Design of an Intelligent Protection Shield

Vanessa Rodewald

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ABSTRACT

Tampereen ammattikorkeakoulu
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Vanessa Rodewald:
Design of an intelligent protection shield

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For practical studies in the field of production engineering and automation the University of Applied Sciences Tampere provides their students with access to industrial machinery. Among others a robot cell with an ABB robot 'IR2600' and welding machine 'Fronius CMT500' is available. The overall objective is to improve the usability of the robot for teaching purposes and increase the quality of teaching lessons. To reach this aim a television screen, which makes the screen of the robot control panel visible to the group, should be installed inside the robot cell. That implied the purpose of this bachelor thesis - the design of an intelligent protection shield, there the television screen needed a cover against the welding sparks. Furthermore a controllable drivetrain for the protection had to be created.

The methodical design process described in the VDI 2221 set the approach for the development of the intelligent protection shield. Additional design rules related to the chosen production methods were researched and the properties of usable materials for the construction were analyzed and compared.

The result of the design process were proved production documents like part lists, technical drawings and circuit diagrams. With this documents the implementation of the installation of the television screen inclusive protection shield is possible. Considerably more work will need to be done to make the control of the protection shield more autonomous. Aside from that the achievement of the overall objective to improve the teaching purposes has to be evaluated.

Key words: Methodical design process, morphological analysis, solution synthesis, additive manufacturing

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STATEMENT OF THE AUTHORSHIP

I, Vanessa Rodewald hereby acknowledge to write this bachelor’s thesis with the name *Design of an Intelligent Protection Shield* autonomous and only with assistance with the declared bibliographies.

Tampere, 16.03.2016 ___________________________

GLOSSARY

3D	Three dimensional
ABS	acrylonitrile butadiene styrene
AM	Additive manufacturing
ASTM	American Society for Testing and Materials
CAD	Computer-aided Design
DIN	Deutsches Institut für Normung (German Institute for Standards)
EN	Europäische Norm (European Standard)
FDM	Fused Deposit Modeling
ISO	International Organization for Standardization
PIRAMK	Pirkanmaa University of Applied Sciences
RPN	Risk Priority Number
RR	Remaining Risk
SLS	Selective Laster Sintering
TAMK	Tampere University of Applied Sciences
VDI	Association of German Engineers

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1 INTRODUCTION

Tampere University of Applied Sciences (TAMK) is the second largest multidisciplinary university of applied sciences in Finland. The University was founded through the fusion of the two precursor universities of applied sciences, TAMK and PIRAMK, in 2010. Now days TAMK offers over 40 degree programs in seven fields of study. TAMK provides diverse and multidisciplinary higher education leading to professional expertise in working life (tamk.fi).

For their technical studies at TAMK, the university provides their students with access to different laboratories. One of them is the open-lab. The open-lab is for practical lessons and visual instructions on industrial machinery such as metal processing machines, robotics, measuring machines and 3D-printers. TAMK purchased a new welding robot 'ABB IR2600' with a welding machine 'Fronius CMT500' for the laboratory. The robot and the welding machine are located in a robot cell, which provides the safety for humans and the environment during the welding process.

The aim of this bachelor thesis is to increase the usability of this robot for teaching purposes. Currently the control panel (figure 1-1) is only visible to a few people, because of its size, while a person enters inserts into it. With the installation of a television screen inside the robot cell, the handling of the panel would become visible for the entire group. The television screen will be inside the robot cell, the purpose of project is to design a covering for it. The idea is to install an intelligent protection shield around the television screen, which opens and closes automatically; in programming or standby mode it is open and during the welding process closed.

Figure 1-1: The panel board for the ABB IR2600 welding robot

The design of the protection shield will orientate on the methodical design process of VDI 2221. After the clarification of the tasks the requirements of the system will be defined. In the conceptual design first the functions of the system will determined and subsequently various opportunities for the realization will be established. Related to that different solutions for linear drivetrains will be compared.
The mechanic parts of the system will be designed with Solidworks 2015 and then integrated into one system model including the actuators. When the actuation is determined a selection of sensors and if necessary valves can be made. Followed by the design of electric activation of the system. Through the planning phase various outputs will generated:

- System description
- Technical drawings (CAD-models)
- Parts list
- Drafts for the electric activation, signals and the actuation of the system

Within the ‘part list’ will be defined, which parts need to purchased and which can manufactured by TAMK. In TAMK are 3D printers available for the own production of mechanical parts.
After the design process of the system the results will documented. A final safety engineering evaluation will be made.
As non-committal aim the system could be assembled, followed from testing the system, if all parts are on-hand. These phases could generate as output an assembled, integrated and tested system.

This bachelor thesis is multidisciplinary and offers various possibilities for theoretical studies. Therefore the focus will be on the mechanical design. First the approach of the methodical design will be explained and two of the utilized tools will be introduced. The next part gives an impression of the state of the art of additive manufacturing and an overview over the design rules. In addition the safety engineering as one of the supporting processes, which occur to the product engineering process will be explained.

2 Methodical design process

The development and design model according to VDI 2221 (1986) represents a universal process model. The VDI process model combines several earlier developed process models (Feldhusen, Grote 2013, 16). The model in figure 2-1 gives a synopsis of the different tasks and their expected results (Geis, Birkhofer 2010). The tasks are distributed to four phases, which can classified into 1) clarification of the tasks and analysis, 2) conceptual design, 3) design and 4) elaboration (Theumert, Fleischer 2007, 1). For controlling and improving the results is it normal to skip back and forth between the different stages (Feldhusen, Grote 2013, 17).

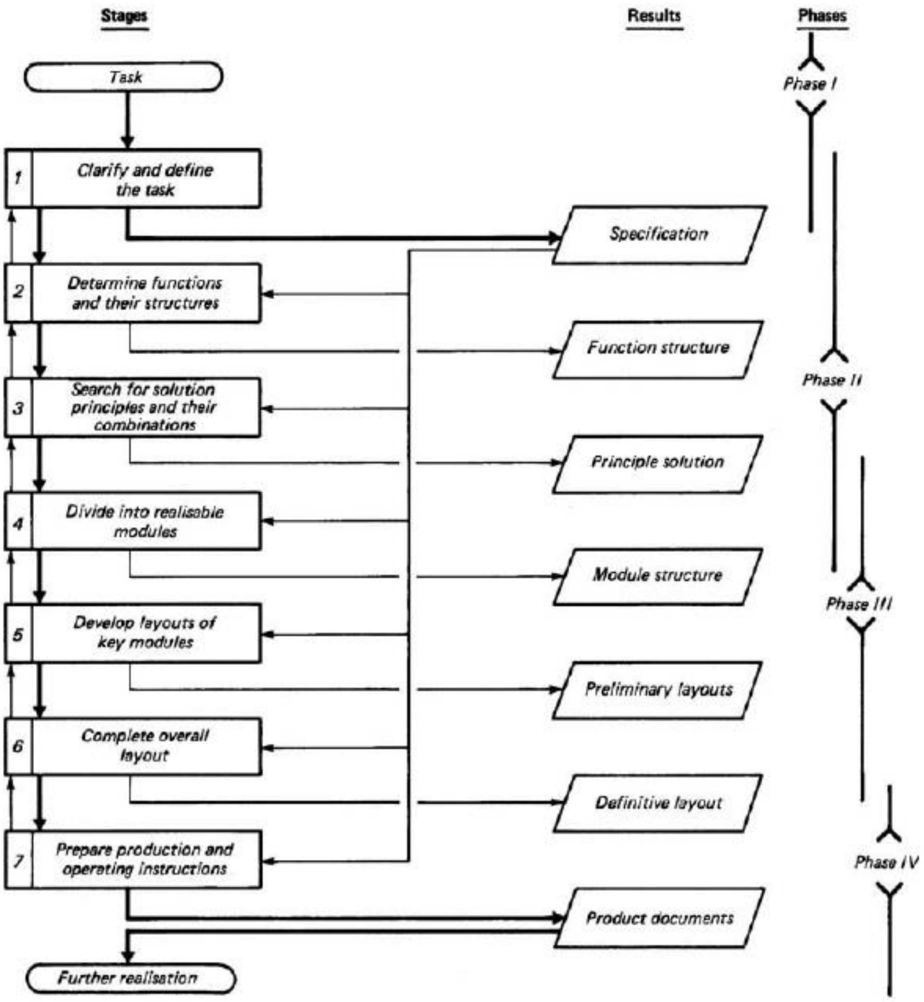


Figure 2-1: General approach of the development and design process according to VDI 2221 (Geis, Birkhofer 2010)

To process the several tasks various tools are given. Two important tools are the morphological box and the technical economic evaluation, both used in task three.

The morphological box is a matrix (figure 2-2), in which the different solutions for the single functions of a system can be combined. The tool is helpful for the synthesis of a great amount of combination possibilities. Only solutions should be combined, that meet the requirements and are compatible with one another. In the end the most useful combinations are selected. Criteria therefore are besides meeting the requirements e.g. that an admissible effort is expectable, the solution fulfills ergonomically and safety engineering requirements, materials and production methods are feasible etc. (Feldhusen, Grote 2007, F4, F7).

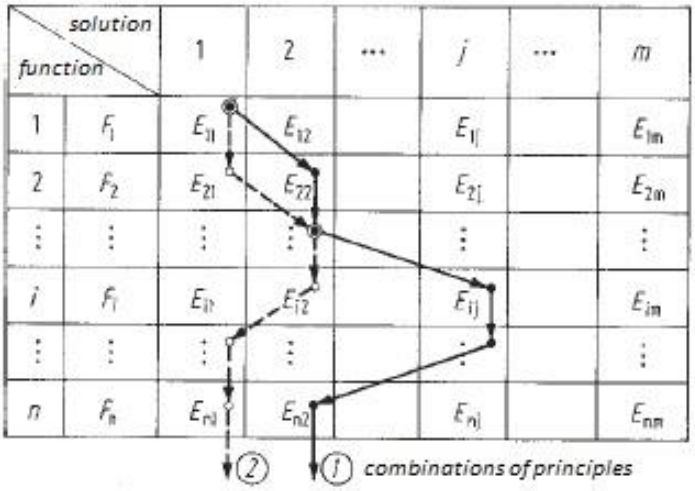


Figure 2-2: Concept of a morphological box (Feldhusen, Grote 2007, F7)

To evaluate the combination of principles at the end of the conceptual design phase the technical economical evaluation is one of various tools, which can applied. On the basis of the list of requirements different technical and economic criteria are created. Often it is practical to weight the criteria. The VDI 2225, which describes the methodology of technical and economical design, scores the criteria then with a rating scale from 0 (unsatisfactory) to 4 (very well/ ideal) (Feldhusen, Grote 2013, 393).

The model according to VDI 2221 does not consider, that the design process is supported from several processes. These processes are proceeded concurrent and include: Project management, risk management, cost management, standards, research on patent and property rights, change management, production planning and procurement, documentation management. The characteristics, intensity and the content of these concurrent processes depends on the product, quantity and kind of construction (Grote, Feldhusen 2013, 21 et seq.)

The design process for the intelligent protection shield will follow the approach presented here. For a clearer understanding of the different phases and the used tools a more detailed explanation will follow in future chapters.

3 Additive Manufacturing

Additive Manufacturing is defined by the ASTM International as “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies” (ASTM International 2012). It includes various manufacturing technologies, which are enabled to produce free formed, three dimensional objects without the need for individual tooling. The precondition is a consistent and complete 3D-CAD model. This model is sliced digitally perpendicular to the working plane (Feldhusen, Grote 2007, F14; Klahn, Leutenecker, Meboldt 2015). One possibility to classify the technologies is shown in the following overview (table 1). The subsumption is according to the aggregate phase of the base material and the physical principle of stabilization (Feldhusen, Grote 2007, S86).

Table 1: Classification of the additive manufacturing technologies (according to Feldhusen, Grote 2007, S87; 3D-druck.comm 2011)

Stabilization of fluid materials with polymerization processes		Stereo Lithography (SL) Digital Light Processing (DLP) Multi Jet Modeling (MJM) Film Transfer Imaging (FTI)
Generation out of the consolidated phase	Cutted from foils and sheets	Laminated Object Modeling (LOM)
	Fusing of consolidated materials and powders	Fused depositing modeling (FDM) Selective Laser Sintering (SLS) Electron Beam Melting (EBM)
	Glueing of granulate material and powders with binder	3D Printing (3DP)

3.1 From Rapid Prototyping to Rapid Manufacturing

The very first additive manufacturing technology, operational for industrial applications, was the Selective Laser Sintering (SLS). Originally additive manufacturing (AM) technologies were used for prototyping. In the product development are prototypes needed over the complete development process, therefore about 25% of the development time was used for manufacturing prototypes (Klocke 2015, 128). AM is advantageously for cross- departmental development projects, which follow development processes as Simultaneous Engineering. The application of AM technologies implicates a shortening of the development time and a faster time to market (Feldhusen, Grote 2007, F14). In the last thirty years AM was more sophisticated, new methods were developed, which allows also the processing of metal materials. AM has the potential to replace conventional processes, especially for the production of small to middle sized series or one-off fabrication. One of the biggest advantages is the freedom in design, complex geometries with undercuts and mesh structures are possible. (Feldhusen, Grote 2007, S86; Klocke 2015, 128; Ituarte et al. 2015). Opportunities like the integration of various functions through the using of one process together with another process, remanufacturing or repairing parts are opened (Vayre et al. 2012). At increasing intervals AM is used for industrial production of prototypes, master forms for following casting processes etc. and also the number of end-user applications rises (Klahn, Leutenecker, Meboldt 2015; Feldhusen, Grote 2007, F14). Ben Stucker (2012) state, that 2010 more than 5,978 'personal' AM machines were sold (the sale price is amount between 700$ to 1500$). Although the increasing business with AM technologies and mechanical properties, reliability and repeatability of AM processes have improved, the standardization and characterization is not yet well-engineered. The quality of additive manufactured parts differs considerable from machine to machine on consideration of achievable mechanical and dimensional properties (Ituarte et al 2015). Also the range of application is not exhausted. For example the integration in process successions for a higher and flexible automatization offers manufacturing capabilities (Klocke 2015, 128)

3.2 Design for Additive Manufacturing

3.2.1 Design Strategies

The literature describes different strategies for the design for additive manufacturing. However for each of them the designer has to understand the characteristics of additive manufacturing, before creating an additive design. As described AM offers some advantages, so it is necessary to identify the parts in a product, which are adding the most value to the customer by using AM. Klahn, Leutenecker and Meboldt (2015) describe two strategies applicable for existing or new products. The choice, which strategy will make to use, has to decide before, there it causes the development process. The manufacturing driven design strategy want to use the cost benefits for manufacturing small lot size and objects with complex structures by using AM technology. The designer follows the conventional design, to be able to choose or later change (if going over to mass production) the production process depending on the number of units and the costs. However for the function driven design strategy the production process with an AM technology is determined before the development process. While designing the part/ product the designer follows the requirements for AM production and is able to create an object with complex internal structures or integrated joints. Often these objects are not manufacturable with conventional technologies (Klahn, Leutenecker, Meboldt 2015).

Frequently companies need to redesign existing parts in their products, if they want to apply AM technologies to their processes. For this case Vayre et al. (2012) describe a four step design process, shown in figure 3-1.

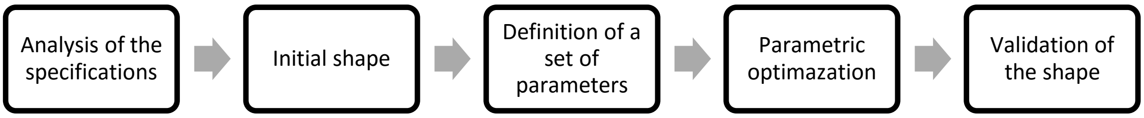


Figure 3-1: Design strategy for the redesign, when changing the production process to AM (according to Vayre et al. 2012)

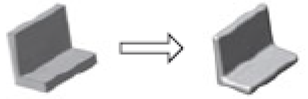
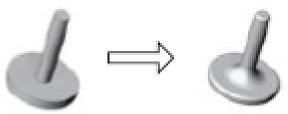
In the first step the specification are analyzed e.g. the purpose of the surface functions as transmitting mechanical and thermal loads. Other criteria are the clearing volume, mechanical load. The second step to initial shapes is often the most difficult one, there designers often stick on existing designs. It is helpful to consult experts or following guidelines. A good start is to define the functional surfaces, since these establish the junction to adjacent parts. Additionally the surface has to accomplish the requirements on the mechanical load, thermal load etc. Also, the type of the chosen AM technology put demands on the shape. After initialing a shape it need to be optimized. For this parameters must be defined and subsequent optimized. The benefits of AM processes are linked to the volume of the part, there the manufacturing duration, use of raw material, energy consumption and costs are all linked to it. In conclusion this means to reduce the volume for optimizing a part. The last step of the redesign is the validation of the part. There virtual validation is not yet matured, is the way to manufacture the parts directly for testing those (Vayre et al. 2012).

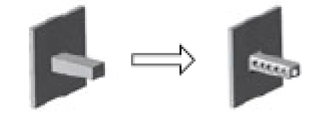
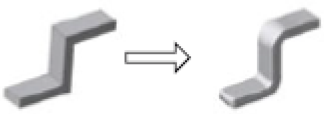
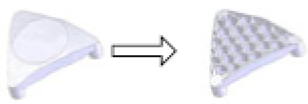
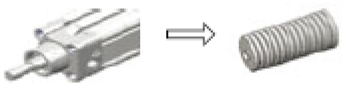
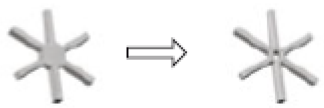
3.2.2 Design rules

To design an object for additive manufacturing processes is challenging for the designer, because of two reasons. The design process and the rules for the design have to unresolved completely. The object always has to be manufactural with the chosen production process. But AM gives such a big freedom in designing and possibilities for innovation, that nearly everything what can be designed also can be produced. As against conventional production methods the complexity of an object has no influence on the production time and consequently on the cost. It is even possible to reduce production time and costs with the design of complex structures. The second reason is that CAD programmes are not yet optimized for AM design (Breuninger et al. 2013, 113et seq.) While the AM technologies have developed over the last 30 years, CAD programmes have not undergone changes in their role and format. So the conventional CAD tools cumber the designer in his thinking for AM (Lipson 2012).

The following table (table 2) shows the constructional changes for additive manufacturing and explains the design strategy. Which changes the designer should use depends on the chosen additive manufacturing technology. For example is a layer-based process used, the initial shape cannot have any closed hollow volume. Additional the shape should make the powder removal as easy as possible. By direct additive manufacturing processes the acceleration and decelerations stages of the nozzle movements must be minimized. This is possible by avoiding sharp corners. Additional the outline of sections have to consist in lines and high radii curves (Vayre 2012).

Table 2: Constructional changes for the design for additive manufacturing (Breuninger et al. 2013, 114)

Suboptimal → Optimal	**Description of the approach**
	Sharp edges should be provided with curves. Edges with no function should be provided with radii. This saves material, reduce injury risks and improves the flux of force.
	Joints of elements should be provided with radii. Rounded joints prevent stress peaks.

	Material saving constructions. The material should be reduced, everywhere it is not mandatory because of the mechanical stress.
	Soft transitions and one-piece designs. The element is not designed for conventional transitions as screwing, glueing, welding etc.
	Use lightweight constructions. If big volumes are needed, use e.g. honeycomb structures to decrease the amount of material and production time.
	Integration of actuators/ function parts in the design.
	Accumulation of material, especially on points of intersection and joining, should be provided to save material and production time.

