tag{5.1}$$

As shown in Figure 5.15, S_{x2} and S_{y2} are placed opposite of S_{x1} and S_{y1}. The values from S_{x2} and S_{y2} corresponds to a desired movement in the "negative" direction relative to the handle, hence they are negated in equation 5.1.

If the handle is pushed from an angle, θ, which triggers two sensors simultaneously, it is possible that the resulting vector magnitude $|\ \vec{F}_s\ |$ becomes larger than 40 N. This phenomenon is visualised in Figure 5.16.

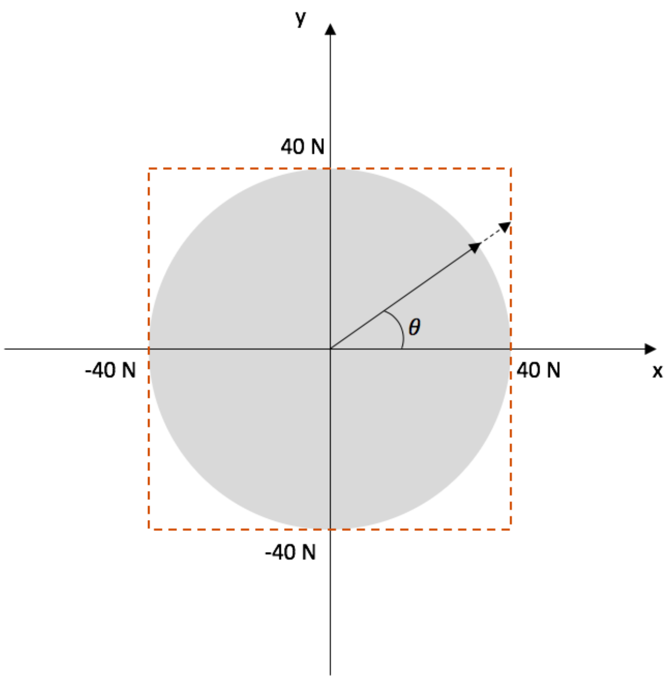


Figure 5.16: Visualisation of $|\ \vec{F}_s\ |$ becoming larger than 40 N. The grey area shows the "allowed" range, where the magnitude of the resulting force is 40 N or less and the red square depicts the possible range that $\vec{F}_s$ can become.

If the input is not limited when this occurs, it will result in the device moving faster than allowed. For example, if both motors are set to move at maximum speed, the resulting movement will be at a 45 ° angle and at a combined speed which is greater than allowed. Thus, when performing the calculations that translate input signals from the handle to motor signals, this has to be accounted for. This is done by calculating the angle of the force vector

$$\theta = \angle\, \vec{F_s} = \tan^{-1}\left(\frac{S_y}{S_x}\right) \tag{5.2}$$

as well as its magnitude

$$\mid \vec{F_s} \mid = \left|\frac{S_x}{\cos\theta}\right| \tag{5.3}$$

If the magnitude is greater than 40 N, the force vector is scaled down to $\mid \vec{F} \mid = 40$ N. Then, by using the angle θ and the scaled down $\mid \vec{F} \mid$, new vector components are calculated as

$$\begin{aligned} F_x &= \mid \vec{F} \mid \cos\theta \\ F_y &= \mid \vec{F} \mid \sin\theta \end{aligned} \tag{5.4}$$

which are then used instead of the actual sensor values. This ensures that the device can move at a universal maximum velocity, as opposed to being dependant on the angle θ. The downscaling of $\mid \vec{F_s} \mid$ is visualised in Figure 5.17.

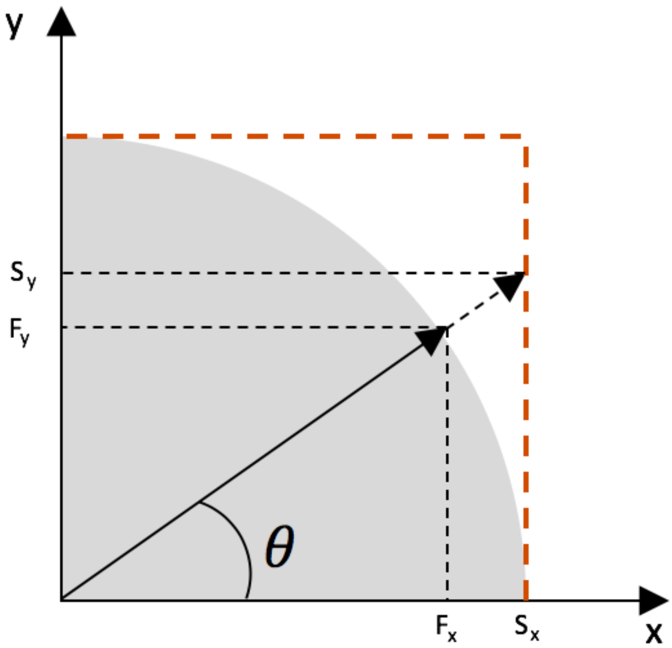


Figure 5.17: Visualisation of the down scaling of $\mid \vec{F_s} \mid$, the original sensor values S_x and S_y and the new vector components F_x and F_y.

The final aspect that needs to be considered is that the entire bottom part of the device can be rotated independently of the overhead rail and motor system. Hence the coordinate frame for the sensors in the handle no longer aligns with that of the motors. For example this means that if the bottom part is rotated 180° and the operator pushes on the handle, the device will move in the opposite of the desired direction. To address this the angle α, as shown in Figure 5.15, of the rotation has to be known in order to transform the sensor information into the motor coordinate frame before passing the information to the motors. By doing this, the device can determine the actual direction desired by the operator. The angle α is used to form the rotation matrix describing the transformation between the two coordinate frames:

$$\begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} F_x \\ F_y \end{bmatrix} = \begin{bmatrix} M_x \\ M_y \end{bmatrix} \tag{5.5}$$

Where M_x and M_y are the vector components for the desired movement in the coordinate frame of the overhead rails and motors.

5.6.1.2 Horizontal Movement

The minimum performance requirements formed for the electrical motors in the overhead movement system are mostly centred around speed and acceleration. Regarding the speed, it was decided that being able to move at approximately normal walking speed is important for the device to feel swift. Movomech and Binar offer electric drives with various horizontal speeds as mentioned in Chapter 2. The Movomech PowerDrive is capable of speeds ranging from 0 - 2.4 km/h [16]. The Binar Quick-Lift Driven is capable of 0 - 3.6 km/h [10]. These values provide a frame of reference for what speeds might be feasible for this type of solution. Through reasoning it was concluded that a horizontal speed similar to that of normal walking is preferred. The Binar system is slightly faster than the Movomech PowerDrive and similar to the speed of a slow walk. Based on this, it was concluded that $\sim$ 4 km/h would be sufficient for the task and a speed that should be aimed for. Therefore, the minimum speed requirement was set to $\sim$ 4 km/h to ensure that the operator does not experience the assist as slow and that he or she constantly has to wait for the assist to come along. While this being a minimum speed, it is also important to limit the top speed to no more than 5 or 6 km/h so there is no risk of the device moving too fast. With the speed requirements covered, acceleration was considered as it is an important aspect in creating a feeling of a smooth, swift and responsive device. Through estimation and reasoning, it was concluded that the preferred acceleration would be for the device to reach approximately walking speed in one second. This is to make the device fast enough that the operator does not feel he or she has to wait for the device to gain speed. As such, reaching a speed of $\sim$ 4 km/h which equals 1.1 m/s in one second results in a desired acceleration of $\sim$ 1.1 m/s^2. Through reasoning and estimation, this acceleration was considered to be fast enough to make the assist feel responsive but not fast enough to constitute a safety hazard by being too fast. Besides these performance requirements, this application also relies on some basic functionality of the electrical motors. One of these is the ability to handle a spectrum of speeds, distributed between zero and the maximum speed. This is to enable the possibility to move the device slowly, for example when adjusting the position slightly to pick up a part. Another desired functionality is that the motors can act as brakes when not powering the movement of the assist. The reason for this is that the device does not drift or continue to move when the operator "lets the handle go, and also to make picking of parts easier since the assist can stay completely still while lowering the gripper. This part of the concept is heavily inspired by the Movomech powered drive system which features similar functionality such as the braking system and is capable to move larger cranes than needed in this particular concept. The Movomech powered drive is a product available on the market and was therefore used to determine that the idea for movement of this concept is feasible to implement and something that can be achieved.

5.6.1.3 Vertical Movement

With horizontal movement covered, the vertical movement was then addressed. To control movement up and down, two more sensors and springs need to be placed inside the handle, one spring and sensor in each end of the handle as shown in Figure 5.6. The control unit also needs to handle this information in order to translate it in to vertical movement of the device. The minimum performance requirements for this part of the concept concerns the speed at which the assist moves up and down as well as making sure the components are strong enough to handle the weight. Just like the horizontal movement system, it is important that the lifting assist feels fast, unencumbered and responsive while still not being too fast to be dangerous. Therefore it is of interest to find a speed at which the operator experiences these properties.

The Mechlight Pro 50 and the Electric Powerdrive from Movomech have a speed interval of 0 - 0.7 m/s [15][16]. Using this as a reference for reasoning about a suitable maximum vertical movement speed it was decided that 0.7 m/s is probably more than enough for this concept. Thus a lower maximum speed of 0.4 m/s was deemed to be more suitable. It is worth noting that this speed is something which can be tuned and changed quite easily later on should it be necessary.

For lifting, the device should be able to handle parts weighing up to 10 kg as this is the range specified in the beginning of the project. This is the weight to be lifted and the components should therefore be able to handle a total of at least 10 kg plus its own weight. However if it is of interest to make a more flexible assist that can handle different applications, this requirement can easily be increased. The concept suggests powering the vertical movement using pneumatics. Since this would be the same technology currently being used in the current lift assists, feasibility is easily proven for this part of the concept. The current devices can lift the weight of the objects using pneumatics which means that it would be possible in this concept as well.

5.6.1.4 Summary

To conclude the implementation of this concept, Figure 5.18 shows a flow chart containing all components needed to for controlling the concept and how they are coupled together and listed are all controllable components present in this concept. The only necessary component not yet mentioned is an *Electronic Control Unit*, ECU. This is a computer that is needed to control all components mentioned.

- Handle sensors
  - Force Registration: Linear, 40 N minimum
  - Size: Small enough to fit four inside the handle and one on top and bottom
  - Durable to handle near constant use
- Electrical Motors
  - Speed: 4 km/h horizontal movement, minimum
  - Acceleration: 1.1 m/s^2
  - Ability to lock motor in position
  - Ability to handle variable speeds
- Telescopic Gripper
  - Pneumatic or electric powered
  - Speed: 0 - 0.4 m/s
  - Ability to stay in place
- Custom gripper depending on part

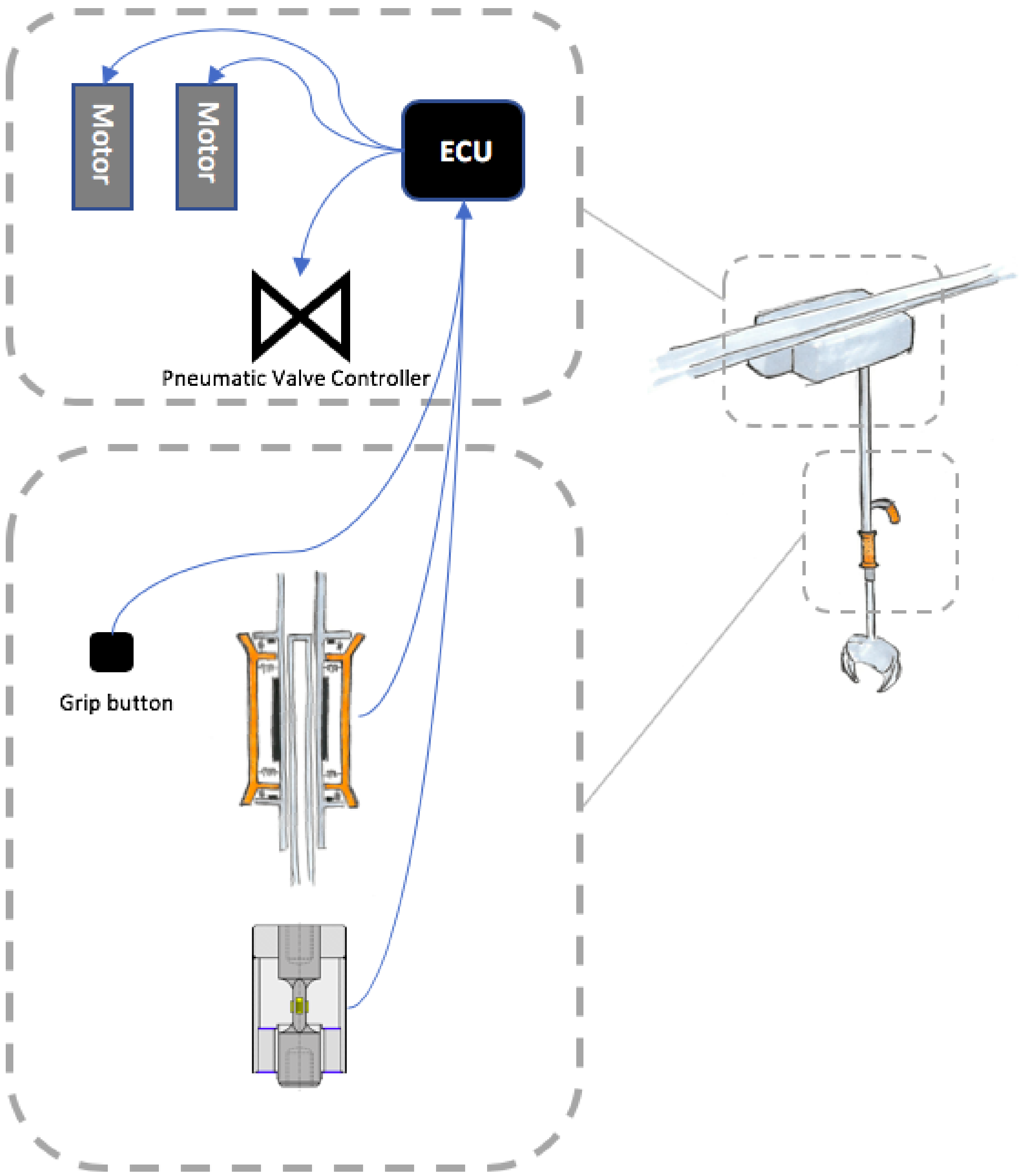


Figure 5.18: Flow chart showing all controllable components present, excluding the gripper, in the Overhead Crane concept.

5.6.2 Actuated Lifting Glove

The Actuated Lifting Glove concept is very different from the Overhead Crane and requires investigation of different aspects for implementation. The implementation investigation has been split up and described according to the different parts of the concept.

5.6.2.1 Grip Assistance

As described previously this concept utilises actuators fitted to a glove with wires running along the palm of the hand and are anchored in the fingertips. The actuators are triggered by force sensors placed on the fingertips of the glove and provide the grip strength. It was considered to be of interest to verify the general functionality of the idea and this was done by crafting the simple prototype that can be seen in Figure 5.19. As can be seen, string and a work glove has been used to simulate the actuated glove. The gripping functionality was then verified by wearing the glove and pulling on the strings as shown in Figure 5.20. The results were that, like expected, the grip tightened without any effort from the hand in the glove and objects such as a glass of water could easily be gripped and lifted while the hand wearing the glove was completely relaxed.

Figure 5.19: Prototype of actuated glove for verifying gripping function

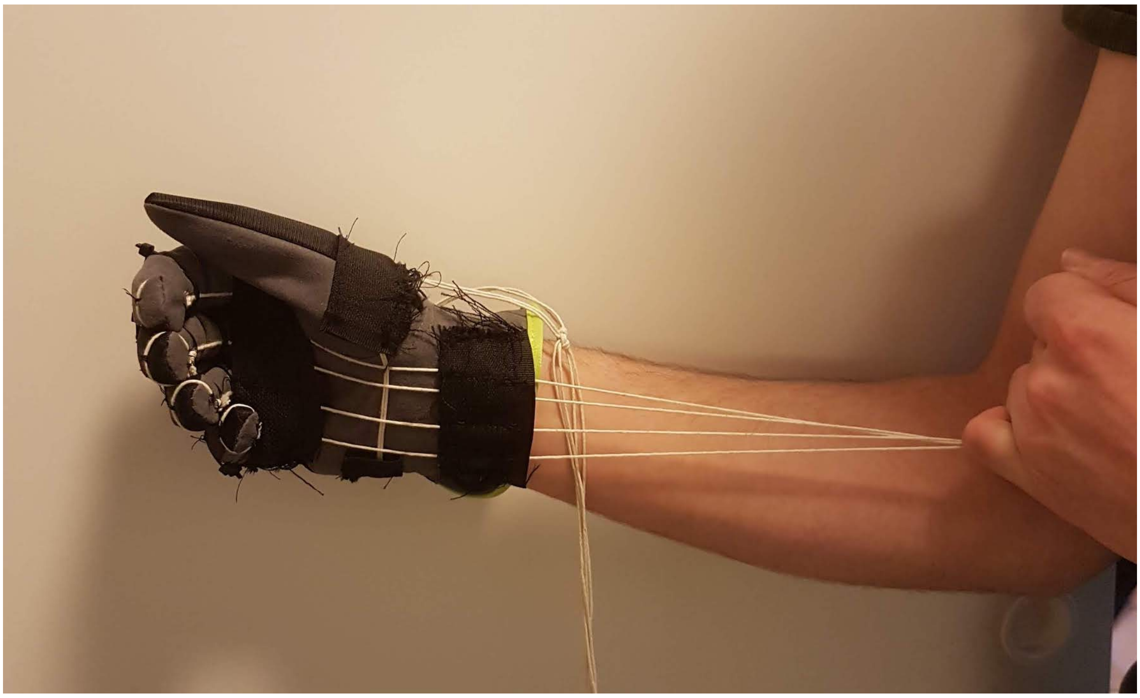


Figure 5.20: Verification of gripping functionality

To be able to accomplish this same functionality in a full scale product, the actuators have to be strong enough to provide enough grip strength to hold parts weighing up to 10 kg split among all five fingers. They also have to be able to extend and retract far enough to retain the full range of motion of the operators fingers and be fairly fast. Moreover the actuators also have to be fairly lightweight and small to allow for five of them to be worn on the forearm without being to heavy or cause discomfort. Finally the actuators have to have a high duty cycle, estimated at least $\sim 80\%$ to allow for nearly constant usage and to ensure the operator does not have to wait until he or she can lift a part.

Mechanical Analysis
In order for the actuators to give an appropriate force corresponding to the force registered in the fingertip sensors, the relationship between the actuator and the actuator cord anchor point in the finger must be determined. More specifically the relationship between the pulling force exerted by the actuator and the resulting force in the fingertip. The principle behind the gripping function in this concept is called underactuation (see Definitions). The mentioned relationship is investigated and described for an underactuated robotic hand in the report *A highly-underactuated robotic hand with force and joint angle sensors* by Long Wang et al. [29]

The report covers the modelling and simulation of a tendon-pin underactuated (TP-UA) robotic hand which utilises a tendon attached to the finger segments with pins and divides the process of gripping an object into three distinct stages. This mechanism is very similar to the gripping mechanism used in this project where tendons run along, and are attached to the fingers. The model and the three gripping stages are illustrated in Figure 5.21.

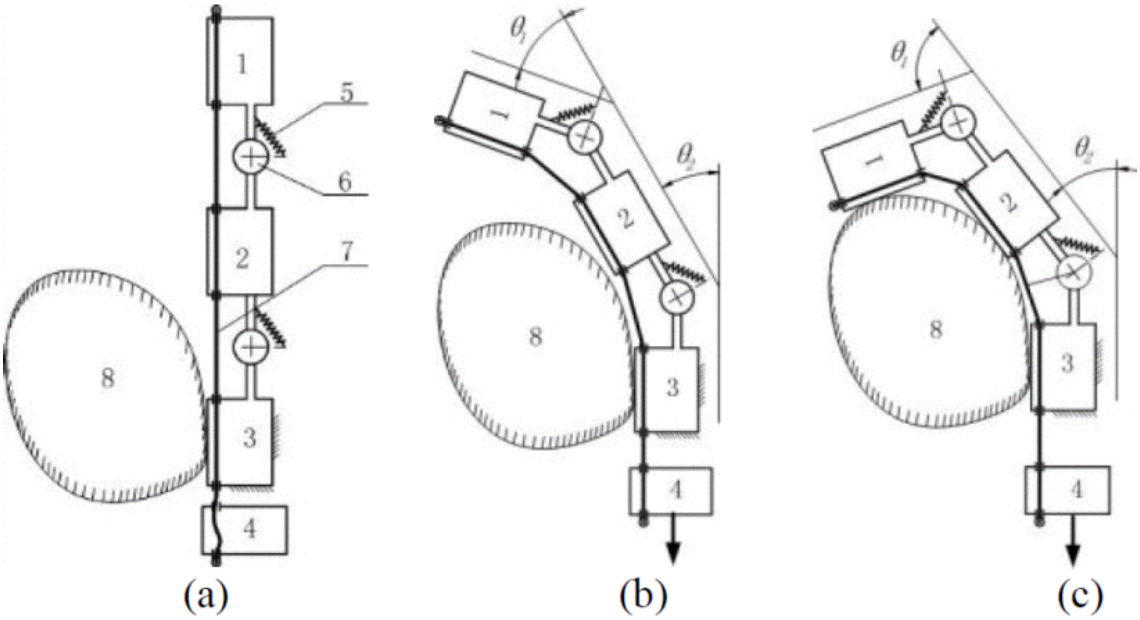


Figure 5.21: Model used for developement of underactuated robotic hand by Long Wang et al. Depicting: (a) the initial stage, (b) the pre-shaping stage, and (c) the closing stage. From [30].

In Figure 5.21, 8 represents the object to be gripped, 1-3 are the solid links in the finger, 4 represents the actuator pulling, 7 is the actuator tendon cord, 6 is a joint in the finger and 5 is a spring used for the finger to return to a straightened shape when the actuator is not applying any force.

In the paper by Wang et al. some assumptions and simplifications of reality had to be made for the mechanical analysis. The first assumption is frictionless joints in the fingers which allows the tendon contact points to be modelled as pulleys. The finger segments are assumed to be massless resulting in no gravitational forces acting on the joints and the finger segments are also assumed to be symmetric and identical. Lastly the finger movements are considered to be quasi-static (see Definitions).

