

Design of an Automated Sheet Metal Transfer System for Die Hardening



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ABSTRACT

The purpose of this thesis was to design an automated facility that transfers a heated sheet metal specimen from the oven to a press hardening die, assembled in a hydraulic press. This project was commissioned by Sheet Metal Centre; a research and development department of HAMK University of Applied Sciences located in Hämeenlinna. A primary target of this thesis was to achieve a complete automated system, which would provide consistent specimen transfer time, leading to comparable test results for die hardening research.

Initially, a manual system was designed and a prototype was manufactured to be used in the transfer of hot sheet metal specimens, but inconsistencies were observed in the hardening results due to differences in the transfer time when using the manual transfer system. Hardening process is sensitive to the rate of cooling, which in turn, is related to the transfer time and this demanded an automated system to be designed. In developing the existing prototype, research was conducted to find an existing transfer system. Multiple automated systems were found for cold sheet metal transfer but none for hot sheet metals. This necessitated a completely new system design that could be used in elevated temperatures. A general approach to design was adopted to develop the manual prototype. This process involved multiple discussions with the customer and supervisor. Multiple ideas were generated and discussed with supervisor and the customer to validate the mechanism that performs each necessary mechanical actuation. Later these actuations were combined to form a complete system.

Multiple visits to the research site and meeting reviews played an important role in getting familiarised and understanding of the work. Implementing general design steps such as research, brainstorming, ideation, concept design and virtual prototype development resulted in two different transfer systems. One of the systems was selected by the customer for further development. The system designed will be manufactured and assembled at the Sheet Metal Centre to assist the die hardening research. The gripping tool for the system will be designed later in another project and any optimization or further development of the system, if needed, will be carried out then.

Keywords Automated sheet metal transfer system, die hardening, Sheet Metal Centre.

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CONTENTS

1	INTRODUCTION.....	1
1.1	Customer requirement.....	1
2	HARDENING	2
2.1	Die hardening	6
2.2	Specimen	6
3	DESIGN PROCESS	7
4	FEASIBILITY STUDY.....	9
4.1	Market research	9
4.2	Customer needs and market	10
5	MANUAL TRANSFER SYSTEM	11
5.1	Design of manual transfer system	11
5.2	Manufacturing of manual transfer system.....	15
5.3	Manual transfer system; advantages and disadvantages	15
6	FINAL DESIGN; AUTOMATED SYSTEM	16
6.1	Oven door operation.....	18
6.2	Transfer system with linear and rotary actuator.....	20
6.2.1	Gripping tool	21
6.2.2	Rotary actuator	23
6.2.3	Arm design	23
6.2.4	Linear actuator.....	25
6.2.5	Transfer time	27
6.3	Transfer system with linear motion only.....	29
6.3.1	Gripping tool	31
6.3.2	Arm design	33
6.3.3	Linear actuator.....	36
6.3.4	Supporting structure for actuator.....	36
6.3.5	Transfer time	36
7	PROPOSED IDEAS	38
7.1	Position of moving components.....	38
7.2	Linear actuation.....	38
7.2.1	Pneumatic cylinder and guide rail	39
7.2.2	Rodless pneumatic cylinder.....	40
7.2.3	Belt driven linear actuator	41
7.3	Work holding mechanism	43
7.3.1	Hook based solution	43
7.3.2	Magnetic gripper	44
7.3.3	Commercial work holding gripper	45
7.3.4	Designing a new gripper; a concept design	46
7.4	Rotary actuator	48
7.5	Oven door mechanism.....	49
7.5.1	Pneumatic cylinder	50
7.5.2	Rotary actuator	51

7.5.3 Custom designed actuator.....	51
8 OPERATION	53
8.1 Control system.....	53
8.2 Operation sequence	54
9 MAINTENANCE AND SAFETY	54
10 RESULTS AND CONCLUSION	56
SOURCES	58

Appendix 1	Milestone meetings
Appendix 2	Beam profile calculations results for system without rotation
Appendix 3	Aluminium beam profile catalogue for system without rotation
Appendix 4	Results of arm beam selection calculation for transfer mechanism without rotation
Appendix 5	Arm beam selection calculation from Mathcad for transfer system without rotation
Appendix 6	Technical drawings of linear actuator for horizontal actuation
Appendix 7	Technical drawings of linear actuator for oven door operation
Appendix 8	Main assembly drawing of sheet metal transfer system without rotation
Appendix 9	Assembly drawing of oven door actuation system
Appendix 10	Technical drawing of handle and vertical actuator connector for oven door operation
Appendix 11	Technical drawing of bottom plate for actuator stand in door operation
Appendix 12	Technical drawing of actuator stand for vertical actuator in door operation
Appendix 13	Technical drawing of rolling hose for vertical actuator in oven actuation
Appendix 14	Assembly drawing of horizontal actuator support structure
Appendix 15	Technical drawing of leg part for horizontal actuator support structure
Appendix 16	Technical drawing of support base for horizontal actuator support structure
Appendix 17	Technical drawing of bottom plate for horizontal actuator support structure
Appendix 18	Assembly drawing of arm and gripper
Appendix 19	Technical drawing of arm
Appendix 20	Assembly tree for automated sheet metal transfer system
Appendix 21	Product part list and manufacturer or reseller

LIST OF FIGURES

Figure 1	Arrangement of oven and die presented as required by customer (Kärppä, e-mail 01.04.2015).	2
Figure 2	Iron–Iron Carbide (Fe–Fe ₃ C) Phase Diagram (MSE 300 Materials Laboratory Procedures n.d.).....	3
Figure 3	Austenite transformation (MSE 300 Materials Laboratory Procedures n.d.).	4
Figure 4	TTT diagram (MSE 300 Materials Laboratory Procedures n.d.).....	5
Figure 5	Layers of zinc and its oxide on specimen.	6
Figure 6	A crossbar robot holding sheet metal (Schuler n.d.).....	9
Figure 7	Servo press with coil feeding line, blank holder and a three axis transfer system (Schuler n.d.).....	10
Figure 8	Oven used to heat sheet metal specimen (Kärppä, e-mail 01.04.2015).	10
Figure 9	Automated solution for small specimen in Tampere University of Technology Laboratory.....	11
Figure 10	Manual transfer system assembly tree.....	12
Figure 11	Dome shaped projections with nut as solution for cooling issue.	13
Figure 12	Hook and its assembly in lifted position.	13
Figure 13	Movable handle with hooks and specimen (hooked position) assembled on wall of manual transfer system.	14
Figure 14	Manual transfer system along with oven and die.	14
Figure 15	Commercial hooks used in manual transfer mechanism.	15
Figure 16	ANSYS analysis for deflection of sheet at 900 °C.....	17
Figure 17	CREO analysis for deflection of a sheet at 900 °C.	17
Figure 18	Specimen position in ceramic base and in oven.	18
Figure 19	Connection bracket for handle of oven door.	19
Figure 20	Opening and closing of oven door and respective slider positions.	19
Figure 21	Initial idea sketch for the mechanism.	20
Figure 22	Steps in automated system with rotation of specimen.....	21
Figure 23	Pneumatic sheet metal gripper (DE–STA–CO Sheet Metal Grippers n.d.)... ..	22
Figure 24	Selecting the rotary actuator.	23
Figure 25	Linear actuator with its payload.	24
Figure 26	Load diagram for linear actuator selection.	24
Figure 27	Dynamic allowable moment for linear actuator (SMC Electric actuator n.d.).....	26
Figure 28	Workload vs speed graph for linear actuator (SMC Electric actuator n.d.).....	27
Figure 29	Cycle time calculation for linear actuator (SMC Electric actuator n.d.)..	28
Figure 30	Transfer system with rotation.	29
Figure 31	Steps of transfer in automated system without rotation.	31
Figure 32	Custom designed pneumatic gripper.	32
Figure 33	Custom designed electric gripping mechanism.	33
Figure 34	Datasheet for aluminium alloy EN AW-6063 T5 (Purso profile design manual, 2014).	34
Figure 35	Load for arm in system without rotary actuator.	34
Figure 36	Mass properties of arm after holes were created to reduce mass.	35
Figure 37	Deflection analysis with ANSYS.	36
Figure 38	A section view showing complete model of transfer system.	37
Figure 39	Position of linear actuator.....	38
Figure 40	A section model of a double acting pneumatic cylinder (Hitchcox, Hydraulics & Pneumatics, 2013).	39