In the following section the basic construction framework are explained, which a designer should take into account (the framework is mainly for selective laser sintering).

Removal of the powder

For AM processes, which are using powders for generating objects, must minded that the unmelted powder is removable after the construction process. Therefor each cavity should have an opening. The size depends on the complexity of the cavity (for simple geometries a small opening is acceptable, for complex geometries an additional opening could be necessary) In figure 3-2 is as example an additive manufactured pen pictured, on the right side the opening for the powder removal is visible (Breuninger et al. 2013, 122).

Figure 3-2: A pen produced with additive manufacturing. On the right side the opening for the powder removal is visible (Breuninger et al. 2013, 122)

Maximal construction volume

All AM machines have a limited installation space. Currently the biggest selective laser sintering machine has an installation space of 750mm x 550mm x 550mm (3D Systems Sinterstation Pro230) (Breuninger et al. 2013, 122). The company Voxeljet offers with the VX400 the worldwide biggest 3D printing system for sand molds. The installation space measures 4000mm x 2000mm x 1000mm (LxBxH) (voxeljet.de).

Precision

For additive manufacturing are the design data at once the production data. The produced part is composed of one part and normally post-processing is not needed. The dimensional accuracy must be warrant in one process for all geometries. Outer contour as well as inner contour must produce with sufficient precision. At the moment state of art are the tolerances, which are reachable with Selective Laser Sintering, not very high. Also the repeatability poses often a problem. The precision of the parts depends on several factors. The following factors for example influence the production process with Selective Laser Sintering, but some of them are transferable (Breuninger et al. 2013, 124).

Design related factors:

- Observance of the minimal wall thickness
- Observance of the design rules for edges and corners
- Resolution of the STL-database (STL Stereolithography)

Machine related factors:

- X-, Y-, Z-scaling
- Laser offset (just for SLS)
- Temperature distribution inside the machine
- Placement of the objects inside the machine

Distance between component walls

Against interconnecting moveable parts or sections of a part need a minimal complied distance, since the energy and the thermal conductivity causes an edge breezing. This means, that powder, which remained on the parts melts, can cause the parts to become unmovable. The needed distance is dependent on the machine, model and their parameters (Breuninger et al. 2013, 128).

4 Safety Engineering

Safety engineering includes the functional safety of the product as well as the safety for humans and environment. Manufacturers are obliged to detect and document the hazards and risks related to their products (Feldhusen, Grote 2013, 507). But also the designer has the task to orientate towards the principles for safety design, there humans often ignore safety rules. Additional accidents, because of handling errors, are often attributable to inappropriate designs (Neudörfer 2013, 80).

Employees are exposed to various impacts on their workplaces. These impacts originates in three categories – substances, energies and information. Substances includes for example physical effects like climatic conditions. Mechanical and electrical effects on humans are connected to energies. The category information approaches effects from lacks of organisation or stress situations (Neudörfer 2013, 78).

Support for the risk assessment are given from the EN ISO 12 100, which catalogue methodical hazards and from the RAPEX-technique, developed from the European Commission. The risk assessment approaches the four steps shown in figure 4-1. First the possible hazards are searched and afterwards the dangerous situations, while working with or on a machine, are analysed. The third step is important, there the magnitude of the hazard consider the probability of the occurrence of the hazard, the severity of the injuries and sometimes also the possibilities to avoid the accident. At least the results are documented. The risk assessment evaluate the complete life cycle of a product or machine (transportation, assembly, operating, disassembly etc.) (Neudörfer 2013, 77; Feldhusen, Grote 2013, 510 et seq.).

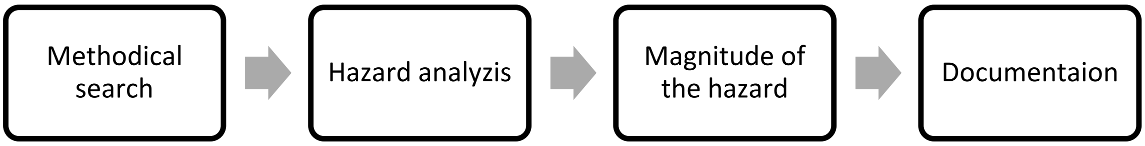


Figure 4-1: Approach of risk management (compare Neudörfer 2013, 77)

It does not exist a generally binding technique for the risk assessment, but all techniques interrelate frequency and severity and sometimes the possibility of avoidance. The following risk matrix (figure 4-2) uses the first two mentioned criteria. The combinations of severity and likelihood are evaluated with risk priority numbers from one to five. Whereas the risk graph (figure 4-3) uses all three criteria to evaluate the hazard. The first decision has to be made regarding the consequences, then the exposure time is decreed. The third step evaluate the probability of avoiding the hazardous event. At least the frequency of the scenario leads to the risk priority number (safety-sc). For a more detailed description of the different criteria compare appendix 2 (page X).

Severity / Likelihood	Slightly harmful	Harmful	Extremely harmful
Highly unlikely	1 Trivial risk	2 Tolerable risk	3 Moderate risk
Unlikely	2 Tolerable risk	3 Moderate risk	4 Substantial risk
Likely	3 Moderate risk	4 Substantial risk	5 Intolerable risk

Figure 4-2: Risk matrix (Koskela)

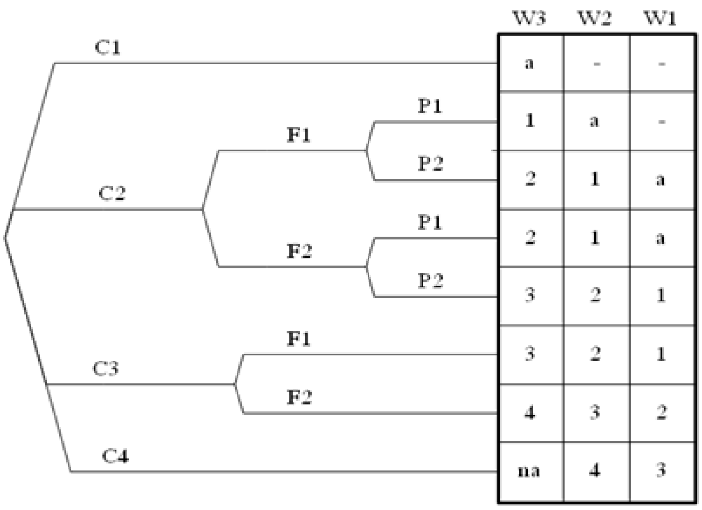


Figure 4-3: Risk graph (safety-sc)

The identified and evaluated hazards are documented in tables (example table 3), which contains the location and type of hazard, the risk assessment with the risk priority numbers (RPN) and safety arrangements with a new evaluation of the remaining risk (RR), if the detailed type of documentation is chosen (Neudörfer 2013, 147).

Table 3: Template for the detailed documentation of the risk assessment (Neudörfer 2013, 147)

Risk analysis		Risk assessment				Safety arrangements		
Location	Hazard	Severity	Frequency	Escaping	RPN	Safety function	Implementation	RR

5 Project Management

Before a project can be executed, it is essential to organize the approach. The four main contents of project management are the temporal scheduling, cost management, risk management and creating effective organizational forms. The last point is not necessary within this project, there is no team working on it. But of course communication with the customer and the employees of TAMK's open lab are essential.

For the scheduling and creating a focus on the aim a project plan is made. The project plan (appendix 1) contains the main steps of the project. The system development orientates on the waterfall model. The approach of the work packages is sequential, each activity must be completed before the next one begins. The planning of the system will takes the most time, especially the design of the mechanics. Concurrent to the practical work the documentation and thesis writing will proceeded. During the design process the components and materials, which need to be purchased are defined.
If the project would be processed by an interdisciplinary team the concurrent engineering or V-model would be the better choice.

For all projects exist several kinds of risks to fail. The reasons for failing are variably. They can concern to the function or performance of the product and to the economic efficiency in operation (Grote, Feldhusen 2013, 36). In the following mind map are the recorded risks for this project (figure 2-1). The greatest challenge of the project is to meet the time schedule, there the design process itself includes six steps and besides the mechanics also the actuation has to be designed.
Another risk is that the designing and calculation of the mechanical load, especially for the AM manufactured parts, could not be sufficient. Potentially because a determinant is disregarded or the design was not functional enough for the manufacturing with AM.

The third essential project management process is the cost management. A product is successful, if it fulfill the market-conform prices (Grote, Feldhusen 2013, 26). There the designed system is a single copy and won't be sell on the market a cost management is not necessary. The cost management normally tries to reduce the costs to guarantee the business success of the developed product and increase the profit (Ehrlenspiel, Kiewert, Lindemann 2005, 19). Additional there was no cost limit given from the customer

(TAMK). For a preliminary estimate of the costs the production costs will be evaluated on the basis of the part list (chapter 9.2.2).

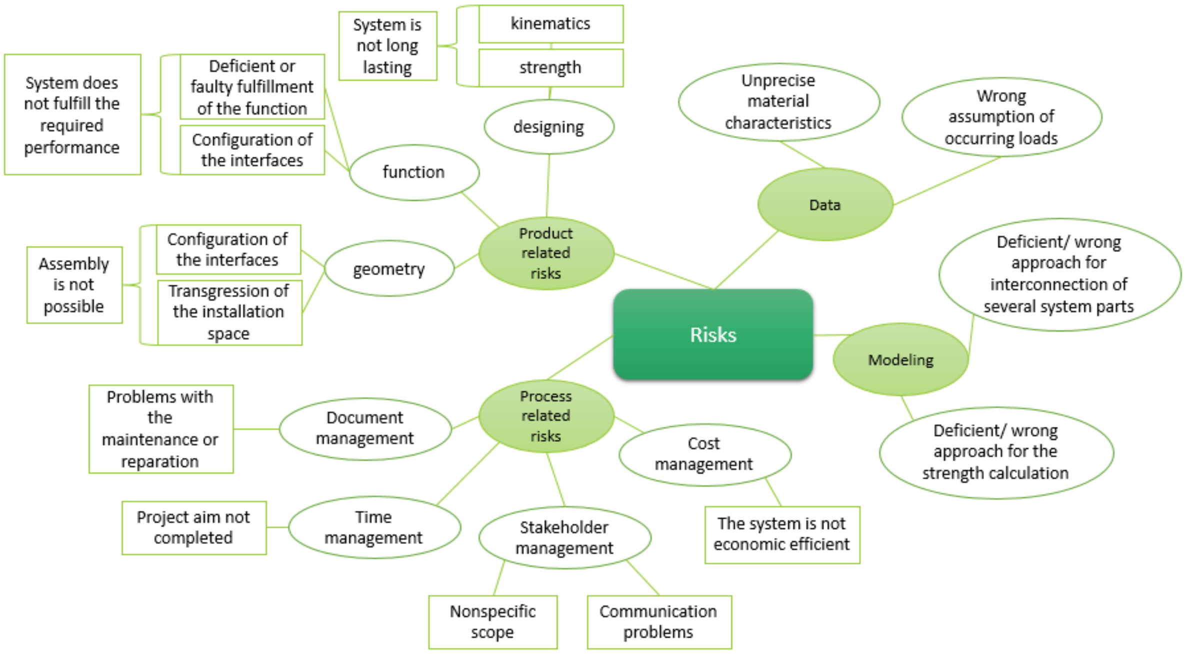


Figure 5-1: Risks related to the project

6 Task analysis

The design process follows the methodical approach stated from the VDI 2221, which is introduced in chapter 2 and also described by Theumert and Fleischer (2007) in 'Entwickeln, Konstruieren, Berechnen'[1]. The design process consist of the stages 1) analysis, 2) conceptual design 3) design and 4) elaboration. The first step of the design process is to clarify the task.

6.1 Scope

For the protection against welding sparks of a television screen a protection shield should be designed. The protection shield itself has to be a sheet metal construction. The opening and closing principal is similar to a grand drape. For the fixture of the television screen and the protection shield is a metal beam available. The actuation of the opening/closing will be automated later with a linear drivetrain, which should be installed behind the television screen. There the opening and closing has to work autonomous a connection with the robotic and sensors for controlling the status of the protection shield are needed. Furthermore the installation of needed valves, sensors and cable lines should be minded. The assembly of the complete system should be simple.

Figure 6-1 shows the initial situation for the design. Behind the welding robot on the marked metal beam will be the system installed.

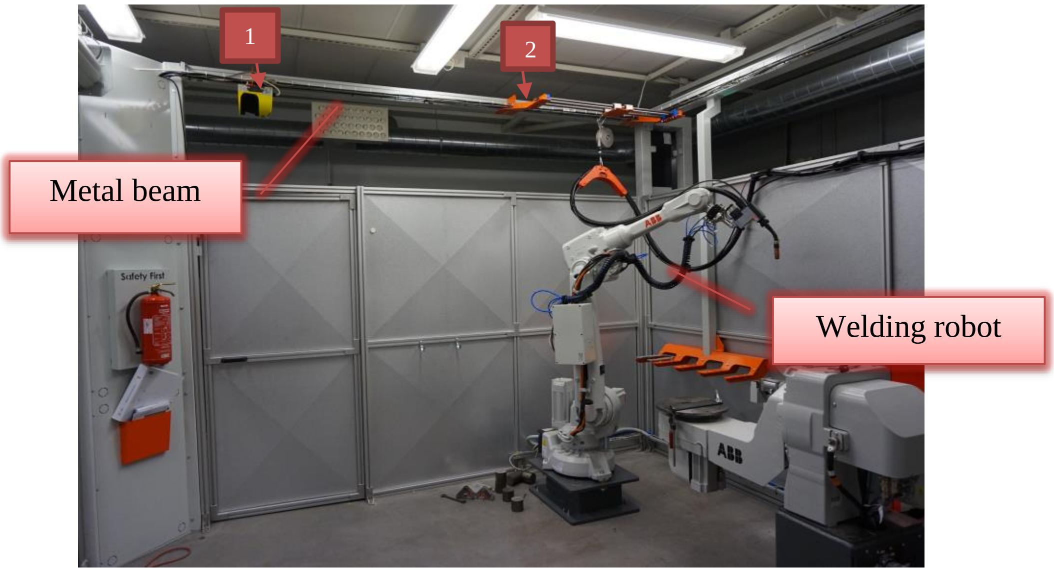


Figure 6-1: Robot cell from the inside with the metal beam

[1] Translation of the title: 'Development, design, calculation'

6.2 Marginal conditions

The marginal conditions are defined from the environment. This measures like the installation space have to be taken into consideration during the design process.

- Installation space
  - Distance between number 1 and number 2 (figure 6-1): 1646mm
  - Height (ground to bottom side of the metal beam): 2815mm
  - Distance between upper side welding spray wall and bottom side of the metal beam: 650mm
- Television screen measures
  - Weight: 3,5 kg
  - Measures: 730mm x 445mm x max. 67,08mm (W x H x D)
- Metal beam measures given in figure 6-2
  - Thickness: 4mm

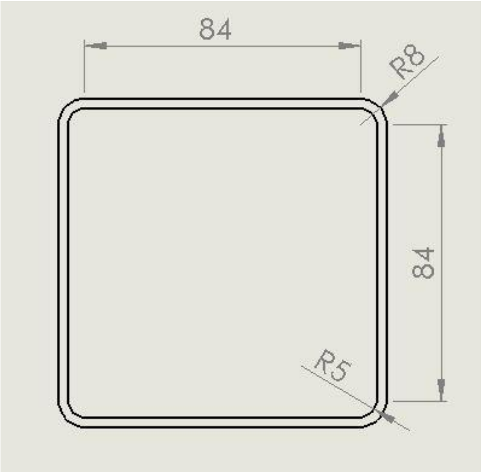


Figure 6-2: cross section of the metal beam (all measures in millimeter)

Scope of the mechanical design:

- Fixture for the television screen
- Fixture for the protection shield
- Metal sheet protection shield
- Integration of the linear drivetrain

Scope of the electric design:

- Automation of the closing/ opening of the protection shield according to the status of the robot

6.3 List of requirements

In the list of requirements (table 4) the constructional parameters are analyzed. These parameters result from the customer requirements (TAMK), safety rules and design guidelines and the marginal conditions. The requirements are categorized in groups. Every requirement is characterized with the note ‘R’ for request or ‘W’ for wish to pose their importance for the design. Since the requirements are not stable, the list can complement during the design process. Complements will be denoted with the creation date. Normally the list of requirements also include a determination of responsibilities, in this case this can relinquished.

While the requirements 4, 5 and 15 concern directly to the electrical design, are the other requirements already from importance for the mechanical and actuation design. The most requirements arise from the customer requirements and the conditions of the environment for example requirement 9. For a better view on the screen it needs to be fixed in a narrow angle.

Table 4: List of requirements for the design:

Number	**R = Request W = Wish**	**Requirement**	**Creation date**
01	R	Number of produced systems: 1	12.01.2016
		ACTUATION	
02	R	The protection shield should close/open through the actuation of a linear drivetrain. Stroke length > 365mm	12.01.2016
03	R	A good precision for the closing process - the gap between the two parts of the protection shield is smaller than 5mm.	12.01.2016
04	R	The protection shield closes autonomous before the robotic starts the welding process.	12.01.2016
05	R	The protection shield closes autonomous when the robotic ends the welding process.	12.01.2016

		GEOMETRY	
06	R	The protection shield covers the screen from the front and from the sides.	12.01.2016
07	R	The linear drivetrain should be installed on the back-side of the television screen.	12.01.2016
08	W	The protection shield has a symmetrical form.	12.01.2016
09	R	The television screen should be fixed in an angle of 100° to the horizontal line for a better view on it.	17.01.2016
		MATERIAL	
10	R	The material of the protection shield is resistant against welding sparks.	12.01.2016
11	R	Use of non-flammable materials and substances, because of the possible contact with welding sparks.	12.01.2016
12	W	Some constructed parts are possible to produce with the available 3D-printer (Fused Depositing Modelling).	12.01.2016
		MAINTAINANCE	
13	W	Easy and non-cost intensive maintenance of the system.	12.01.2016
		SAFETY	
14	R	Deburred, radiused edges.	12.01.2016
15	W	For controlling the status of the protection shield sensors are needed.	12.01.2016
		COSTS	
16	W	Economical use of materials (no cost limit set)	12.01.2016
		PRODUCTION	
17	W	Simple and non-cost intensive production methods	16.01.2016
18	W	Use of standard parts (if possible)	16.01.2016
		ASSEMBLY	
19	R	The assembly of the system should be simple.	12.01.2016

7 Conceptual design

The conceptual design is the second phase of the methodical design process. In this phase a resolution for the problem is designed. The resolution finding consist of two parts. First the analysis of the system, which includes itself two steps –the black-box illustration and the function analysis. Then the process changes from analyzing to the synthesizing. In a morphological[2] box various solution for the single functions are collected and combined. The most useful combinations are evaluated in the end regarding technical and economic criteria.

7.1 Function analysis

To observe the system independent and unbiased the black-box illustration is a helpful tool. The black-box of the intelligent protection shield is shown in figure 7-1. In a rough figure the black-box synthesizes the system with it's in- and outputs, emissions and immissions. An input/ output is a factor, which gets from the outside into the system/ from the system into the outside. The factors can grouped in material, energy and information. Emissions are all possible negative influences on the environment for example safety risks. Immisions are all influences, which affect the system like regulations from authorities (Theumert, Fleischer 2007, 2).