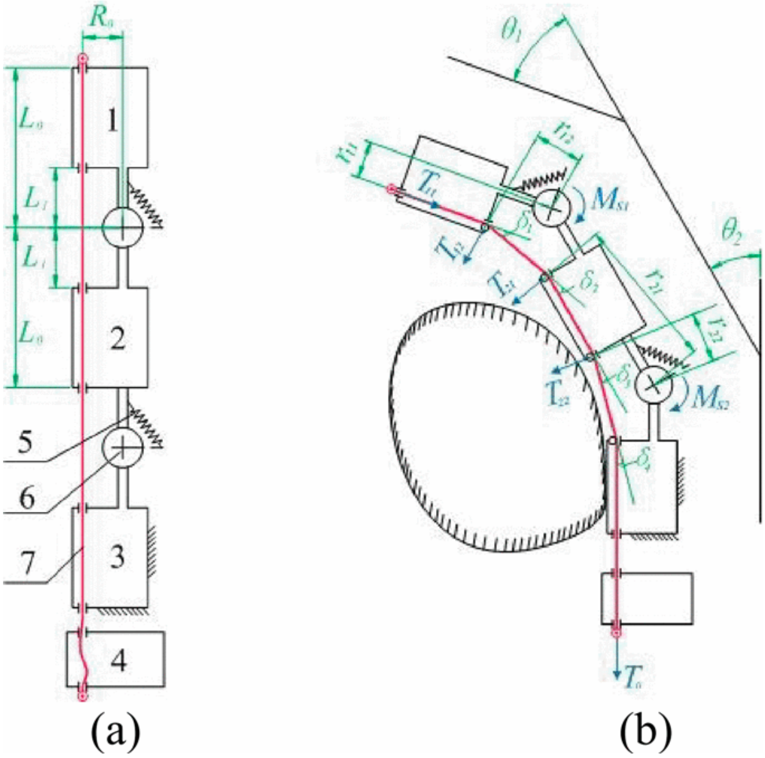


Figure 5.22: Model for mechanical analysis of the pre-shaping stage. From [31].

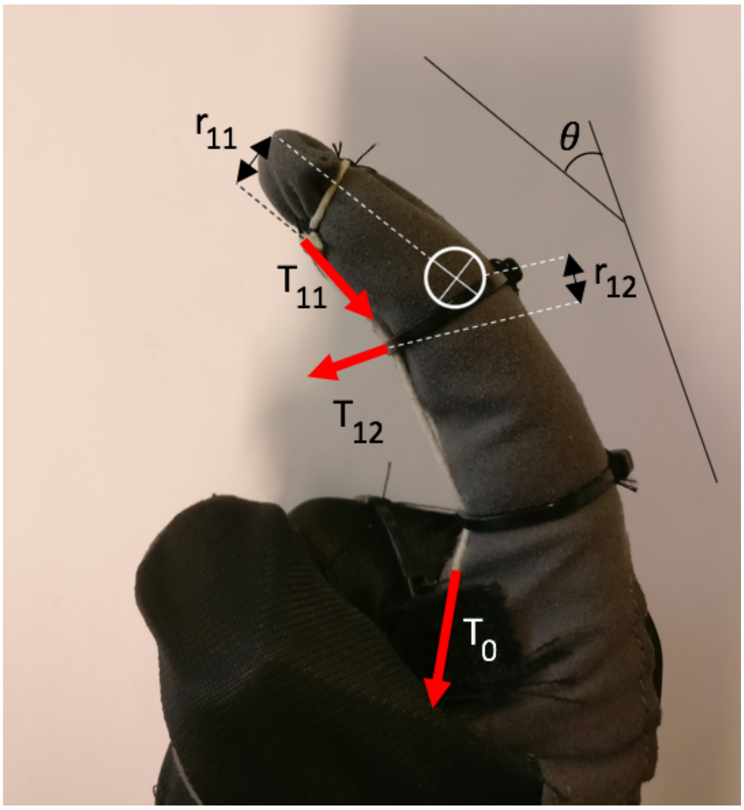


Figure 5.23: Model derived from model presented in [29] according to the concept and mechanics presented in this report.

From Figure 5.22 (a), four design parameters are deduced, L_0, L_1, R_0 and K. K is the stiffness of the return springs used to straighten the fingers when the actuators are not pulling. Unlike the paper by L. Wang et al., this project does not have an entirely mechanical hand, but a glove worn by an actual human hand. This means that in this project the return springs corresponds to the muscles and tendons in the operator's fingers. Furthermore, it is the operator who provides the corresponding spring force in the joints. However, since the actuators only activate when the operator is gripping it is assumed that the operator does not provide resistance to the actuator, thus including the return springs is redundant. Therefore, for this project K and the resulting torques M_{s1}, M_{s2} are assumed to be 0.

In the work by L. Wong et al., both the pre-shaping stage and the closing stage are modelled since the actuators control the entire motion of grasping an object. In the case of this project, only the last of the three stages, the closing stage, is relevant since it is the only stage where the actuators exert any force on the system. The pre-shaping stage is done entirely by the operator and is considered completed when all finger segments of the glove is in contact with the object and the fingertip sensors start registering force values. Therefore the initial stage and pre-shaping stage is beyond the control of the actuators and the mechanics of these stages need not be studied.

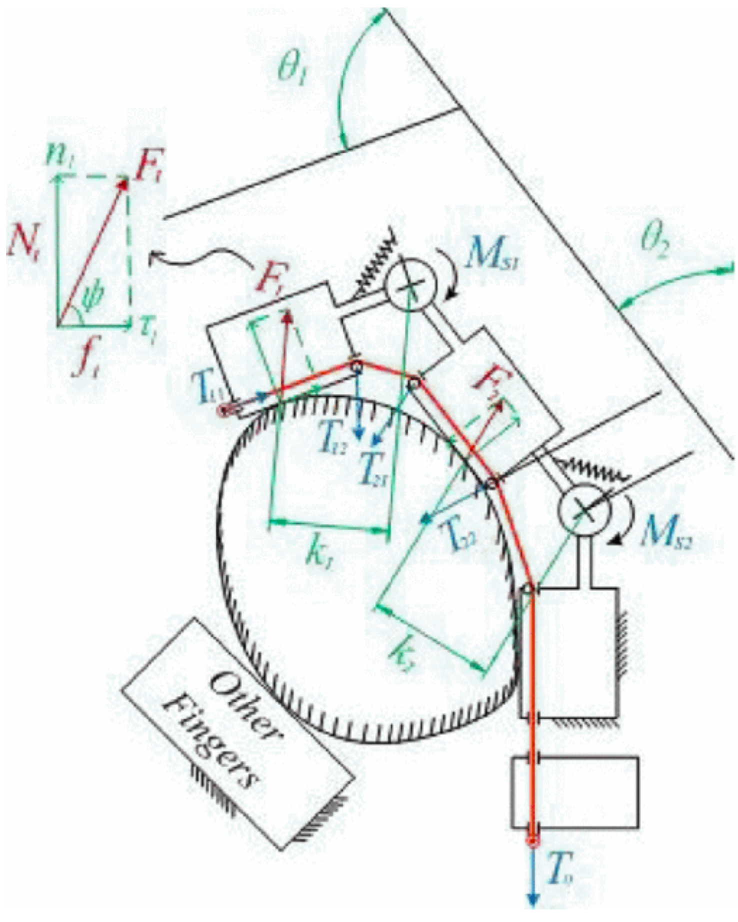


Figure 5.24: Model for the mechanical analysis of the closing stage. From [32].

Illustrated in Figure 5.24 are two contact forces, F_1 and F_2, resulting from the pulling force of the actuator T_0. For this project only F_1, the force at the fingertip, is of interest since it is this force which will be registered by the sensors and be used to control the actuators. From Figure 5.22 (b) and Figure 5.24, Wang et al. derives the following torque equilibrium equation regarding the force, F_1, in the fingertip.

$$T_{11}r_{11} + T_{12}r_{12} - F_1k_1 = M_{s1}(\theta_1) \tag{5.6}$$

T_{11} and T_{12} are forces in the tip of the finger. r_{11} and r_{12} are leverages as shown in Figure 5.22 and k_1 is the leverage between the contact force and the outermost joint as shown in Figure 5.24. M_{s1} is the torque in the outermost joint. To determine the force F_1 for the actuated glove concept, the components T_{11}, r_{11}, T_{12}, r_{12} and $M_{s1}(\theta)$ have to be derived from the system in Figure 5.23. First the assumption is made that

$$M_{s1}(\theta) = 0, \quad \forall\ \theta \tag{5.7}$$

as previously mentioned. Further, the simple equations

$$T_{11} = T_0 \tag{5.8}$$

$$r_{11} = R_0 \tag{5.9}$$

are derived from Fig. 5.23 and Fig.5.24 a) based on the geometry of the concept. T_{12} is calculated from a quasi-static force equilibrium of the system and r_{12} is calculated based on the geometry of the system as

$$T_{12} = 2T_0 \sin\left(\frac{\theta}{2}\right) \tag{5.10}$$

$$r_{12} = R_0 \cos(90 - \theta) \tag{5.11}$$

With the presented equations and k_1 being the distance between the contact point and the finger joint, perpendicular to the contact force F_1, the contact force in the fingertip depending on the actuator pulling force, T_0, can be calculated from Equation 5.6. This relationship can then be used as a basis for controlling the actuators. By using the force measured from the fingertip sensor and acquiring knowledge about the angles in the finger joints, the relationship allows for the possibility of precisely controlling the pulling force produced by the actuator depending on the grip.

Estimating exactly how strong the actuators have to be is difficult, but since the concept draws inspiration from products such as the NASA RoboGlove, this was a natural place to begin. NASA uses a modified actuator derived from their own R2 Finger Actuator previously developed for use in a completely robotic hand [25]. For continuous use, the R2 Finger Actuator is capable of providing slightly more than 50 N of force [25]. Using Equation 5.6 with $T_0 = 50$ N and $r_{11} = R_0 =\sim 0.01$ m results in a torque at the joint in the fingertip of 0.5 Nm which is enough to counter a weight of roughly 5 kg at the fingertip. With this in mind 50 N should be more than enough to grip a 10 kg object split among all five fingers. Therefore the actuator strength requirement is set to 50 N for each actuator.

By measuring the distance the strings had to be pulled when gripping with the prototype in Figure 5.25, it could be determined approximately what stroke length would be needed from in the actuators for this implementation. The results showed that 65 mm stroke length would be enough for the case of the prototype but to account for larger hands and to have a margin, the minimum performance requirement was set to ~ 80 mm.

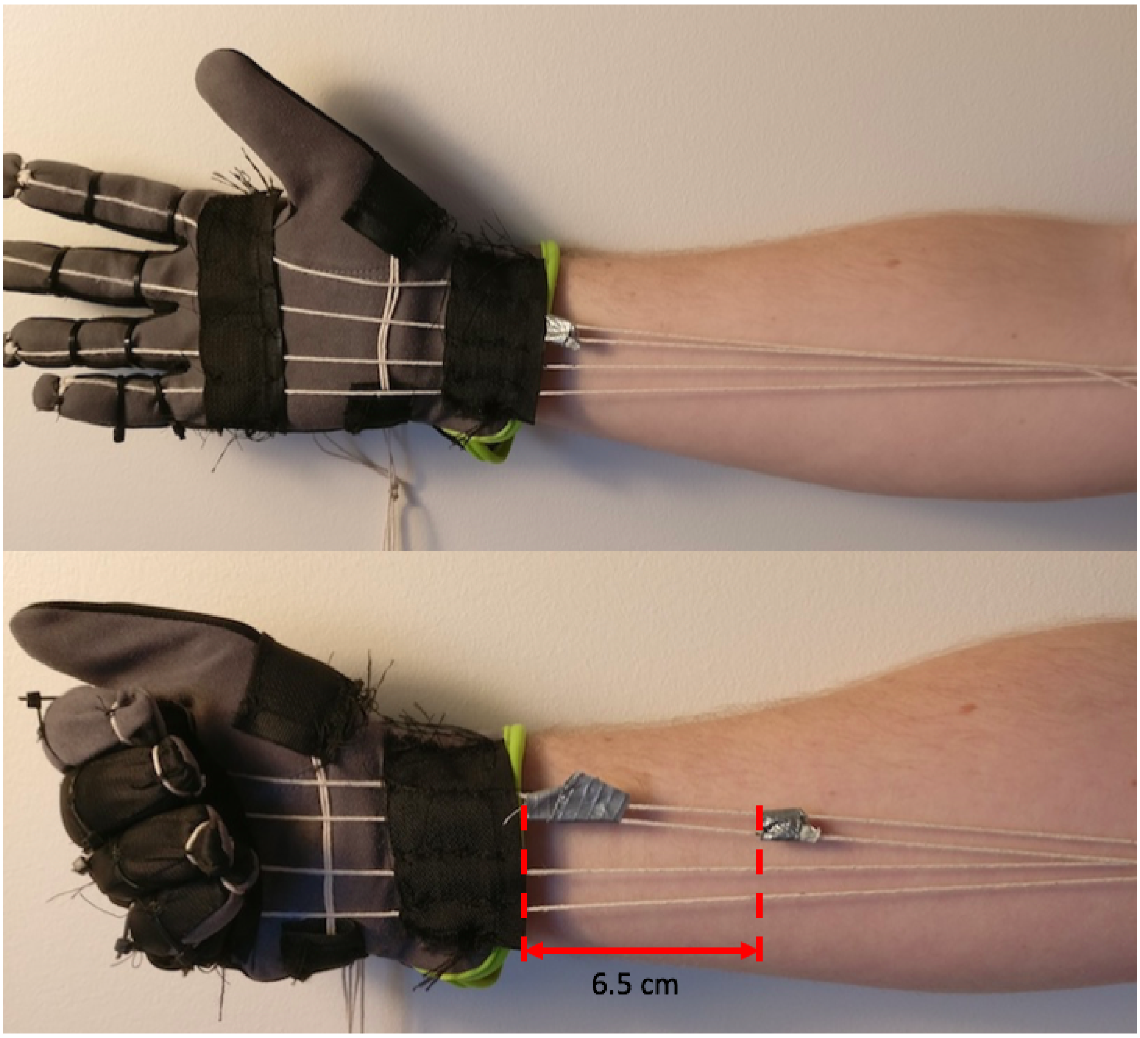


Figure 5.25: Measurement of distance strings have to be pulled for full grip.

The force sensors used to control the actuators have to be able to register a range of forces in order to give the operator better precision control of the grip strength. They also have to be small enough to fit in the fingertip of the glove and durable to withstand constant use.

5.6.2.2 Lifting Assist

In the concept description, two ways for solving the issue of providing lifting assistance are presented. It is also mentioned that one of these ways is not compatible with the safety standards available today. However, this solution was studied anyways as it was considered to possibly be the better solution if an exception in the generalised safety standards was to be made. Therefore both of these ways to solve the lifting issue were investigated with regards to implementation.

The first idea to solve this problem was by attaching the glove to a winch which is in turn attached to an overhead rail system like the one that exists today. This solution is fairly simple and with regard to defining minimum performance requirements and picking components, only one component and its requirements has to be investigated. The lifting in this case only relies on one controllable component which is the winch and the only performance requirement needed for this is the weight which it can pull. The weight to be compensated for is the combined weight of the glove and a part. Thus, the part and the glove is rendered virtually weightless and the lifting operation requires no more effort than moving ones arm. The weight of the parts is no more than 10 kg. Therefore a winch capable of lifting at least 20 kg should be enough for this application. Apart from this the winch also has to have some functions such as being able to act as a brake so that loads can be kept suspended at a certain height. Just like in the overhead crane concept, vertical speed is an important factor in creating an assist that feels responsive. In this case it was concluded that a similar vertical speed to that of the overhead crane concept, $\sim$ 0.2 m/s would be sufficient. Horizontal speed does not need to be considered for this concept since it does not utilise powered horizontal movement.

The other alternative for providing lifting assistance works similarly to the actuated fingers for gripping and is described in detail in the concept description. This means that another actuator would have to be added for lifting the arm. This actuator has to be stronger than the ones used for gripping strength since it has to lift the entire weight of the object and the glove, just like the winch. Furthermore it pulls alongside the arm and not directly from above as the winch does. This of course means that a larger force is needed than that from the finger actuators and requires a larger, heavier actuator. However this actuator would be placed on the back of the operator, on a fixed plate to keep it in place. The actuator for the arm is also controlled by the sensors in the fingertips but in a different manner. This actuator does not use a linear scale of how hard the sensor is pressed. Instead it recognises the input in a binary on/off fashion meaning that any input above a small threshold on the sensors count. Since constantly measuring the weight held would prove very difficult, the system has to determine when lifting assistance is needed. This means that the system has to determine when a part is gripped and when it is let go. This is done by using the sensors as described. When all sensors in the hand register above the defined threshold, the actuator is activated and gives assistance according to the predefined weight of the product lifted at that station. Similarly, when all sensors register below the threshold, meaning the operator lets go of the part, the actuator is deactivated. When a part is not being lifted and the actuator is deactivated, it is not completely switched off but instead only compensating for the weight of the glove and not the glove and the part.

Mechanical Analysis
The main aspects to consider for the actuators providing lift assist are that they need to be strong enough to compensate for the weight of the parts and the glove. They also need to have a high duty cycle to allow for near constant use and be fairly fast. Their stroke length must be long enough to retain the arm and elbow range of motion. Lastly they need to be small and lightweight enough to be worn comfortably on the back.

Regarding how much force is needed from the actuator, this mechanical analysis lays the foundation for performing these calculations based on the weight of the part and the rest of the glove. The lifting mechanism in the arm is very similar to that of the gripping function. The lifting assistance in the arm is designed to revolve around the elbow of the operator. When the operator is holding an object, a force is generated in the system and is the result of the weight of the held part and the weight of the glove. Figure 5.26 depicts the profile of an arm, the forces present when lifting an object as well as the actuator cord. The forearm of the worker acts as a lever which when multiplied with the generated force results in a torque at the elbow joint. The lever is denoted with l in Figure 5.26 and is calculated as

$$l = L\cos\theta \tag{5.12}$$

where L is the length of the forearm. The purpose of the actuator is simply to counter this torque by pulling on the cord with the force T_0. This creates another torque at the elbow joint, comprised of T_0 and the perpendicular distance between the anchor point at the wrist and the elbow joint, R_0, also shown in Figure 5.26. In the same manner as previously described for the gripping function, this forms a relation that if given the angle at the elbow joint and the weight held, can be used to determine the pulling force necessary from the actuator. F_g is the gravitational force from the object being held.

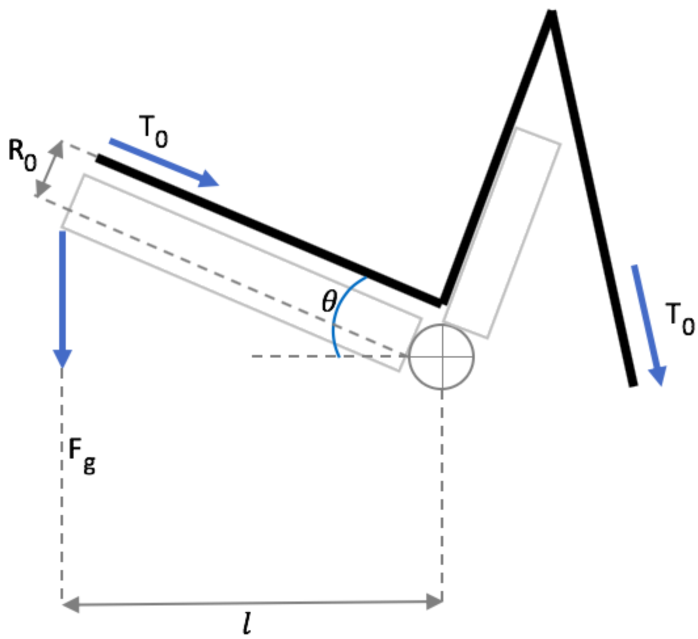


Figure 5.26: Mechanical visualisation of lifting assistance of the arm.

Again, assuming a frictionless elbow joint and quasi-static system, the torque equilibrium equation for this part of the system then becomes

$$F_g l = T_0 R_0 \tag{5.13}$$

One problem with this configuration is that when F_g is perpendicular to the lower arm i.e. when l is at its maximum value, T_0 has to be very large to be able to compensate for F_g. This is because of the large difference in leverage between the distances R_0 and l. There are two possible ways to address this: the first by designing the work station so that the natural behaviour is to pick parts in such a way that large values of l are avoided. The second option is to include another anchor point for the actuator cord further up the upper arm as shown in Fig.5.27. This would slightly change the angle that T_0 acts on the lower arm and therefore R_0 will become greater, creating a better leverage for the actuator, allowing T_0 to be smaller. Thus by making slight adjustments to make R_0 and l more similar in size, the force with which the actuator has to pull becomes smaller.

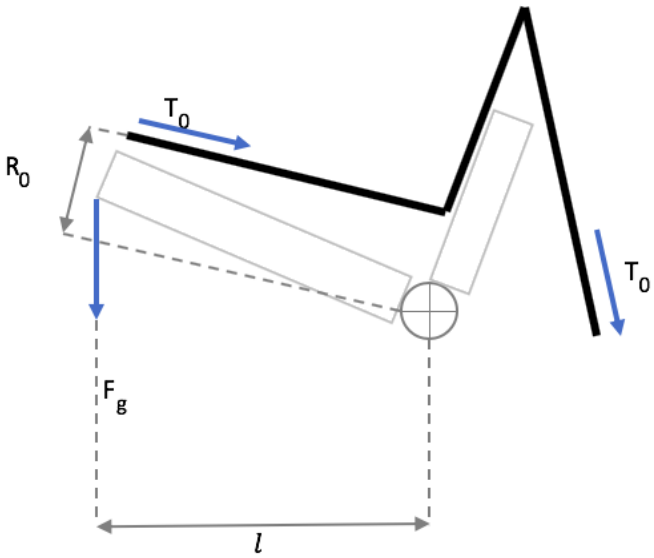


Figure 5.27: Example of how the configuration of the actuator cord can result in a greater R_0.

Estimating the needed stroke length of the actuators was done in a similar way as for the finger actuators in Figure 5.25. The stroke length was measured using a string attached to the wrist which ran along the arm up to the shoulder. By then measuring how the length of the string changed while bending the arm an estimate was made that at least 200 mm would be necessary.