Figure 41	Schematic illustration of application of pneumatic cylinder and guide rails.	40
Figure 42	A section view of rodless pneumatic cylinder (RLF Rodless Cylinder n.d.).	40
Figure 43	A commercial rodless pneumatic cylinder (Rodless cylinders n.d.).	41
Figure 44	An electric actuator, belt drive (SMC, Product catalogue n.d.).....	41
Figure 45	Slider on the linear actuator.....	42
Figure 46	Hooks for specimen holding.....	43
Figure 47	Manual sheet metal grabbing pliers.....	44
Figure 48	Magnetic grippers.....	44
Figure 49	Electric 2 finger parallel gripper (Schunk n.d.).....	45
Figure 50	Pneumatic sheet metal gripper (DE-STA-CO Sheet Metal Grippers n.d.)...	46
Figure 51	Gripping mechanism for new gripper design.....	46
Figure 52	Scissor mechanism (Scissor lifts information n.d.).....	47
Figure 53	3D model of the rotary actuator (SMC digital catalogue n.d.).....	48
Figure 54	Rotary actuator MSQ model (Rotary Table / Rack-and-Pinion Type n.d.)..	49
Figure 55	Rotating connection of door handle.....	50
Figure 56	Initial sketch for pneumatic cylinder position in door operation.....	50
Figure 57	Using a rotary actuator for door operation.....	51
Figure 58	Rotary actuator from Festo (Semi-rotary actuators with rotary vane n.d.)..	51
Figure 59	Idea sketch for connection between handle rod and actuator.....	52
Figure 60	Mechanism for custom design actuator.....	52
Figure 61	Location of home position, picking and dropping points.....	53
Figure 62	Limit switch (left) and its positions (YEInternational n.d.).....	54
Figure 63	Sheet metal transfer system and surrounding.....	55

LIST OF TABLES

Table 1	Milestone meetings.	8
Table 2	Idea selection matrix for linear actuation mechanism.....	42
Table 3	Idea selection matrix for work holding mechanism.....	47
Table 4	Idea selection matrix for oven door mechanism.	53

1 INTRODUCTION

Automating a manufacturing process, service or a task by introducing automatic or distant control over machinery is automation. Automation can be established in a system for various purposes such as reduction in labour, improving precision and quality of the task, higher safety, higher productivity and optimizing energy as well as raw materials being used. It is widely used in industrial sector as well as research based tasks. Involving machines to do a task instead of human being often opens door of new possibilities of working in extremes such as high temperature, high radiation and other hazardous zone. (Sure Controls n.d.)

History of automation dates back to the early Greek civilization. Around 50 A.D., a Greek inventor called Hero developed an automated system that would open a temple door when a priest lit a fire on the temple altar. Despite of an early birth of the concept, automation flourished during the Industrial Revolution of the early eighteenth century. Many of the steam-powered devices built by James Watt, Richard Trevithick, Richard Arkwright, Thomas Savery, Thomas Newcomen, and their contemporaries were simple examples of machines capable of taking over the work of humans. (Automation History n.d.)

The design of an automated system deals with the principles, proper functionality as well as the production of the system itself. It also includes the industrial design aspect such as colour, texture, assembly pattern and all the consumer appeal to be dealt with as well. In the first stages of designing a mechanical system, starting point is a market need followed by conceptualization of reasonable ideas as solutions leading to a full product specification at the end. Here, as the starting point for this thesis, Sheet Metal Centre which is the research department of HAMK University of Applied Sciences, needed an automated mechanism to transfer a hot sheet metal specimen from the oven to the die for die hardening research. The primary objective was to design a system which would deliver each successive transfer in a uniform time of travel. (Ashby 2005, 12.)

1.1 Customer requirement

Steel is one of the most common materials used in the construction of static and mobile devices. The automotive industry and the ship construction industry as well as almost all other transportation related industries use steel as the basic material for their vehicles. Steel is the strongest and most affordable material for applications. It can also be recycled and reused multiple times for the same application. Unlike aluminium, steel does not degrade in quality during the recycling process and this makes it even more suitable as the main construction material. It can be engineered up to a microscopic level in a lot of different ways to meet the requirements of crash safety and performance of a vehicle. For higher safety, the material used in vehicles has to absorb crash energy so that it dissipates that energy from reaching the passengers. Also, during a side collision, the material has to be strong enough to deflect energy with minimum deformation into the passenger

area. Using low strength steels a higher amount of material is required to reach desired strength levels, this increases the mass of the vehicle making it less efficient. This issue has been solved through the history by utilizing advanced higher strength steels; developed versions of steel with applications such as heat treatment and alloying. They not just reduce the mass of a car but also provide better strength and allow more flexibility in the design process. To fulfil this need, Sheet Metal Centre needs the die hardening process research facility. (The future of Steel in the Automotive Industry 2014.)

This thesis introduces the manual mechanism developed as a prototype during summer and then describes in detail the design of automated mechanism from a basic ideation to the final specifications of the product. Each step of the design process is described in the respective topic. A general arrangement of the oven and die as presented by customer are shown in Figure 1 below.

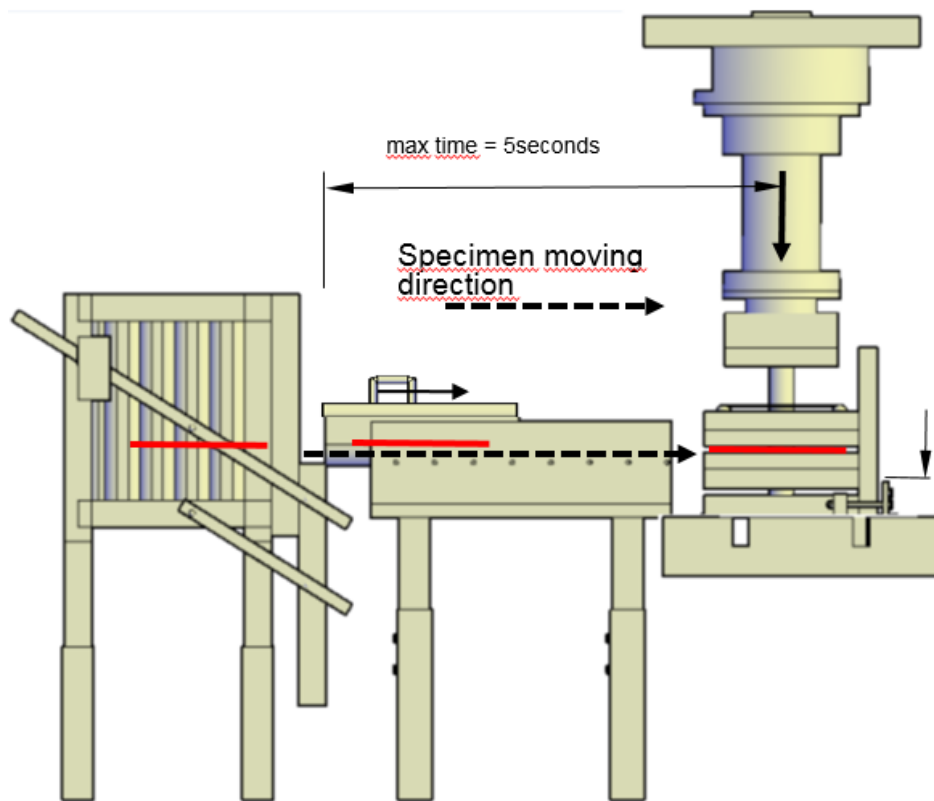


Figure 1 Arrangement of oven and die presented as required by customer (Kärppä, e-mail 01.04.2015).

2 HARDENING

The hardening process of a metal is based on the modification of its crystal structure and composition at a microscopic level. This is achieved by controlling the rate of diffusion and the rate of crystal transformation within the microstructure during different phases of steel. Fe-C phase diagram in Figure 2 shows the phases achieved by heating steel to higher temperatures. Steel exists in different phases, the α -ferrite phase is stable form of iron at room temperature, and the γ -austenite phase is achieved by heating steel to

the austenite region shown in Figure 2. The austenite area extends from 727 °C to 1493 °C depending on carbon concentration in the steel. Steels usually have carbon less than 1% so all the ferrite will be transformed to austenite when heated above 900 °C. This phase is not stable below 727 °C and is crucial to be attained for hardening which is why the specimen is heated to above 900 °C in this hardening process. The δ -ferrite phase is another phase which is achieved by heating steel above 1394 °C (MSE 300 Materials Laboratory Procedures 2016).