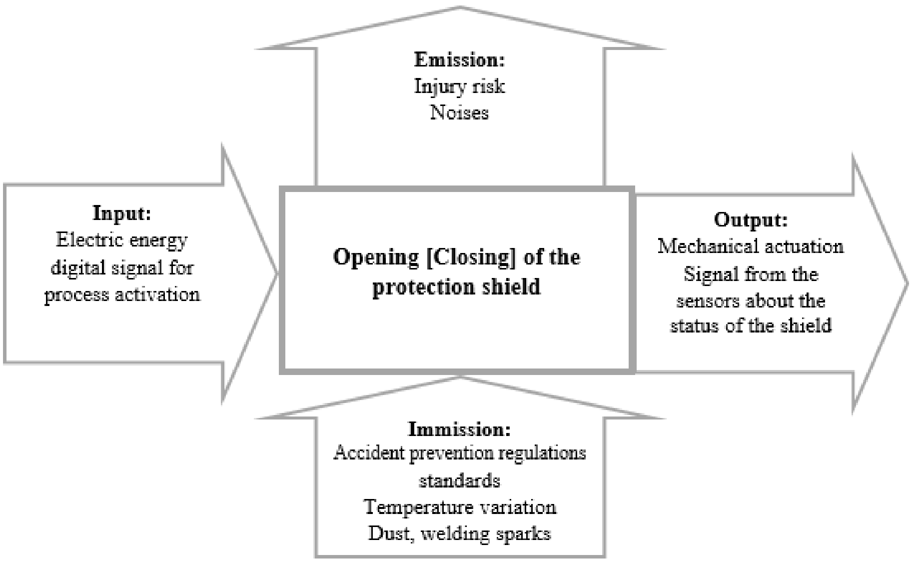


Figure 7-1: Back-Box illustration of the intelligent protection shield

[2] Morphology: Science of shape and structure (Duden Online)

The last step of the analysis is the function analysis (table 5). The single function are identified, which are needed to fulfill the whole system. The outline of the complex problem serves later as a basis for the idea generation. In the following table the system is structured in its structural elements and each of them is a function dedicated.

Table 5: Analysis of the mechanical functions

Number	Structural element	Single function
01	Metal sheet protection shield	Protection of the television screen against welding sparks
02	Linear drivetrain	Transmission of the electric energy to an opening/closing actuation of the protection shield.
03	Linear guideline of the protection shield	The protection shield needs a linear guideline, so that it is moveable and can follow the action of the linear drivetrain.
04	Fixture of the television screen	Connection to the metal beam
05	Fixture of the protection shield	Connection to the metal beam. Fixation of the protection shield in the right position around the television screen

7.2 Synthesis with the morphological box

For the in table 5 determined single functions are now opportunities for the implementation dedicated. The options are tabled in the morphological box (table 6). In this step are undertake any valuation of the different options. For the function number one is already state to use a metal sheet construction, the selection of the material will take place within the design process. For the actuation of the protection shield are even more possibilities available as shown in the morphological box. Beside these options exists more linear drivetrain solutions for example the ball screw drive. For the design of the fixtures are found similar solutions. For the fixture of the television screen it would be also possible to search for a commercial suspension.

Table 6: Morphological Box

Option → / **Single function ↓**	**Option A**	**Option B**	**Option C**	**Option D**
Protection against welding sparks	Metal sheet protection shield	-	-	-
Transmission of the energy for the actuation of the protection shield	Pneumatic cylinder	Linear motor drive	Toothed belt drive	Lead screw drive
Guideway for the actuation of the protection shield	Guideway with circular profile and bearings	Slide guide on dovetail nut	Slide guide on T-nut	
Television screen – beam connection	Bracket and pillar made of metal sheets	-	-	-
Protection shield – beam connection	Bracket and pillar made of metal sheets	-	-	-

In the next step the most suitable options are chosen (table 7). The green triangle shows the options for variant 1, the blue pentagon those for variant 2.

Summarizing the results are the main differences of the two variants in the actuation and in the kind of guideway:

Variant 1 (Green):

- Linear drivetrain: Pneumatic cylinder
- Guideway: Circular profile and bearings

Variant 2 (Blue):

- Linear drivetrain: Toothed belt drive
- Guideway: Slide guide on dovetail nut

Table 7: Selection of variants within the morphological box

Option → Single function ↓	Option A	Option B	Option C	Option D
Transmission of the energy for the actuation of the protection shield	Pneumatic cylinder	Linear motor drive	Toothed belt drive	Lead screw drive
Guideway for the actuation of the protection shield	Guideway with circular profile and bearings	Slide guide on dovetail nut	Slide guide on T-nut	
Television screen – beam connection	Bracket and pillar made of metal sheets	-	-	-
Protection shield – beam connection	Bracket and pillar made of metal sheets	-	-	-

7.3 Technical-economical evaluation

In the following table (table 8) are the advantages and disadvantages of the options identified, which are helpful for the following evaluation of the variants.

Table 8: Advantages and Disadvantages of the options

Variant → Structural element ↓	Variant 1	Variant 2
Linear drivetrain	**Pneumatic cylinder** Advantages: Simple handling, costs, weight, stroke length	**Toothed belt drive** Advantages: Flexibility, stroke length, Total costs of ownership

	Disadvantages: Low precision and flexibility	Disadvantages: Overload capacity, additional engine is needed
Linear guideway	**Circular profile/ bearings** Advantages: Simple handling, weight, costs Disadvantages: Attrition of the bearings	**Slide guide/ dovetail nut** Advantages: state-of the-art, frequent use Disadvantages: costs

For evaluating the variants are the criteria costs, function and weight with different weighting defined. As scale of values is the scale of VDI 2225 usable. The scale reaches from 0 (unsatisfactory) to 4 (very well/ ideal). The criteria values are added to one value, the ideal value would amount 32.

According to the technical-economical evaluation (table 9) is variant 1 the best solution. A pneumatic cylinder as linear drivetrain fulfill all requirements. It offers various stroke length, so that it is possible to reach the two positions – open and close. Additional the handling of pneumatic cylinder is simple, so that no special knowledge is needed. Another advantages is that pneumatic cylinders are efficient in their energy consumption, there they don’t consume during time without work (Kühnle; Roddeck 2012, 226).

Table 9: Technical-economical evaluation

Scale of Value related to VDI 2225: 0 = unsatisfactory, 1 = barely sustainable, 2 = sufficient, 3 = good, 4 = very good										
Single function	**Variant 1** Costs: one fold evaluated Function: twofold evaluated Weight: one fold evaluated	Costs	Function	Weight	**Value**	**Variant 2** Costs: one fold evaluated Function: twofold evaluated Weight: one fold evaluated	Costs	Function	Weight	**Value**
02	Pneumatic cylinder	1x2 = 2	2x3 = 6	1x3 = 3	3+6+3=11	Toothed belt drive	1x2 = 2	2x2 = 4	1x2 = 2	2+2+2=8
03	Circular profile with bearings	1x2 = 2	2x3 = 6	1x3 = 3	2+6+3=11	Slide guide on dovetail nut	1x1 = 1	2x3 = 6	1x2 = 2	1+6+2=9
04	Bracket + Pillar	/	/	/	/		/	/	/	/
05	Bracket + Pillar	/	/	/	/		/	/	/	/
∑ V Y	Economical Value Y = 22/32				**22** **0,69**	Economical Value Y = 17/32				**17** **0,53**

8 Design phase

After defining a principal solution the methodical design process proceed to step four "divide into releasable modules". This is the first step of the phase III "design phase" (compare chapter 2 illustration 2-1). As preparation it is useful to divide the system in a top-down process into its different assembly groups and parts. Additional the interfaces between and within the components and outwards are determined. This structuring leads to a step-wise design and is needed for a concurrent approach of a project.

In the tree diagram (illustration 8-1) is the breakdown of the system into its assembly groups shown. There are three groups – the television group, protection shield group and actuation group. In the third level of the diagram are the components of each group defined, some of them are composed of more separate parts (level four). The concretization of the system increases from level to level, while the complexity decreases. These structuring also serves as support for make or buy decisions. In this system the pneumatic cylinder, the bearings, circular profile and the television screen are default parts and will purchased from qualified suppliers.

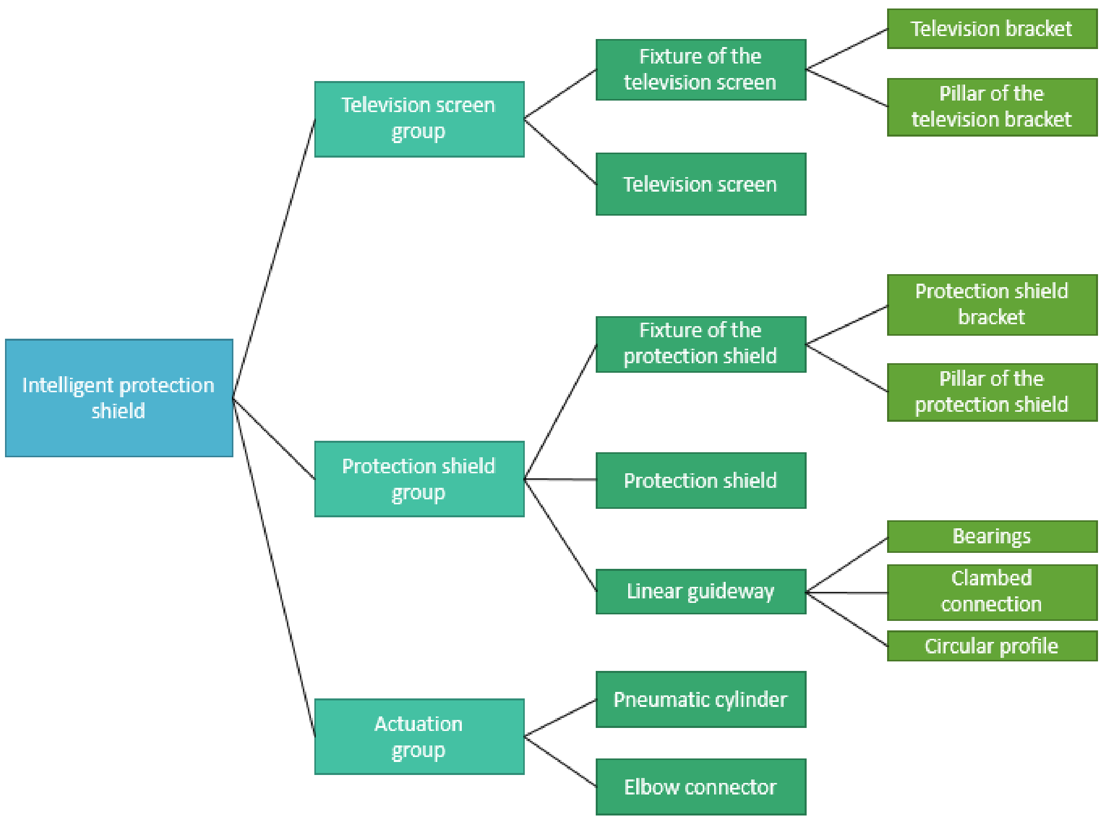


Figure 8-1: Assembly groups of the intelligent protection shield

Figure 8-2 shows the relations between and within the assembly groups. Relations between the assembly groups are shown with blue lines and within assembly groups with red lines. According to that the pneumatic cylinder of the actuation group is the connective of the television screen group and the protection shield group, there it will connected with the television bracket as well as the protection shield. Another group-across relation is the fixture of pneumatic cylinder with television bracket. These structure is related to the requirement 7 (from chapter 6.2.1 table 3), that the actuator should be installed on the backside of the television screen. Within the assembly groups have all components intersections.

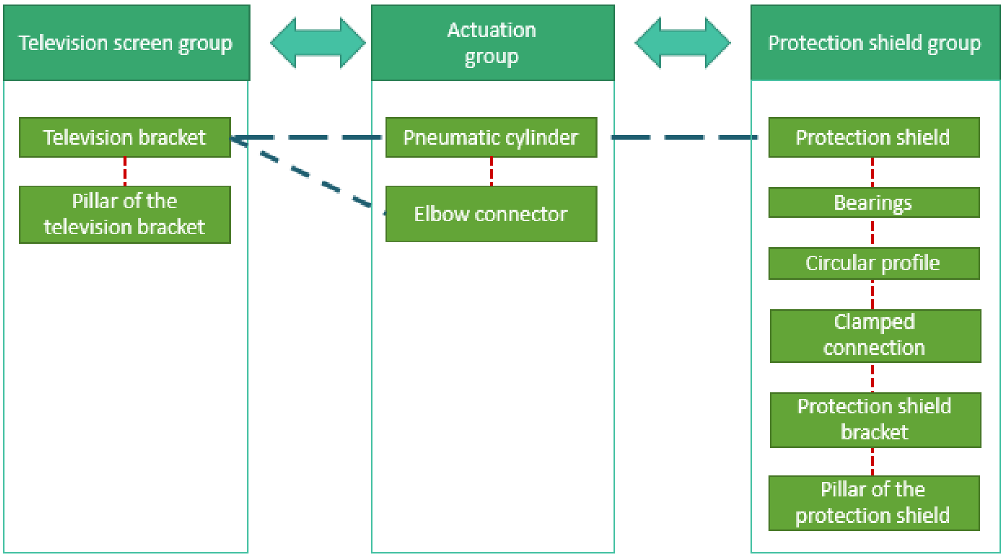


Figure 8-2: Intersections between and within components of the assembly groups

Intersections outwards are also present:

- The television bracket and its pillar as well as the protection shield bracket and its pillar are mechanical connected to the beam.
- The pneumatic cylinders are connected with the compressed air supply, which is regulated from a valve.
- The valve is electrical plugged in the digital Input-Output-Unit of the welding robot ABB IR2600

8.1 Design of the components

In the fifth step of the design process the components of the assembly groups are designed. In this phase the materials, the production processes and the kind of assembling are defined. If these selections can be used across the assembly groups the choice is explained once. Additional approximate calculations are made. The order of the design will be at first the television group. Afterwards the protection shield group will be designed. At least the actuation group will be integrated in the first mentioned groups. For a better structure of the approach the sections are additionally titled.

8.1.1 Television screen group

It is obvious to use metal sheets for the design of the fixture, because of several reasons. There the protection shield is a piece production it is reasonable to use available production opportunities and semi-finished materials like steel sections and metal sheets. For a design for ease of recycling the variety of materials should be reduced. This simplifies the assorting at the product end of life. Form the customer was already the requirement given to use metal sheets for the protection shield. Additional bended metal sheets offer a sufficient scope for design to realize the given requirements.

Material and production method selection

As material for the metal sheets comes into question a plain structural steel. The most frequent used structural steels are S235 and S355. The mechanical properties are given in DIN EN 10025-2 and will compared in the following table. Both structural steels offer good machinability and are cold-workable with bending. The advantages of S335 over S235 are the higher tensile and yield strength, but the use of S235 would be more reasonable, there S335 is more expensive. Comparing albeit the relative material costs related to the tensile strength the use of S335 would be more economical. High tenacity materials are more cost-effective especially under tensile (compressive) loading, there the strength could be used over the complete cross-section (Ehrlenspiel, Kiewert, Lindemann 2005, 195). Regarding the comparison the choice for the metal sheet material is S335.

Table 10: Material properties of S235 and S355 (Fischer et al. 2011, 127)

Material	**S235**	**S335**
Group	Plain structural steel	Plain structural steel
Tensile strength R_m	360…510 N/mm²	470..630 N/mm²
Yield strength R_e	235 N/mm²	335 N/mm²
E-Modulus	210000 N/mm²	210000 N/mm²

Usage	Moderately stressed machine parts Weldment for the steel construction and machine-building	Highly stressed weldments for the steel construction, crane and bridge building
Relative material costs	1,0	>1,0

The metal sheet components can manufactured from a subcontractor using laser cutting. Laser cutting has the advantages that mostly no rework of the parts is needed and it doesn't causes warpages because of heat (Feldhusen, Grote 2013, 623 et seq.). To design the metal sheets for design of ease for production the edges are blunted.

Assembling method

To design for ease of assembly should be the assembling of all parts and assembly groups simple and cost-effective. Other criteria are the opportunities to recycle the system and feasible maintenance. Screw connections enable a simple disassembling, there screws are easily detachable connections. Additional screws are standardized, which reduce the variety of needed tools. So for the complete system the assembling method should be realized with screw connections.

Realizing the requirements and adaptation in the environment

For the television screen bracket is a metal sheet construction designed, which lies on top of the metal beam. The bended edges realize the gap for the cable channel and the required angle of 100° to the horizontal line (compare figure 8-3). Furthermore the bending effects a stiffening.

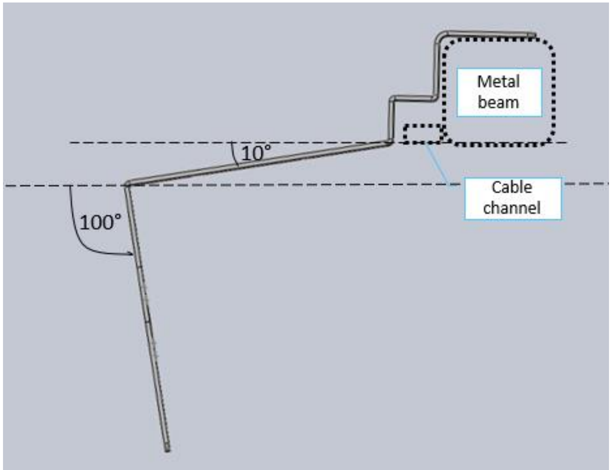


Figure 8-3: Design of the television bracket

Figure 8-4 shows the compounded television group. The two pillars are connected with the metal beam from below, the television bracket is supported from them. The pillars functions similar to a brace, which effects an improved application of force. As support for the insertion and justification has the pillar two trunnions at the end, which fits inside elongated holes of the television bracket.

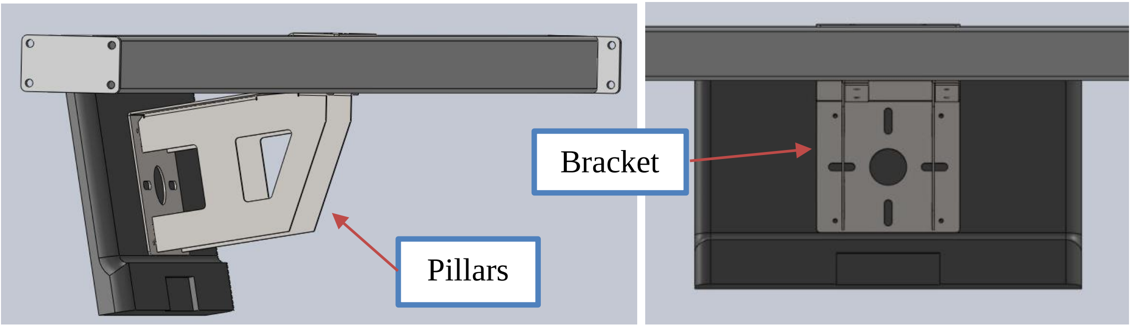


Figure 8-4: compounded television group from various angles

Fore calculation of the screw size

For selecting the essential diameter of the screws the guidelines of the TB 8-13 from Roloff Matek (appendix 3) are used. First the axial (across) effective operating power has to be identified. There the system is statically the weight force measures up to the operating force. This value is rounded up to the next higher value of the table. It will used screws of the strength class 8.8. The metal sheet construction with a metal sheet thickness of t = 4mm has a weight of 10,92 kg. Together with the television screen the assembly group weights about 14,42 kg. All exposure of the weight are calculated with CAD-program Solidworks 2015. The calculation reveals to choose as nominal diameter M5.