5.6.2.3 Power Supply

As previously mentioned an operator is not allowed to be attached to a fixture in any way according to Volvo Cars safety regulations. This means that a power cord cannot be used to supply the actuators, sensors and an ECU with power. Instead batteries have to be used and carried around when wearing the Actuated Lifting Glove. Since Volvo Cars produce cars 24 hours a day, multiple batteries are needed so they can be swapped out and recharged. The operators rotate work stations every two hours so the batteries have to have at least a two hour capacity. They also have to be fast and easy to swap out since the operators work by strict time schedules. Finally the batteries also have to be of light weight since the operator will be carrying them for a long period of time and a heavy batteries will increase the work strain and discomfort.

If it is possible to attach the glove to a winch on a rail, as was the original idea, the issue of power supply would be much easier to solve. Then a power cord could be hung from the rail fixture and run along the winch down to the actuators and sensors and provide them with power. This would also relieve the operator from having to carry around batteries and eliminate the need to swap batteries out when they run out of charge.

5.6.2.4 Summary

To conclude the implementation of the Actuated Lifting Glove, this list summarises what components would be needed and their performance requirements. Just like the Overhead Crane Concept, an ECU is also needed in this concept and is placed onboard the device and worn by the operator.

- Finger Actuators, one per finger
  - Stroke Length: 80 mm minimum
  - Strength: 50 N
  - Size: Small enough to fit five on a forearm
  - Weight: As light as possible
  - Duty Cycle: At least 80%
- Fingertip Sensors
  - Force Registration: Linear
  - Small enough to fit on a fingertip
  - Durable enough to handle near constant use
- Arm Actuators
  - Stroke Length: 200 mm minimum
  - Strength: Calculated using Equation 5.13
  - Size: Small enough for two to be worn on the back
  - Weight: As light as possible
  - Duty Cycle: 100%
- Battery Power Supply
  - Capacity: 2 hours minimum
  - Battery Change: Preferably less than 1 minute
  - Size: Small enough to be worn on the back
  - Weight: As light as possible

Furthermore, a flow chart was also made for this concept and Figure 5.28 shows the complete system containing all components mentioned, except power supply, and how they are connected to each other.

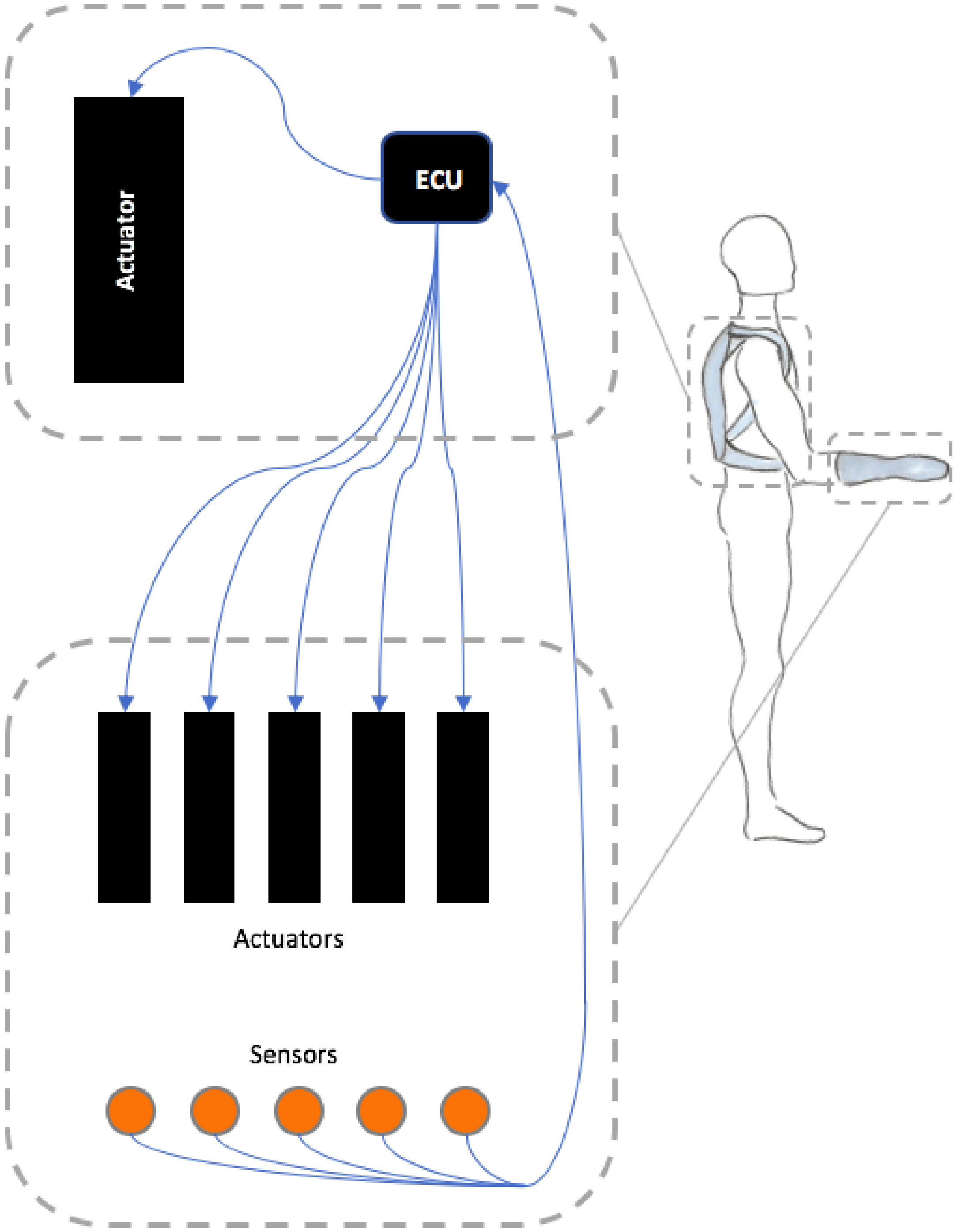


Figure 5.28: Flow chart showing all controllable components present in the concept for assistance in one arm.

6
Discussion

This chapter reflects on the project in its entirety, discussing the work itself that has been done, the results and conclusions reached as well as the validity of the process and results.

6.1 Assessing the Situation at Volvo Cars

Assessing the current situation was considered to be a very important part of the entire project. Without laying a proper foundation for the project work, one can never be sure that the results later achieved are of value. Therefore in order to validate and trust the results, one must question the method used for gaining an understanding of the problem. To gather information about the problem at Volvo Cars operators were interviewed, managers spoken to and the devices present were tested by the project members. During this stage, the operator interviews were the most challenging part to get right.

The interviews were held at the work station while the operators were working because it was not possible for them to step away without falling behind schedule. This might not have been optimal and one might prefer a quiet, secluded room to talk freely and without preoccupation. However doing the interview at the work station allowed the operators to show first hand exactly what they meant and the problems they experienced while answering the questions. The interviews themselves where kept short as to not take up too much time and after some initial reluctance the operators opened up and provided satisfactory answers and valuable insights.

The other option considered was to hand out a survey, its main advantage being the possibility to target a larger number of workers. It was ultimately decided that the operators would be interviewed instead due to a survey not being practically doable for a number of reasons. The main issue with the proposed survey was when to hand it out and how to collect it afterwards. The operators are only gathered once a week for brief start up meetings with little time to spare before being spread out at different work stations. Another issue was when the operators would have time to fill out the survey since most of them work on the manufacturing line under a high work pace. One option discussed was to conduct the survey during a break, but was quickly ruled out since the operators spread out over different break rooms and it would require intruding on their free time.

Based on this a risk was identified that it could be too inconvenient for the operators to fill out a survey, resulting in a low response rate and answer quality. Thus the survey would lose its one advantage of a potentially larger number of respondents and it was decided to conduct interviews instead. With interviews the response rate could be guaranteed and the quality of the answers somewhat influenced.

Discussing the situation with the other relevant parties such as managers and area experts was a significantly easier task since a simple meeting could be held for these discussions. By not being limited in time or what questions could be asked, many topics surrounding the issue could be covered. By investigating all these different aspects enough information is considered to have been gathered to form a comprehensive understanding of the situation.

6.2 Requirement Specification

The requirement specification was formed after assessing the current situation. The specification was based upon information gathered from the operator interviews, meetings with experts and by investigating the current lifting assist. The focus during the meetings and interviews were mostly on the current device or similar existing technology and hence the specification became more applicable for solutions similar to the current existing lifting assist. As concepts began to be generated and evaluated, it became clear that the requirements set earlier were heavily biased towards overhead crane concepts and not of very much use for some of the other ideas generated. This posed an issue in the project since the requirement specification was meant to be a tool for evaluating and comparing all concepts using the same reference frame. As a result, the requirement specification was revised at the concept evaluation stage of the project and made more general in order to be applicable for a wider range of solutions.

Another consequence from this was that the requirements could no longer be as specific as previously. However it was considered to be more important, and also more interesting for the project and Volvo Cars, to be able to use the requirement specification to compare a wider range of concept ideas rather than being very specific for a certain type of solution.

It is also interesting to discuss what level of detail a requirement specification should contain. One option is that it should match the level of detail one is aiming for in the presented concepts. In this project however, some parts of the requirement specification are very detailed and more specific than the information presented in the concepts. The reason for this is that the Volvo Cars standards used as a basis for many of the requirements presented very specific values for some cases.

In retrospect, it was also discussed that having a non-binary scale for filling out the requirement specification might have added some extra value to the results. This would give more information to use as a basis for comparing concepts. However it would also require more detailed answers to the questions presented, which might not be known. This would make such a scale redundant and the answers uncertain as there might not be any real reason behind a particular answer.

6.3 Concept Generation and Evaluation

The concept generation stage is difficult to tie to a specific part of the project since ideas and solutions were thought of continuously while assessing the work station at Volvo Cars. However, in order to generate ideas in a structured and orderly manner, established methods for concept generation were followed as much as possible. These methods were mainly Brainstorming, Attribute Listing and Analogical Thinking.

The goal with the concept generation was to be open minded and come up with many different types of solutions and ideas and try to minimise bias towards a certain type of concept. This proved to be quite challenging since almost all existing solutions for similar applications utilise some form of overhead crane or rail system. This made it difficult to "think outside the box" and thus the majority of concepts generated were in the shape of an overhead crane of some sort. Due to an interest from Volvo Cars to also find a more original concept, an effort was made to come up with some ideas that did not utilise some sort of overhead crane which amongst others, resulted in the actuated glove concept. One problem that arose during this was that the crane type concepts were more detailed since there exists many similar solutions to draw inspiration from, which was not the case for the other concepts. Thus when generating these other concepts much time had to be spent discussing the basic idea and its feasibility.

Another problem that was encountered because of this was evaluating the concepts. Having concepts that were fundamentally different in the basic principles and level of detail proved very difficult to compare against each other in a meaningful way. This led to the concepts mainly being evaluated individually and the main comparison being through the requirement specification. Eventually, after a selective process the two concepts presented in this report remained. In order to finally be able to compare them against each other, much effort was spent elaborating the details of the concepts further, especially the actuated glove concept, so that they contained roughly the same amount of detail.

Delving deeper into the topic of level of detail one can also discuss in general how specific one should be and what level of detail is suitable during which stage of a product development process. In this project the concepts generated are still in the fairly early stages of a product development process. Thus it was decided that in order to promote further development of the concepts it would be better not to go into too much detail. Instead the focus was to provide a framework and general thoughts and ideas for the concepts. Again, going into too much detail at this stage might limit future concept development or lead to unnecessary work since the specifics of the concepts will be decided later in the process. Thoroughly investigating the specifics will be done by Volvo Cars regardless of if it is also done at this point or not. Therefore, doing these investigations in this project were considered to be of little or no future value.

6.4 Chosen Concepts and Implementation

Two concepts were presented in the end, an overhead crane and an actuated glove. In this section the concepts are discussed regarding their general feasibility, their potential future and the advantages and disadvantages they imply.

6.4.1 Advantages and Disadvantages of the Presented Concepts

Two concepts were in the end presented to Volvo Cars, covering both the idea behind the concepts as well as investigations into the feasibility and possible ways to implement said solutions. In case Volvo Cars chooses to make a change to the work station according to the recommendations of this report, one final evaluation would have to be carried out; choosing between the two concepts presented. Since the two concepts are very different from each other, this final choice might require building and testing of prototypes and in general a very thorough investigation that is outside the scope of this project. However the two concepts were discussed in this section and briefly compared against each other.

6.4.1.1 Overhead crane

Compared with the Actuated Lifting Glove concept the Overhead Crane has a few advantages. Firstly, the technology used in the crane concept have been in use for manufacturing purposes for quite some time. This means that the technology involved in this solution already exists and has been tried and tested so no heavy development is needed. The concept itself is also very similar to other already existing cranes available on the market. This leads to the concept being familiar for operators and that there are already well established manufacturers who could build the concept in reality.

From an implementation perspective the crane concept also has a few key strengths since it does not require any installation of new fixtures at Volvo Cars. The concept can utilise the pneumatic system and rail system already in place at Volvo Cars today.

Moving on to the functionality of the crane it takes the entire work load off of the operator who does not have to lift any weight at any point during an operation. The concept itself is very flexible since the control interface can be combined with different grippers allowing for a wide variety of parts to be picked and operations to be performed. The crane can also lift a wide range of weights, with its weight measurement system automatically compensating for the weight lifted the crane is ultimately only being limited by the power supplied by the pneumatic system.

Overall the design of the concept is fairly simple and should be quite easy to implement for an experienced manufacturer.

As with any concept the crane has a few disadvantages and interestingly many of the advantages can also be seen as such. The fact that it utilises tried and tested technology means that it is not very innovative and since there are many similar solutions this concept is not unique either. This can be regarded as not being exciting and forward thinking and it is also easy to get stuck in old solutions to old problems instead of coming up with something new and fresh. Another advantage that can be a disadvantage is the flexibility through multiple grippers. Requiring different grippers for different parts or tasks means it will not just be more flexible but also more expensive. It is also time consuming having to swap grippers which also take up extra storage space when not in use compared to having a universal gripping device. Besides this, the utilisation of the current rail systems limits the movement and operating space of the device. The rail system itself also has to be able to handle relatively high speeds and large accelerations in order for the crane to be responsive and feel natural to use.

In the following part the advantages and disadvantages discussed above are summarised.
Advantages:

- Tried and tested technology
- Similar to other cranes, familiar for operator
- Uses the pneumatic system already in place at Volvo
- Uses rail system already in place at Volvo
- Device lifts entire load, no load on operator
- Flexible, can change gripper to pick different parts
- Wide range of weights possible to lift
- Fairly simple design
- Power can be supplied externally

Disadvantages:

- Not unique, there are many very similar solutions on the market
- Not very innovative
- Requires different grippers for different parts, more expensive
- Limited operating space and movement
- Requires high speed and quick response to feel natural to use

6.4.1.2 Actuated Lifting Glove

The main advantage with the actuated glove is its extreme flexibility. Since it acts as a strength enhancement for the operators hands and arms it is not limited by an object's geometrical shape. Thus, as long as the object is pickable by the human hand, it is pickable by the actuated glove. With this flexibility and dexterity the glove can also be used in other applications than picking parts, such as relieving strain on an operator when handling heavy tools or in assembly operations. Besides this, the device is portable and can easily be moved between work stations or be used in operations where the operator constantly has to move. The concept itself is innovative and is designed to be as intuitive as possible, serving as an extension of the human body rather than a device which needs to be controlled.

However, as with the overhead crane concept every advantage comes with a trade off. The biggest disadvantage with the glove concept is that the technology is new and fairly untested. This means that much testing and development is still needed before it is ready to be implemented in reality. This development process can often be long and expensive and require special competence to conduct. Design wise the concept is relatively complex when compared to existing lifting devices which makes modelling and testing of the concept more difficult.

Another big disadvantage stems from the high flexibility. Since the glove serves as an extension of the human body, the lifted weight is "transferred" to a stronger part of the body rather than relieving the operator of the load entirely. This combined with the concept being worn by the operator limits how big and strong actuators can be used and ultimately significantly limits the maximum load the device can lift. Because of safety reasons an external power supply cannot be utilised and batteries have to be carried by the operator, adding to the weight of the device making it more cumbersome to wear. The battery capacity limits how long an operator can work before having to swap batteries resulting in a short down time. With batteries comes an increased safety risk since batteries can be flammable and pose a risk to the environment if not recycled properly at the end of their lifetime. Finally, having an operator wear a lifting assist provides new challenges in ensuring the safety and well being of the operator. This might lead to new safety standards having to be formulated and extensive testing performed before the device can be implemented in reality.

Another issue that has to be addressed with this concept is that it does not fulfil the requirement of allowing the worker to operate solely in the "green area" of Appendix A, Figure 1 regarding the height. The worker would still have to reach down to pick the parts. To overcome this in the case of implementing such an assist, height adjustable material presentation would have to be implemented as well.

The advantages and disadvantages discussed are summarised as follows
Advantages:

- Flexible, can pick anything the operator can by hand
- Portable, is not bound to a specific work station
- Possible to apply to different problems such as holding tools etc.
- Innovative
- Intuitive use, simply extends the human body functions

Disadvantages:

- New and untested technology
- Complex testing and development, expensive

- Fairly complex design
- Does only transfer lifted weight to another part of the body
- Limited range of weights possible to lift
- Cannot make use of external power supply, batteries needed
- Batteries flammable, pose a risk to the environment
- Must be worn, added weight to the operator
- Operator is strapped in - requires safety functions to avoid injury

Like mentioned, the concepts are very different from each other and this becomes especially evident when listing both of their advantages and disadvantages. When listing these points next to each other the concepts appear to be almost polar opposites. What can be seen for many of the points is that one concepts weakness is the others strength. An example of this is the attribute of flexibility or lifting strength. The actuated glove concept allows for very good flexibility, which is one of the biggest weaknesses of the crane concept. Furthermore the actuated glove suffers from the fact that it can only be used for lighter objects whereas the overhead crane has the potential for handling greater weights.

6.4.2 The Authors' Comments on the Concepts

When researching the NASA Roboglove [20] for details about the actuators used to provide the gripping function it was discovered that NASA had designed and built their own actuators. These actuators are a modified version of the actuators used in the Robonaut 2's hand [25]. The reason for why NASA opted to build actuators instead of using ones readily available on the market is unknown, but it could be attributed to performance and dimensional aspects. A concept like the Roboglove or the Actuated Glove presented in this project requires actuators to be small and lightweight enough to be worn on the forearm, but be strong and have a high duty cycle. There is also not much room for over dimension of the actuators since this may add unnecessary weight.

Another interesting topic is the potential future of the two presented concepts and the general feasibility of ultimately implementing them. This is an aspect of the concepts that is very difficult to quantify and has been purposely left out of evaluation steps such as the requirement specification. The reason for this is that the focus has been kept on the end product and considering for example how much work would be needed might affect the evaluation of the product itself. As mentioned it is still an interesting matter to discuss at this stage as Volvo Cars have to decide whether to proceed with one of the ideas or not.

Based on issues such as investigating what actuators to use in the Actuated Glove concept as discussed earlier, combined with generally being newer and untried technology, the Actuated Glove concept is believed to require more work and time to develop. This means a potentially higher total cost and a longer time before it can be fully implemented. On the contrary, the possibilities of this concept are believed to be greater as such a device could be used for a wide variety of tasks. In conclusion it might be a bigger and more expensive project but could also have a greater usage, both in material handling and manufacturing processes.

The Overhead Crane concept is considered to be the opposite in this case. Implementation is believed to be easier and faster as it is less technologically advanced, proven and existing technology and could be outsourced to a supplier. The disadvantage of this is that it is not as flexible and is only designed for this particular type of work station. Therefore this concept is considered to be more of a "quick-fix" to the problem initially studied whereas the Actuated Glove might be more of a long term investment.

6.5 The Project Seen From a Broader Perspective

When coming up with a new product or solution to a problem it is always important and interesting to take a step back and view the project and its results from an ethical, environmental and sustainability aspect.

The project has its background in continuing with the quest of automation and the project is a result of an ergonomic issue. The project has shown that there exists a problem at the work stations and with the lifting assists available today and that as a result from this workers are put in the line of ergonomic risk. By addressing this problem and presenting a basis for a solution, this project has made an attempt at improving the ergonomics of this type of workstation. This could in turn improve the life of affected workers and in the long run have a positive effect on worker health. This is beneficial for both the worker and the company as the workers may live a longer and healthier life and potentially work for a longer time.

Another common cause for concern is the belief that the push towards automation will eliminate factory jobs. However both of the concepts presented in this report are not designed to replace the operator. On the contrary, the concepts require and are dependent on an operator, just like before.

7
Conclusion

The two concepts presented align well with the aim to continue automation and approaching the topic from a different angle. The operators mainly desire a device that provides assistance without hindering work and want the device to feel swift, easy to use and as an extension of themselves. The developed concepts satisfy these wishes as well as requirements stemming from other aspects of such a device, such as a development and ergonomic point of view. Overall, the comprehensive investigations and work in this report have produced two ideas both well suited to solve the given problem and the conclusion is that both concepts have great potential for further development. With this said, the overhead crane concept is a more well established type of lifting assist than the actuated glove and can serve as a relatively easy and quick fix to the problematic work situation. While still being very interesting and a promising solution, there exists an uncertainty if today's technology is sufficiently developed to allow for the actuated glove to be implemented in reality. Having spent much time investigating and designing these concepts, a feeling has slowly emerged during the project that this might not be the case and that the technology surrounding the actuated glove still needs development. However, the project members remain enthusiastic and with research being done on similar concepts such as the NASA Roboglove and the Bioservo Ironhand, we believe that this type of solution will be commonly utilised in manufacturing in the near future.

To conclude, the main recommendations to Volvo Cars are: a) Look into the implementation of the overhead crane concept or a similar type of solution as a more direct step in the continuous work of improving the situation for their operators. b) Pursue further investigations of the actuated glove concept.

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A
Volvo Cars Ergonomic Standard

The English language version is the original and the reference in case of dispute.

Den engelska språkversionen är originalversion och ska åberopas i händelse av tvist.

Ergonomic requirements — Application

Orientation

This document conforms to Council Directive 90/269/EEC issued by the Council of the European Communities.