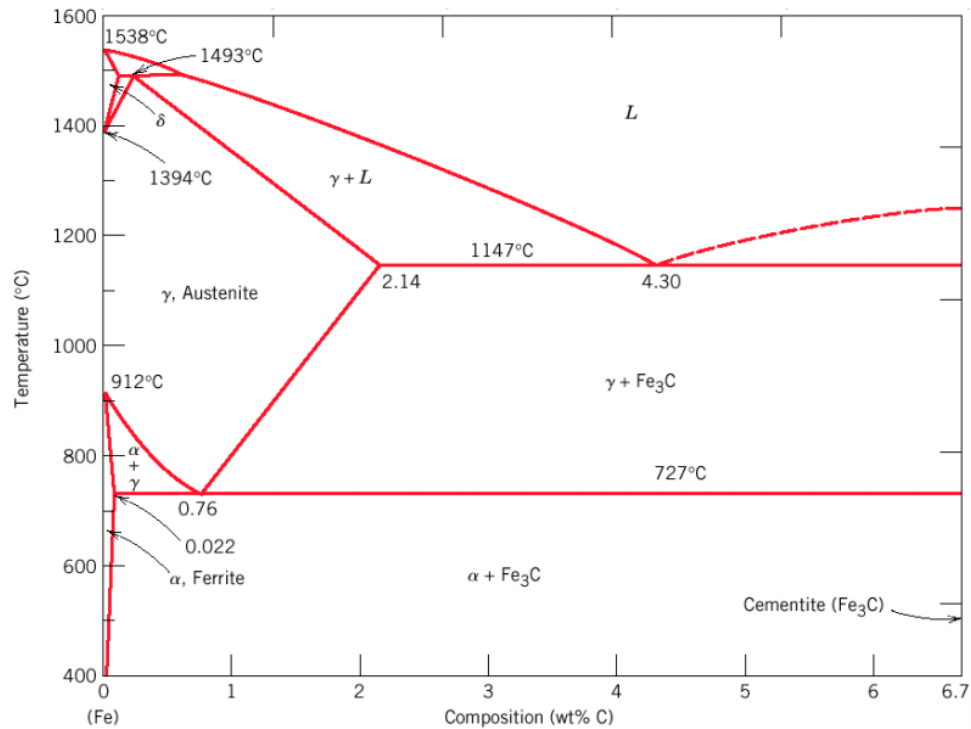


Figure 2 Iron-Iron Carbide (Fe-Fe₃C) Phase Diagram (MSE 300 Materials Laboratory Procedures n.d.).

Steel is cooled after attaining the austenite phase to achieve the desired product in heat treatment. Microstructures in steel exist in different forms and sizes. The strength and hardness of steel is related to the grain size in its microstructure; smaller the grain size, the stronger is the steel material and vice versa.

Austenite transforms into different microstructures such as pearlite, bainite and martensite depending on the rate of cooling. Pearlite is soft as the grains are larger, bainite is harder and stronger than pearlite but these are not the final targets desired in steel after the heat treatment. Martensite is the hardest and strongest microstructure in steel. Figure 3 gives an overview of the hardening process.

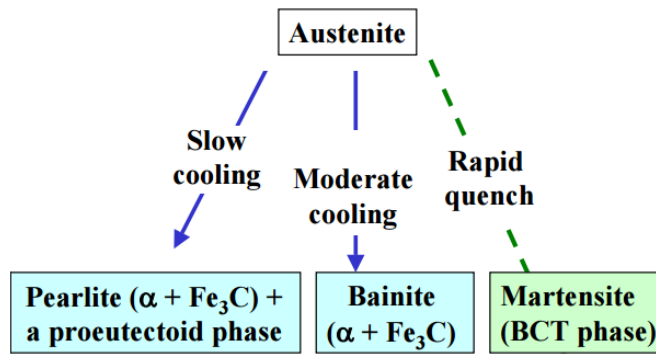


Figure 3 Austenite transformation (MSE 300 Materials Laboratory Procedures n.d.).

The time of cooling is crucial information for obtaining the desired microstructure in the hardening process. Here, the desired microstructure is martensite as it offers the hardest and strongest structure. Martensite forms when austenite is rapidly cooled to room temperature. The allowed time for cooling or the rate of cooling is estimated using isothermal transformation diagram or TTT diagram shown in Figure 4. The letters A, P, B and M represents austenite, pearlite, bainite, and martensite microstructure in the product. From the diagram, if the specimen starts cooling from 800 °C, it should cool down to 500 °C in one second or less, and then, to about 200 °C in less than the next 100 seconds. This is the maximum cooling time for austenite to turn into martensite. Here, the first few seconds of active cooling are crucial, the cooling curve cannot touch or pass through the S curve but should only touch or pass through the horizontal line indicating the start of martensite formation. This is the reason for the transfer of the specimen taking place in the minimum time possible.

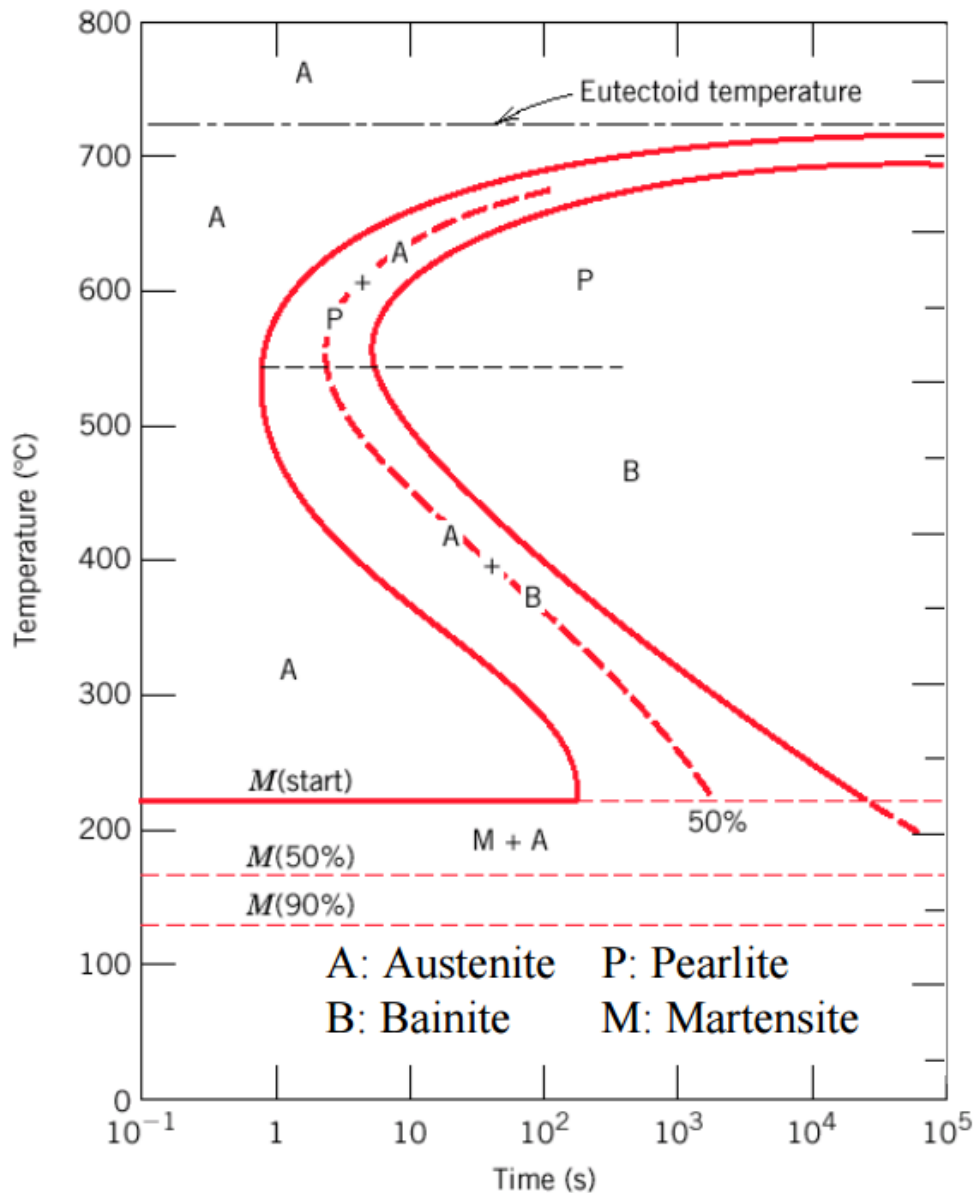


Figure 4 TTT diagram (MSE 300 Materials Laboratory Procedures n.d.).