$F_B = F_G = 0{,}141\ kN$	$F_G = m \cdot g$ [1] formula for the weight force m = 14,52 kg; g = 9,81 m/s²
$F_B\ per\ screw = 0{,}035\ kN$	The operation force is distributed to 4 screws.
$\rightarrow M4$	Chosen nominal diameter following table 8-13.
$\rightarrow \boldsymbol{M5}$	The snap factor following TB 8-11 amounts κ = 2,5-4, there the screws will tighten from hand, the diameter of the next higher load step is finally chosen.

8.1.2 Protection shield group

This group contains of three sub groups (compare figure 6-4). The protection shield should be opened and closed from the linear actuation of the pneumatic cylinder in the end, therefore a linear guideway is needed. With linear-motion bearings the protection shield can be mounted and guided in once. The bearings are moving on a circular profile, which is connected with the clamped connection and the fixtures (bracket and pillar) to the metal beam.

Design of the linear guideway

First the linear-motion bearing need to be chosen. The appendix 2 compares the properties of different linear guideway systems. From interest are the anti-friction and hydrodynamic systems. Against the hydrodynamic systems an anti-friction bearing has the advantages, that through the use of balls or rolls the friction resistance is low. An additional lubrication decrease the friction as well. Furthermore are antifriction bearings modest in maintenance and operate safe and precise (Wittel et al. 2015, 508). These advantages leads to the decision to choose the anti-friction bearings.
The ball type are the most common types of linear-motion bearings. The ball bushing guides a cylindrical profile along a single-axis. In the periphery of the bushing are several orbital units of rolls (compare figure 8-5 left) (Wittel et al. 2015, 546). The chosen linear ball bearing is a closed type unit with an inscribed circle diameter of 20mm from the company Rollco (figure 8-5 right).

Figure 8-5: Linear ball bearing left) function diagram of the ball bushing (Wittel et al. 2015, 546) right) chosen unit KBA20UU (Rollco)

There the surface of the circular profile is the runway of the rolling elements, the material of it has to comply high requirements to insure the complete load capacity:

- Material hardness higher than 650 HV (Vickers hardness)
- The surface finish is plain (roughness average $R_a \leq 0,2\mu m$) (meadias.schaeffler)

Rollco also offers suitable circular profiles. Possible materials are the stainless steels X90 and X46 as well as the quenched and tempered steel Cf53. In the following table the material properties are compared.

Table 11: Properties for shaft materials (Rollco; Fischer et al. 2011, 134)

Material	X90CrMoV18 (1.4112)	X46Cr13 (1.4034)	Cf53 (1.1213)
Group	Stainless, martensitic chrome steel	Stainless, martensitic steel	Quenched and tempered steel
Surface hardness - **Vickers** - **Rockwell**	550 HV[3)] Min. 52 HRC	570 HV[3)] Min. 54 HRC	670 HV[3)] Min. 59 HRC
Tensile strength	-	850…1000 N/mm²	-
Usage	Cutting blades, ball bearings etc.	Cutting blades, ball bearings	For hardened precision shafts

The stainless steels X90 and X46 do not fulfill the requirement of the material hardness. But under consideration of the operation frequency of the linear guideway (up to five times the day[4]) the abrasion of the runway material has no influence on the decision of the material. Therefore the material X46Cr13 is chosen. The stainless, martensitic chrome steel offers a high dimension and shape accuracy. Together with the linear ball bearings a loadable, ready to install and precise linear guide can be formed.

Design of the clamped connection

The clamped connection will be manufactured with the 3D-printer Dimension Elite from Stratasys available at TAMK. The printer uses FDM (fused deposit modeling) as additive manufacturing technology. The technical thermoplastic, which is used for printing the clamped connection, is ABS (acrylonitrile butadiene styrene). In table 12 the material properties are shown. ABS has good mechanical strength characteristics. Components printed with ABS are durable and solid (Stratasys).

[3)] Reassessment of the hardness's related to DIN EN ISO 18265 (Fischer et al. 2011, 195)
[4] Information from the interview with the laboratory employee (22.02.2016)

Table 12: Mechanical properties of ABS (Feldhusen, Grote 2007, E126)

Material	**ABS**
Group	Technical Thermoplastic
Material density	1,06…1,08 g/cm³
Yield tensile strength	30…55 N/mm²
E-Modulus	1500…2900 N/mm²

The clamped connection contains of two parts, which shut in the circular profile. Regarding the design rules for additive manufacturing all edges are provided with radii. The joint is realized with two cheese-head screw, since their head is suitable for a close installation space. The screws are loaded with an across operating force. The operating force corresponds approximately the weight force of the protection shield, the linear bearings and the circular profile. The chosen diameter of the screw is M5.

$F_B = F_G = 0{,}192kN$ — $F_G = m \cdot g$ (Formula 1) formula for the weight force

m = 23,33 kg; g = 9,81 m/s²

$F_B\ per\ screw = 0{,}023kN$ — The operation force is distributed to eight screws (by four clamped connections).

$\rightarrow M4$ — Chosen nominal diameter following table 8-13.

$\rightarrow \boldsymbol{M5}$ — The snap factor following TB 8-11 amounts κ = 2,5-4. There the screws will tighten from hand, the diameter of the next higher load step is finally chosen.

The protection shield and the fixture will be manufactured from the plain structural steel S355 (compare chapter 8.1.1). Although the weight of the components, which are carried from the protections shield fixture, is higher than the weight of the television screen group the calculation reveals the same nominal diameter for the screw joint with the metal beam (M5).

Figure 8-6 shows the jointed components. The protection shield is visible from the back-side. Each side of the protection shield is guided from four linear ball bearings. The protection shield covers the television screen from the front and from the sides (requirement 6 table 4).

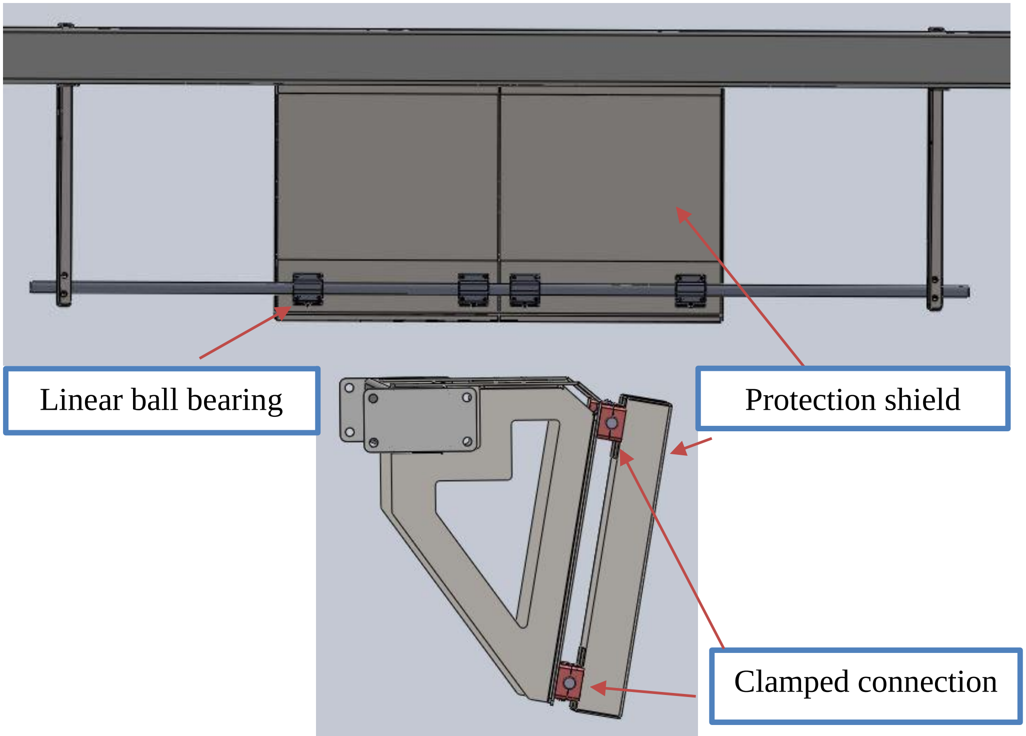


Figure 8-6: Protection shield group from the back (top), protection shield group from the side (below)

8.1.3 Integration of the actuation group

For realizing the two positions of the protection shield (open and close) a double-acting cylinder is needed. The supplier for the cylinders is SMC Pneumatics Finland Oy. The chosen cylinder is standardized (ISO-cylinder). The stroke length results from the size of the protection shield, the width of it amounts 400mm. There the available stroke of 320mm would be to less, the 400mm stroke is chosen. The smallest bore size is 32mm.
The basic version of the pneumatic cylinder is chosen, there the joint of the cylinder will be self-designed. For installing the pneumatic cylinders on the backside of the television screen (compare table 4 requirement 7) few changes in the previous assembly groups has to be made. After positioning the cylinder in the system, are edges added to the television bracket (figure 8-7 bottom) with boreholes for countersunk screws. For mounting the end of the rod edges are also added to the protection shield (figure 8-7 top).

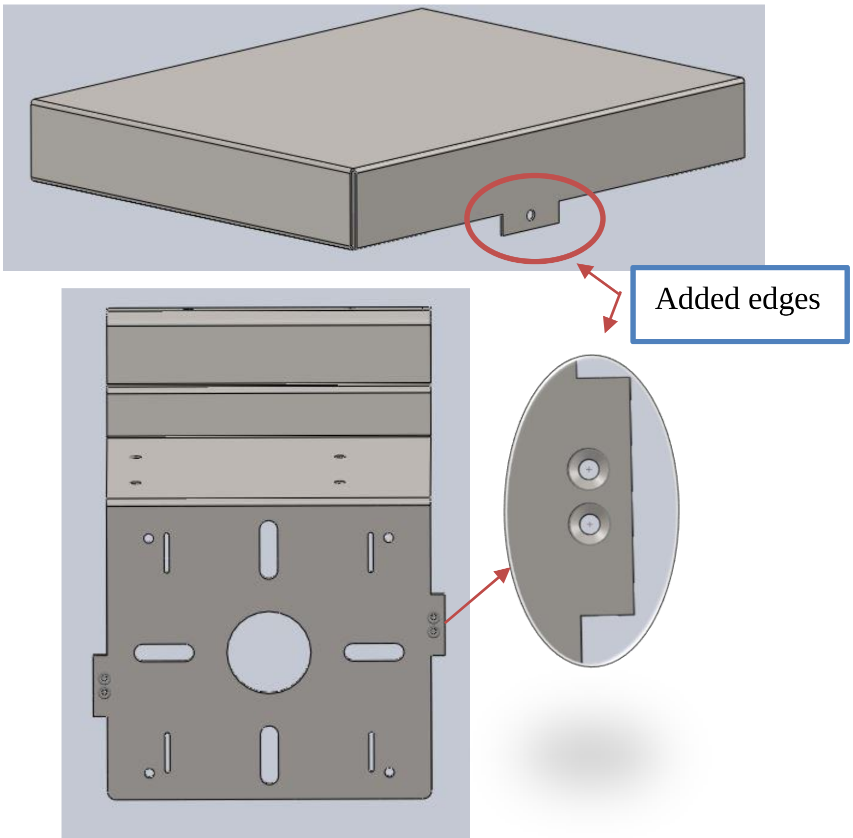


Figure 8-7: Complements of the protection shield (top) and television bracket (bottom) for integration of the actuator

For fixing the cylinder on the television bracket an elbow connector (figure 8-8) is designed. The connector should be additive manufactured with the FDM printer. Regarding the design rules for additive manufacturing all edges are provided with radii. The junction is blunted as well with a radii, additional this design avoids stress peaks.

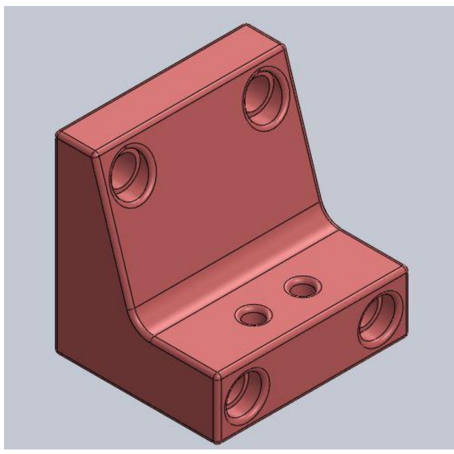


Figure 8-8: Elbow connector of the pneumatic cylinder

For calculating the joint screws of the elbow connector and the television bracket, first the cylinder forces need to be determined. The forces are ascertained with the operating pressure, the area of the piston and the efficiency factor.

Operating pressure	p_e = 7bar = 70 N/cm²
Area of the piston	d_{piston} = 32mm → A_{piston} = 804,25 mm²
Area of the piston Minus the area of Piston rod	d_{rod} = 12mm → $A_{piston\text{-}rod}$ = 691,15mm²
Efficiency factor	η = 0,88

Compression force: $F_c = p_e \cdot A_{piston} \cdot \eta = 495{,}42N$

Tensile force: $F_T = p_e \cdot A_{piston-rod} \cdot \eta = 425{,}75N$

With the compression force the nominal diameter is designed. The chosen nominal diameter is M4.

$\mathrm{F_B} = 0{,}495kN$	The compression force load the screw joint across.
$F_B\, per\ screw = 0{,}248\ kN$	The operation force is distributed to two screws.
$\rightarrow M4$	Chosen nominal diameter following table 8-13.

8.1.4 Overall design of the system

After explaining the design process of the components the overall design is shown as result in figure 8-9 to 8-11. Additional the complete weight of the system is calculated.

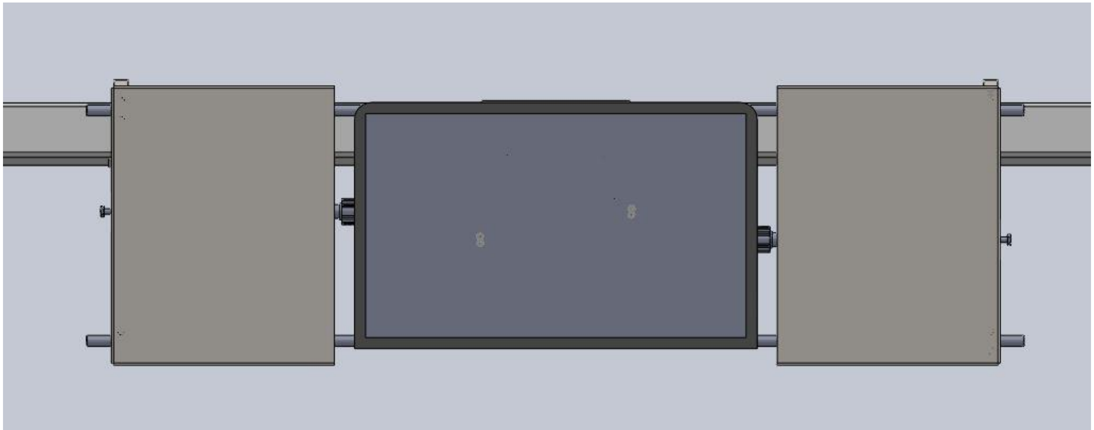


Figure 8-9: Front view of the opened system

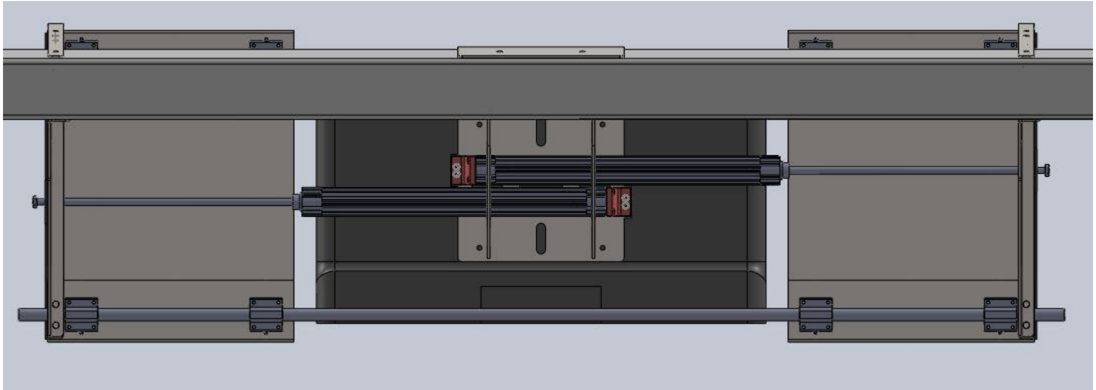


Figure 8-10: Back view of the opened system

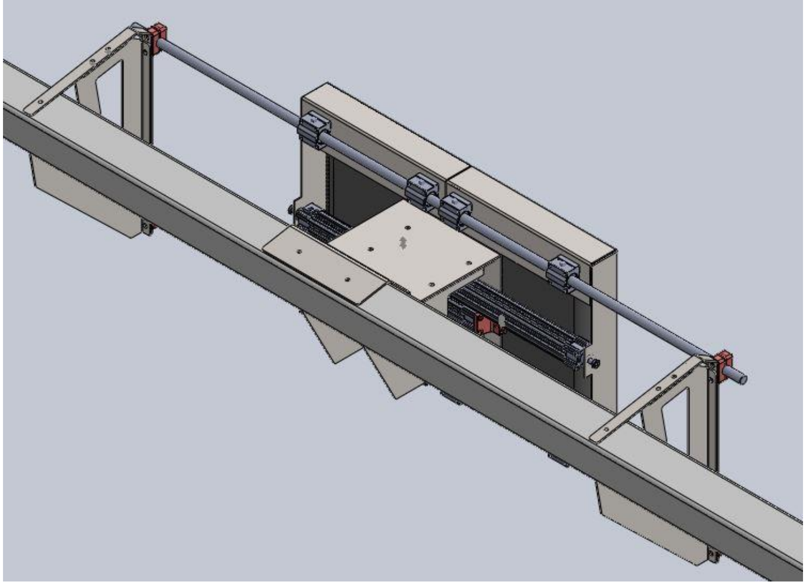


Figure 8-11: Isometric view of the closed system

Television Screen Group			**13534,76 g**
	TV bracket	1x 5952,46 g	
	TV bracket pillar	2x 2041,15 g	
	TV screen	1x 3500 g	
Protection Shield Group			**29551,12 g**
	Protection shield	2x 7283,89 g	
	Shield bracket	2x 631,18 g	
	Shield bracket pillar	2x 2481,39 g	
	Clamped con. top	4x 18,97 g	
	Clamped con. bottom	4x 16,02 g	
	Linear Roll Bearing	8x 77,28 g	
	Circular Profile	2x approx.4000g	
Actuation Group			**1136,7 g**
	Pneumatic cylinder	2x 524,55 g	
	Elbow connector	2x 43,8 g	
			∑ 45103,06 g

8.2 Design of the pneumatic control

For controlling the opening and closing of the pneumatic cylinders (compare table 3 requirement 4 and 5) a pneumatic valve and an electrical signal from the welding robot unit is needed.

The two pneumatic cylinders can controlled by one valve, since their actuation should be simultaneous. A 5/2-way pilot-controlled electro-magnetic valve is used, the cross-section is shown in figure 8-12. Number 1-5 are the compressed air connections. The circled numbers are (SMC):

1) housing
2) adapter plate
3) cover plate
4) piston
5) valve-slider unit
6) solenoid valve

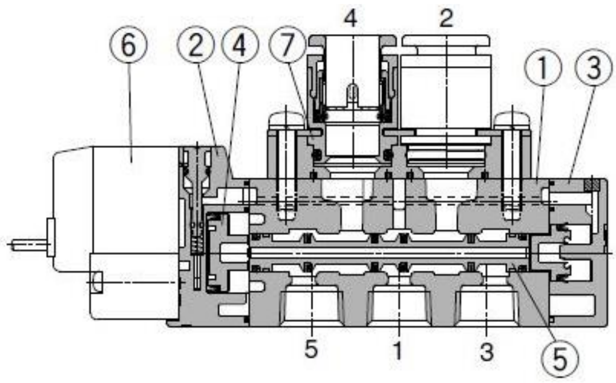


Figure 8-12: 5/2-way pilot-controlled electro-magnetic valve (SMC)

In inoperative state the compressed air flows from connection 1 to 2 and from 4 to 5, connection 3 is closed. Is the valve activated, the air flows from 1 to 4 and 2 to 3, the connection 5 is closed.