To Volvo Cars' production facilities in Sweden, the requirements of this document apply together with Swedish work environment legislation: AFS 2012:2 Ergonomics for the prevention of musculoskeletal disorders (available in Swedish only).

To Volvo Cars' production facilities in other countries, the requirements of this document apply together with the work environment legislation of the respective country.

Each country's legislation is minimum requirement. In case of stricter requirement in this standard, the requirements specified in this standard apply.

This standard also refers to European requirements specified in EN 1005, parts 1-4, Safety of machinery – Human physical performance, and to EN 614-1 Safety of machinery – Ergonomic design principles.

This issue differs from issue 4 in that section 3.7.3 "Reaction torques", sub-section "Angle nutrunner, electronically controlled", a requirement has been introduced stating that a mechanical counterhold shall always be used at torques exceeding 50 Nm. In section 7 "References", some references with respect to assembly at VCBC have been updated.

Contents

Belastningsergonomiska krav — Tillämpning

Orientering

Detta dokument överensstämmer med Europarådets direktiv 90/269/EEC.

För Volvo Personvagnars produktionsanläggningar i Sverige gäller kraven i detta dokument samt svensk arbetsmiljölagstiftning: AFS 2012:2 Belastnings-ergonomi.

För Volvo Personvagnars produktionsanläggningar i övriga länder gäller kraven i detta dokument samt respektive länders arbetsmiljölagstiftning.

Respektive lands lagkrav är minimikrav. I de fall denna standard ställer högre krav än lagstiftningen gäller kraven i denna standard.

Denna standard hänvisar även till europeiska krav som anges i SS-EN 1005, del 1-4, Maskinsäkerhet – Människans fysiska förmåga, samt SS-EN 614-1 Maskinsäkerhet – Principer för ergonomisk design.

Denna utgåva skiljer sig från utgåva 4 genom att i avsnitt 3.7.3 "Reaktionsmoment", underavsnitt "Vinkelmutterdragare, elektroniskt styrd" har krav på att mekaniskt mothåll alltid ska användas vid vridmoment över 50 Nm införts. I avsnitt 7 "Referenser" har viss uppdatering gjorts av dokument som rör sammansättning vid VCBC.

Innehåll

1 Scope and field of application

The standard complies with current legislation and shall be used when planning new workplaces.

The term “ergonomics” is in this standard to be interpreted as “ergonomics for the prevention of musculoskeletal disorders”.

In case of doubt or difficulty of interpretation of this standard, contact an ergonomist within Volvo Cars.

1.1 Guidelines

To be able to obtain good working conditions with respect to ergonomics, physical freedom of movement together with a possibility of variation with respect to work content and movement pattern are required.

A workplace that is good from an ergonomic point of view places demands on the product, process, operator as well as on the organization.

At an early stage in the projects, the ergonomic requirements shall be linked to the organizational and technical development. During the production-planning phase, an ergonomics risk analysis with respect to product, process and organization respectively shall be made. A final evaluation shall be made after the production start.

Work tasks and workplaces shall be so designed as to provide variation and job rotation/change of tasks.

People are different and have different capacities that can change. This means that the workplaces must be able to meet the different requirements and needs that exist with respect to age, sex and physical capacity.

When planning and designing new workplaces, consideration must therefore be given to the varying capacities of different individuals.

1 Omfattning och tillämpning

Standarden följer gällande lagstiftning och ska användas vid planering av nya arbetsplatser.

Termen “ergonomi” ska i denna standard tolkas som “belastningsergonomi”.

Vid oklarheter eller tolkningssvårigheter av denna standard, kontakta ergonom inom Volvo Cars.

1.1 Riktlinjer

För att uppnå goda belastningsergonomiska förutsättningar krävs rörelsefrihet samt möjlighet till variation beträffande arbetsinnehåll och rörelsemönster.

En ergonomiskt bra arbetsplats ställer krav på såväl produkt, process, operatör som organisation.

De ergonomiska kraven ska tidigt i projekt kopplas till den organisatoriska och tekniska utvecklingen. Under produktionsberedningsfasen ska ergonomisk riskanalys göras ur produkt-, process- och organisationsperspektiv. En slutlig utvärdering ska utföras efter produktionsstart.

Arbetsuppgifter och arbetsplatser ska vara så utformade att de ger variation och arbetsväxling.

Människor är olika och har olika förutsättningar som kan förändras, vilket medför att arbetsplatserna måste kunna tillgodose de olika krav och behov som finns p.g.a. ålder, kön och fysisk förmåga.

Vid planering och utformning av nya arbetsplatser, måste därför hänsyn tas till olika individers skilda förutsättningar.

1.2 Product/Process

The styling and design of the product is often decisive for the ergonomic result in connection with manufacture, service and maintenance. Great demands on ergonomic considerations must therefore be placed during the product development phase already. When ergonomic consideration has been given to a product already at the design stage, good quality is also obtained.

1.2 Produkt/Process

Produktens utformning och konstruktion är ofta avgörande för det ergonomiska utfallet vid tillverkning, service och underhåll. Därför måste stora krav på ergonomiskt tänkande ställas redan vid produktutvecklingen. En produkt som är utformad för god ergonomi ger även god kvalitet.

2 Work postures – working movements

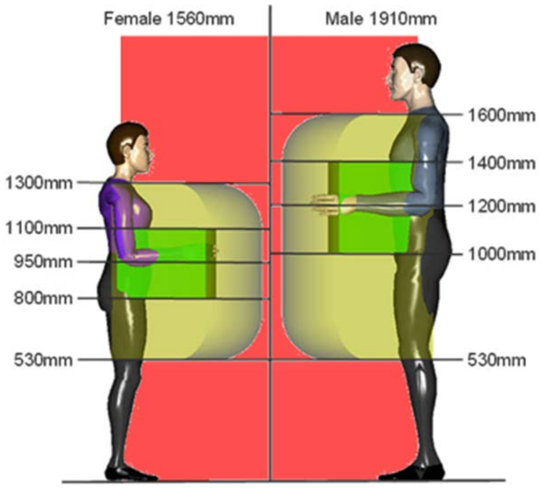
This factor concerns the position of the body or parts of the body when carrying out work. During at least 80 % of the working time throughout the day, the operator shall be able to work in a comfortable and ergonomically correct work posture, which means that the body can be postured in neutral positions and there are various working movements. Incorrect work postures/working movements as well as static muscular work or highly repetitive work using, e.g., lifted arms, raised shoulders or the back bent forwards, means that joints and muscles are subjected to an unfavourable strain, which means a risk of injurious effects.

A fixed working height does not suit everyone. Individual height adjustment must be possible where the task so requires.

2 Arbetsställningar – arbetsrörelser

Denna faktor avser kroppens eller kroppsdelars position vid utförande av arbete. Minst 80 % av arbetstiden utspritt under dagen ska operatören kunna arbeta i en bekväm och riktig ergonomisk arbetsställning där kroppen kan inta neutrala arbetspositioner och varierade rörelser. Felaktiga arbetsställningar/arbetsrörelser liksom statiskt eller högrepetitivt arbete, t.ex. med lyfta armar, höjda axlar eller framåtböjd rygg, medför en ogynnsam belastning på leder och muskler vilket innebär risk för skadlig inverkan.

En fast arbetshöjd passar inte alla. Individuell höjdjustering måste kunna utföras där arbetsuppgiften så kräver.



The working distance is of decisive importance to the load applied to the body. As short a distance as possible to the gripping and working area shall always be strived for.

Arbetsavståndet är mycket avgörande för belastningen på kroppen. Ett så kort avstånd som möjligt till grip- och arbetsyta ska alltid eftersträvas.

2.1 Static load

Static load means an increased risk of musculo-skeletal disorder. Static loads can occur at, e.g., incorrect working height, wrong working distance or repetitive, physically monotonous work without adequate recovery, precision work, poor lighting, unfamiliarity/lack of experience and stress. The static tension inhibits muscle function. Work intensity and work duration as well as number of breaks are decisive for the muscle’s ability to recover. The risk of static load shall be considered when planning the working arrangements, such as job content, job rotation and work enlargement.

2.1 Statisk belastning

Statisk belastning innebär en ökad risk för belast-ningsbesvär. Statisk belastning kan bl.a. uppstå vid felaktig arbetshöjd, felaktigt arbetsavstånd eller vid repetitivt ensidigt upprepat arbete utan tillräcklig återhämtning, precisionsarbete, dålig belysning, ovana/bristande erfarenhet och stress. Den statiska spänningen hämmar muskelns funktion. Arbetsintensiteten och arbetstidens längd och antalet pauser är avgörande för muskelns återhämtningsförmåga. Risken för statisk belastning ska beaktas vid planering av arbetsupplägg, t.ex. arbetsinnehåll, arbetsrotation och arbetsutvidgning.

3 Manual handling and other exertion of force

Efforts should focus on creating variations of movement and load variations in the work. The employee, regardless of age and gender, shall be able to work with materials, equipment and controls without being exposed to physical loads that are harmful to the health or unnecessarily fatiguing.

To avoid musculoskeletal injuries, the total load level should be considered (postures, movements, manual handling and other exertion of force).

3 Manuell hantering och annan kraftutövning

Insatserna bör inriktas på att skapa rörelse- och belastningsmässig variation i arbetet. Arbetstagaren, oberoende av ålder och kön, ska kunna arbeta med material, utrustning och reglage utan att utsättas för hälsofarliga eller onödigt tröttande fysiska belastningar.

För att undvika belastningsbesvär bör den totala belastningsnivån beaktas (arbetsställningar, arbetsrörelser, manuell hantering och annan kraftutövning).

3.1 Materials handling

Materials handling often constitutes a large share of the work at the workplace and is thus of great importance to the load dose (the total load level).

For recommended working distance, working height and weight, see figures 1, 2 and 3 and table 1 in the appendix.

The operator shall be able to handle materials with the point of balance near the body.

Simultaneous power and accuracy requirements shall be avoided.

The degree of compaction of the material and packing pattern shall allow easy access and appropriate hand grips, such as underhand grip instead of overhand grip.

3.1 Materialhantering

Materialhantering utgör ofta en stor del av arbetet på arbetsplatsen och har därför stor betydelse för den totala belastningsdosen.

För rekommenderat arbetsavstånd, arbetshöjd och vikt, se figur 1, 2 och 3 samt tabell 1 i bilaga.

Operatören ska kunna hantera material med tyngdpunkten nära kroppen.

Samtidiga kraft- och precisionskrav ska undvikas.

Materialets packningsgrad och packningsmönster ska medge god åtkomlighet och lämpliga handgrepp, t.ex. underhandsgrepp istället för överhandsgrepp.

3.2 Fixtures/Magazines

3.2.1 General

Clamps, guide lugs and pins shall be placed so that the operator can work with the hand close to his/her functional base position, see figures 1, 2 and 3 in the appendix.

Accessibility and field of vision must not be restricted by safety fencing, clamps, guide lugs, etc.

Pedals and controls shall be designed so that little force needs to be used for prolonged and repeated work.

3.2.2 Working heights for manual work in fixture/magazine

When the produced part shall be loaded into a fixture without any special requirements concerning precision, the working height should be between 800 mm and 1000 mm. For parts that are large or heavy, the working height should not exceed 900 mm. Note that when loading, it should not be necessary to lift the parts over clamps or lugs.

When the produced part shall be loaded into a magazine, the working height stated above is permitted to vary both upward and downward. The decisive factor is the weight and size of the part, and how easy it is to handle the part. A relatively small part that is easy to handle can, for example, be loaded at a working height of approximately 600-1400 mm.

3.2.3 Working distances for manual work in fixture/magazine

Loading into fixtures should, if possible, be performed in the green area (see appendix, figures 1, 2 and 3). Loading is <u>not</u> allowed in the red area.

Loading into magazines is <u>not</u> allowed in the red area. (See appendix, figures 1, 2 and 3)

The distance from the maneuvering device to the fixture shall be minimized, and this distance shall be taken into consideration in the choice of optical barrier (light curtain) or scanner. The time required for each lift and carrying shall be as short as possible 羊with short walking times/distances.

3.2 Fixturer/Magasin

3.2.1 Allmänt

Spännen, styrklackar och pinnar ska placeras så att operatören kan arbeta med handen nära hans/hennes funktionella utgångsläge, se figur 1, 2 och 3 i bilagan.

Åtkomlighet och synfält får ej begränsas av säkerhetsstaket, spännen, styrklackar, m.m.

Pedaler och reglage ska vara utformade så att liten kraft behöver användas vid långvarigt och upprepat arbete.

3.2.2 Arbetshöjder vid manuellt arbete i fixtur/magasin

I de fall detaljen ska laddas i en fixtur utan några speciella krav på precision bör arbetshöjden vara mellan 800 och 1000 mm. För stora eller tunga detaljer bör inte arbetshöjden överskrida 900 mm. Tänk på att man inte ska behöva lyfta detaljerna över spännen och klackar för att ladda.

I de fall detaljen ska laddas i ett magasin kan arbetshöjden enligt ovan tillåtas variera både uppåt och nedåt. Avgörande för hur mycket är detaljens tyngd, storlek och hur detaljen går att hantera. En mindre detalj som är lätt att hantera kan t.ex. laddas vid en arbetshöjd av ca 600-1400 mm

3.2.3 Arbetsavstånd vid manuellt arbete i fixtur/magasin

Laddning i fixturer bör om möjligt ske inom grönt område (se bilaga, figurerna 1, 2 och 3). Laddning får inte ske inom rött område.

Laddning i magasin får <u>inte</u> ske inom rött område. (Se bilaga, figur 1, 2 och 3)

Avståndet från manöverdon till fixtur ska minimeras och avståndet ska beaktas vid val av ljusridå/scanner. Tiden för varje lyft och bärande ska vara så kort som möjligt 羊korta gångsträckor som går snabbt att avverka.

3.3 Packaging

Opening and closing devices in packaging shall be designed so that they are easy to handle.

Heavy constructions, such as gates, bulky pallet constructions and boundary details, shall be avoided.

The packaging shall be easy to pack and to empty. The operator shall not have to turn or rotate the part. Snap racks (stacker pillars), for example, should be avoided and any slots should be bevelled.

The packing pattern shall be chosen so that the risk of materials hooking into each other or sticking to each other is minimized.

The packaging shall be designed for use with devices such as lift tables, tilts, or lifting devices. For example, high, permanently fixed sides are not permitted.

If an operator is required to enter the packaging, level differences shall be eliminated.

3.3 Emballage

Emballagets öppnings- och stängningsanordningar ska utformas så att de är lätthanterliga.

Tunga konstruktioner, t.ex. grindar, otympliga pallkonstruktioner och avgränsningsdetaljer, ska undvikas.

Emballaget ska vara lätt att packa och tömma, operatören ska ej behöva vända eller vrida detaljen. Exempelvis bör snäppracks (kläppelare) undvikas och eventuella spår bör vara fasade.

Packmönster ska väljas så att risken för att material hakar i varandra eller fastnar minimeras.

Emballaget ska vara konstruerat för att kunna användas tillsammans med hjälpmedel som lyftbord, tipp eller lyfthjälpmedel. Exempelvis ska inte höga fasta sidor förekomma.

Om operatören behöver gå in i emballaget så ska nivåskillnader elimineras.

3.4 Visual inspection

At continuous visual inspection, fixtures shall be adjustable in heights between 950-1200 mm and be able to tilt to guarantee a short working distance.

The visiual conditions shall be adapted for visual inspection work.

3.4 Avsyning

Vid kontinuerligt avsyningsarbete ska fixturerer vara justerbara i höjd mellan 950-1200 mm och tiltbara för garanterat kort arbetsavstånd.

Synförhållanden ska vara anpassade till avsyningsarbete.

3.5 Lifting aids

The need for lifting aids shall be investigated. Note that production engineer, operator, safety delegate or equivalent and ergonomist shall take part in planning of installation of lifting devices. The labour management has the overall responsibility for seeing to it that lifting aids are used.

Operator(s) using lifting aids shall have taken part in adequate training, including a practical part.

3.5 Lyfthjälpmedel

Behov av lyfthjälpmedel ska utredas. Observera att produktionstekniker, operatör, skyddsombud och ergonom ska medverka/samverka vid planering av installation av lyfthjälpmedel. Arbetsledningen har yttersta ansvaret för att lyfthjälpmedel används.

Operatör(er) som använder lyfthjälpmedel ska ha genomgått lämplig utbildning och praktisk träning härför.

3.6 Pressure forces

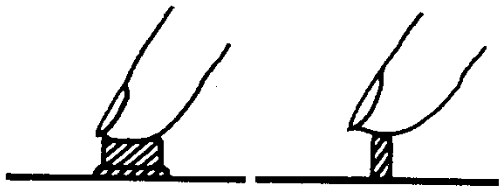
The following shall be considered:

The pressure area shall be so large that there is room enough for a thumb (diameter 15-20 mm). The pressure area should preferably be slightly concave in order to distribute the pressure equally on the finger tip area. Sharp sections which can cause too high spot pressure on hand/fingers shall not occur.

3.6 Tryckkrafter

Följande ska beaktas:

Tryckytan måste vara så tilltagen att en tumme får plats (15-20 mm i diameter). Tryckytan bör med fördel vara svagt konkav för att fördela trycket jämnt över fingerytan. Vassa delar som kan orsaka för högt punkttryck i hand/fingrar ska ej förekomma.



Correct
Rätt

Incorrect
Fel

The pressure force allowed for:

- finger 15 N (1,5 kp)
- several fingers 30 N (3,0 kp)
- whole hand 50 N (5,0 kp))
- operating devices/ control buttons – finger-controlled 5 N (0,5 kp)
- hand-lever controls 20 N (2,0 kp)

It is not possible to automatically double the force when working with both hands.

The pressing direction should be in the longitudinal direction of the forearm to avoid extreme positions of the joints.

Fasteners shall be placed so they are easily accessible during assembly. Fasteners which require force in combination with precision shall not be used at manual assembly.

Fasteners which require great force and which exceed the pressure forces specified above shall be assembled with tools or automated.

Hidden assembly without guide should not be used.

Fasteners and clips shall snap, alternatively give an indication to the operator/fitter when they are correctly mounted.

3.7 Hand-held machines and tools

The vibration level shall be kept as low as possible due to, among other things, the risk of white fingers. When purchasing machines, they shall have been vibration classified in accordance with the inspection regulations issued by the Swedish National Testing and Research Institute (SP) or equivalent. Machines belonging to class 4 or higher may be used in exceptional cases only.

Tillåten tryckkraft för:

- finger 15 N (1,5 kp)
- flera fingrar 30 N (3,0 kp)
- hela handen 50 N (5,0 kp)
- manöverdon/ reglageknappar – fingerreglerade 5 N (0,5 kp)
- spakreglage 20 N (2,0 kp)

Man kan inte per automatik fördubbla kraften genom att använda båda händerna.

Tryckriktningen bör ligga i underarmens längdriktning så att ytterlägen i leder undviks.

Fästelement placeras så att de är lättåtkomliga vid montering. Fästelement som kräver kraft i kombination med precision ska inte förekomma vid manuell montering.

Fästelement som kräver stor kraft och som överskrider angivna tryckkrafter enligt ovan ska monteras med verktyg eller automatiseras.

Dold montering utan instyrning bör inte förekomma.

Fästelement och clips ska knäppa till, alternativt ge kvittens så att montören vet när de sitter rätt monterade.

3.7 Handhållna maskiner och verktyg

Vibrationsnivån ska hållas så låg som möjligt med hänsyn till bl.a. risk för vita fingrar. Vid anskaffning ska maskiner vara vibrationsklassade enligt kon-trollbestämmelserna från Sveriges Provnings- och Forskningsinstitut eller motsvarande. Maskiner tillhörande klass 4 eller högre får användas endast undantagsvis.

General ergonomics considerations lowering the need of holding firmly hand grips and hand tools also reduce the exposure to vibrations. These include factors like weight, ratio hand/handle and gripping surface friction.

Allmänna ergonomiska hänsynstaganden som sänker behovet av fasthållningskraft för handgrepp och handmaskiner minskar också exponeringen för vibrationer. Hit hör faktorer som vikt, storleksförhållanden på hand/handtag och friktion i greppytorna.

Low-vibrating machines may be a basic condition to obtain a sufficiently low noise level in the work premises. Decisive factors for the level of vibration for grinding machines are handling, choice of grinding wheel as well as maintenance (see AFS 2005:16 Noise (in Swedish only) and Council Directive 2003/10/EC issued by the Council of the European Communities).

Lågvibrerande maskiner kan vara en förutsättning för att erhålla tillräckligt låg bullernivå i arbetslokalen. För slipmaskiner är hantering, val av slipskiva och underhåll avgörande för vibrationsnivån (se AFS 2005:16 Buller samt Europarådets direktiv 2003/10/EC).

In connection with the development or purchase of new equipment, this shall be done in consultation with an ergonomist and other persons concerned, such as technicians, maintenance personnel, safety delegate or equivalent and operators.

I samband med nyutveckling eller inköp av ny utrustning ska detta ske i samråd med ergonom och övriga berörda såsom tekniker, underhållspersonal, skyddsombud och operatörer.

Regular maintenance and service are necessary for maintained function and performance.

Regelbundet underhåll och service är nödvändigt för bibehållen funktion och prestanda.

The requirements specified below shall be considered:

Nedanstående krav ska beaktas:

3.7.1 Weight

The tools shall be as light as possible considering their function. Tool weight, torque, frequency as well as the working distance decide if load-relieving devices are required (e.g. load-relieving lever, suspension device or similar).

Battery-type machines shall not be used in frequently repeated assembly work due to their weight and reaction torques. Alternative machine type shall be investigated.

3.7.1 Vikt

Verktyg ska vara så lätta som möjligt med hänsyn till funktion. Verktygets vikt, moment, frekvens och arbetsavståndet avgör om avlastningsanordningar behövs (t.ex. avlastningsarm, upphängningsan-ordning el. dylikt).

Batterimaskiner ska inte användas i frekvent monteringsarbete p.g.a. tyngd och reaktions-moment. Alternativ maskintyp ska undersökas.

3.7.2 Grips, handles, controls

Machine/equipment shall allow a good line of sight.

Tools shall be well balanced. The ratio between the grip/handle and the working parts shall be so adapted that extreme positions of joints in hands and arms can be avoided.

Grips/handles shall be long enough to hold the entire width of the hand (incl. glove when used), i.e. > 120 mm. Different sizes of handles shall be considered to suit both big and small hands.