As can be seen in Figure 4, slight variations in cooling rate can result in different grain sizes and microstructures, leading to varying mechanical properties in the resulting product. The time of travel between the oven and die is not involved in active cooling of specimen but variation in that time during different tests can result in inconsistent result of the overall research. During manual transfer, the transfer time does not just depend on the transfer system but also on worker. Two different transfers cannot be guaranteed to have similar times of transfer when done manually due to several factors such as worktime, health, motivation, work environment and other physical causes.

Test results should be compared with each other in this research project and all the tests should be conducted in same conditions to be compared. Manual transfer as it is now, has an uneven transfer time leading to variations in the results. Automated systems on the other hand are designed to execute subsequent tasks in identical conditions. Introducing automation into this transfer system will ensure similar conditions and transfer times in every test,

giving comparable results for the research project. Also, the transfer time can be calculated or measured in an automated system which will stay the same in each following transfer and its effect on the results can be analysed. Hence, it was essential to use automation in this transfer process to gain comparable test results for the research project.

2.1 Die hardening

Despite the same theoretical background, there are several methods of heat treatment based on the apparatus used and the sequences involved. Die hardening is a hardening process which involves applying pressure to the specimen while cooling. The hot specimen is placed in between two dies which press the specimen slowly with minimum impact. After the operation, a hardened sheet with more martensite structures is obtained and further research will be conducted.

2.2 Specimen

The specimen to be transferred was a 200 mm x 300 mm sheet metal 1 to 2 mm thick weighting 0.5 kg (1 mm) to 1 kg (2 mm). They are usually hot formed grades of steels intended for automotive structural and safety components. The most common material used as a specimen is Boron steel 22Mn5B coated with zinc. Zinc coating prevents steel from rusting and is commonly used to get rid of corrosion. Though steel has high melting and boiling points, zinc melts at 419.5 °C and boils at 907 °C. Under normal conditions, being exposed to 880°C - 950 °C, zinc melts and starts vaporizing. However, in this case, the zinc layer still exists after heating to 950 °C. Zinc on the outermost surface of the specimen forms zinc oxide which has much higher boiling point of 2360 °C. Hence, though the zinc melts, the protective layer of zinc oxide keeps zinc from escaping and the zinc coating still stays after hardening process. Figure 5 shows the specimen and zinc coating layers on it along with the oxide layer.

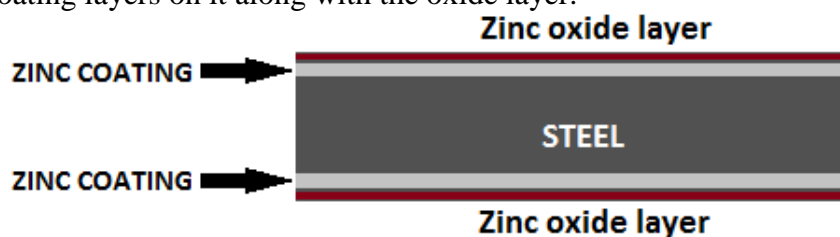


Figure 5 Layers of zinc and its oxide on specimen.

The specimen was heated in oven to 950 °C and is in between 880°C to 950 °C during transfer. The time of transfer should be less than 5 seconds and should be prevented from cooling as much as possible. The cooling of the material takes place in three main ways: conduction, convection and radiation. During transfer, the specimen is cooled by air through convection. This is responsible for low rate of cooling and needs a vacuum environment to eliminate the convection, so is not of primary concern. Radiation happens due to the high temperature of specimen, the radiation cannot be eliminated as the specimen is required to have higher temperature. In conduction, heat

is transferred from a hotter body to a colder body by direct molecular collision. Energy is transferred from higher energy particles to lower energy particles without an actual transfer of mass during the conduction. The rate of cooling in conduction depends on the temperature gradient, the physical material property, the thickness of the barrier (if any used) and area of contact. The rate of cooling (Q/t) is related to area of contact A , thickness of barrier d , heat transfer coefficient k and temperature gradient ($T_{\text{hot}} - T_{\text{cold}}$) as,

$$\frac{Q}{t} = \frac{kA(T_{\text{hot}} - T_{\text{cold}})}{d}$$

Here, the surface contact area of the specimen with other metal can be reduced to lower the rate of cooling. If the specimen is dragged, dome shaped or pointed projections can be used as a sliding base to minimize surface contact. Since the specimen remains stiff enough after heating, the specimen is gripped and transferred through air without using any sliding base. This significantly reduces the rate of cooling and provides better hardening results as there is no surface contact at all except at the gripping area.

3 DESIGN PROCESS

Designing a product is a long and complex process that starts with a customer requirement or an idea of a certain product and ends to a developed product, may it be a part or a complex assembly with multiple parts and sub-assemblies. Different institutes and companies have been designing products for the market using their own strategies and methods. During the long age of industrial development, there have been numerous approaches in design processes and hence the design itself has diverged into many different combinations of steps optimized for various fields of applications. Design in the fashion world, architecture, web based applications, engineering design as well as computer and smartphone software are examples of the diversity in the design world.

Despite the diversity, there are some basic steps every design process has to follow. An identification of the needs or customer requirements is the first step followed by research for solutions. After defining the needs, ideas and new concepts are gathered. The best ideas are selected based on possibilities and benefits, taking the process further to detailed design. Idea selection are done with idea selection matrix as well as discussions with supervisor and clients. This phase decides the basic details needed for complete product development which leads to knowledge and material gathering. After testing and refining the ideas and prototypes (if applicable) the product is ready to be manufactured and launched. The lifecycle of a product including its retirement and environmental issues also need to be considered in the process design of a product.

An engineering design process is a series of different steps interrelated and linked with each other in multiple ways. The main steps in a design cycle are as follows:

- Defining the problem

- Feasibility study
- Research for solution
- Brainstorming and ideation
- Selection of idea
- Design and assembly of parts and components needed
- Prototype development
- Prototype testing and optimization
- Product recycle

Engineering design leads to a product that is designed to be manufactured and follows same basic steps explained above but with few modifications. New problems need innovative solutions while designs related to general product development are manipulation of technologies and materials already available. Most of the design works are development of existing products, this project is a combination of redesigning the manual mechanism and introducing automation in the process.

Design projects are guided by national and international standards to ensure minimal environmental impact, enhanced and certified level of safety and so on. Designing a mechanical system in Europe needs to follow machine safety directive as described in directive 2006/42/EC of the European parliament and of the council on machinery, and amending Directive 95/16/EC. On this case however, as mentioned in article 1, section 2 (h), it is not needed to follow up the directive for machinery specially designed and constructed for research purposes for temporary use in laboratories. (Council directive 2006/42/EC.)

The progress of design is process is checked with milestone meetings. A milestone is an event during project that is used to give insight of progress about achievements of predefined goals. If there is a failure in milestone, the task is taken into consideration again knowing its flaws and corrective measures are implemented. There are several milestone meetings during the project and the number of meetings depend on the progress of meeting. Table 1 below lists the milestone meetings during the design process of the automated transfer system. Further details of milestone meetings are attached as an appendix 1.

Table 1 Milestone meetings.