In the exhaust air one-way-restrictors are integrated to avoid the stick and slip effect. So a smooth movements of the cylinders is guaranteed. In appendix 4 the alignment of the valves is shown in the pneumatic circuit diagram.

Figure 8-13 shows the block diagram of the control unit of the welding robot. The panel board is connected over the computer unit with the I/O-Unit. In the panel board a command is installed, which enables the user to control the signal for the electromagnetic valve. As control signal, which activates the 5/3 way valve, a new electrical connection to the Input-Output-Unit of the welding robot ABB IR2600 is made. In inoperative state of the valve the pneumatic cylinders are open and from that the protection shield is open. Does the inductor live, the cylinders are closed and according to that the protection shield is also closed. The electromagnetic valve is energized with 24 DV voltage.

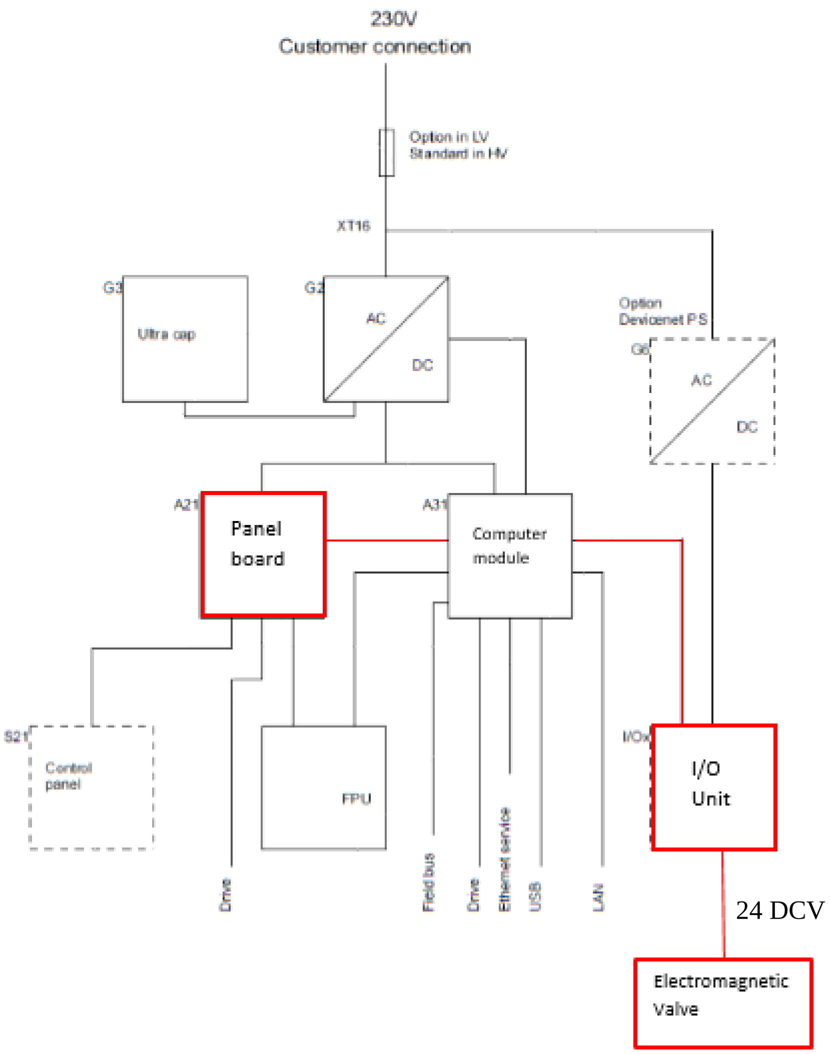


Figure 8-13: Block diagram for the electrical connection of the electromagnetic valve (red)

While the user is programming the welding process the command for closing and open the protection shield has to be integrated into the program.

But till now the protection shield is just controllable. If the user forgets to add the closing command to the sequence control or a failure occurs, the robot will start welding even when the protection shield is not closed. To avoid this supplements in the programmable logic controller has to be made. The pneumatic cylinders are expandable with final position sensors. The sensor signal, which is generated from the closed cylinder, has to be a requirement (for example with an AND operation in the sequence control of the programmable logic controller) for starting the welding process. The electrical. These changes in the programmable logic controller has to be made from ABB.

9 Elaboration

In the fourth and last phase of the methodical design process the elaboration takes place. This phase contains the specification of the components as well the verification of the safety and strength. Before the results (part list, technical drawings etc.) of the design process are documented, a comparison of early determined requirements is made.

9.1 Detailed design and safety calculation

9.1.1 Clamped connection – selection of fits

For fasten the circular profile between the clamped connection an interference fit is needed. The interference fit can be chosen from the basic hole system related to DIN ISO 286-2. There the connection does not transfer a torque, a locational interference fit should be satisfactory. The combination H7/n6 accomplishes this requirement, there it is more an interference than a clearance fit. To move the components of the fit a low pressing force is needed.

Tolerances following DIN ISO 286-2 for a nominal dimension of Ø 20

Hole H7: above allowance +21µm	below allowance 0µm
Shaft n6: above allowance +28µm	below allowance +15µm

9.1.2 Flexural stress of the circular profile

The circular profile is loaded with the weight of the protection shields, because of this the profile is stressed with a flexural stress. First the occurring flexural stress for the profile is calculated, for this the bending moment has to be determined. For the calculation the condition shown in figure 9-1 is assumed. The weight of each protection shield (≈7,28kg) is distributed on two circular profiles, with the result that the weight force comes to 37,24 Newton.

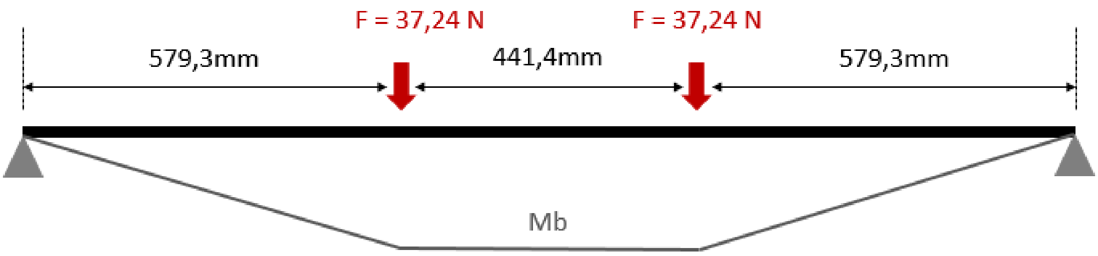


Figure 9-1: Simplified load of the circular profile with flow of the bending moment

Occurring flexural stress

$$\sigma_b = \frac{M_b}{W}$$

Formula 2: Occurring flexural stress

Bending moment

$$M_b = F \cdot l$$

Formula 3: Bending moment

$$F = 37{,}24N$$

$$l = 579{,}3mm$$

Section modulus

$$W = \frac{\pi}{32} \cdot d^3$$

Formula 4: Section modulus

$$d = 20mm$$

$$W = \frac{\pi}{32} \cdot 20^3 = 784{,}4\ mm^3$$

$$M_b = 37{,}24N \cdot 579{,}3mm = 21573\ Nmm$$

Occurring flexural stress

$$\sigma_b = \frac{21573\ Nmm}{784{,}4\ mm^3} = 27{,}5\ \frac{N}{mm^2}$$

The occurring flexural stress has to be compared with the acceptable flexural stress.

Acceptable flexural stress

$$\sigma_{b,acceptable} = \frac{\sigma_{b,lim}}{\upsilon}$$

Formula 5: Acceptable flexural

The acceptable flexural stress is the quotient of the stress limit of the material X46Cr13 and safety factor ν. The stress limit is given with R_m = 800…1000 N/mm². The safety factor depends on the material and the load type. Here the load is statically, which means that the load is constant after stressing the circular profile. Additional a flexural stress is occurring. Regarding the conditions and for guaranteeing the safety a factor of ν = 1,5 is chosen (Wittel et al. 2015, TB60).

$$\sigma_{b,acceptable} = \frac{800\ N/mm^2}{1,5} = 533,3\ \frac{N}{mm^2}$$

The basic requirement for a safe designing is that the occurring flexural stress is smaller than the acceptable flexural stress. This requirement is fulfilled.

$$\sigma_{b,acceptable} > \sigma_{b,occuring} \qquad \rightarrow \qquad 533,3\ \frac{N}{mm^2} \gg 27,5\frac{N}{mm^2}$$

9.1.3 Analysis of the strength

The analysis of the strength is accomplished with the static calculation of Solidworks 2015. The linear static calculation ascertains displacements, the elongations and tension. Thereby is believed that all loads are increased slowly step by step till the full magnitude is reached. From this moment on the load is constant. Furthermore it is assumed a linearity, which means that the relation between the loads and the induced reactions is linear. This assumption can be made, if following requirements are true:

- All materials of the model comply with Hooke’s law.
- The induced reactions are small, so that the changes of the rigidity can be ignored.
- The fringe conditions does not change (the magnitude, direction and distribution of the loads is constant). (Solidworks)

Elbow connector

In the study the elbow connector is loaded with the compression force F_C = 500N of the pneumatic cylinder. The bore holes for the connecting bolts with the television bracket are defined as fixed geometry. The simulation calculates the equivalent stress according to von Mises. The theory of von Mises says that a structural component fails, if a set point value is exceeded. For the elbow connector made from ABS the set point value is the yield strength R_e = 31MPa. The simulation colors the part depending on the occurring stress (compare figure 9-2). The highest occurring stress is σ = 24,15 N/mm². So the yield strength is not exceeded. Additional the safety factor can be calculated. This analysis reveals that the lowest safety factor for the elbow connector is ν = 1,3. A safety factor of ν = 1 would mean that the material begins to deform malleable. As result of the simulation it can said the elbow connector is designed safe enough for the occurring loads.

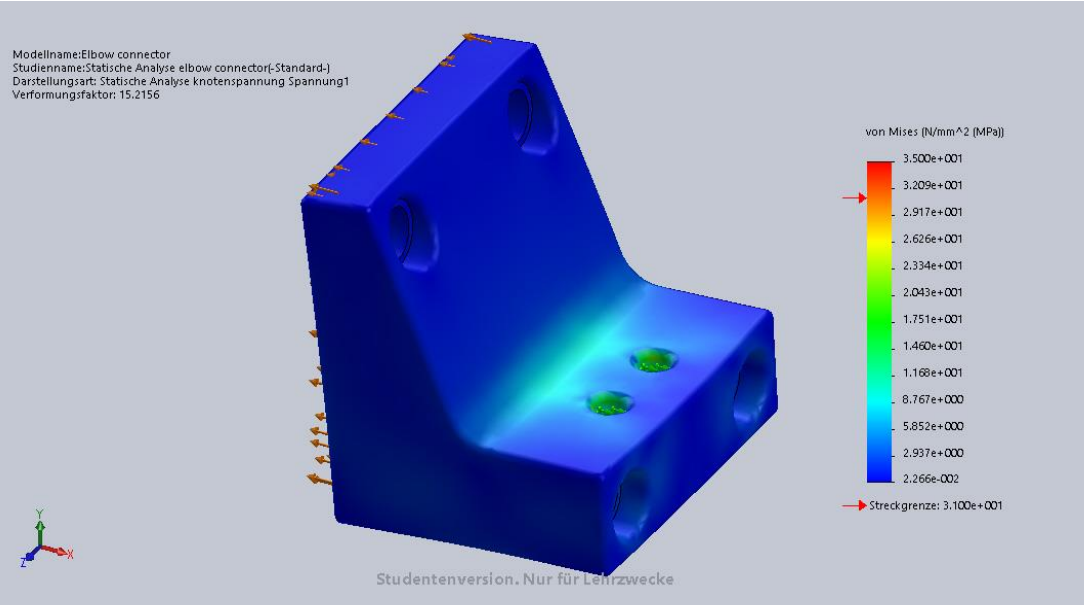


Figure 9-2: Distribution of Von Mises stress in the elbow connector

Fixture of the television screen

The metal sheet construction has to be checked regarding its strengths. The contact faces with the metal beam are assumed as fixed geometry (green arrows in figure 9-3). The bracket is connected to each pillar with two M4 screws. For the simulation the fastening torque for the screws is calculated. This is approximately calculated with

$$M_A = 0{,}17 \cdot F_{VM} \cdot d$$

Formula 6: Fastening torque

The mounting prestressing force results from formula 7.

$$F_{VM} = k_A \left(F_{KL} + F_B (1 - \Phi) + F_Z \right)$$

Formula 7: Mounting prestressing

In this case the clamping force F_{KL} is negligibly. The working load F_B is equivalent to the weight force F_G of the pillar F_B = 20,01N. F_Z is the loss of assembling preload force, which is calculated over the settling amount f_z divided by the sum of the bolt elongation due to preload δ_S and the bolted flange compression due to preload δ_T. For this connection

F_Z amounts F_Z = 149,11N. With the snap factor the kind of fastening the screws is considered. There the screws will fastened from hand the factor is k_A = 4. Through putting the values the fastening torque amounts:

$$F_{VM} = 4\,(20{,}01\,N\,(1 - 0{,}014) + 149{,}11N) = 675{,}36\,N$$

$$\boldsymbol{M_A = 0{,}17 \cdot 675{,}36\,N \cdot 4 \cdot 10^{-3} m = 0{,}46\,Nm}$$

Additionally the assembled components are loaded with their own weight force (red arrow) and the weigh force of the television screen (violet arrows). The simulation calculates a maximum occurring stress of σ = 17,89 N/mm² (figure 9-3). The set point yield strength of the steel S355 is R_e = 275N/mm², the occurring stress is far below this value. Consequently the associated lowest safety factor is ν = 11,67. These results portend that the metal sheet construction is overdesigned.

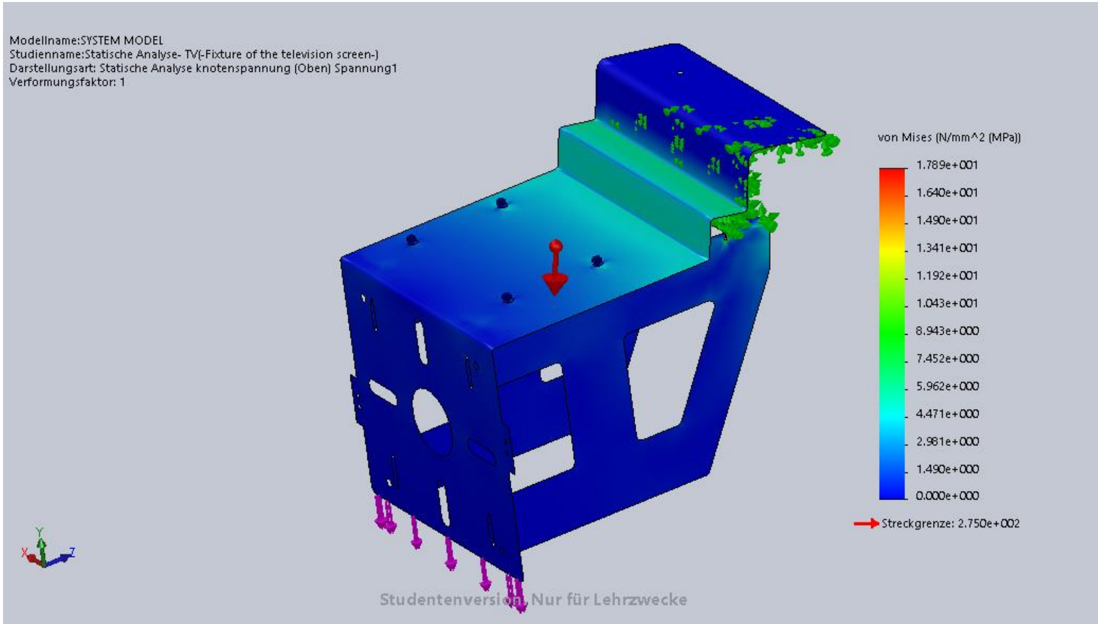


Figure 9-3: Distribution of Von Mises stress in the assembled television fixture

Fixture of the protection shield

Simultaneously to the analysis of the stress in the television fixture is the analysis of the fixture for the protection shield proceeded (figure 9-4). The highest occurring stress amounts σ = 72,1 N/mm². That implies a minimal safety factor of ν = 5,04. The design of the protection shield fixture is also safe.

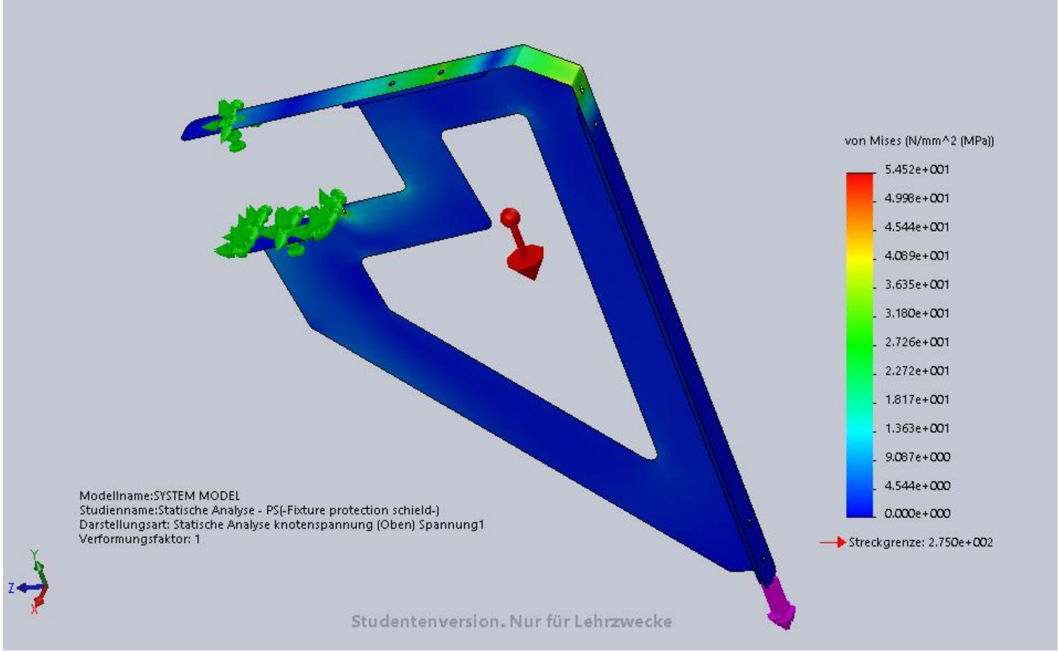


Figure 9-4: Distribution of Von Mises stress in the assembled protection shield fixture

9.2 Documentation

The documentation is an important supporting product engineering process, there the documents are needed the complete product life cycle (Feldhusen, Grote 2013, 99). For implementing the intelligent protection shield TAMK needs several documents.