3.7.2 Grepp, handtag, reglage

Maskin/utrustning måste medge goda siktförhållanden.

Verktyg ska vara välbalanserade. Förhållandet mellan handtaget och de arbetande delarna ska vara avpassat så att man kan undvika ytterläges-belastningar i händer och armar.

Handtag ska vara så långt att hela handens bredd ryms (inklusive handske när sådan används), d.v.s. > 120 mm. Olika storlekar på handtag ska beaktas för att passa både stora och små händer.

The grip/handle parts shall be designed to accommodate for the requisite grips and forces so that the operator can easily change his/her grip.

The material in grip parts shall provide sufficient friction also with oily/moist hands without giving high spot load on hand/fingers.

Hand grips with a pressure > 25 N/2,5 kP shall be avoided.

All controls shall be easy to manoeuvre and easily accessible for both right- and left-handed persons.

If necessary, it shall be possible to activate the starter with the index finger and/or long finger.

It shall be possible to reach the reversing knob with both left and right hand respectively without changing grip.

The material on the handle shall dissipate heat/cold.

The material should not cause allergy (for example rubber, nickel).

Machines and tools shall be efficient, that is, they shall carry out the work intended in a correct and quick manner.

Greppdelar ska vara anpassade till de grepp och den kraft som behövs så att det går lätt att växla grepp.

Materialet i greppdelar ska ge god friktion även med oljiga/fuktiga händer utan att ge hög punktbelastning i hand/fingrar.

Handgrepp som innebär > 25 N/2,5 kP ska undvikas.

Samtliga reglage ska vara lätt manövrerbara och lättåtkomliga för både höger- och vänsterhänta.

Pådraget ska vid behov kunna aktiveras med pek- och/eller långfinger.

Reverseringsknapp ska kunna nås med både vänster resp. höger hand utan att byta grepp.

Materialet på handtaget ska avleda värme/kyla.

Materialet bör inte vara allergiframkallande (t.ex. gummi, nickel).

Maskiner och verktyg ska vara effektiva, d.v.s. utföra avsett arbete på ett snabbt och riktigt sätt.

3.7.3 Reaction torque

Stall-type pistol grip machine: At torques exceeding 8 Nm, counterhold shall be used and it shall be possible for the operator to use two-hand grip.

Angle nutrunner, air: At torques exceeding 40 Nm, counterhold shall always be used. For tools with distinct recoil, counterhold shall be used at torques exceeding 25 Nm.

Angle nutrunner, electronically controlled: At torques exceeding 40 Nm, mechanical and/or software/electronic counterhold always be used. Counterhold may in certain cases be needed at lower torques due to difficult conditions. This is to be decided from case to case. At torques exceeding 50 Nm, mechanical counterhold shall always be used.

Pulse machine has no significant reaction torque. It is important to use a guide sleeve to minimize the risk of vibrations.

Hammering machine has no significant reaction torque. It shall only be used sparingly, for example at dismounting.

Ratching machine shall be used sparingly due to the high risk of vibration and the high noise level.

3.7.3 Reaktionsmoment

Segdragande pistolmaskin med frånslag: Vid vridmoment över 8 Nm ska mothåll användas och operatören ska kunna använda tvåhandsgrepp.

Vinkelmutterdragare, luft: Vid vridmoment över 40 Nm ska mothåll alltid användas. För maskiner med tydlig rekyl ska mothåll användas över 25 Nm.

Vinkelmutterdragare, elektroniskt styrd: Vid vridmoment över 40 Nm ska mothåll, mekaniskt och/eller mjukvarumässigt/elektroniskt, alltid användas. Mothåll kan i vissa fall behövas vid lägre vridmoment på grund av försvårande omständigheter vilket avgörs från fall till fall. Vid vridmoment över 50 Nm ska mekaniskt mothåll alltid användas.

Pulsmaskin har inget nämnvärt reaktionsmoment. Det är viktigt att använda styrhylsa för att minimera risken för vibrationer.

Slående maskin har inget nämnvärt reaktionsmoment. Ska endast användas sparsamt t.ex. vid demontering.

Rappande maskin ska användas sparsamt med hänsyn till vibrationsrisk och hög ljudnivå.

3.7.4 Air

Air outlet shall be directed so no cooling of arm/hand can take place. Air connection on the top side of the tool shall be possible if necessary.

Hose/hose suspension devices shall be arranged so they do not get in the way.

3.7.4 Luft

Luftutblås ska riktas så att nedkylning av hand/arm inte förekommer. Luftanslutning ska kunna göras på ovansidan av verktyget vid behov.

Slang/slangupphängningsanordningar ska ordnas så att dessa inte är i vägen.

3.7.5 Accessories

Sleeves/adapters

Impact hexagon sockets shall be used for machine use and thin-wall sleeves for hand tools.

Jointed sleeves shall be avoided.

For pulse machines, guide sleeves or extended guide sleeves shall be used.

Swivel

Correctly dimensioned swivel designed for the air consumption of the machine shall always be used.

3.7.5 Tillbehör

Hylsor/förlängare

Krafthylsor ska användas för maskinellt bruk och tunnväggade hylsor för handverktyg.

Ledade hylsor ska undvikas.

För pulsmaskin ska styrhylsa alternativt förlängd styrhylsa användas.

Svivel

Rätt dimensionerad svivel anpassad till maskinens luftförbrukning ska alltid användas.

3.7.6 Maintenance

Routines for preventive maintenance and regular functional inspection of machines, casings, accessories, etc., shall be carried out to ensure functionality and to prevent personal injuries.

There shall be machine supports or suspension devices for all machines. These shall be designed to avoid overhand grip.

3.7.6 Underhåll

Rutiner för förebyggande underhåll och regelmässig funktionskontroll av maskiner, hylsor, tillbehör m.m. ska genomföras för att säkerställa funktionalitet och förebyggande av personskada.

Maskinhållare alternativt upphängningsanordning ska finnas till varje maskin. Dessa ska utformas så att överhandsgrepp undviks.

4 Materials-handling vehicles

There is a number of materials-handling vehicles available for different purposes. The design of the truck with respect to driver seat ergonomics, driving characteristics, viewing conditions, etc., are of great importance to the truck operator, to efficiency and also to safety. Since the operation of trucks normally includes manual handling of packages, this often needs to be assessed at the same time.

4 Truckar

En mängd varianter av truckar finns anpassade för olika ändamål. Truckens utformning avseende förarplatsergonomi, köregenskaper, siktförhållande m.m. har stor betydelse för truckföraren, för effektivitet och ur säkerhetssynpunkt. Eftersom truckkörning normalt innefattar manuell hantering av emballage behöver detta oftast utvärderas samtidigt.

4.1 Driver’s environment

Getting on and off the truck shall be safe and non slippery, i.e. the foot steps shall be deep enough (minimum 15 cm) and wide enough (minimum 30 cm). The distance between the steps should be 20-30 cm.

If the footboard height above ground/floor exceeds 30 cm, there shall be a hand-hold. The distance to the first footboard should not exceed 40 cm.

4.1 Förarmiljö

På- och avstigning ska kunna ske säkert och halkfritt, d.v.s. fotstegen bör ha tillräckligt djup, minst 15 cm, och bredd, minst 30 cm. Avståndet mellan stegen bör vara 20-30 cm.

Instegshandtag ska finnas om instegets höjd ovan mark/golv överstiger 30 cm. Avstånd till första insteg bör inte överstiga 40 cm.

The operator's space shall be of adequate size. The distance between floor and roof in a truck that is operated from a seated position shall be > 1600 mm and for trucks operated from a standing position, it shall be > 2000 mm. The operator's space shall provide adequate leg and feet room.

Förarutrymmet ska vara tillräckligt stort. Avståndet mellan golv och tak i sittruck ska vara > 1600 mm och avstånd för ståtruck > 2000 mm. Det ska finnas tillräcklig plats för benen och fötter i förarutrymmet.

The operator's seat shall be easy to adjust with respect to lumbar support, sitting height, sitting depth, inclination of backrest, height and length of arm rests; it shall have adequate vibration damping and, when required, be swivellable. The backrest must not restrict the rear view.

Förarstolen ska vara lätt inställbar vad gäller svankstöd, sitthöjd, sittdjup, ryggstödets lutning, höjd och längd på armstöd och ha tillräcklig vibrationsdämpning samt vid behov vara vridbar. Ryggstöd får ej hindra sikt bakåt.

Visual display and keyboard shall be placed within comfortable viewing and working range. Specially tried-out computer terminal glasses/prescription safety glasses may be needed.

Bildskärm och tangentbord ska vara placerade inom bekvämt syn- och arbetsområde. Speciellt utprovade terminalglasögon/ skyddsglasögon med korrektion kan behövas.

The truck shall have power-assisted steering and the steering wheel should be both height and depth adjustable.

Trucken ska vara utrustad med servostyrning och ratten bör kunna regleras i höjd- och djupled.

Controls/pedals shall be placed within a comfortable working range, that is, so that operators of all physical sizes and heights can find a comfortable working position.

Reglage/pedaler ska vara placerade inom bekvämt arbetsområde, d.v.s. så att personer av olika kroppsstorlek och längd kan inta bekväm arbetsställning.

Instruments shall be placed within comfortable viewing range and be easy to read.

Instrument ska vara placerade inom bekvämt synfält och ska vara lätta att läsa av.

The truck shall be equipped with adjustable rear-view mirrors.

Backspeglar ska finnas och de ska vara inställbara.

5 Vibrations

Risks due to vibrations shall be minimized by eliminating the vibrations at the source or reducing them to the lowest possible level.

Exposure values for vibrations:

Limits:

Hand and arm vibrations	5,0 m/s²
Whole-body vibrations	1,1 m/s²

Action values:

Hand and arm vibrations	2,5 m/s²
Whole-body vibrations	0,5 m/s²

If the daily exposure to vibrations exceeds any of the action values or when risk assessment is justified, the reasons for the risks shall be evaluated and technical and/or organizational actions shall be taken.

5 Vibrationer

Risker till följd av vibrationer minimeras genom att vibrationerna elimineras vid källan eller sänks till lägsta möjliga nivå.

Exponeringsvärden för vibrationer:

Gränsvärden:

Hand- och armvibrationer	5,0 m/s²
Helkroppsvibrationer	1,1 m/s²

Insatsvärden:

Hand- och armvibrationer	2,5 m/s²
Helkroppsvibrationer	0,5 m/s²

Överstiger den dagliga vibrationsexponeringen något av insatsvärdena eller när riskvärdering motiveras ska orsakerna till riskerna utredas samt tekniska och/eller organisatoriska åtgärder vidtas.

Medical check-ups shall be offered in the following cases:

- To employees exposed to vibrations exceeding the limits
- When there is suspicion of harmful effects even if the limit is not exceeded
- If signs of strain or injury are detected at a medical examination, medical check-ups shall be offered to all other employees who have been exposed in similar ways.

Medicinska kontroller ska erbjudas i följande fall:

- Till de arbetstagare som exponeras för vibrationer som överskrider insatsvärdena
- Då det finns skäl att misstänka att skadliga hälsoeffekter kan uppstå även om insatsvärdet inte överskrids
- Om tecken på skada upptäcks vid undersökning ska medicinsk kontroll erbjudas till övriga arbetstagare som exponerats på liknande sätt.

6 Work pace/work tasks/work organization

Work organization from an ergonomic viewpoint means how the tasks are combined, spread over time and distributed between individuals.

An important factor in avoiding musculoskeletal injuries during the working life is the possibility of the individual to enjoy change and variation. This need for flexibility applies both with respect to work pace and work tasks.

The employee must be given the chance to exert a certain amount of own control of the work through the possibility of influencing the arrangements and the performance of his/her own work.

6 Arbetstakt/arbetsuppgifter/ arbetsorganisation

Arbetsorganisation i ergonomisk bemärkelse omfattar hur arbetsuppgifterna sätts samman, fördelas över tiden samt fördelas mellan individerna.

Viktigt för undvikande av belastningsskador i arbetslivet är individens möjlighet till omväxling och variation. Detta behov av flexibilitet gäller både arbetstakt och arbetsuppgifter.

Arbetstagaren måste beredas viss egenkontroll av arbetet genom påverkansmöjlighet av arbetets uppläggning och genomförande.

6.1 Job rotation, work enlargement

Job rotation and work enlargement shall be planned in such a way that work postures, work movements and workpiece loads vary and provide variation to joints, muscles and the circulatory system. Should it prove impossible to exclude physically monotonous work operations, the work shall be designed to accommodate breaks.

Work enlargement, i.e. including other work operations of a different nature that are not carried out on a frequent basis, is a way of creating variation and shall be strived for.

Job rotation between different types of work in order to provide variation with respect to movement and load is often a good way of reducing the total load over the day.

6.1 Arbetsrotation, arbetsutvidgning

Arbetsrotation och arbetsutvidgning ska planeras på ett sådant sätt att arbetsställningar, arbetsrörelser och arbetstyngd varierar och ger leder, muskler och cirkulationsapparaten omväxling. Om ensidiga arbetsmoment inte kan undvikas ska utrymme för pauser planeras in.

Arbetsutvidgning, d.v.s. att lägga in andra olikartade arbetsmoment som inte utförs med hög frekvens, är ett sätt att skapa variation och ska eftersträvas.

Arbetsrotation mellan olikartade arbeten för att ge rörelse- och belastningsmässig variation är ofta ett bra sätt att reducera totalbelastningen över dagen.

6.2 Technical work organization

Physical and psychological factors should be regarded simultaneously and as a whole. The physical factors shall be considered in combination with work organization/work contents and education/training.

Important prerequisites are:

- Knowledge of the product as a whole
- Job rotation to physically differing work tasks
- Work enlargement such as quality inspection, adjustment, maintenance, planning and result follow-up
- Work enlargement such as quality inspection, adjustment, maintenance, planning and result follow-up
- Man shall control the machine and not vice versa
- Accelerated work shall normally not occur
- Buffering gives some technical autonomy and provides an opportunity for varying work rates and less stress.

6.2 Teknisk arbetsorganisation

Fysiska och psykologiska arbetsmiljöfaktorer bör beaktas samtidigt och som en helhet. De fysiska faktorerna ska vägas ihop med arbetsorganisation/ arbetsinnehåll och utbildning.

Viktiga förutsättningar är:

- Kunskap om produktens helhet
- Arbetsrotation till fysiskt olikartade arbetsuppgifter
- Arbetsutvidgning såsom kvalitetskontroll, justering, underhåll, planering och resultatuppföljning
- Flexibla arbetsmönster, t.ex. genom egenkontroll av arbetsresultat, arbetsmetoder och arbetstakt
- Människan ska styra maskinen och inte tvärtom
- Upparbetning ska normalt sett inte förekomma
- Buffertering ger viss teknisk autonomi och innebär en möjlighet till varierad arbetstakt och mindre stress.

7 References

Assembly:
Before contract: Checklist – Environment, media and ergonomics for assembly equipment, form No. 50751 (in swedish only)

After contract: Checklist – Assembly follow-up, tab 2 Ergonomics, form No. 50668

Stamping: Checklist – Physical work environment – Stamping at VCBC (Volvo Cars Body Components), form No. 50431 (in Swedish only)

For marketplace: Ergonomics for the Small Box Marketplace, 0204142448ANN in BMS.

Industrial Vehicles ergonomics – Standardized industrial vehicles; 0812102324ANN in BMS

Lifting aid: Lifting and Rigging / Lyftanordningar / Hijstoestellen: 0202161411ANN in BMS

7 Referenser

Sammansättning:
Innan kontrakt: Checklista – miljö, media samt ergonomi för sammansättningsutrustnig, blankettnr 50751

Efter kontrakt: Checklista – Assembly follow-up, flik 2 Ergonomics, blankettnr 50668

Pressning: Checklista – Fysisk arbetsmiljö – Pressning på VCBC (Volvo Cars Body Components), blankettnr 50431

Ompackningsstationer: Ergonomi för "Small Box Marketplace" 0205103401ANN i BMS.

Industrial Vehicles ergonomics – Standardized industrial vehicles; 0812102324ANN i BMS

Lyfthjälpmedel: Lifting and Rigging / Lyftanordningar / Hijstoestellen: 0202161411ANN i BMS

EU Directives:	EU-direktiv:
90/269/EEC on the minimum health and safety requirements for the manual handling of loads	90/269/EEG om minimikrav för hälsa och säkerhet vid manuell hantering av laster där det finns risk för skador, särkilt i ryggen
89/391/EEC “Framework directive” on the introduction of measures to encourage improvements in the safety and health of workers at work	89/391/EEG ”Ramdirektiv” om arbetstagarnas säkerhet och hälsa i arbetet
2003/10/EC on the minimum safety and health requirements regarding the exposure of workers to the risks arising from physical agents (noise)	2003/10/EG om minimikrav för arbetstagarens hälsa och säkerhet vid exponering för risker som har samband med fysikaliska agens (buller) i arbetet
2002/44/EC on the minimum healsth and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration).	2002/44/EG om minimikrav för arbetstagares hälsa och säkerhet vid exponering för risker som har samband med fysikaliska agens (vibration) i arbetet.

Work load, work postures, working movements

Assessment templates

Non-injurious impact

Possibly injurious impact depending on number of movements or the duration of the posture

Injurious impact when occurring for longer periods of time, lengthy or often

Tabell 1 **Lifting diagram*) **)**

Lifting area	Lifting frequency times/hour			
	1-10	10 -30	30 - 60	60 -120
A	12,0	7	3	2
B	7,0	5	2	1

*) For higher frequencies/weights/distance an ergonomics risk assessment is required

**) VCBC shall use:

Assembly: Before contract: Checklist “Checklista – Miljö, media samt ergonomi för sammansättnings-utrustning”, form No. 50751 (in Swedish only)
After contract: Checklist “Assembly follow-up”, tab “2 Ergonomics”, form No. 50668

Stamping: Checklist: Physical work environment – Stamping at VCBC (Volvo Cars Body Components), form No 50431 (in Swedish only)

172 cm = man/woman of average height

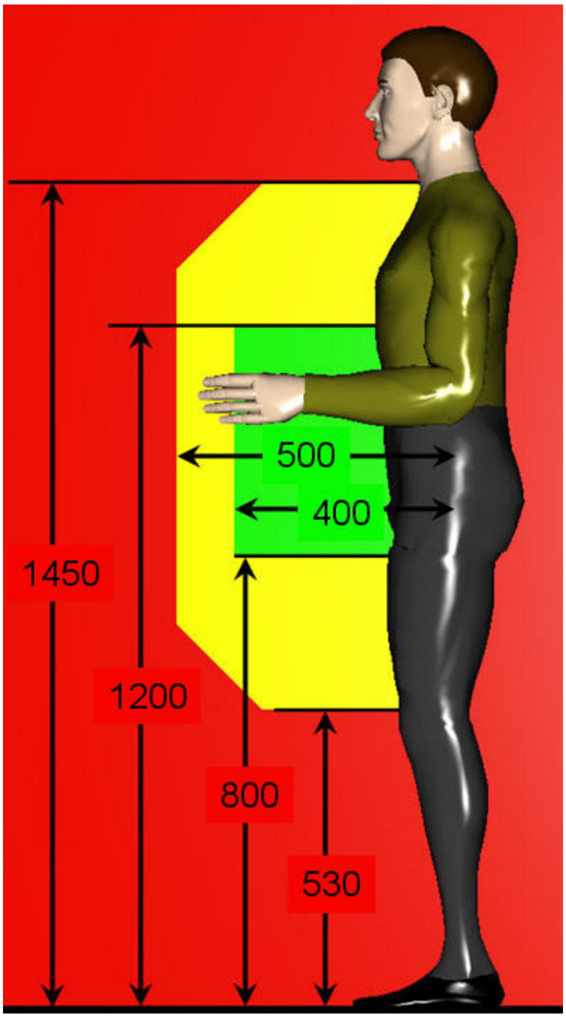


Fig.1

When handling several objects in the same work cycle, the frequency values shall be added.

When working sitting down, the mass values in the diagram shall be halved. A maximum of 7 kg shall be lifted when sitting.