S.N.	Milestone	Objective	Result
1	Thesis review meeting 1	Thesis orientation in Sheet Metal Centre Hämeenlinna	Passed
2	Thesis review meeting 2	Idea/Concept discussion	Passed
3	Thesis review meeting 3	Detailed design review/prototype review	Passed
4	Thesis review meeting 4	Final design review	Passed

4 FEASIBILITY STUDY

Automation has become an essential part of industries and business now. Automated industries are even aiming for lights off production; a production plant completely automated which needs no human to process the tasks. A lot of car industries and other sheet metal using facilities are being involved in automation as well. For the given development in this field, there are many sheet metal transfer based automation solutions available in industrial scale.

The automated platform that is to be designed for this process has multiple constraints. Limited dimensional separation in between the die plates allows only limited sized components to pass through. Due to extreme temperatures, not all components can be used and selection of components should be done with extreme caution. Other than that, the research facility demands high repeatability of the automation process. The transfer time is limited and system needs to be reliable as multiple tests are to be carried out using the same facility. Safety of worker is always one of the main requirements in design. However, transfer time, repeatability and reliability are the main requirements for this design.

4.1 Market research

Sheet metals are not as heavy for transportation compared to other solid metal products and raw materials, but they are delicate as it is easy to bend and deform them during transportation. Usually, industries use vacuum technology for transportation of sheet metals within the automated facilities. The technology is based on creating a vacuum between the surface of sheet metal and a suction cup, which holds the sheet and transport it anywhere as designed. The flexible property of polymer cup allows working with various materials, geometries and surfaces qualities. A lot of companies are dedicated to supplying automation solutions to industries and most of them are designed according to the individual needs of customer. A crossbar robot used for sheet metal transfer is shown in Figure 6 below.



Figure 6 A crossbar robot holding sheet metal (Schuler n.d.).

Companies such as Dreher Automation, Schuler, TCR Incorporation, etcetera are examples of companies that provide complete automation solutions for sheet metal operations. Figure 7 demonstrates an automated solution of a servo press with a coil feeding line, a blank holder and three axis transfer system developed by Schuler. In such industrial solutions, sheet metal is gripped by rolling wheels which pull or push the sheet metal into its destination.

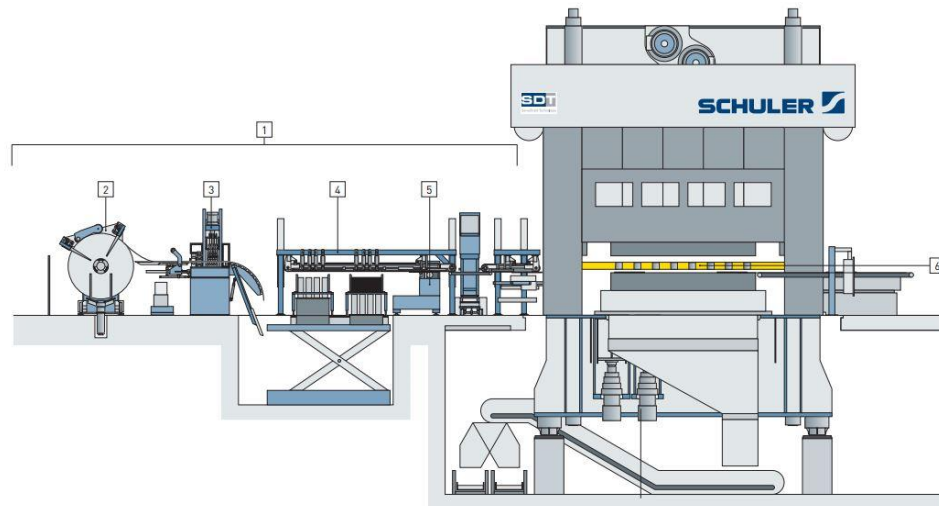


Figure 7 Servo press with coil feeding line, blank holder and a three axis transfer system (Schuler n.d.).

4.2 Customer needs and market

The oven and die press in Hämeenlinna are there for a die hardening research project which deals with sheet metals at elevated temperatures up to 950 °C. Rodhe ME 45/13 oven, as shown in Figure 8 is used to heat the sheet metal. The oven door opens down, the figure shows the oven with its door in an open position.

Oven ROHDE ME 45/13



Model	Volume l	Tmax. °C	Interior dimensions (mm)			Exterior dimensions (mm)			Output kW	Voltage V	Current A	Weight kg
			w	d	h	W	D	H				
ME 8/13	7,5	1300	250	250	120	500	600	700	2,5	230 1/N	13	69
ME 12/13	12,5	1300	250	250	200	500	700	700	3,6	230 1/N	16	75
ME 17/13	17,5	1300	250	350	200	500	700	700	6,0	400 3/N	16	91
ME 25/13	25,0	1300	250	500	200	500	850	700	7,0	400 3/N	16	105
→ ME 45/13	44,0	1300	350	500	250	1000	1300	1400	13,0	400 3/N	19	268
ME 65/13	66,0	1300	350	750	250	1000	1400	1400	20,0	400 3/N	29	330
ME 87/13	87,5	1300	350	1000	250	1000	2000	1400	22,0	400 3/N	32	380

Figure 8 Oven used to heat sheet metal specimen (Kärppä, e-mail 01.04.2015).

A hot sheet metal sheet in this temperature needs specialized design or materials to carry it. Commercially available solutions are favourable in environment with temperature close to room temperature only. Suction cups, which are the contact surface between sheet metal and transfer mechanism, are made of flexible materials such as rubber and composite materials that create airtight seal when attached to a smooth surface. Such polymer materials have low melting point and hence are not appropriate for applications in elevated temperatures.

Apart from the commercially available solutions, Tampere University of Technology has developed a similar system that deals with elevated temperature and similar machineries. It has a door mechanism that opens up, allowing the user to attach a string along with a test piece before heating and pulling it directly after the door opens. Figure 9 demonstrates the solution applied at the Tampere University of Technology Laboratory. The solution shown here is feasible but it cannot be applied to the arrangement in Hämeenlinna as the door there opens down.

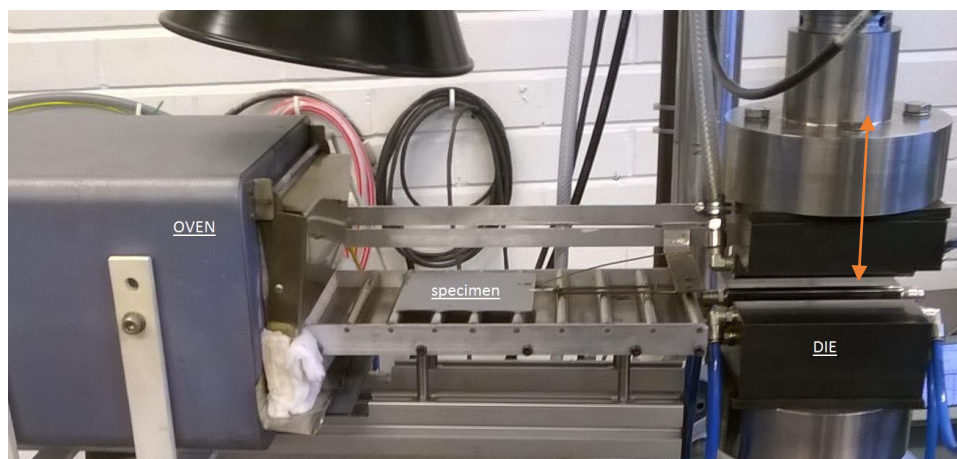


Figure 9 Automated solution for small specimen in Tampere University of Technology Laboratory.

5 MANUAL TRANSFER SYSTEM

The manual transfer system was designed and produced at HAMK University of Applied Sciences, Riihimäki during summer 2015. During the design, the primary requirements were similar to the current requirements but the system had to be inexpensive and manual. Several ideas were discovered and designed for the manual mechanism but one final idea was manufactured as a prototype. The product was made of sheet metal and the frame to support the system was made from leftover frames from the construction work for lockers at the HAMK Riihimäki building during the manufacturing period.

5.1 Design of manual transfer system

All the components needed were to be manufactured at HAMK Riihimäki using sheet metal technology, thus the design was focused on manufacturability and limitations of sheet metal processing machines available in the

Riihimäki laboratory. Several ideas were gathered and presented during meetings, a selection of ideas was made based on the manufacturability and simplicity of the mechanism. A 3D model of the final idea was prepared and drawings were extracted for manufacturing.