9.2.1 Part list

For describing the product a complete part list is needed, which complements the technical drawings. The part list includes from left to right number of position, amount and unit of the amount, designation, article code and/or standard indication and notes (Feldhusen, Grote 2007, F35). The notes include for example advices for production method and if the part will be purchased or produced from TAMK. Table 13 shows the first lines of the part list, the complete one is accessible in appendix 5. The part list is followed from the technical drawings of the position numbers 2 to 11 (except of number 7). For a better illustration it is dispensed with the technical drawings in accordance with DIN standard. All technical drawings are provided with general tolerances or the tolerances depend on the manufacturing process Fused Deposit Modeling.

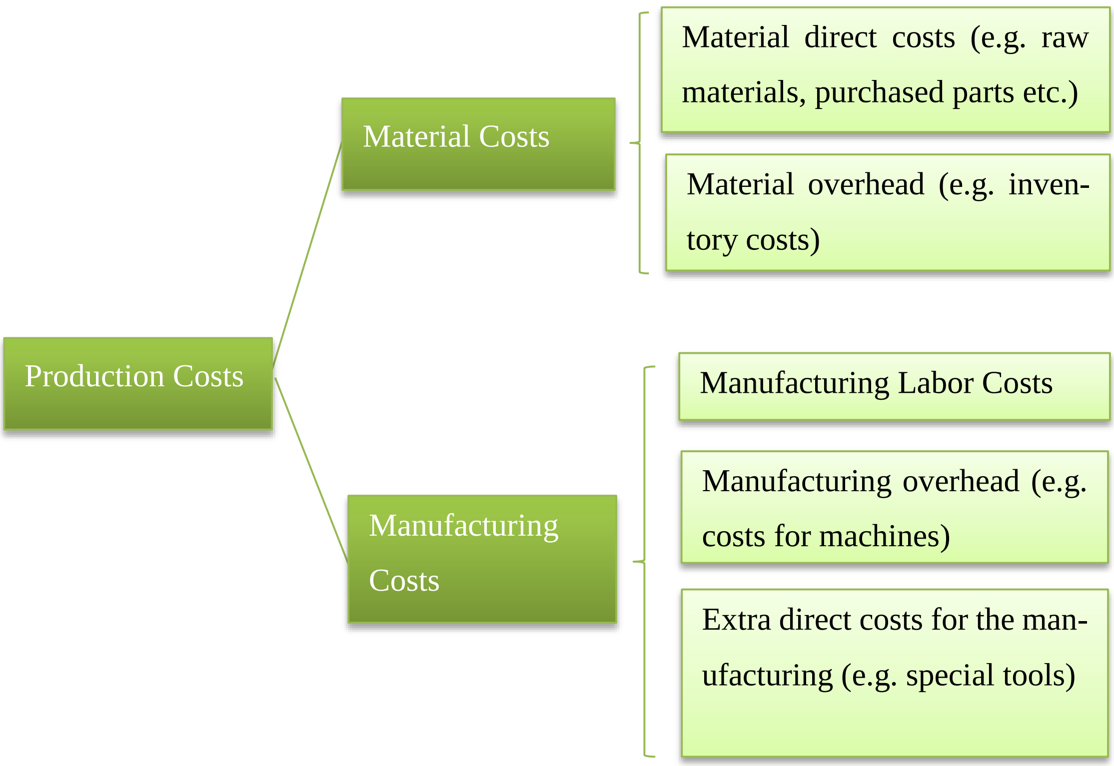
Table 13: Extract of the part list

Position	Amount	Quantity Unit	Designation	Article code/ standard	Notes
1	1	Pc	Television screen		Purchased
2	1	Pc	TV bracket	EN 10051 – 4,0 – steel EN 10025-2 – S355	Laser Cutting, Bending/ Purchased
3	2	Pc	TV bracket pillar	EN 10051 – 4,0 – steel EN 10025-2 – S355	Laser Cutting, Bending / Purchased
4	2	Pc	Protection shield	EN 10051 – 2,5 – steel EN 10025-2 – S355	Laser Cutting, Bending / Purchased

9.2.2 Production cost

On basis of the part list the preliminary production costs can be calculated. These calculation is part of the cost management. The production costs are composed of the material costs and the manufacturing costs, and these costs includes also various matters of expenses. The table 14 breakdowns the production costs in its components.

Table 14: Composition of the production costs (Bode 2015)



According to table 15 the production costs for the intelligent production shield are calculated. The costs arises from material direct costs for the purchased parts (table 15).

Table 15: Cost calculation or the purchased parts and materials

Purchased parts /materials	Price per Unit	Total Costs
Pneumatic cylinder including ports	62,57 Euro	125,14 Euro
Electro-magnetic valve	44,80 Euro	44,80 Euro
One-way restrictors	8,47 Euro	33,88 Euro
Machined metal sheets	43,60…120,50 Euro	648,80 Euro
Linear ball bearings	27,00 Euro	216 Euro
ABS (material for extrusion)	212,90 Euro/ 688cm³	6,96 Euro (22,45cm³)
		∑ 1075,58 Euro

9.2.3 Assembly instruction

The assembly instruction gives advices for the assembling chronology and safety advices.

Pre-processing

1. Gouge the holes into the metal beam
2. Tap the holes

   Attention because of the working height

Television screen group (number of persons: 2)

1. Television bracket

   Attention because of the assembly height

2. Both television bracket pillars

   Attention because of the assembly height

3. Elbow connectors (of the actuation group)
4. Television screen

Protection shield group (number of persons: 3)

1. Protection shield brackets
   Attention because of the assembly height
2. Protection shield bracket pillars
   Attention because of the assembly height
3. Connect the bearings with the protection shield
4. Insert the circular profiles to the bearings
5. Preposition of the clamp connectors and the needed screws, nuts and tools, fixation of the clamp connectors around the circular profile
6. The protection shield is fixed in the position 'open'
7. Two people are lifting the prepared protection shield, the third one fasten the clamp connectors with the shield brackets and the pillars
   Attention the weight of the preinstalled components

Actuation group (number of persons: 1-2)

1. Connect the pneumatic cylinder with the elbow connector and the protection shield
2. Wiring of the pneumatic and electric related to the pneumatic circuit diagram
   Attention compressed air system pressureless and I/O-Unit disconnected

9.3 Comparison of the defined and reached requirements

Concluding the design process a comparison of the most important earlier defined requirements on the function of the protection shield with the reached requirements is made (table 16). Additional it is resumed how these requirements are realized. A green point means that the requirement is met completely, an orange point means that the requirements is just met partly.

Table 16: Comparison of defined and reached requirements

Number	Requirement	Reached	Implementation
01	Actuation with a linear drivetrain		Usage of pneumatic cylinders
02	The closing/ opening of the protection shield is autonomous		The closing/ opening is just controllable from the user.

03	The protection shield covers the television screen from the front and the sides	●	Multiple bended metal sheet construction
04	Installation of the linear drivetrain on the backside of the television screen	●	Fixing of the pneumatic cylinders with self-designed elbow connectors
05	Economical use of materials	●	The variants of the materials is reduced, if possible the components are additive manufactured
06	Simple assembly	●	As assembly process just screw connections are used
07	Usage of resistant material against welding sparks	●	The main material is steel
08	Simple maintenance	●	Parts are good replaceable, there screw connections are easily detachable

10 Manufacturing of the 3D-printing parts

The elbow connector and the clamped connections are printed with the 3D printer Dimension Elite from the company Stratasys. The printer is using the FDM (Fused Deposit Modeling) technology. FDM means that consolidated materials or powders are fused and then applied layer by layer to the model.

Before printing a preprocessing is needed. The 3D CAD file is uploaded to the CatalystEX-Software. The software converts the file to a 3D-printable file and calculates the extrusion path for the printing material and the support material. In figure 10-1 one part of the clamped connection is sliced into 240 layers. The amount of the layers depends on the layer resolution, for these parts the minimal resolution of 0,178mm is chosen.

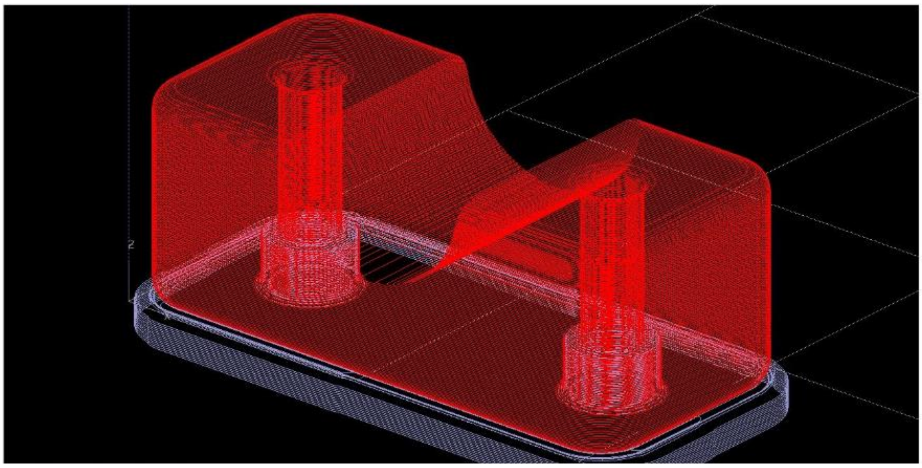


Figure 10-1: Clamped connection digitally sliced into layers

All needed parts are uploaded to the software and be arranged on the printing plate. The Dimension elite offers a construction volume of 203mm x 203mm x 305mm (W x D x H).

As printing material thermoplastics are used, which is heated up to 180° to 260° degree. Then the thermoplastic is semifluid and can extruded through a nozzle, which applies droplets in ultra-fine beads along the extrusion path. For segments, which need support or borderlines the printer uses removable material. This material can removed from the user in the end manually or in detergent and water. To avoid stress cracks, effected from temperature differences between the just extruded material and the material printed on the printing plate, the construction volume is warmed (Stratasys). The figure 10-2 shows the production process of the parts. First a base of support material is printed, so the parts can be removed manually from the printing plate. The next pictures shows the parts directly after the printing process, the support material is clearly visible. The next two pictures show the cleaned and ready to install elbow connector (left) and a clamped connection (right). To produce all parts the printer needed about 36,5 hours.

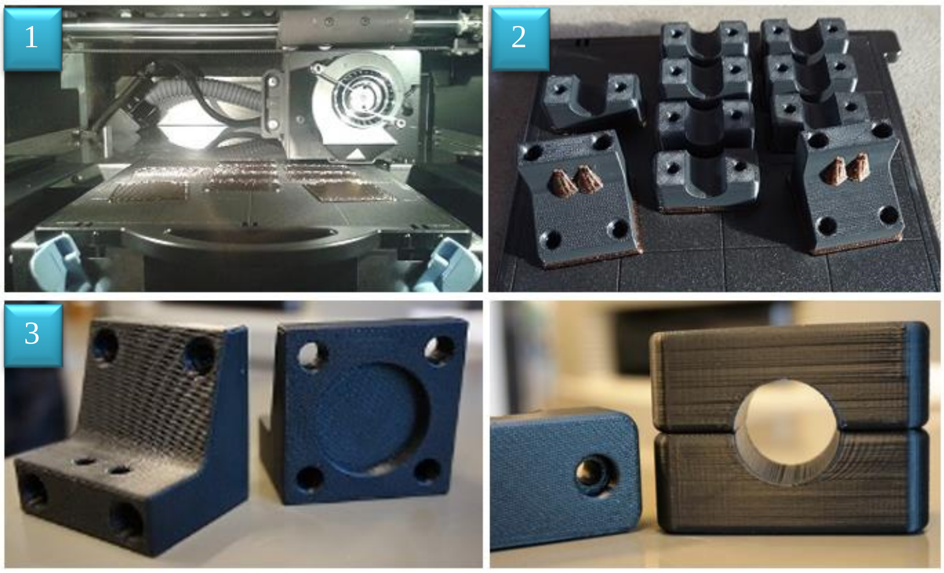


Figure 10-2: Production process of the additive manufactured parts

The precision of FDM manufactured parts depends on the configuration of the printer for example on the speed of the nozzle (3-Druck). As reference line is given a tolerance of +/- 0,178mm, whereas the smallest thickness of the layer can be 0,178mm (Additively). Additional the quality of parts printed with support material is a great contrast to parts printed without support material. The figure 10-3 shows the backside of the elbow connector printed with the Ultimate elite (using support material) and with the Ultimaker 2+. The surface defects inside the holes are conspicuous. Furthermore a step-structure on the surface is visible, this is one disadvantage of the FDM technology (additively).

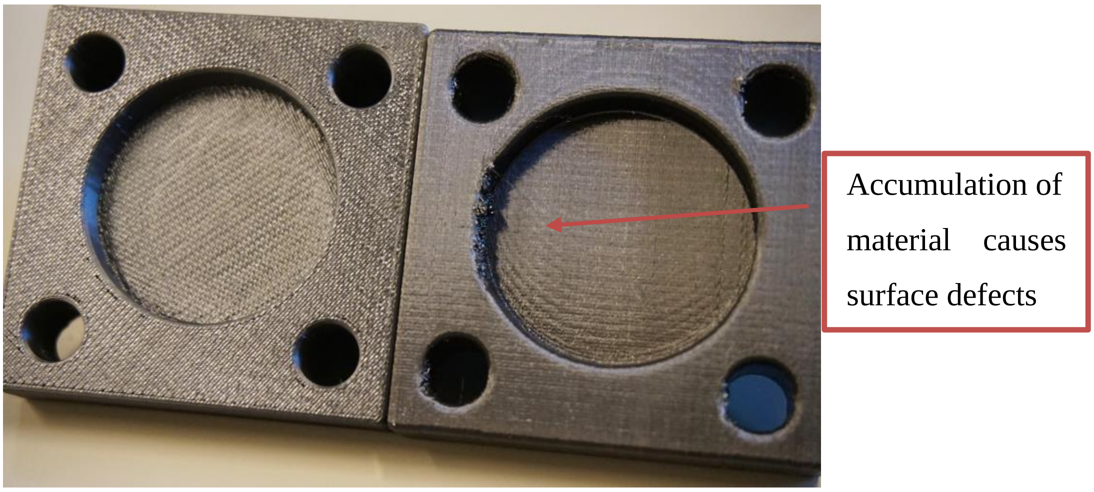


Figure 10-3: Comparison of the printing quality

11 Safety Engineering Analysis

At least a safety engineering analysis for the protection shield is made to control if the design is humane. That means that the design has to meet safety and ergonomic conditions. A work system can be differed in two functional ranges: operating range and reach of efficacy (Neudörfer 2013, 59). Within the operating range the human is working on the machine using e.g. control panels, while in the reach of efficacy the machine is machining the product with tools.

First it can be mentioned, that the protection shield system is not a typical work system, since the protection shield is not machining parts. However within the system movements are implemented and forces are generated. Possible occurring hazards are evaluated regarding the introduced risk graph (figure 4-3 and appendix 2) in the criteria severity, presence, escaping possibility and frequency. The risk assessment is made for different stages of the life cycle: assembly, operating time and disassembly. As example the assessment for the assembly is shown in table 17. The greatest hazards occurs while the holes are gouged and tapped in the metal beam. The working height amount nearly three meters. For this the person has to stand on a ladder and handle the drilling machine at the same time. This situation is obvious dangerous, since the person can fall down and additional the drilling machine can hit somebody. But there the lab is not equipped with more safe equipment the risk has to be took or the work has to be outsourced, which would mean more costs. The risk assessment reveals a risk priority number of 2. To prevent an accident safety precaution has to be organized before starting with work. The hazards number 2 to 4 are evaluated with risk priority number a, therefore no special safety requirements are needed.

During the operating time the protection shield does not pose a great danger to humans or the environment, there the movements of the cylinders are just proceeded shortly before welding and after finishing the welding process. At this moment nobody is inside the robot cell. Additionally it is installed in a height of 2,40m (lowest point), so it is not possible to reach. For maintenance work the pneumatic lines has to be pressureless and the electrical lead has to be disconnected from the mains to prevent accidents.

The disassembly at the end of product life cycle involves similar hazards as the assembly. The heavy components has to be lifted without a lifting device and could fall down. Additional it is not ergonomically to lift the components by hand.

Table 17: Risk assessment for the assembling

Risk analysis			**Risk assessment**					**Security arrangements**	
Number	Location	Hazard	Severity	Presence	Escaping	Frequency	RPN	Safety function	Implementation
01	Assembly: bore and tap the holes for the fixtures	Working in a height of 2,90m: falling down	C2	F2	P2	W2	2	Prevent to fall from heights	Working in a team, secure the ladder
	Assembly: bore and tap the holes for the fixtures	Slivers from the material	C2	F2	P2	W1	1	Protection of the eyes	All persons wear safety googles
02	(Dis-) Assembly the fixtures on the metal beam	The parts fall down before they are fixed. Hit a part of the body	C2	F2	P2	W1	a	-	-
03	(Dis-) Assembly of the preinstalled protection shields	The parts fall down before they are fixed. Hit a part of the body	C2	F2	P2	W1	a	-	-
04	(Dis-) Assembling the parts	Bruise a finger	C1	F2	P2	W1	a	-	-
	(Dis-) Assembling the parts	Cut the skin	C1	F2	P2	W1	a	-	-

12 Conclusion

The targeted purpose of this bachelor thesis is to the greatest possible extend reached. Following the methodical design process stated from the VDI 2221 the mechanical design of the protection shield is completed. After a detailed analysis of the requirements on the function, were different solution created. With the use of the morphological box these solutions were presented and subsequent combined to the most suitable variants. Observing technical and economic criteria the combination of a pneumatic actuation and linear guideway with ball bearings was chosen. As a result of the design process, the fastening constructions of the television screen and the protection shield as well the protection shield itself with integrated linear actuation were created. After finalizing the mechanical design with the elaboration the pneumatic control was developed. The requirement to design an autonomous control is not met completely, since the programmer of the welding process has to give the command for the closing and opening of the protection shield. Here exist more capability to develop the protection shield for example by using sensors and integrating these signals into the sequential control of the welding robot. For implementing these the support from the supplier of the welding robot ‘ABB’ is needed.

Furthermore the non-committal aim to assemble the television screen and the protection shield in the robot cell is not yet fulfilled, there the order of the metal sheet parts were not delivered yet. On delivery of the parts the assembling and testing can proceeded. For the installation of the actuation the adjustment of the one-way-restrictors is important to generate a smooth and uniform movement of both pneumatic cylinders.

On the other hand the parts designed for 3D printing are produced. Besides providing ready-to-mount parts, the estimation from the literature of the potential of additive manufacturing technologies can be confirmed. To own a 3D printer offers a great flexibility of producing various parts for different applications. Additional the cooperation with suppliers is not anymore essential, which decrease the waiting time for a finished part. Through the usage of two different 3D-printers (printing with and without support material) the variance in the results were conspicuous. The surface defects in the holes of the part printed without support material were visible to the unaided eye. For sure TAMK does not have the newest and best available printers, but like Iuarte (2015) mentioned the quality differs considerable from machine to machine.

Another complement for the protection shield would be fastening clamps for the pneumatic line and electric lead. These clamps could be also additive manufactured.

The overall objective and background for this thesis work was to improve the usability of the welding robot for teaching purposes. As a matter of fact the screen of the panel board will be visible to the complete student group after the installation of the television screen. The efficiency for the learning of the students and application frequency for group work has to be evaluated after the implementation.