Height

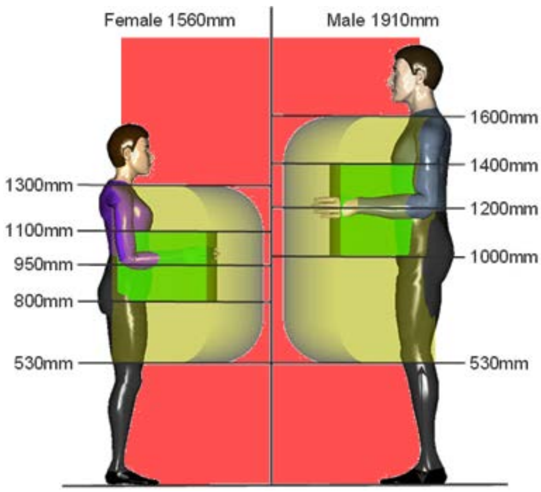


Fig. 2

Distance

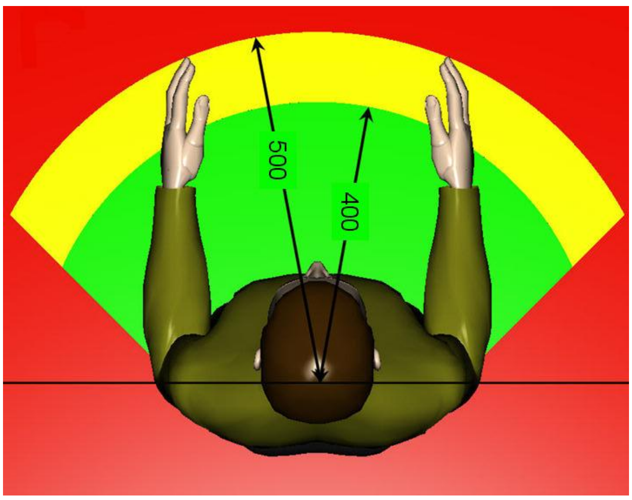


Fig. 3

Neck

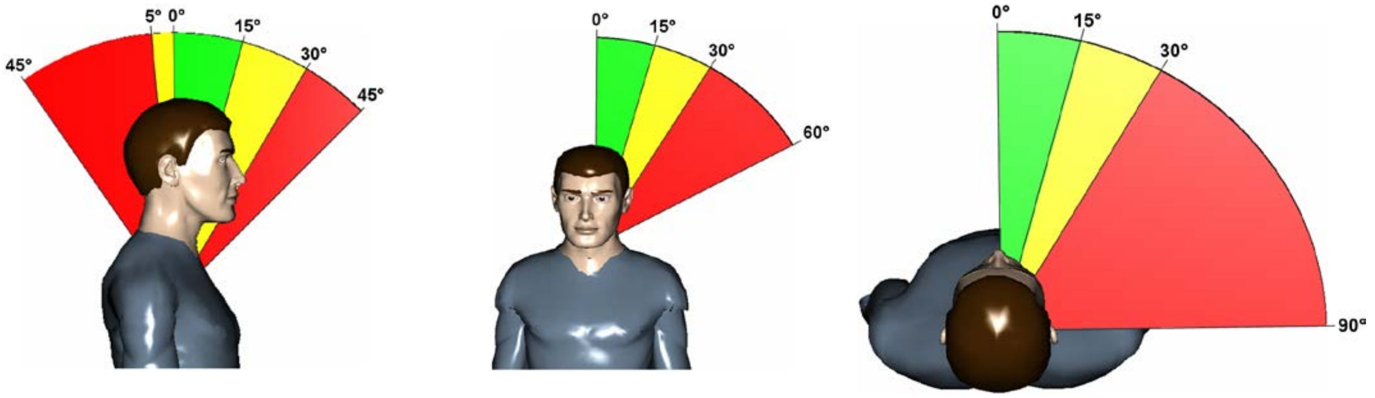


Fig. 4

Back/bending, turning

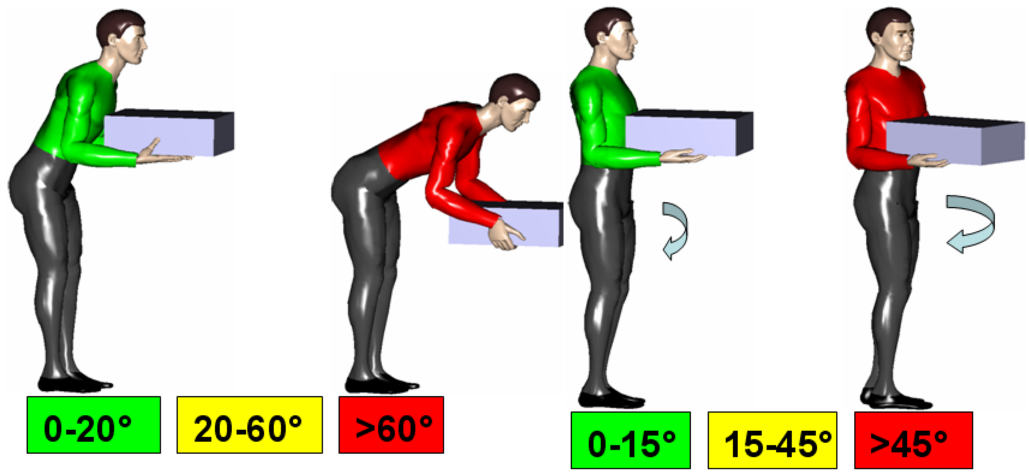


Fig. 5

Grip

Max 0,5 kg – overhand grip

Max 5 kg – underhand grip

Over 5 kg – two-hand grip

Fig. 6

Positions of wrist – gripping force

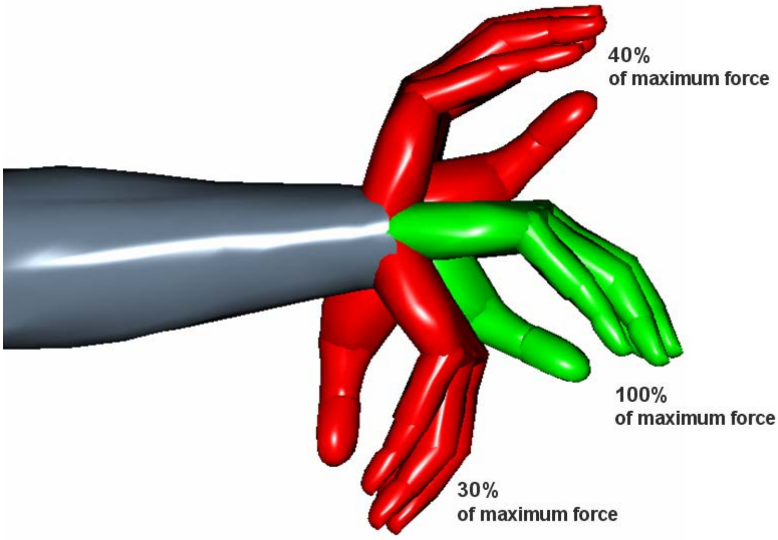


Fig. 7

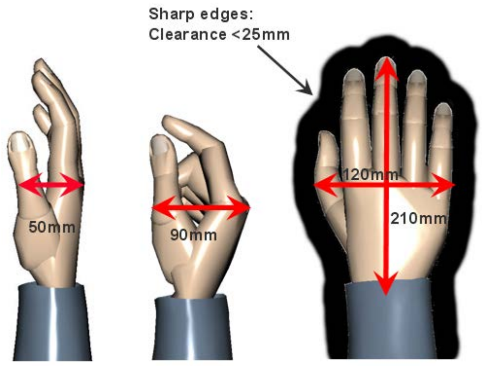


Fig. 8

Clearance arm/hand

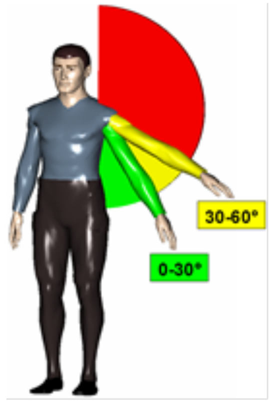


Fig. 9

Shoulder movements

Arm lift forwards and sideways

Work postures imparting stress on hips/knees

Squatting | Sitting on both knees | Sitting on one knee | Stepping | Inclining plane

Fig. 10

Table 2 **Push-and-pull work** – Model for assessing push-and-pull work

A. Carriers, heavy packages

Force (N)	**red**	**yellow**	**green**
Start	> 300 (approx. 30 kP)	300-150	< 150
Continuously	> 200	200-100	< 100

Applies to carriers and heavy packages on wheels or rails. The above model applies to **good** ergonomic conditions, that is symmetric two-hand grip, well designed handles/grips placed at a suitable height, and good ambient conditions. If this type of work is carried out on a frequent basis, the values above shall be reduced by 50 %.

Table 3

B. Suspension devices, travelling cranes, etc.

Force (N)	**red**	**green**
Start	> 50 (approx. 5 kP)	< 50
Continuously	> 40	< 40

Applies to push-and-pull work in the repeated work cycle under otherwise **good** ergonomic conditions (travelling cranes, suspension devices, lifting aids, unloading arms, frames, hand-held tools, welding clamps, workpieces, etc.). See diagram above.

Arbetstyngd, arbetsställningar, arbetsrörelser

Bedömningsmallar

Ej skadlig inverkan

Möjlig skadlig inverkan beroende på antal rörelser eller ställningens varaktighet

Skadlig inverkan vid förekomst längre stunder, långvarigt eller ofta

172 cm = medellängd man/kvinna

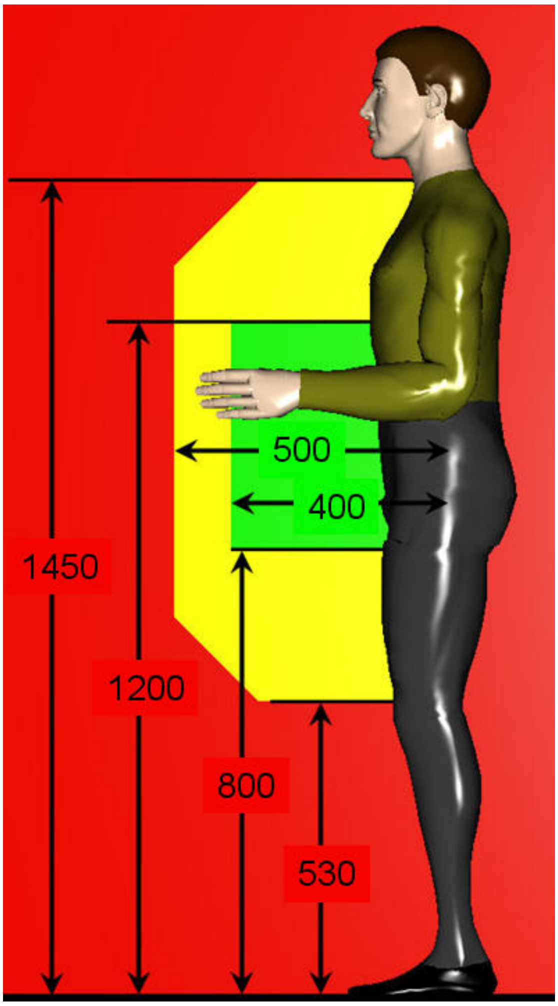


Fig. 1

Tabell 1 **Lyft *) **)**

Lyftområde	Lyftfrekvens ggr/tim			
	1-10	10 -30	30 - 60	60 - 120
A	12,0	7	3	2
B	7,0	5	2	1

*) För högre vikter/frekvenser/avstånd krävs ergonomisk riskbedömning

**) VCBC ska använda:

Sammansättning: Innan kontrakt: Checklista – Miljö, media samt ergonomi för sammansättnings-utrustning, blankettnr 50751
Efter kontrakt: Checklista – Assembly follow-up, flik 2 Ergonomics, blankettnr 50668

Pressning: Checklista; Fysisk arbetsmiljö – Pressning på VCBC (Volvo Cars Body Components), blankettnr 50431 (endast på svenska)

Vid hantering av flera objekt i samma arbetscykel adderas frekvensen.

Vid sittande arbetsställning halveras vikterna i schemat. Max 7 kg får lyftas sittande.

Höjd

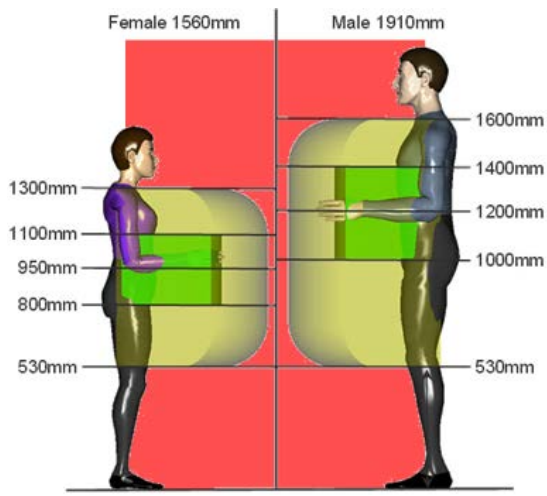


Fig. 2

Avstånd

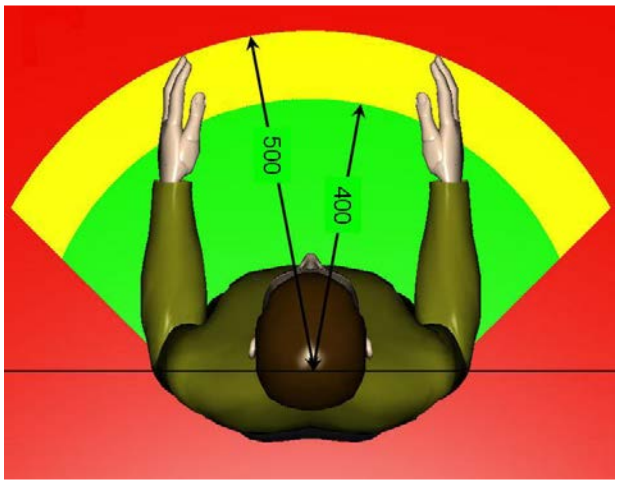


Fig. 3

Nacke

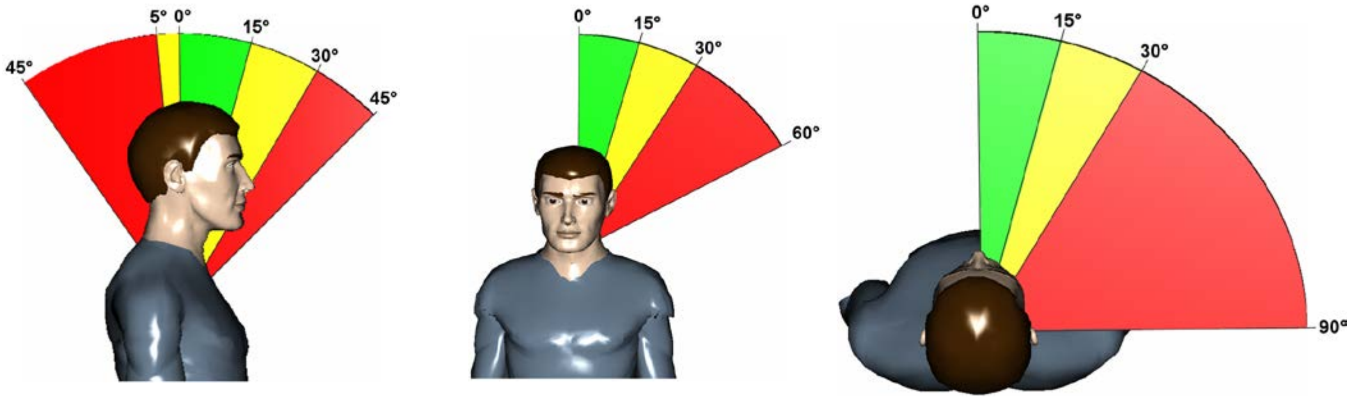


Fig. 4

Rygg/böjning, vridning

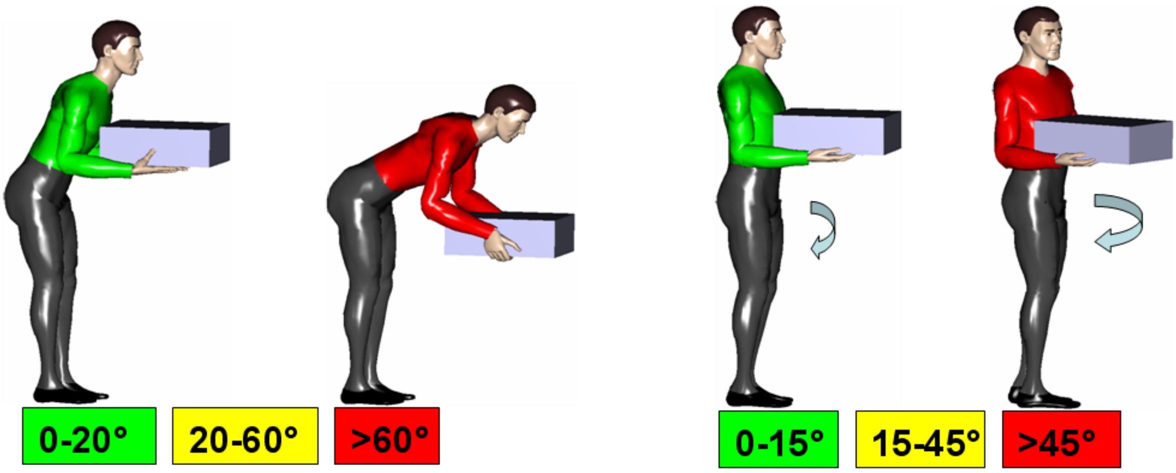


Fig. 5

Grepp

Max 0,5 kg – överhandsgrepp

Max 5 kg – underhandsgrepp

Över 5 kg – tvåhandsgrepp

Fig. 6

Handledsställningar – gripkraft

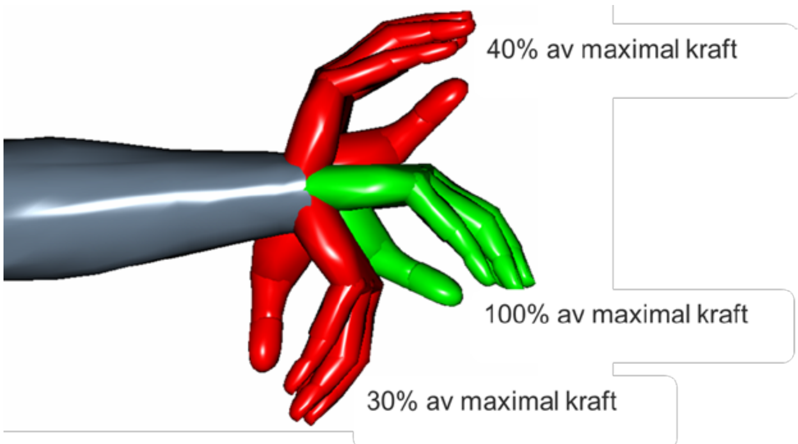


Fig. 7

Frigång arm/hand

Fig. 8

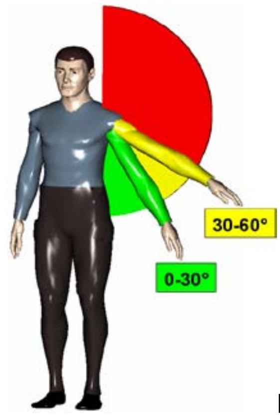


Fig. 9
Skulderrörelser
Armlyft framåt och åt sidan

Arbetsställningar som är höft/knäbelastande

Huksittande Höftsittande Knäsittande Kliv Sluttande plan

Fig. 10

Tabell 2 **Skjuta- och dra-arbete** – Modell för bedömning av skjuta- och dra-arbete vagnar

A. Vagnar, tyngre emballage

Kraft (N)	röd	gul	grön
Start	>300 (ca. 30 kp)	300-150	<150
Kontinuerligt	>200	200-100	<100

Gäller för vagnar och tyngre emballage på hjul eller skenor. Modellen ovan gäller vid bra ergonomiska förhållanden, d.v.s symetriskt tvåhandsgerpp, väl utformade handtag placerade i lämplig höjd och under goda omgivningsbetingelser. Om denna typ av arbete utförs ofta ska värdena ovan halveras.

Tabell 3

B. Upphängningsanordningar, traverser, etc

Kraft (N)	röd	grön
Start	>50 (ca. 5 kp)	<50
Kontinuerligt	>40	<40

Gäller för skjuta- och dra-arbete i den upprepade arbetscykeln vid för övrigt bra ergonomiska förhållanden (traverser, upphängningsanordningar, lyftverktyg, avlastningsarmar, grimmor, handverktyg, svetstänger, arbetsobjekt etc). Se schemat ovan.

B
Volvo Cars Safety Standard

MACHINE SYSTEMS

Safety of machinery - General principles for design - Risk assessment and risk reduction

Orientation

This standard has been completely re-worked and is based on the new standard ISO 12100:2010.

This document constitutes Volvo Car Corporation’s **Supplementary requirements** to ISO 12100:2010 Safety of machinery - General principles for design - Risk assessment and risk reduction.

All deviations from this standard shall be documented and approved by Volvo Car Corporation (VCC).

1 Scope and field of application

Where Volvo Car Corporation’s requirements differ from ISO 12100:2010, an indication is provided under the relevant heading. It should be noted that the requirements of ISO 12100:2010 still apply unless directly in conflict with VCC’s requirements.

Harmonized standards shall apply unless otherwise agreed in writing.

Supplementary requirements to ISO 12100: 2010

Contents

3 Terms and definitions

In addition to the definitions in ISO 12100, the following also apply:

safety stop
an interlock state of a machine or a hazard zone, reached by the operation of an interlocking guard (3.27.4) or a protective device (3.28)

NOTE – A safety stop is reset by a "Manual reset" as described in ISO 13849-1, section 5.2.2.

safety zone
zone corresponding to a combination of "safeguarded space" and "span of control" as defined in ISO 11161, where the machine actuators within the safeguarded space are controlled by the same control mode

turntable
conveyor turning or changing the direction of transportation for the part

circular feeder
fixture feeding the parts to various operations

contractor/supplier
contractor is defined as responsible also for the requirements placed on the supplier;
the term "supplier" is replaced by the term "contractor"

safety stop circuit
electric circuit intended to be used as part of an electric system for safety interlocks

4 Strategy for risk assessment and risk reduction

The contractor's risk assessment shall be performed per hazard source and starting from "naked" non-safeguarded hazardous objects.

This means that the risk assessment documentation shall include:

– risk evaluation figures without safeguarding
– the safeguarding or other safety means
– evaluation figures for the residual risks with the safeguarding in place or other safety measures taken.

The risk assessment shall also be summarized and documented per machine and/or per operator workplace using the numbering of hazards listed in ISO 12100, Appendix B, table B1 together with a selection of appropriate words also given in table B1 to describe the hazard in the most convenient way.

The contractor is always responsible for carrying out a documented risk analysis. The contractor shall ensure that VCC's Machine Safety Specialist is advised of each risk analysis and given the opportunity to participate at all such analyses.

5 Risk assessment

5.4 Hazard identification

The machines shall be provided with CE marking before being used. If VCC employees are to participate in test runs, etc, of non-CE marked machinery, some basic requirements must be fulfilled. All equipment/ machinery shall be inspected by VCC. The VCC Health & Safety organization is responsible for drawing up instructions and requirements for VCC employee participation.

6 Risk reduction

6.2 Inherently safe design measures

6.2.1 General

Safety concepts shall be adapted to production as well as to maintenance, i.e. they are to be designed in such a way that they do not disturb production. They shall also be practical so that no one is tempted to remove safety devices or in any other way manipulate with safety.

6.2.2 Consideration of geometrical factors and physical aspects

6.2.2.1 Geometrical factors

The robot/machine shall not be able to reach over/through the safeguarded perimeter, including tools and parts. This requirement shall be verified in practice and the result(s) documented.

If a robot/machine placed next to an operator's workplace can reach outside the fence, the robot shall be limited mechanically or electrically. If this is not possible, the fence shall be designed to withstand the forces of the robot (mechanical barrier).

The safety area shall be open to the back so that the operator can exit (escape route) the hazard zone easily if the robot should fail.

The position of robot-limiting devices shall be documented in the 2-D layouts of the robot cell.

All safety-related distances shall be documented in 2-D layouts, e.g. safety distance to light curtains.

6.2.2.2 Physical aspects

The noise generated by harmonics shall be considered when arranging frequency converter and engine combinations. Sound from the frequency converter shall be outside the audible range.

Measurement of noise conditions around machines and equipment shall be carried out in accordance with ISO 3740.