The final product was an assembly of multiple parts and sub-assemblies. Figure 10 gives an overview of the final assembly tree.

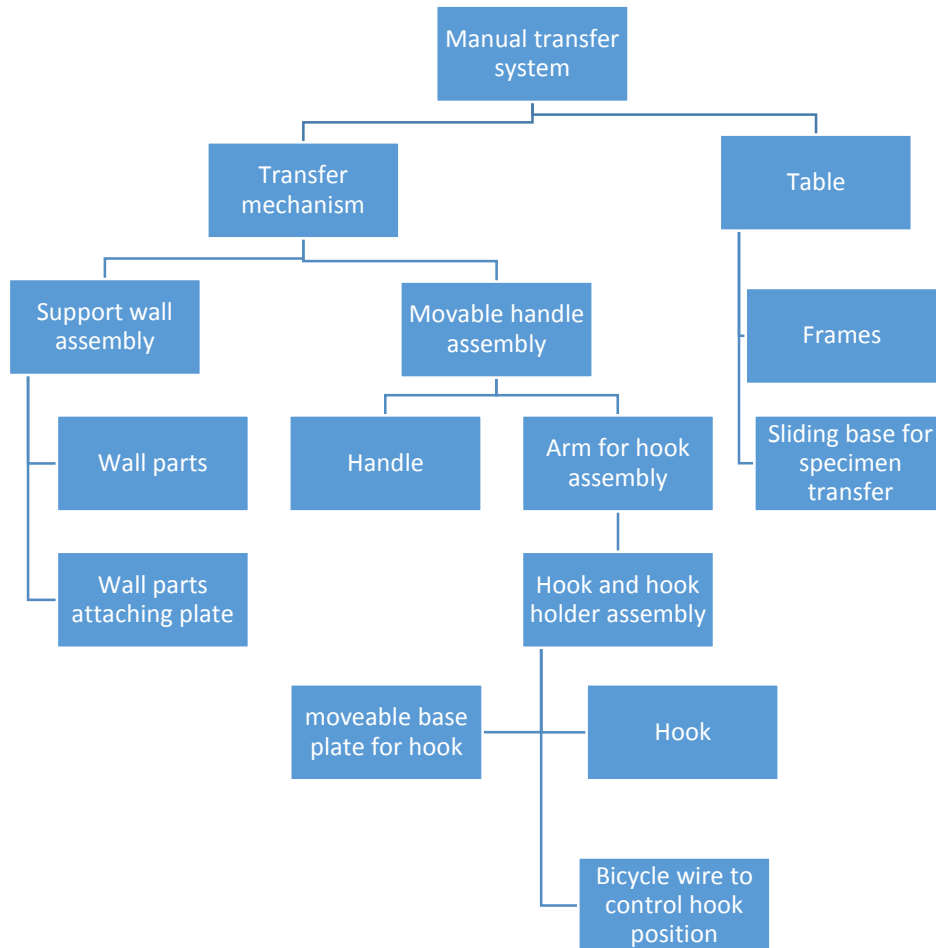


Figure 10 Manual transfer system assembly tree.

The manual transfer system also had to solve the cooling rate issue. The rate of cooling is high when there is more surface contact. This had to be reduced and as a solution, dome-shaped projections were designed on the sliding base for the specimen as shown in Figure 11.



Figure 11 Dome shaped projections with nut as solution for cooling issue.

Manufacturing of dome shape was not possible in production site, so, dome shaped nut were assembled on a sheet metal profile. The assembly was riveted to table later during production.

An arm with hooking mechanism was designed so that it could move along the length of the wall and table. There were no bearing wheels or any other components to check the friction in the sliding mechanism. User would have to drag the moveable handle assembly from oven to die and back.

Figure 12 shows the hooking mechanism, the plate with hooks rotates to a certain degrees allowing the hook to enter and leave the holes in specimen.

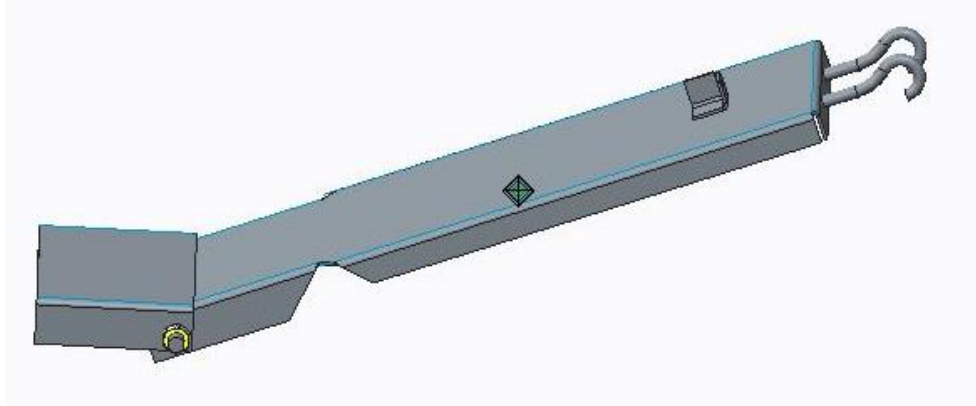


Figure 12 Hook and its assembly in lifted position.

The hooking mechanism was installed on an arm with a handle and assembled on the wall of the transfer system, allowing it to move along the length of the wall. Figure 13 shows the assembly of the hooking mechanism and the handle to the wall where it slides during its operation. The rotation of the hook holding plate was controlled by pulling a wire attached to the plate and an arm holding it.

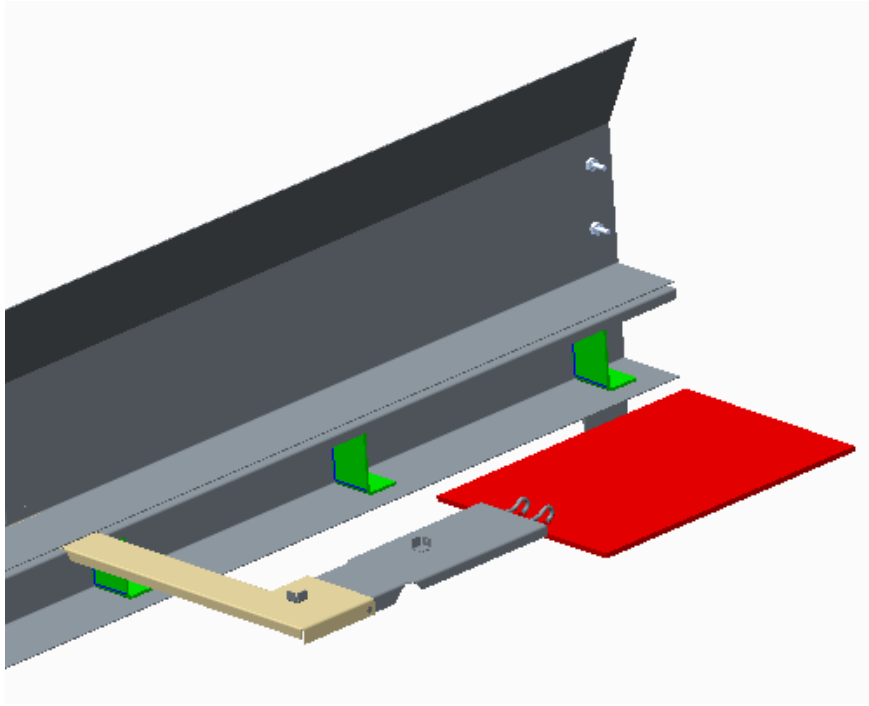


Figure 13 Movable handle with hooks and specimen (hooked position) assembled on wall of manual transfer system.

The wall was assembled to the supporting table along with sliding base (green coloured long plate like parts seen in Figure 14) for the specimen. Figure 14 shows the final product along with a manikin for a better understanding of the dimensions. On the right to the transfer system is the oven (brown colour) with a vertically opening door and on the left there is the die assembly.