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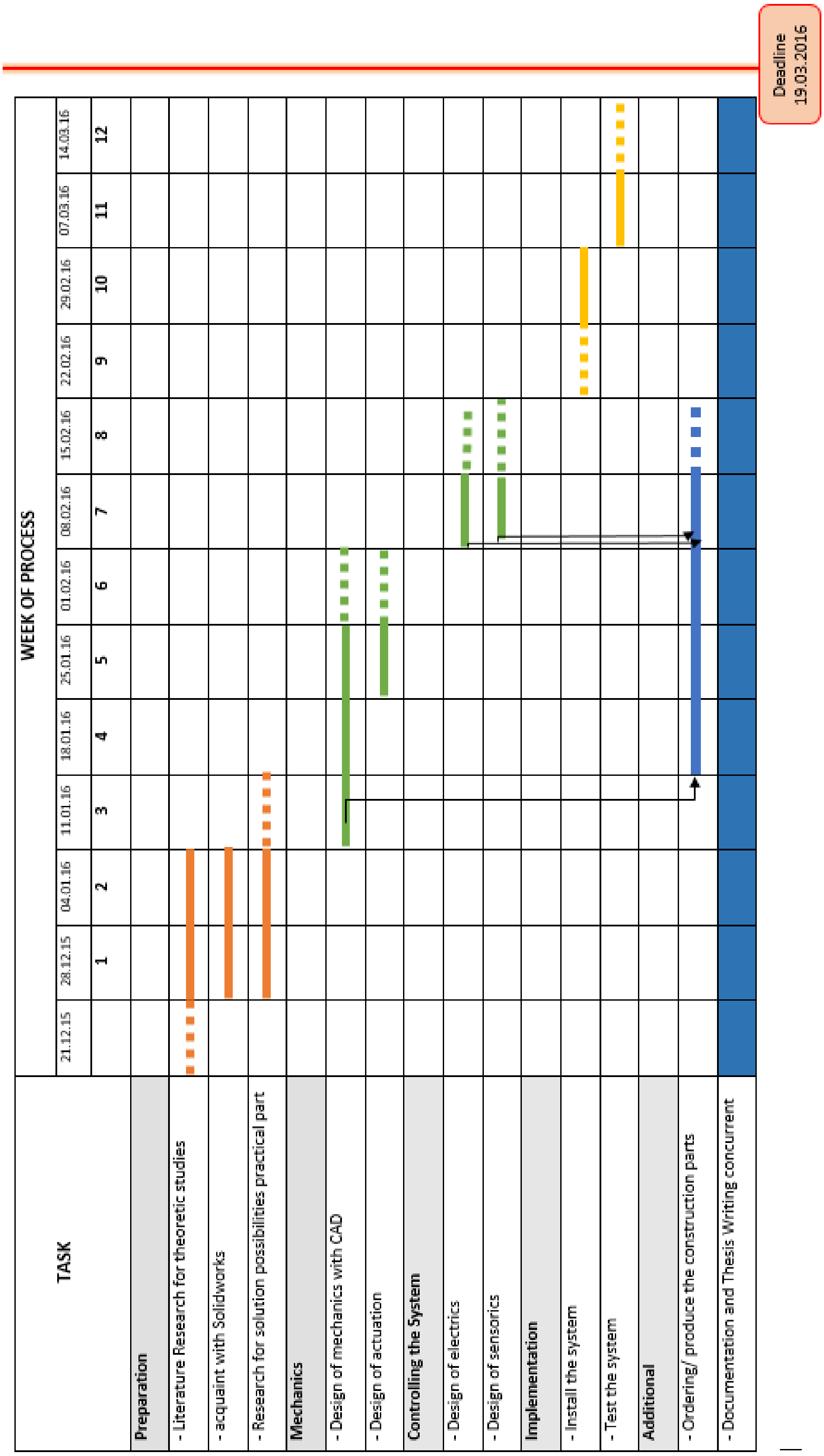
APPENDICES

Appendix 1. Project Plan Diagram



Appendix 2. Legend for the criteria of the risk graph

Consequences:

- C1 Light injuries
- C2 Serious injuries and/ or one dead
- C3 multiple deaths
- C4 Large number of deaths

Presence of people:

- F1 in the hazard area is someone less than 10% of the operating time present
- F2 in the hazard area is someone more than 10% of the operating time present

Escaping:

- P1 in more than 10% of the cases an escaping is possible
- P2 in less than 10% of the cases an escaping is possible

Frequency of the scenario:

- W1 relatively low frequency
- W2 default frequency for the failure of the control system and operators
- W3 relatively high frequency (through better design reach W2)

1,2,3,4	safety priority number
a	no special safety requirements
na	a single safety-instrumented function is not sufficient (this safety level should be avoided and eliminated if possible)

(safety-sc)

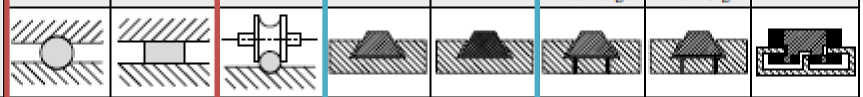
Appendix 3. Properties of linear guides

TB 8-13 Roloff Matek: Nominal diameter in mm for setscrews in force per screw (Wittel et al. 2015, TB 111)

Festig-keits-klasse	stat. axial / dyn. axial / quer	Nenndurchmesser in mm für Schaftschrauben bei Kraft je Schraube[1)] F_B bzw. F_Q in kN bis											
		1,6 1 0,32	2,5 1,6 0,5	4 2,5 0,8	6,3 4,0 1,25	10 6,3 2	16 10 3,15	25 16 5	40 25 8	63 40 12,5	100 63 20	160 100 31,5	250 160 50
4.6		6	8	10	12	16	20	24	27	33	–	–	–
4.8, 5.6		5	6	8	10	12	16	20	24	30	–	–	–
5.8, 6.8		4	5	6	8	10	12	14	18	22	27	–	–
→ 8.8		4	5	6	8	8	10	14	16	20	24	30	–
10.9		–	4	5	6	8	10	12	14	16	20	27	30
12.9		–	4	5	5	8	8	10	12	16	20	24	30

1) Für Dehnschrauben, bei exzentrisch angreifender Betriebskraft F_B oder bei sehr großen Anziehfaktoren sind die Durchmesser der nächsthöheren Laststufe zu wählen, bei sehr kleinen Anziehfaktoren die der nächstkleineren.

Properties of linear guides (Wittel et al. 2015, 547)

Eigenschaften	Wälzführungen			Hydrodynamische Gleitführungen		Fluidostatische Gleitführungen		Magnetführungen
Properties	Kugel-führung	Rollen-führung	Laufrollen-führung	Metall-Metall	Metall-Kunststoff	Hydro-statische Führung	Aero-statische Führung	Magne-tisches Schweben
								
Belastbarkeit	3	3	2	3	3	3	0	3
Steifigkeit	2	3	1	3	2	3	0	1
Genauigkeit	2	2	2	1	1	2	2	3
Reibungsverhalten	2	2	2	1	1	3	3	3
Geschwindigkeit	3	3	3	1	1	3	3	3
Dämpfungsverhalten	1	1	1	3	3	3	3	3
Betriebssicherheit	3	3	3	3	3	1	1	1
Standardisierung	3	3	3	1	1	0	0	0
Lebensdauer	2	2	2	2	2	3	3	3
Kosten	2	2	2	3	3	1	1	0

3 sehr gut 1 befriedigend
2 gut 0 ausreichend

Bild 14-51 Eigenschaften von Linearführungen

Properties from top:

Load ability, rigidity, accuracy, friction, speed, attenuation, reliability, standardization, durability and costs.

Comparison is made between: in red linear anti-friction guideways (ball guideway and roller bearing) in blue hydrodynamic guideways (metal-metal and metal-plastic).

Appendix 4. Pneumatic circuit diagram

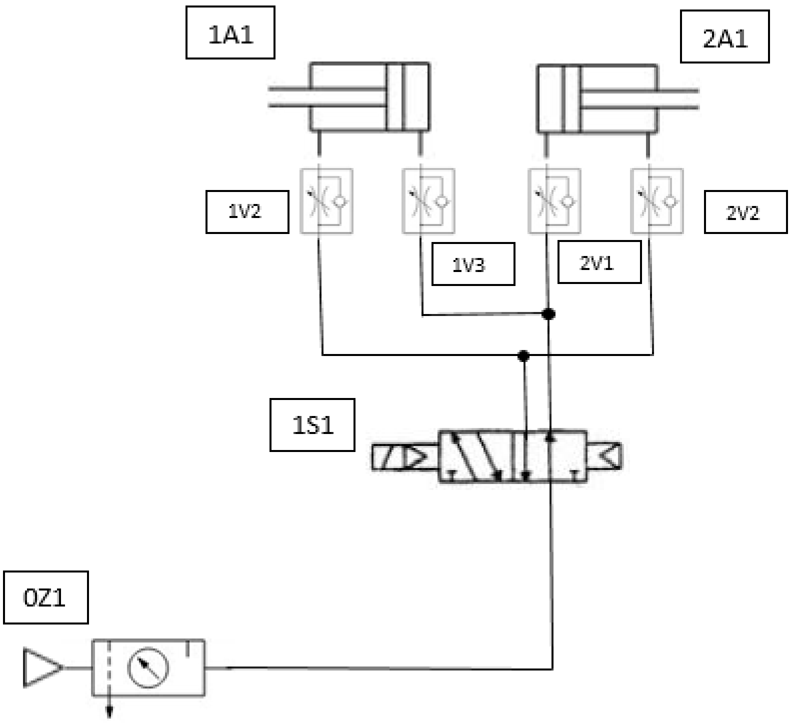


Figure 12-1: Pneumatic circuit diagram

Appendix 5. Documentation

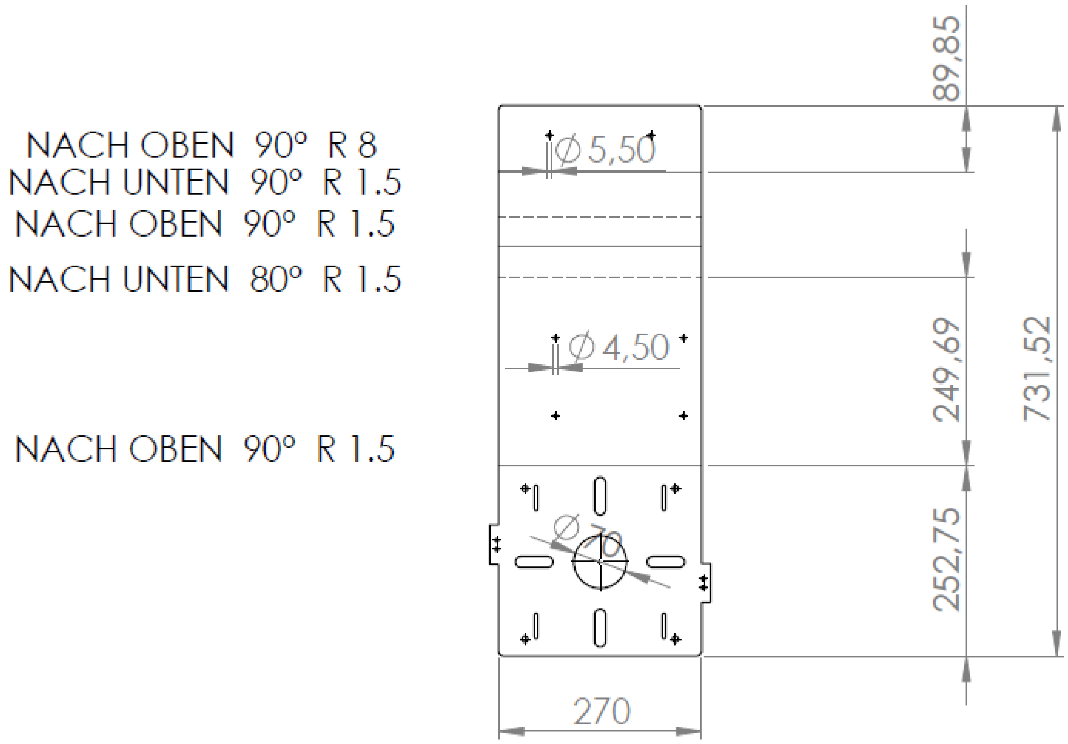
Complete part list

Position	Amount	Quantity Unit	Designation	Article code/ standard	Notes
1	1	pc	Television screen	Samsung	Purchased
2	1	pc	TV bracket	EN 10051 – 4,0 – steel EN 10025-2 – S355	Laser Cutting, Bending / Purchased
3	2	pc	TV bracket pillar	EN 10051 – 4,0 – steel EN 10025-2 – S355	Laser Cutting, Bending / Purchased
4	2	pc	Protection shield	EN 10051 – 2,5 – steel EN 10025-2 – S355	Laser Cutting, Bending / Purchased
5	2	pc	Shield bracket	EN 10051 – 4,0 – steel EN 10025-2 – S355	Laser Cutting, Bending / Purchased
6	2	pc	Shield bracket pillar	EN 10051 – 4,0 – steel EN 10025-2 – S355	Laser Cutting, Bending / Purchased
7	8	pc	Linear ball bearing	KBA20UU	Purchased from Rollco
8	2	pc	Circular profile	Round EN 10278 – 20 x 1640 – EN 10088-2 X46Cr13	Purchased
9	4	pc	Clamped connector top	Technical Thermo-plastic ABS	Fused Deposit Modeling / self-produced
10	4	pc	Clamped connector bottom	Technical Thermo-plastic ABS	Fused Deposit Modeling / self-produced
11	2	pc	Elbow connector	Technical Thermo-plastic ABS	Fused Deposit Modeling / self-produced
12	2	pc	Pneumatic cylinder	CP96SDB32-400C	Purchased from SMC Pneumatics Finland Oy
13	8	pc	Hex head screw	DIN 4014-M5x10 - 8.8	Purchased

14	8	pc	Hex head screw	ISO 4014 – M4 x 20 - 8.8	Purchased
15	8	pc	Cheese head screw	ISO 4762 – M5 x 60 – 8.8	Purchased
16	32	pc	Cheese head screw	ISO 4762 – M5 x 45 – 8.8	Purchased
17	4	pc	Cheese head screw	ISO 4762 – M5 x 25 - 8.8	Purchased
18	4	pc	Cheese head screw	ISO 4762 – M5 x 50 - 8.8	Purchased
20	4	pc	Countersunk screw	ISO 10642 – M4 x 25 -8.8	Purchased

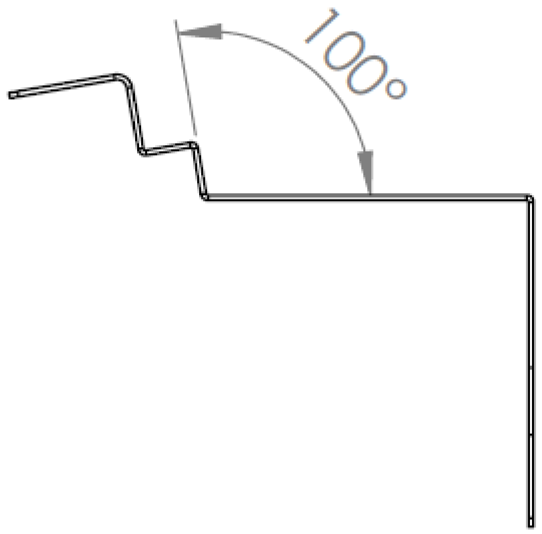
Position 2: Television bracket

Sheet metal unfolding



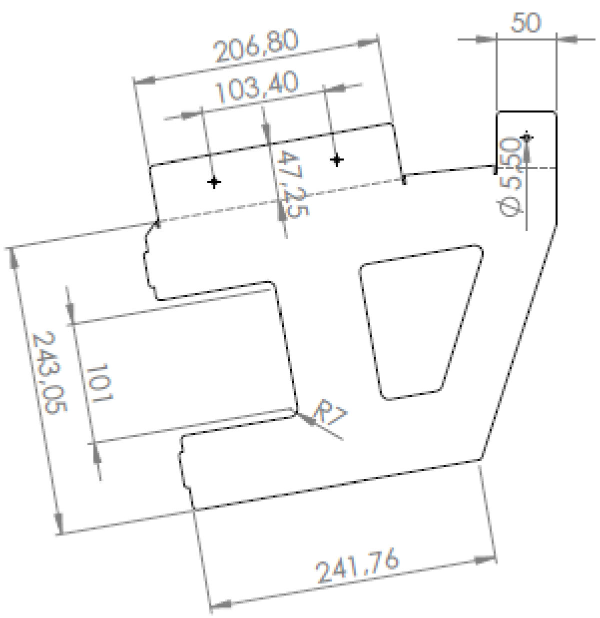
All length tolerances according to DIN ISO 2768-1 tolerance class fine.
All hole tolerances according to DIN EN 20273 H13
Sheet thickness 4.00mm

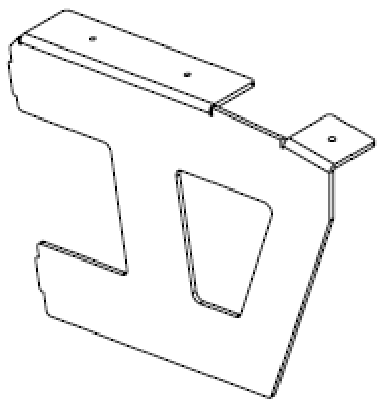
Television bracket bended from the side



Position 3: TV bracket pillar

Sheet metal unfolding and isometric representation

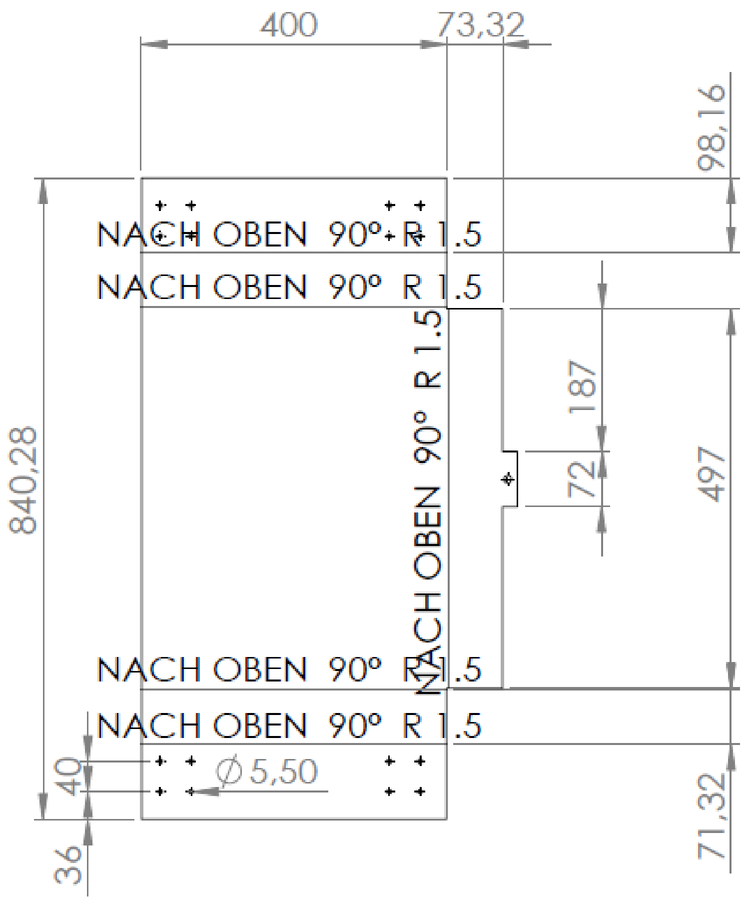


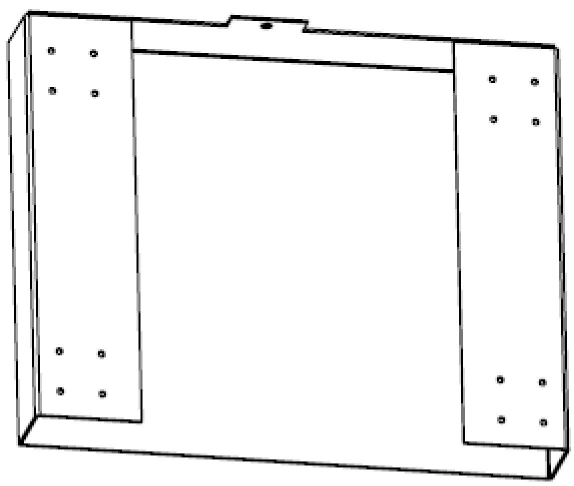


All length tolerances according to DIN ISO 2768-1 tolerance class fine.
All hole tolerances according to DIN EN 20273 H13
Sheet thickness 4.00mm