Measurement points:

- Operator workplace
- 1 m from the equipment's limiting surface in its intended centerlines (four (4) measurement points). If any side of the equipment is 4 m or longer, additional measurement points shall be included at every second metre on both sides of the centre measurement point.

The location of the microphone shall be 1,6 m above the floor or the entrance platform.

The equivalent noise level from individual machines/equipment during a cycle of a machine shall not exceed 75 dB(A).

The noise level of peripheral equipment to the machine, such as hydraulic units, pumps and fans shall not exceed 65 dB(A).

Wherever possible, machines and equipment shall be designed or insulated in a way that limits damaging or annoying vibrations and body noise.

Peripheral equipment that generates too much noise shall be placed in a separate, soundproof area.

The temperature of unprotected larger machine (e.g. washing machine) surfaces shall not exceed 40 °C.

If the installed equipment blocks the general lighting, it is the equipment contractor's responsibility to install supplementary operator lighting.

6.2.6 Provisions for stability

Counterweights shall be positioned and protected in such a way that their movement cannot cause personal injury. It shall not be possible for counterweights to fall off. Adjustable counterweights shall be secured against slipping in all positions.

Stationary objects shall not be placed closer than 500 mm from moveable parts in order to prevent injuries caused by crushing. A stationary pole and a car body shall, e.g., be at least 500 mm apart.

For turntables/lifting tables that are started up when skids or materials activate a sensor, the sensor shall be designed in such a way that a person cannot initiate a movement unintentionally.

6.2.7 Provisions for maintainability

Gates/doors shall be provided in safeguarding fences for each side of a safety zone in a line arrangement. For maintenance reasons, more gates/doors may be needed.

6.2.6.1 Location of electrical control cabinets

Electrical control cabinets shall not be located inside the hazard zone surrounding the equipment. The term "electrical control cabinet" refers to control cabinets or boxes containing components that may require maintenance, e.g. relays, contactors, fuses, I/O units, driving devices, vibration indicators, etc.

It must be possible to perform maintenance tasks at electrical control cabinets without entering the hazard zone.

The location of components, e.g. flow sensors, hydraulic components and pneumatic components that need to be maintained should not be in the hazard zone if this is possible.

6.2.8 Observing ergonomic principles

To achieve the best ergonomic conditions at workplaces, the safety distances for positioning of safeguards shall be calculated from the actual conditions of the hazard sources. This means, for example, that the actual movement paths with maximum set value for the speed of the robot shall determine the safety distance. Thus, the safety distance shall not be based on the maximum possible speed specified in the data sheet for the robot.

The theoretical stopping times submitted by the machine contractor can be used when calculating safety distances. At operator workplaces, ergonomic aspects shall be given highest priority. If there are any uncertainties regarding real stopping times (not theoretical), measuring shall be performed by the machine contractor. See section 6.3.2.5.2 Implementation.

VCC's ergonomics checklist according to VCS 8003,29 and VCS 8003,291 shall be fulfilled.

The location of the maneuver/control (HMI) panel shall be decided in consultation with VCC.

6.2.9 Electrical hazards

The free area shall be at least 1200 mm in front of electric cabinets. For evacuation, there shall be a free way of at least 500 mm also when the doors of the electric cabinet are open.

Minor switching equipment that is protected against dangerous short-circuiting shall have a free area of at least 800 mm.

6.2.10 Pneumatic and hydraulic hazards

Pneumatically powered movements longer than 300 mm shall not be used.

Goods transported vertically must not fall uncontrollably when an emergency stop or when the compressed-air supply is lost.
The pneumatic and/or hydraulic supply to the machine actuators shall be maintained in a safe way. If a risk assessment shows that powering down and powering up is done safely, then the result from the risk assessment shall be the guiding principle. If the contractor decides to switch off the power during a safety stopped state, VCC shall be informed thereof.

6.2.11 Applying inherently safe design measures to control systems

6.2.11.1 General

Sensors or control devices that will trigger a hazardous machine movement outside safeguarded areas shall be arranged so that unintentional triggering is avoided, for example by diverting duplicated sensors.

6.2.11.3 Starting/stopping of a mechanism

The operation of the safety stop/reset function shall immediately activate a warning device.

The machine shall be reset via one of the reset buttons of the safety stop area where the stop occurred.

The machine shall normally be started from the operator panel.

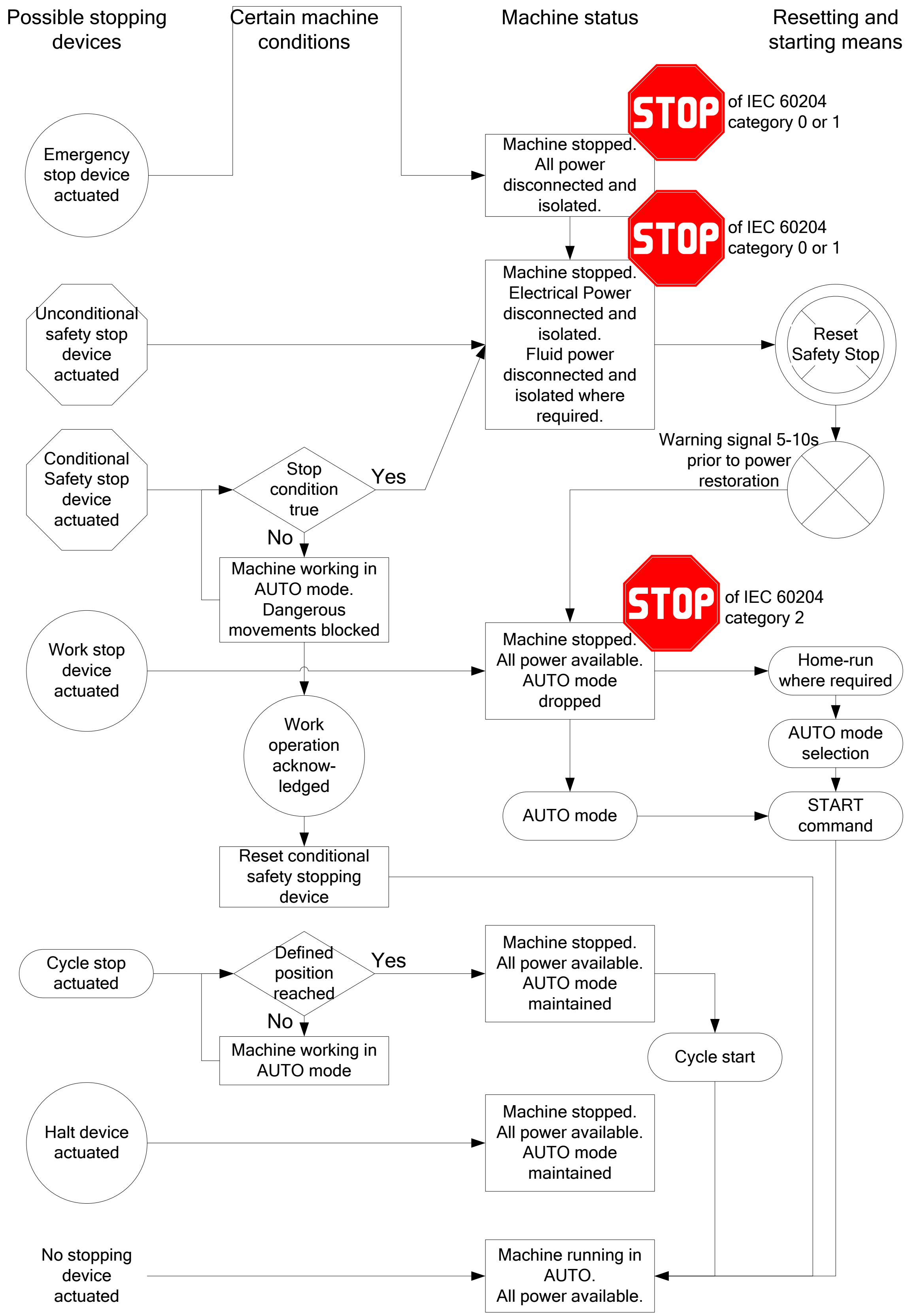
There shall be a start button at each place where you can reset a safety stop and it shall be possible to start from both sides of a station in a production line. If there is no manual operation panel, a separate start button shall be provided.

Exposed persons shall have the time and means to prevent a machine from starting. Necessary sound and/or light devices must be provided for the safety zone, as well as means to interrupt a start.

Table 1 and figure 1 describe all types of stops (stop designations) that can be used within VCC.

Table 1 - Stop types and their causes IEC 60204

Stop types	Stop category	Triggered by	Comments
Emergency stop	0/1	Mushroom-head push-button, pull cord, etc.	Emergency stop button on yellow background with the following text in black: "NÖDSTOPP"/ "NOODSTOP"/EMERGENCY STOP"
Safety stop	0/1/(2)	Safety devices such as gates or doors, ESPDs (Electro-sensitive protective devices), pressure-sensitive mats, push-buttons, switches, fail-safe lockout conditions, etc.	Triggered safety stops shall prevent unintended start. Stop category 2 may be used for hydraulic and pneumatic energy if the risk assessment so permits
Conditional safety stop	0/1/2	ESPD and/or pressure sensitive mats. A safety stop is triggered only when operators enter the zone in conjunction with a hazardous machine movement in the same zone.	Used where operators need to be present in hazardous zones, e.g. for loading/unloading operations. The safety device must trip each time a person enters the zone and be reset by a manual actuation of a “work operation acknowledge” push-button or similar
Working stop	2	Push-button, Mode selector not in AUTO position, certain fault conditions	An immediate stop anywhere in the working cycle. AUTO mode is taken down
Halt	2	Latching-in (mushroom-head) push-button	An immediate stop, with AUTO mode maintained, anywhere in the working cycle
Cycle stop	2	Push-button, certain fault conditions	Stop after the sequence/transport has reached a defined home position(s)
Production stop	2	Manufacturing execution system (supervisory)	Depending on the process either effectuated as a "Halt" or as a "Cycle stop"


Possible stopping devices
Certain machine conditions
Machine status
Resetting and starting means
STOP
of IEC 60204 category 0 or 1
Emergency stop device actuated
Machine stopped. All power disconnected and isolated.
STOP
of IEC 60204 category 0 or 1
Unconditional safety stop device actuated
Machine stopped. Electrical Power disconnected and isolated. Fluid power disconnected and isolated where required.
Reset Safety Stop
Warning signal 5-10s prior to power restoration
Conditional Safety stop device actuated
Stop condition true
Yes
No
Machine working in AUTO mode. Dangerous movements blocked
STOP
of IEC 60204 category 2
Work stop device actuated
Machine stopped. All power available. AUTO mode dropped
Home-run where required
AUTO mode selection
Work operation acknow-ledged
AUTO mode
START command
Reset conditional safety stopping device
Cycle stop actuated
Defined position reached
Yes
No
Machine stopped. All power available. AUTO mode maintained
Machine working in AUTO mode
Cycle start
Halt device actuated
Machine stopped. All power available. AUTO mode maintained
No stopping device actuated
Machine running in AUTO. All power available.

6.2.11.7 Safety functions implemented by programmable electronic control systems

6.2.11.7.1 General

Figures 2 and 3 show the general principle diagrams for electric and pneumatic power supply distribution.

All functions shall be redundant and supervised. This implies that contactors which are controlled by an interlocking device must have their state fed back to the safety control system.

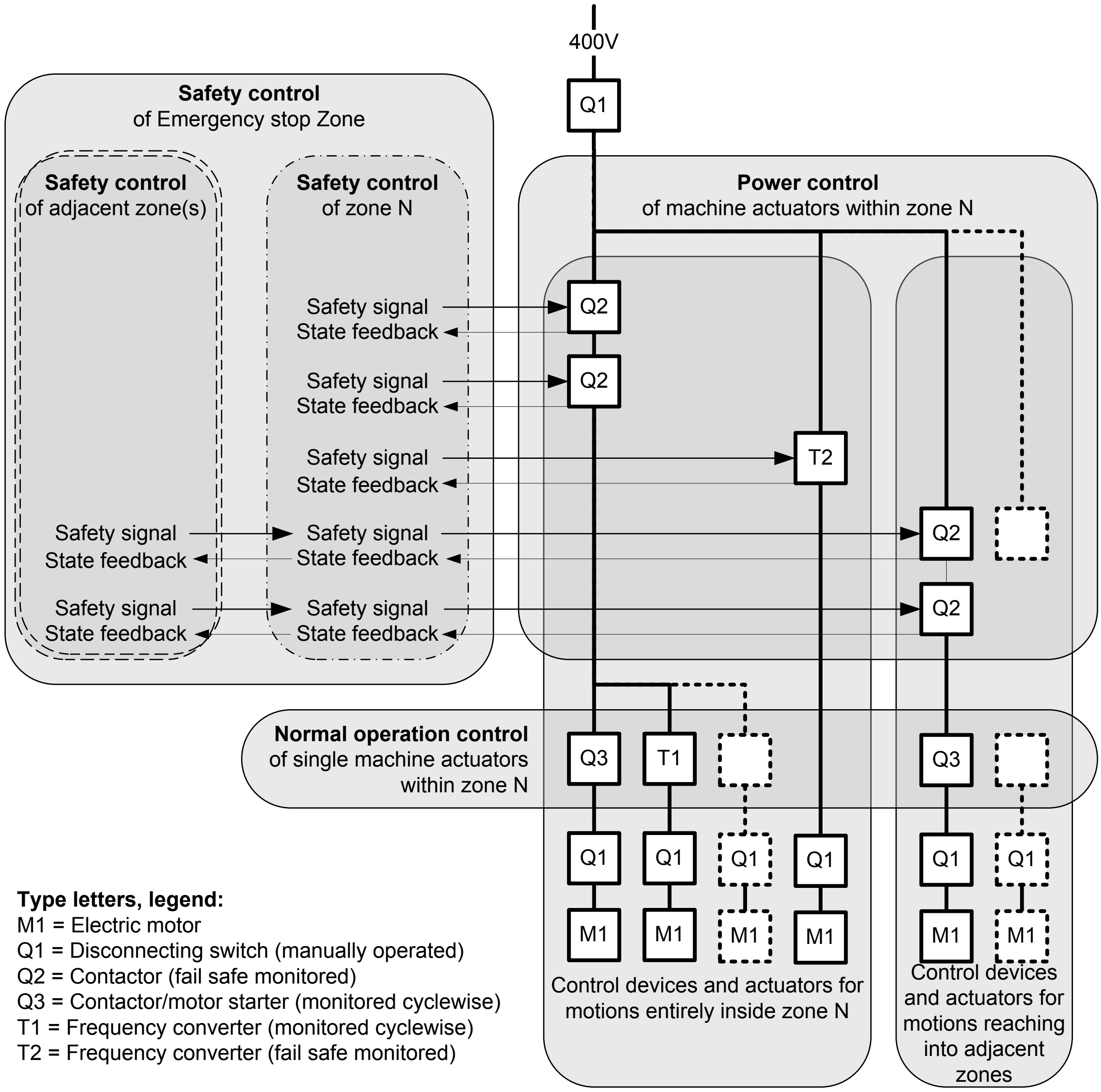


Fig. 2 General principle diagram for electric power supply distribution (dotted lines are possible extensions)

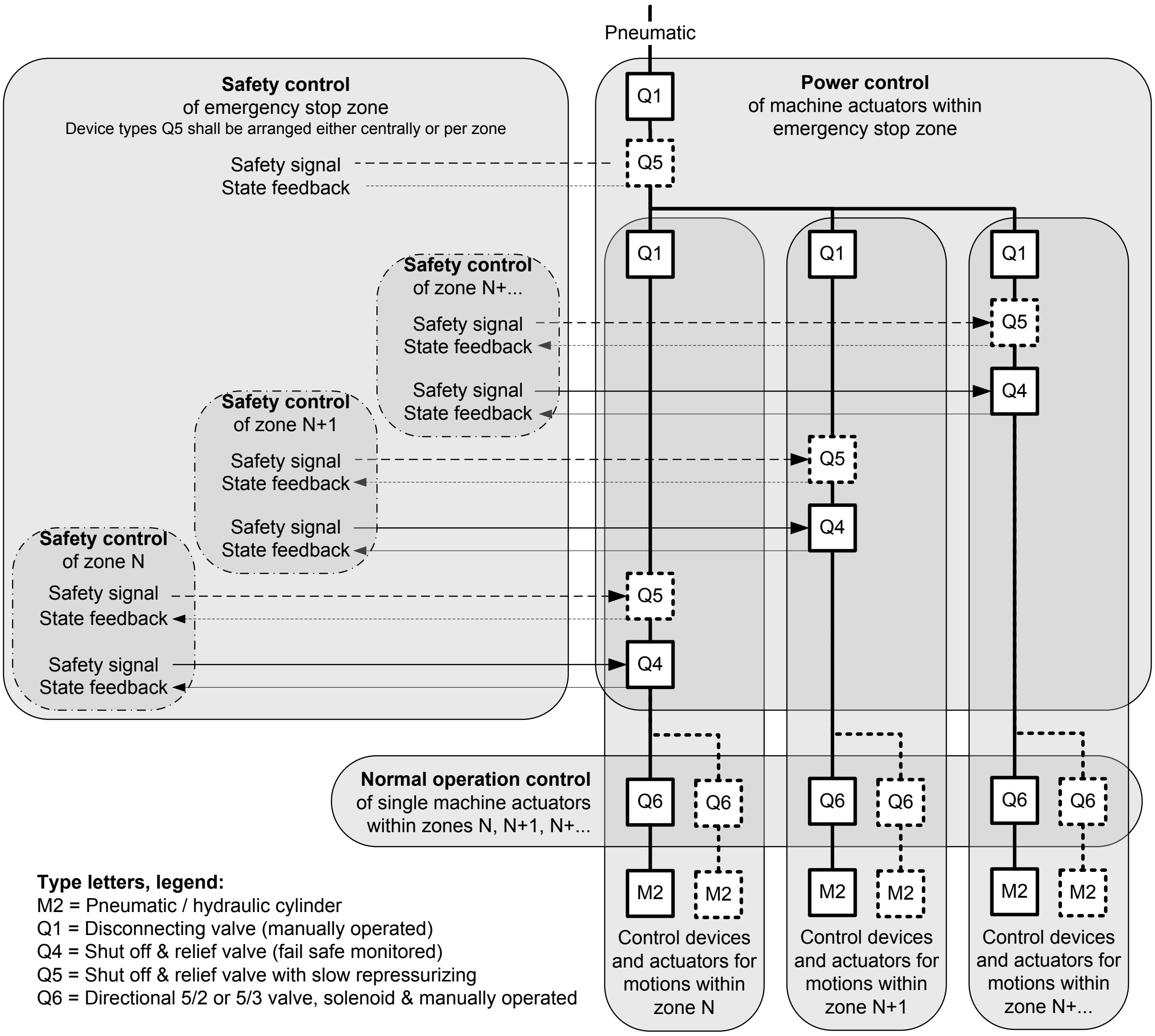


Fig. 3 General principle diagram for pneumatic power supply distribution

6.2.11.8 Principles relating to manual control

There shall be emergency stop buttons in places frequented by people, such as manual loading stations, central control areas, etc.

The maximum distance between a machine and the nearest emergency stop and quantity of emergency stop buttons shall be determined in joint consultation together with VCC. Along assembly lines, the emergency stops shall be placed in a zigzag pattern.

Emergency stop wires shall be provided with emergency stop labels/flags every 10 m.

There is to be a emergency stop device on each side of the station in a machine.

It must be possible to trigger safety stops within a protected area.

If the operator does not have a complete overview of the installation from the Reset/Start-up panel, there shall be a delay of 5-10 seconds from start command until any movements are activated.

During the delay, a warning signal shall sound/flash, and the machine shall remain in the same operating state. When the Reset or Start-up command is issued with a push-button, the button shall be kept pressed down as long as the warning signal sounds in order to enable the reset/start-up. When the reset/start-up command is not issued with a push-button, it shall be easy to interrupt the reset/start-up procedure before the machine is powered.

The duration of the delay and the type of warning device shall be agreed with VCC.

Flashlight lamp with yellow light shall be used only as warning: DANGER - MACHINE STARTING.

6.2.11.9 Control mode for setting, teaching, process changeover, fault-finding, cleaning or maintenance

Where an enabling device is needed, it shall be of the three-position type.

When a safety stop has been activated by means of an enabling device, it shall be possible to reset and start the machine within the hazard zone, but only when the operator has the enabling device in its activated position.

6.2.12 Minimizing the probability of failure of safety functions

Safety-related parts of the control system shall have a combined resulting category of 3 or 4 for safety arrangements in accordance with ISO 13849-1, both for performance level ***d*** or ***e*** <u>and</u> safety category ***3*** or ***4***.

Safeguarding at operator workplaces in the vicinity of robots shall be of category 4 in accordance with ISO 13849, both for performance level ***d*** or ***e*** <u>and</u> safety category ***3*** or ***4***.

6.3 Safeguarding and complementary protective measures

6.3.1 General

All parameters and formulas used in order to design safety distances shall be documented and submitted to VCC.

Hazards related to speed from conveyors (transporters, carriers) shall be analyzed according to guidelines below.

- Hazard type 1.6 (impact hazard) of ISO 14121 table A.1 normally need not be considered for speeds lower than 250 mm/s.
- Conveyors with transport speed above 500 mm/s shall have safeguards.
- The need for safeguards for conveyors with a transport speed between 250 mm/s and 500 mm/s shall be evaluated individually.

Sensors or maneuver devices that will trigger a hazardous machine movement shall be arranged with an additional device or similar so that unintentional triggering can be avoided.

Level crossings over conveyors (roller conveyor) shall be safeguarded in such a way that a person cannot tread in between. There shall be an escape area in the conveyor’s direction of travel.

Openings in conveyers (roller conveyor) intended for passenger traffic should be avoided. If such openings are considered necessary, they shall be provided with protection scanner, pressure sensitive mat or similar to avoid injury by crushing.

If the operator must stay on the conveyor, the surface (rollers) shall be covered to prevent any risk of treading down or stumbling. The cover shall extend over the workplace in the direction of the material to create an escape area.

Level crossings over transport paths shall be placed where appropriate from a safety point of view, with good visibility and not near particularly hazardous zones.

6.3.2 Selection and implementation of guards and protective devices

6.3.2.1 General

For safeguarding devices like ESPD (Electro-Sensitive Protective Devices), gates, etc., a manual reset button shall be available in the vicinity of the device.