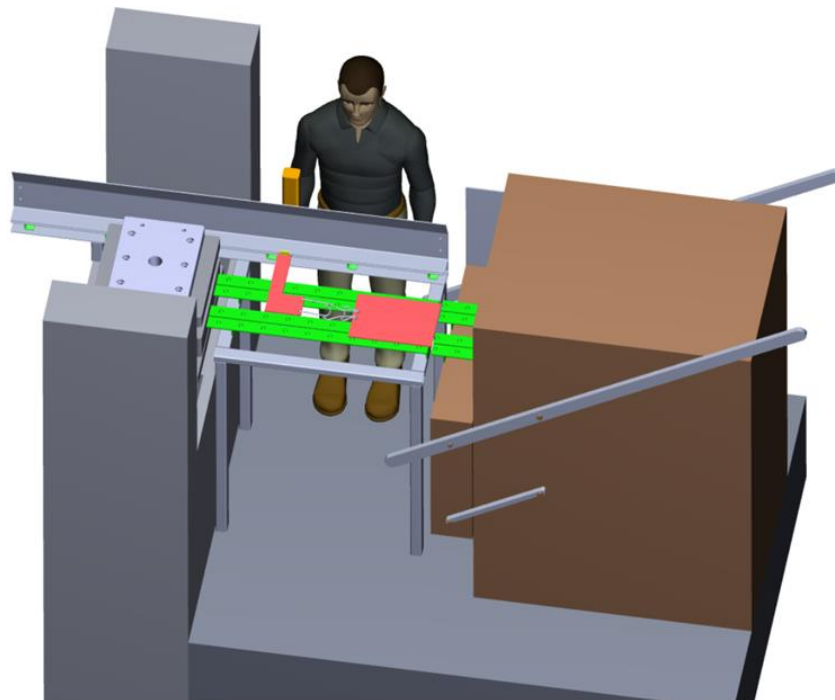


Figure 14 Manual transfer system along with oven and die.

5.2 Manufacturing of manual transfer system

Manufacturing of parts based on technical drawings was conducted at the HAMK Riihimäki laboratory. Most of the parts were manufactured using sheet metal of a thickness between 1 mm to 2 mm available in the laboratory. Basic sheet metal processing operations were used including shearing, punching, bending and spot welding. A sheet metal cutting tool mainly a guillotine was used for shearing. Sheet metal cutting scissors were occasionally used. Bending was done with three bending machines in the HAMK Laboratory, two of them were bending brakes and one press brake machine. Punching tools were used to make circular holes and rectangular cut outs. Joining was done using spot welding machine and normal nut bolt connection. For some thick plates, drilling was done using different size drill bits on the vertical drilling machine. Sawing was performed to cut thick plates on the sawing machine and also using an electric hand saw.

Sheet metal of a thickness between 0.5 mm to 2 mm was used to make all the parts except the table. Hooks and bicycle wire were the only commercially available parts which were bought from a local store. For the profiles designed, stainless steel hooks with brass coating were used as presented in Figure 15.



Figure 15 Commercial hooks used in manual transfer mechanism.

5.3 Manual transfer system; advantages and disadvantages

The manual transfer system was assembled in Riihimäki and delivered to Hämeenlinna for its use. This system is safer to operate as there is no direct contact between the specimen and the user. The sliding base with dome shaped nuts reduces contact surface between specimen and base, which lowers the rate of cooling of specimen leading to better results. The hooking

mechanism could be easily replaced if damaged due to the intense heat, but despite multiple benefits, the system had some flaws as well.

The handle that slides along the wall had no elements to reduce friction between the sliding face of wall and itself which resulted in irregular motion of the moving part during its use. Hooking mechanism was difficult to use due to lower repeatability and rigidity issues. Hooking mechanism itself was not reliable as the specimen would be unhooked if any disturbances were to occur during the transfer. On top of these limitations of system itself, the time of transfer was not constant in any successive transfers due to lack of precision and timing in work done by human. Sometimes the transfer would be faster and other times would be slower resulting variable time of transfer of the specimen. This gave difference in hardening results as the hardening process is very much dependent on time of cooling.

Due to the later reasons, the manual transfer system would not be a reliable system for the research of die hardening. A system with smooth motion and consistent time of transfer would be needed. These demands gave birth to necessity of an automated transfer system.

6 FINAL DESIGN; AUTOMATED SYSTEM

As oven and die are next to each other, path of transferring the specimen can be a simple straight line through dies. This requires the grabbing component to pass through the dies as well or it could contain an extra step in between which would eliminate the necessity of grabbing tool to pass through dies. Considering these possibilities, two different mechanisms were designed. One with a linear path and longer linear actuator to transfer specimen. Another with a rotary sequence in between the oven and die. A rotary actuator would rotate specimen and grabbing tool by 180 degrees so the tool would not need to pass through the dies, hence, any commercial grabbing tool can be used irrespective to its dimensions. In this topic, final solutions are explained and detail information regarding each mechanism and actuation are further described in chapter seven.

Two transfer systems are proposed in this thesis. Both systems use gripping tool to hold the specimen during its transfer. Here, the specimen should be stiff enough also at elevated temperatures for the concepts to work. This can be validated with deflection analysis using virtual analysis tools.

The specimen is 200 mm × 300 mm sheet metal of thickness 1 mm to 3 mm. In the process, there is no external load acting on the specimen but still, deflection occurs due to its own weight. The maximum deflection was on the opposite edge to the one from where it was gripped. Analysis tools CREO 2.0 and ANSYS were used to check the maximum deflection of sheet at 900 °C. Displacement was found to be higher for thinner material, the maximum for 1 mm sheet being 5.50 mm at the edge. Following figures show the deflection while gripped at one end and heated to 900 °C, blue to red colour indicates minimum to maximum deflection.

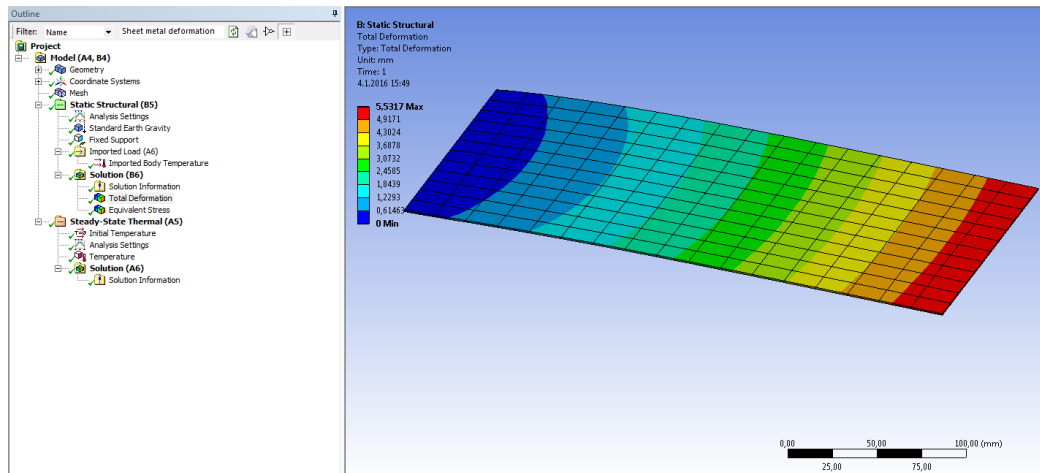


Figure 16 ANSYS analysis for deflection of sheet at 900 °C.

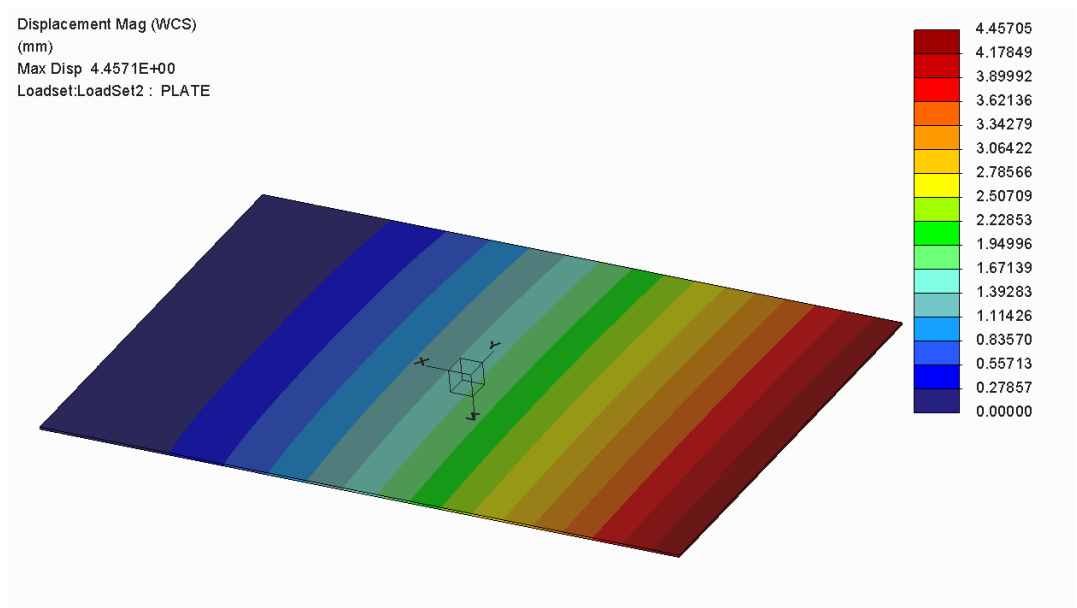


Figure 17 CREO analysis for deflection of a sheet at 900 °C.