Position 4: Protection shield

Sheet metal unfolding and isometric representation

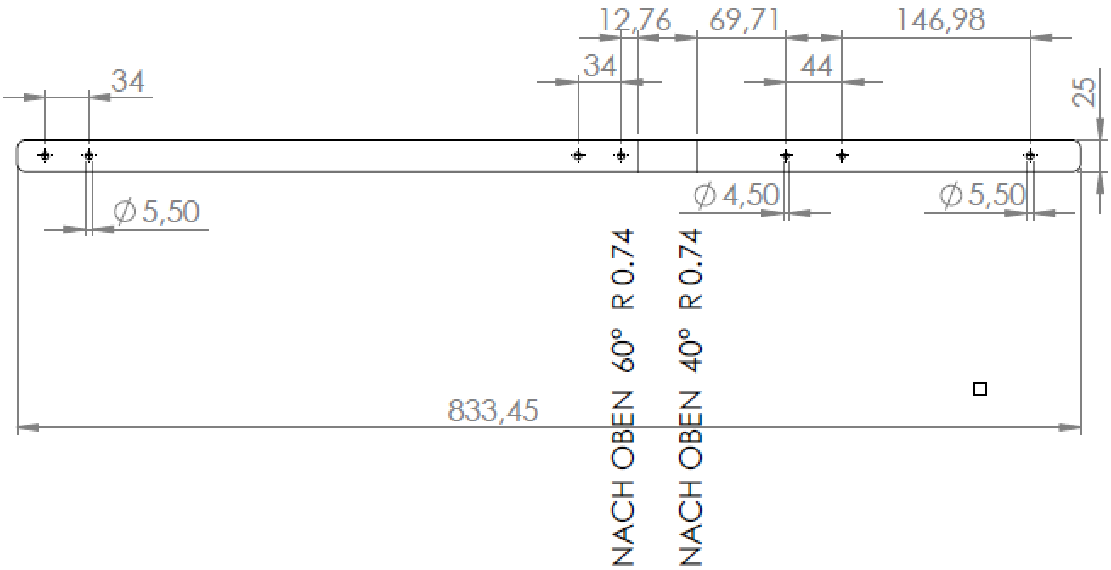


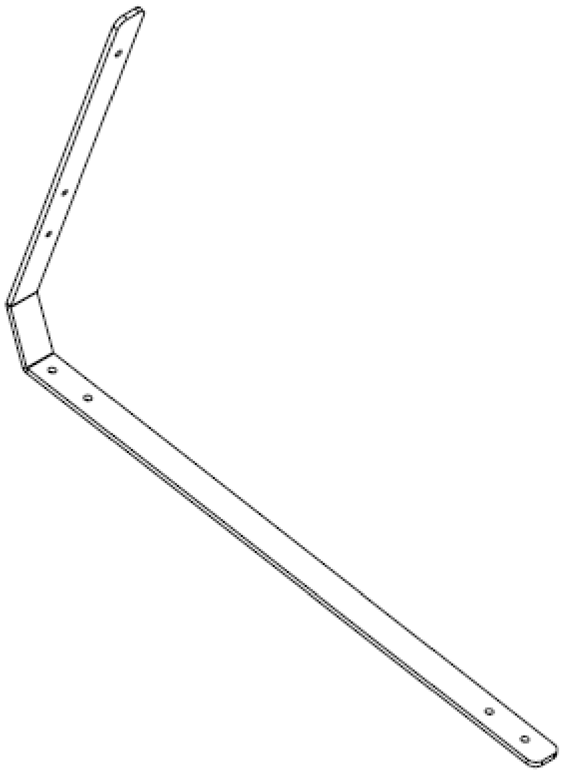


All length tolerances according to DIN ISO 2768-1 tolerance class fine.
All hole tolerances according to DIN EN 20273 H13
Sheet thickness 2,5mm

Position 5: Protection shield bracket

Sheet metal unfolding and isometric representation

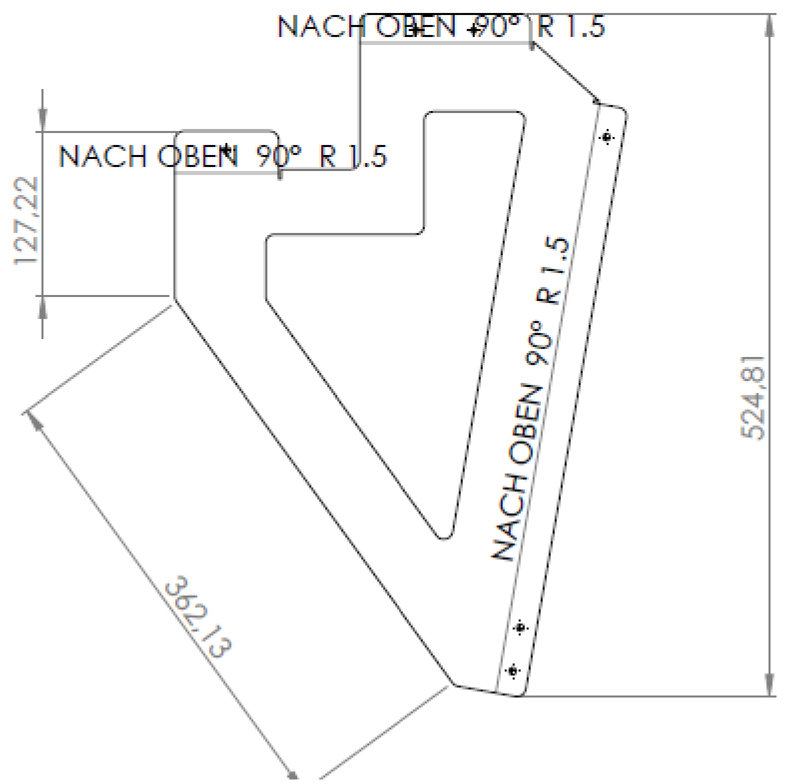


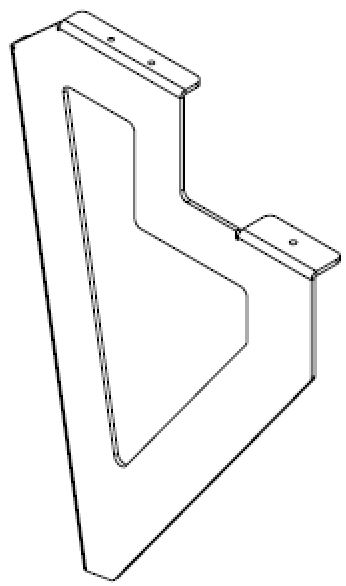


All length tolerances according to DIN ISO 2768-1 tolerance class fine.
All hole tolerances according to DIN EN 20273 H13
Sheet thickness 4.00mm

Position 6: Protection shield bracket pillar

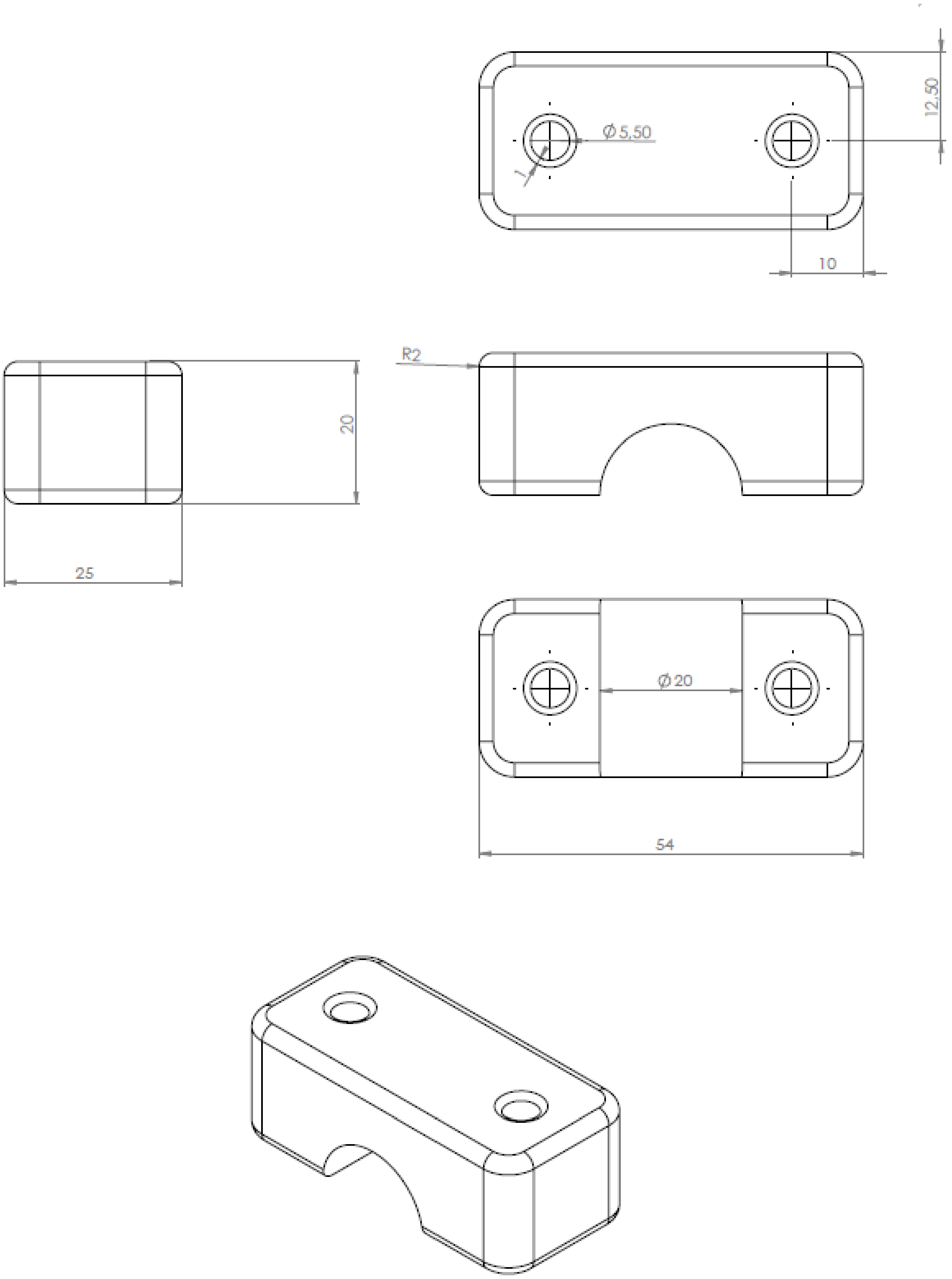
Sheet metal unfolding and isometric representation





All length tolerances according to DIN ISO 2768-1 tolerance class fine.
All hole tolerances according to DIN EN 20273 H13
Sheet thickness 4.00mm

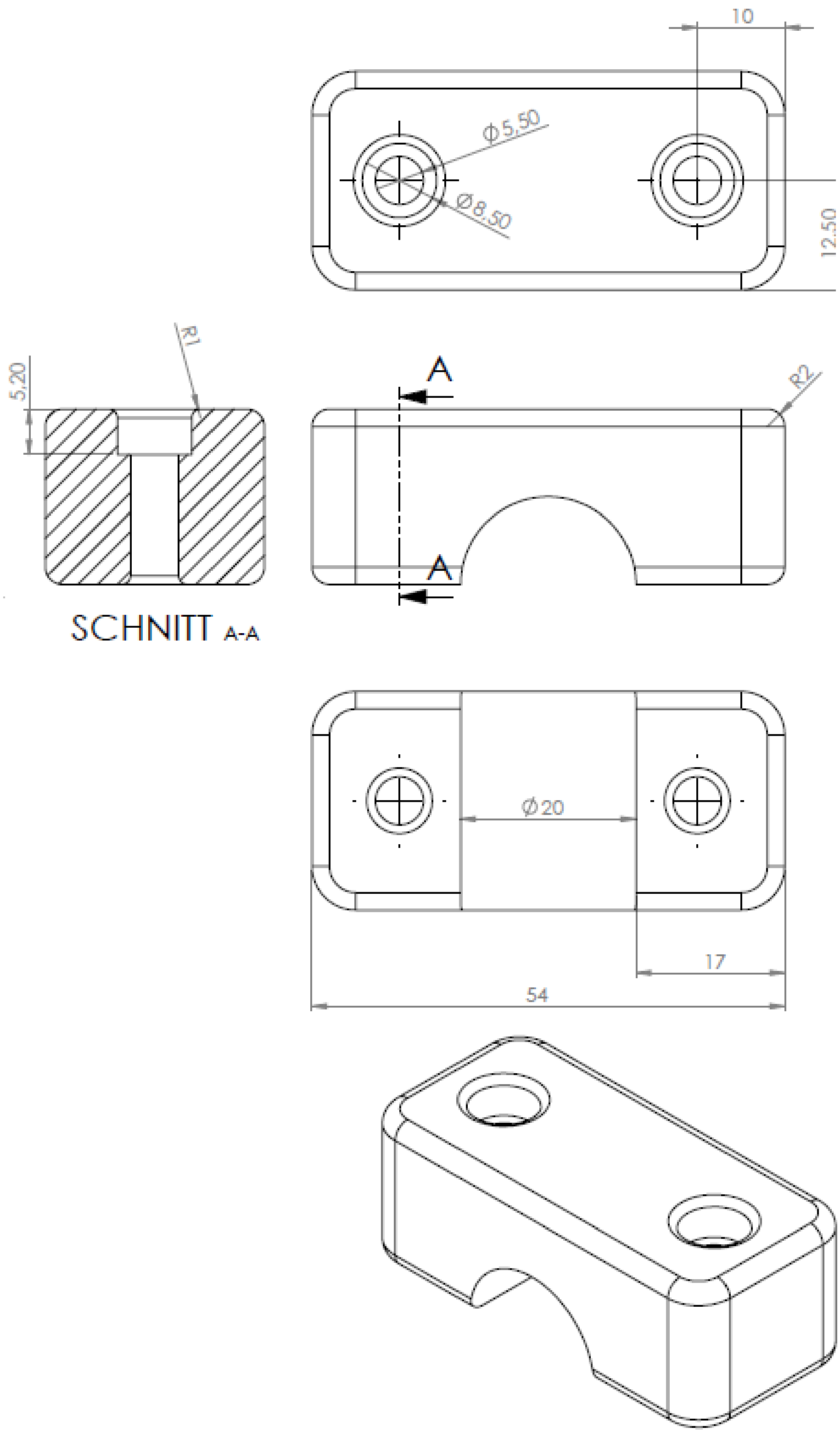
Position 9: Clamped connector top



Surface finish conform to FDM printing process.

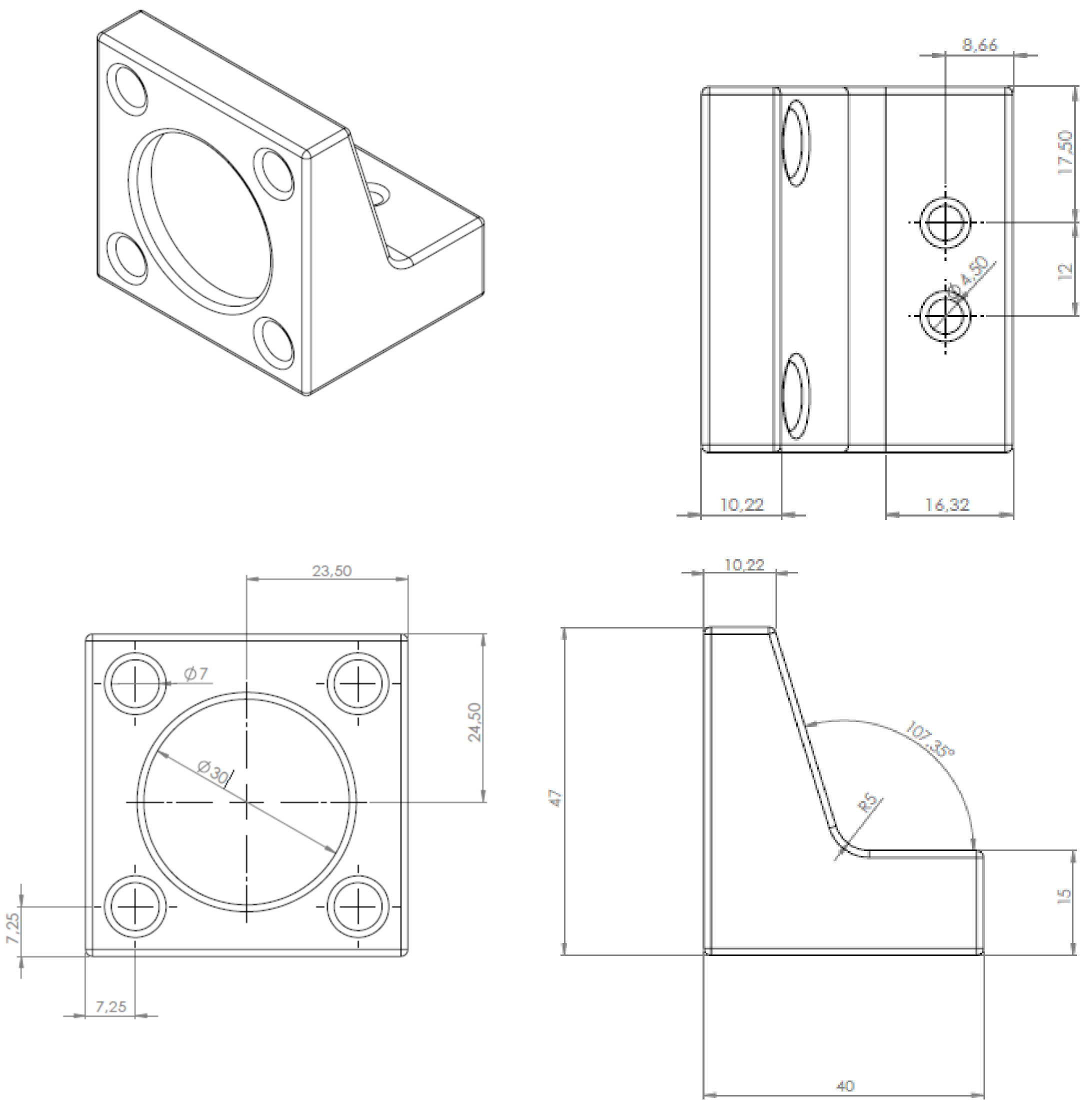
All tolerances conform to the FDM printing process.

Position 10: Clamped Connector bottom



Surface finish conform to FDM printing process.

All tolerances conform to the FDM printing process.



Surface finish conform to FDM printing process.

All tolerances conform to the FDM printing process.

All edges blunt with 1mm round.