Process-flow inlets to safety zones shall be built as corridors with net fences. Saloon doors and light beams/curtains shall be used for personal protection.

Process-flow outlets from safety zones shall be built as corridors with net fences and be narrow in relation to the work piece, making it hard for persons to pass unintentionally. In this case, saloon doors are not required, but light beams/curtains shall be used.

Gates/doors in the fence must not be placed so that they open directly towards the travel path for industrial vehicles.

6.3.2.2 Where access to the hazard zone is not required during normal operation

The risk of injury determines the design of screening and protection in areas to which the operators do not normally have access.

Hazards related to transport system (e.g. roller conveyors) shall be analyzed.

For hazards regarding the transport system speed, the following shall serve as a guideline:

- High speed (exceeding 500 mm/s) and high risk require locked-up space to which only specially appointed and trained staff has access. There must be an emergency stop wire covering the whole area and protection/warning of particularly hazardous zones.
- At lower risk and lower speed (below 250 mm/s), a gate/barrier provided with a warning sign may be sufficient. Only staff informed of the risks may enter the zone.
- The need for safeguards for transport systems with a transport speed in between the above speeds (250 mm/s and 500 mm/s shall be evaluated individually.

6.3.2.3 When access to the hazard zone is required during normal operation

A three-position enabling device shall be used.

6.3.2.5 Selection and implementation of sensitive protective equipment

6.3.2.5.1 Selection

Light beams shall preferably be used as a protective device in openings to prevent inadvertent passage of persons and also where the protective device needs to be muted due to the flow of materials and work pieces.

6.3.2.5.2 Implementation

The safety distance to safeguards shall be made as short as allowed by ISO 13855, with the aperture of the ESPD (Electro-Sensitive Protective Device) being maximum 30 mm.

Workplaces shall be protected by a combination of horizontal and vertical light curtains in order to limit the working area and thus the need to walk about for the operator.

Resetting buttons shall be located so that they cannot be influenced from inside the machine area.

Scanners shall be set up with their protected area limitation 50-100 mm from obstacles to avoid false tripping.

When using a light beam, there must always be at least two rays.

When mirrors are used in connection with light beams and light curtains, they have to be protected from soiling by, e.g. weld spatter, oil, water, etc.

The protective device units, including mirrors, must not be mounted on safety fences or pillars supporting fences.

6.3.3 Requirements for the design of guards and protective devices

6.3.3.1 General requirements

There shall be an interlocked or lockable gate to enable people entering the zone. Light beams shall not be used as a gate for entering into the zone.

Unintentional start shall be inhibited by gates, which must be lockable in the open position by means of padlocks in accordance with the VCC Power Lockout procedure. Power Lockout sign shall be posted on the entrance gate, see Appendix 2.

It shall be possible to open gates from inside the hazard zone.

It shall be impossible to close gates from inside the hazard zone.

It shall be possible to trigger safety or emergency stops within a protected area.

Light beams shall preferably be used as a safety device in openings to prevent inadvertent passage of persons and also where the protection device needs to be muted due to the flow of materials and workpieces.

When muting a light beam where workpieces enter or exit a hazard zone, it is necessary to ensure that muting is established only when workpieces are passing into or out of the hazard zone. During the time of muting, it must not be possible for a person to unintentionally pass into the hazard zone together with the workpiece.

Sensors for muting light beams shall not detect the workpiece (e.g. car body) but the conveyer, skid, pallet or similar as the material varies.

To prevent persons from following the product when muting, the opening shall be provided with a profile opening.

Where the profile opening creates a risk of severe injury by crushing, the profile opening can be hinged according to the saloon door principle or provided with safety bumpers. These must, however, be interlocked like ordinary gates.

In case of an emergency stop, light beam/curtain failure or a power dip, the workpiece shall be able to continue its original flow. In these cases, it shall be possible to temporarily turn off the muted light beam/curtain with a simple maneuver.

6.3.3.2 Requirements for guards

6.3.3.2.2 Requirements for fixed guards

Piping and cable trays shall not replace fences.

The height of the fence shall be 2000 mm - 2300 mm. There shall be an opening 100 mm - 180 mm between the floor and the lower part of the fence to facilitate cleaning from the outside.

For equipment where resistance welding is included in the work process or where there is risk of metal splinters and chips, the safety fences shall also be equipped with polycarbonate sheets (Makrolon). To facilitate maintenance/cleaning, the polycarbonate sheets shall be easy to install/remove. The design of safety fences with polycarbonate sheets shall be approved by VCC.

6.3.3.2.3 Requirements for movable guards

All hinged doors and sliding doors shall be designed so that they can be locked with a padlock in accordance with the VCC standard for Power lockout.

A gate must not be placed closer than 500 mm from the reach of a robot or other machine.

6.3.3.2.5 Requirements for interlocking guards with a start function (control guards)

When light beams are in the muting mode and, at the same time, an emergency stop, sensor error or power dip occurs, it shall be possible to get the part out with the machine set in manual or automatic mode once the power has returned or the emergency stop has been reset.

6.3.3.3 Technical characteristics of protective devices

All safety functions shall be tested. A report, based on a cause-effect matrix where the intended effects of every possible cause are verified, shall be drawn up and submitted as part of the documentation.

6.3.4 Safeguarding for reducing emissions

6.3.4.4 Hazardous substances

When designing the process ventilation, the aim shall be to prevent as many of the impurities as possible from escaping into the indoor air. The discharge of air from the room shall be as small as possible. The process ventilation shall be evacuated outdoors.

Exposure to individual substances within the breathing zone shall be < 25 % of the applicable hygienic limit values. From a technical point of view, the lowest levels possible are preferable. If a person is simultaneously exposed to several substances, the total effect shall be < 25 %.

When working with hazardous substances, suction devices shall be integrated in the machine/equipment.

Stationary spot welding machines shall have a built-in suction outlet.

6.3.5 Complementary protective measures

6.3.5.1 General

6.3.5.2 Components and elements to achieve emergency stop function

Emergency stops shall isolate and dissipate energies, e.g. electrical and pneumatic/hydraulic supplies.

Emergency stops shall cause trigging of safety stops in all safety stop zones concerned.

Emergency stops shall be reset by means of resetting the respective safety stop zone.

The equipment shall be prepared to receive external emergency stop signal (ISO 13849, category 3 or 4).

The equipment shall be prepared to hand over an emergency stop signal to external equipment (ISO 13849, category 3 or 4).

Each operator workplace shall be equipped with an emergency stop device.

The maximum distance between emergency stop devices on one and the same machine shall be 30 m.

Restarting after an emergency stop:

It shall not take longer than 1 min to reset and start after an emergency stop.

Emergency stop zones shall be coordinated with the emergency stop zones of existing machines.

Resetting of an emergency stop shall be done in the same way as if all safety stop zones within the emergency stop area had been safety stopped, i.e. each safety stop zone has to be reset, one after the other, until all zones have been reset.

Restarting after a safety stop:

When a safety stop zone is to be reset, then its slow-pressurizing valve must be energized. Not until all safety stop zones have been reset, the start/stop valve of the emergency stop area shall be energized and, consequently, all fixtures, etc., will be pressurized.

A signal shall sound when safety stops are being reset. The audible warning period shall be 5-10 sec. The reset button shall be kept in the pressed-down position during the entire warning period.

6.3.5.3 Measures for the escape and rescue of trapped persons

Instructions on how to remove persons trapped after the emergency/protective stop has been activated shall be supplied with the equipment.

6.3.5.4 Measures for isolation and energy dissipation

Safety placards (SP)
Machinery/equipment shall be equipped with safety placards (SP) to warn and inform about stored energies which remain hazardous once all the primary energy sources/safety stop devices have been shut off and which may create a hazard to individuals,

A more detailed description is given in Appendix 1.

Machines shall be delivered with:

- A safety placard (SP) where the layout section indicates where the power-disconnecting devices for different energies of the machinery/equipment are located. The SP layout shall also include labeling of what stored/residual energies that may remain.
- A visualization of all power-disconnecting devices shall be visualized in the SP layout. If necessary, they can be visualized on a separate layout in the SP document.

6.3.5.5 Provisions for easy and safe handling of machines and their heavy component parts

Any device for power disconnection and prevention of unexpected start-up (as per EN 1037) shall, if necessary, also be included in the circuit for unconditional safety stop.

For machines divided into stations, there shall be one common device for prevention of unexpected start-up at each station.

Such a device shall be lockable and connected to the safety stop circuit of the station in question. Furthermore, if dangerous movement can start by actions triggered in adjacent stations, the device shall also be connected to the safety stop circuit of such a station.

6.3.5.6 Measures for safe access to machinery

Conveyor crossings in level with the conveying plane shall be provided with an “escape area”, 1000 mm in the conveying direction.

Hoists (elevators) must be safeguarded. Transport openings of hoist shafts at bottom levels shall have a safeguard preventing persons from entering. Maintenance/operator entrance to hoist shafts shall be provided through an interlocked gate, not through the material intake.

Two from each other independent trip guards shall be activated automatically when access to the hazard zone occurs. If the activated locking device is not visible to the maintenance/operator, an indication device shall be installed.

Permanent means of access to machinery shall be used, i.e. no removable ladder.

Stairs shall be selected as an access point. If this is not possible, spiral staircases or ladders can be used.

Spiral staircase shall not be the only access route to machines; in the event of an accident, it is difficult to transport a stretcher in the spiral staircase.

Ladders shall be fixed and firmly attached.

ISO 14122 “Permanent means of access to machines and industrial plants” shall be complied with.

Staircases with more than 3 steps shall have a banister.

Outdoor staircases and ladders shall have metal grids in order to minimize the collection of water and ice.

Work at heights above 2 m is not permitted without satisfactory protection**.**

If unable to reach from floor level (working heights above 2 m), the contractor shall provide equipment with fixed work platforms (scaffolding) with safe means of access in accordance with standard ISO 14122-3A: 2010, Appendix 1, 3.2.4.15**.**

If equipment/machinery cannot be provided with safe service platforms, the contractor shall provide some other safety device. One solution could be to use fall-protection equipment.

The contractor must provide the equipment with points of attachment for fall protection in accordance with harmonized standard.

If a machine contains confined space with hazardous atmosphere, the manhole diameter shall be minimum 600 mm.

Elevators (vertical conveyers), not for passenger transport

Elevators shall be designed for safe maintenance. Passenger transport is prohibited. The elevator shall be surrounded by protection. The operator entrance shall be through an interlocked gate, not through the material intake.

Elevator openings shall be safeguarded unless all of the following four conditions are met:

- the material opening is situated at least 1000 mm above floor level or the work space
- there is a space on “escape area” below the elevator with a height of at least 500 mm
- the danger area cannot be reached from the opening
- there is no operator workplace directly adjacent to the opening.

If the operator workplace is situated directly before or after the elevator, the opening shall be provided with protection, for example light barriers.

The design shall be discussed with VCC.

6.4 Information for use

6.4.4 Markings, signs (pictograms), written warnings

In all places where it is possible to unintentionally step into hazard zones, e.g. at light beams or passages between zones, there shall be warning signs.

The supervised area for light beams, laser scanners, pressure-sensitive mats and/or light curtains shall be marked on the floor.

Where there is risk of crush hazard or other hazard leading to personal injury, the hazard zone or volume shall be marked.

The protected area shall be marked on the floor to make it easy to check and verify the size. This applies in particular to laser scanners. The markings also serve as information for the operator.

The warnings shall be in yellow paint and, when required, have contrast marking in yellow/black paint.

7 Documentation of risk assessment and risk reduction

The risk assessment performed as a part of the EC declaration of conformity shall also be part of the documentation submitted to VCC and shall be written in English or local language.

A list of the essential requirements of the Machine Directive, Annex 1 shall also be a part of the documentation delivered to VCC.

Appendix 1

Safety placards (SP) for machinery and equipment

1 INTRODUCTION

This document describes the rules and procedures governing the preparation of safety placards (SP).

The intention is to enable safe maintenance and service work by warning of hazardous stored or residual energy in machines and machine systems and to indicate how/where this energy shall be eliminated or blocked.

An SP is a document which informs about where power-disconnecting devices are located and spots where remaining, potential hazardous energy is located in the hazard zone.

Normally, SP shall be posted where the staff has access to the machinery/equipment.

Power-disconnecting devices/blockers for residual hazardous energies and remaining hazardous energies shall be marked with a symbol on the SP.

2 PLACARDING PROCESS

2.1 Introduction

SP shall be implemented to all machinery and equipment with multiple energy sources, and to some machinery and equipment with a single energy source, when the unexpected energization, release of stored energy, or start-up could cause injury to employees performing maintenance or service

2.2 Scope

Safety placards SP indicate where power-disconnecting devices/blockers for the residual energy that is left in the machinery/equipment, after the safety-protection device has been affected, are delivered and installed.

Power-disconnecting devices/blockers for residual hazardous energies and remaining hazardous energies shall be marked with a symbol on the SP.

All other power-disconnecting devices shall also be visualized on the SP. If necessary, they can be visualized on a separate layout in the SP.

2.3 Placement of SP

The SP shall be posted in a clearly visible location next to the entrance(s) to the machine/machine area.

2.4 Fabrication of SP

Normally, SP shall be of size A4 (Landscape). However, if all text boxes are filled in so that the text goes over to a second page, A3 (Portrait) size can be used instead.

The SP shall be laminated before posting.

3 SAFETY PLACARD

3.1 Safety placards (SP)

Text on safety placards shall be written in the local language.

3.1.1 Identification section

Identification of the machinery/equipment, the machinery or equipment number and/or designation.

An explanation field where the meaning of different symbols is briefly explained.

3.1.2 Layout section

Includes a drawing/sketch of the machinery/equipment with icons that show where each power-disconnecting device for each energy source is located, and what stored energies that remain hazardous after all the primary energy sources/safety stop devices have been shut off, for example, residual pressure and stored electrical energy (via capacitors).

All power-disconnecting devices/blockers for remaining energy shall be marked with an octagonal, red icon. This icon also marks the type of energy that is present; the letter "P", for example, here means “disconnect pneumatic energy”. The same applies to other forms of energy as described below.

All other power-disconnecting devices/blockers shall be marked with identification number (post designation or serial number).

Stored, contained, remaining energy, residual energy or accumulated energy, shall be marked with a diamond-shaped orange icon. This also indicates the measures to be taken; for example, the meaning of "P" is pneumatic energy. The same applies to other forms of energy as described below.

A blue icon in the form of a padlock indicates where the lockable primary energy/safety stop is located and where it is possible to work with the whole body within a hazard zone.

The location of light curtains shall be marked with two yellow rectangles.

The SP shall have a reference point or marker that shows where you are relative to the machine/ equipment (You Are Here!).

The machine area shall be marked by a blue line.

3.1.3 Energy section

The energy section provides information about the location of the power-disconnecting devices and what type of energy that is disconnected. The icon and the letter supply information about the current energy. Disconnecting devices for remaining hazardous energies shall be marked with a red icon.

All other power-disconnecting devices/blockers shall be marked with identification number (post designation or serial number) together with a description of energy type and equipment.

Remaining energy shall be marked with an orange, diamond-shaped icon, and here too, the letter informs of the type of energy that is present.

3.2 Explanations

The abbreviations to be used on the energy-related icons are given below:

3.2.1 Energy icons

Power-disconnecting devices/blockers for remaining hazardous energy shall be displayed with an alphanumeric two-character code. The letters show the primary energy type:

E = Electrical
H = Hydraulic
P = Pneumatic
G = Gravitation
Gas = Gas
W = Water
T = Thermal energy (heat, radiation)
S = Steam
C = Chemical or extreme cool
M = Mechanical

The digit in the code shall be used as follows:
Power-disconnecting device/blockers for a single energy source (primary energy) to a machine shall be marked and identified as E1, H1, P1, V1, etc.

Several energy sources of the same type, for example electricity for several different engines, shall be sequentially numbered, E1, E2, E3, E4, etc. The equivalence for, e.g., pneumatics, P1, P2, P3, etc.

3.2.2 Icons for stored energy

Contained/stored energy as well as accumulated energy and residual energy shall be denoted by a diamond-shaped, orange icon (see figure 4) with an alphanumeric two-character code in the same way as for energy icons. The letter in the code has the following meanings:

E - Remove electrical energy break, cancel or ground. Applies, for example, to batteries and capacitors

G - Secure gravitational forces (suspended materials or parts which can move when the energy input is closed)

Gas - Remove gas, release or secure. Applies, for example, to pipes, tanks and cylinders

H - Remove hydraulic energy (make depressurized, release contained energy). Applies, for example, to accumulators and cylinders)

C - Secure/release chemical energy (or extreme cold), secure, encase, drain or ventilate. Applies, for example, to pipes, tanks or containers

M - Secure/remove mechanical energy (accumulated mechanical energy that can cause machinery or equipment to move)

P – Remove, make depressurized pneumatic energy (remove residual pressure). Applies, for example, to cylinders and accumulator tanks

R - Secure/remove kinetic energy, rotational (mechanical motion, which can cause mechanical motion). Applies, for example, to flywheels and circular saws

T - Remove thermal energy (dangerous temperatures, e.g., for unprotected skin). Applies, for example, to ovens, cookers, coolers

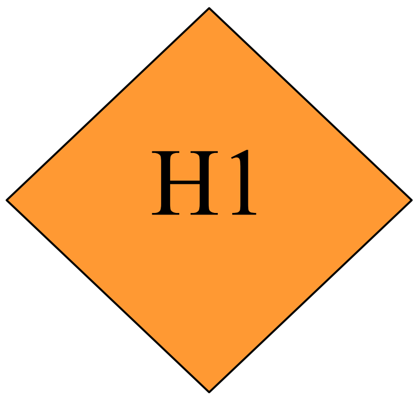
W - Secure water (make depressurized, drain, or secure)

S - Secure steam (make depressurized, drain, or secure)

4 EXAMPLE OF SAFETY PLACARD

The Safety Placard is posted close to the entrance of the machine area

Fig. 1 Example of Safety Placard

Example of symbol for power-disconnecting device of remaining hazardous energy to be visualized on the SP	Example of symbol for remaining, accumulated energy to be visualized on the SP
	
Fig. 2 Symbol for power disconnector	Fig. 3 Symbol for remaining, accumulated energy

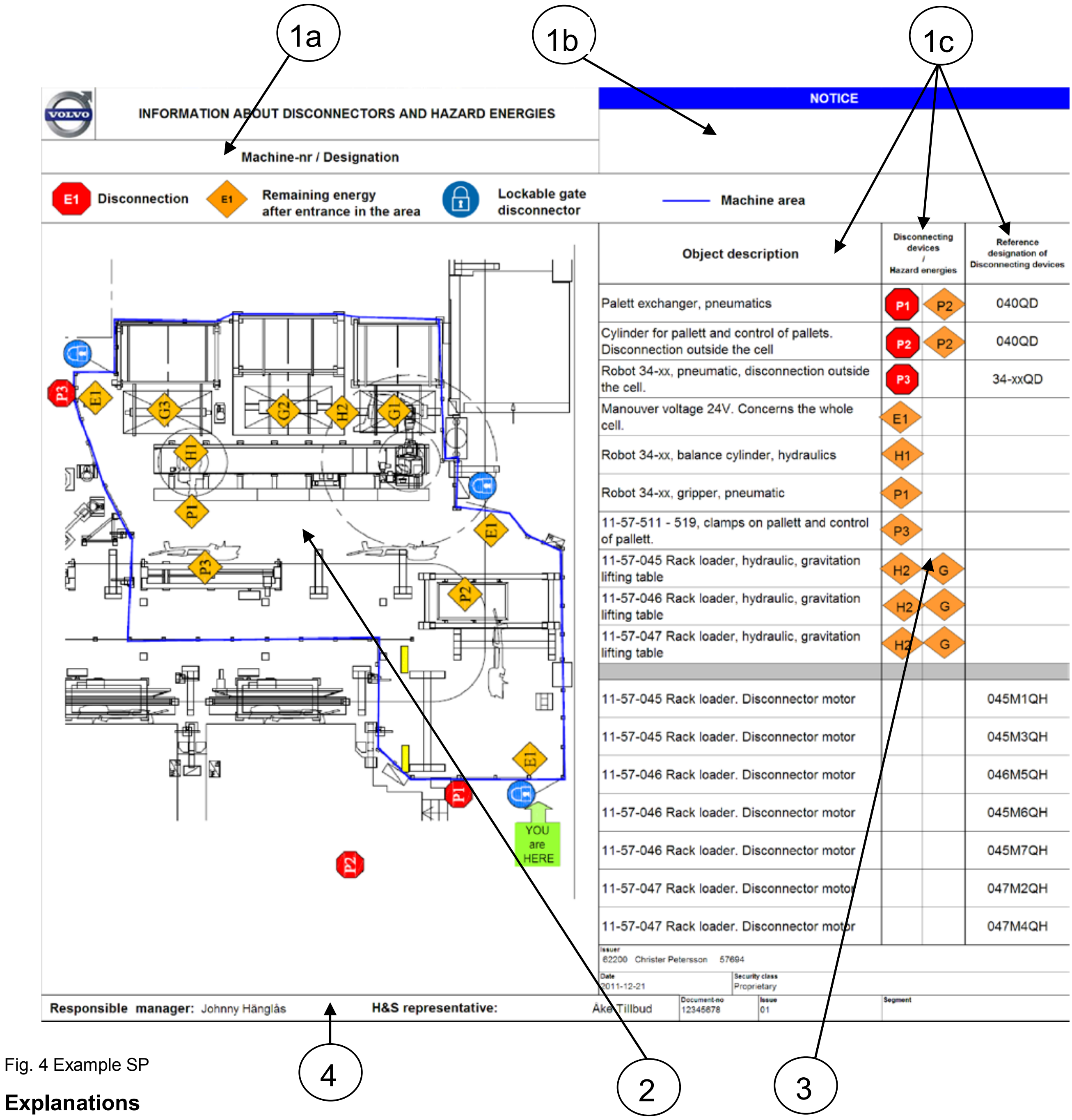


Fig. 4 Example SP

Explanations

1 Identification section

- 1a Identification of equipment, including machine number
- 1b Observation section
- 1c Explanation section

2 Layout section

3 Energy section

4 Final verification. Signing of every new issue by responsible manager and H & S representative

Appendix 2

Power Lockout sign

Risk areas enclosed with fence and with gate breaker or other safety devices, e. g. light beamer, shall have a Power lockout sign, informing that padlocks shall be used.