Now, considering the probable maximum deflection, the dropping point for the gripper should be 6 mm higher than the die for the system that implements rotation. System where specimen is dragged through the die is not prone to deflection of sheet and deflections of few millimetres are not necessary to be considered.

It is also essential for the position of specimen in oven to be fixed for automated system to pick it up properly. This can be ensured by using ceramic base with a predefined area to place the specimen so that the specimen cannot be placed anywhere else. A ceramic base with a rectangular space for specimen as represented by yellow part in Figure 18 can be used. It can be placed in oven as illustrated in following section diagram of oven. Here, the yellow L shaped cross section of ceramic structure stops the specimen from moving back deeper into oven. Side walls of ceramic base itself around specimen physically stops it from being placed wrong during heating.

Current ceramic block being used as base in oven stays stationary because of friction between contact surfaces. To ensure immobility of new base,

holes can be drilled in ceramic base of oven and new ceramic part can be fixed on that. If modification of oven material is not preferred, a base of larger dimension and weight can be used so that the friction between new ceramic base and oven floor will keep it stationary in oven. The new ceramic base for specimen can have rough surface to enhance friction.

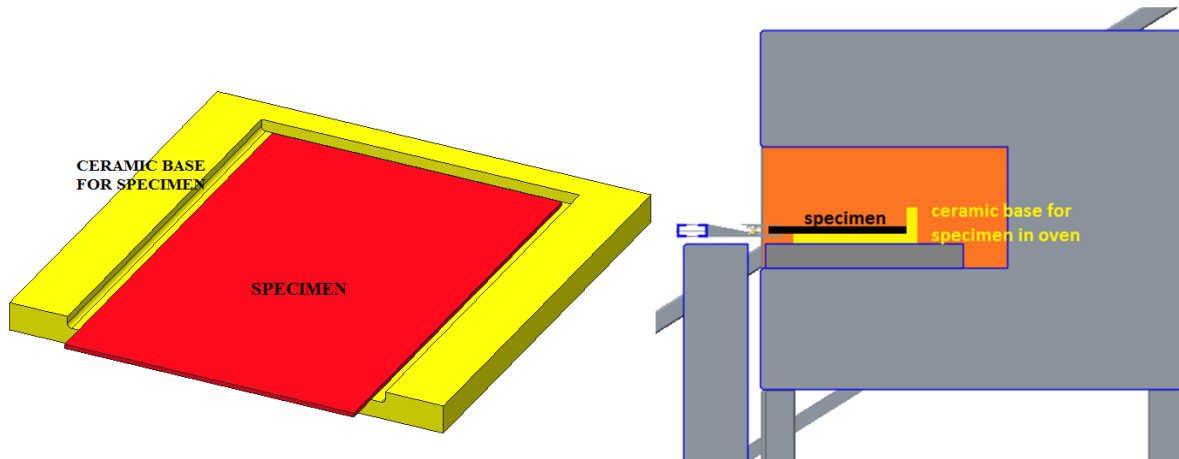


Figure 18 Specimen position in ceramic base and in oven.

6.1 Oven door operation

An electric linear actuator was selected and a connecting bracket was designed to connect slider of linear actuator and oven handle. The mechanism selection and proposed ideas are explained in section 7.5.3. The connection bracket consists of two rods or standard screws of 8 mm diameter assembled to a base plate. Handle of oven will stay in between the rods and whenever it moves up and down, the handle as well as oven door is dragged along. The base plate holding rods is bolted to slider of linear actuator so that its vertical motion can be controlled to operate oven door. Figure 19 shows assembly of connection bracket with slider of linear actuator.

The actuator is assembled to a vertical rectangular beam with standard screws and nuts which is then fixed on the side of oven handle. All rectangular beams used have same profile so that same raw material can be used to manufacture them. The whole assembly is fixed at 520 mm behind oven door. Figure 20 shows open and closed positions of door as well as slider during operation.

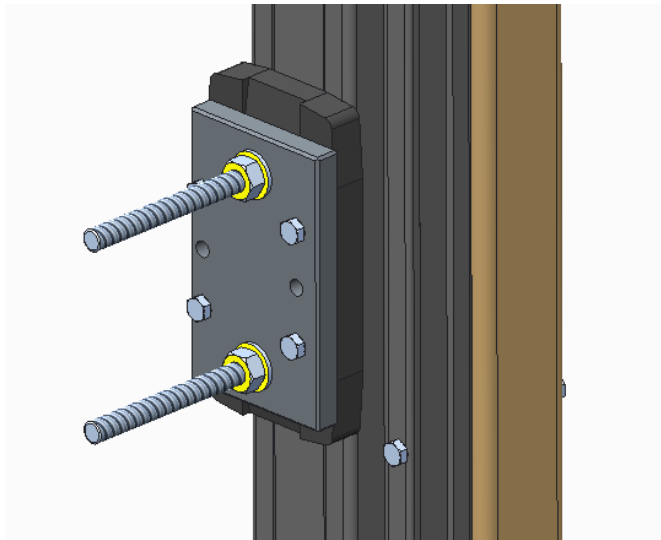


Figure 19 Connection bracket for handle of oven door.

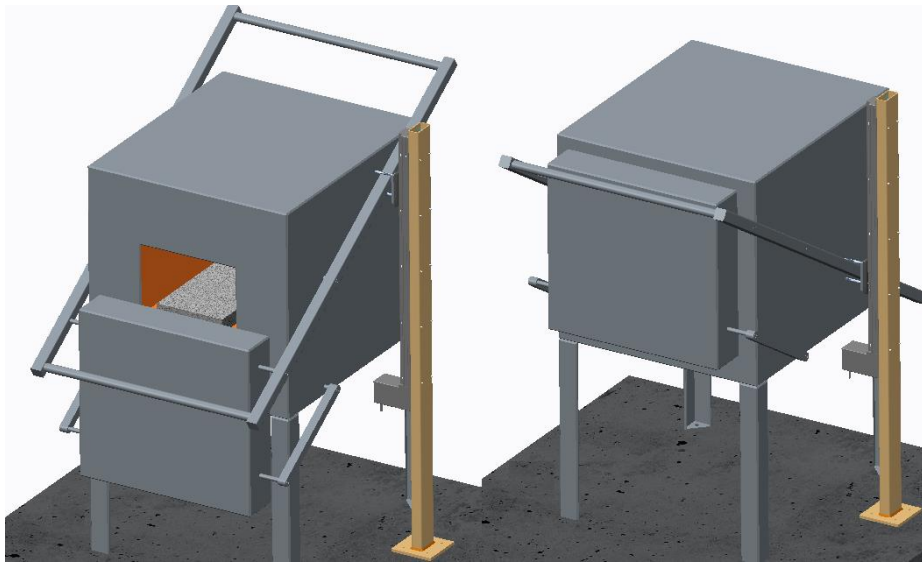


Figure 20 Opening and closing of oven door and respective slider positions.

Initially, similar actuator as that of horizontal linear actuation was selected with a smaller stroke length. Control system of the actuator was discussed with supplier in email and it was recommended to use actuator with ball screw instead of belt drive for vertical actuation. If belt in belt driven actuator fails, it may lead to sudden drop of door and can harm the system as the brakes of actuator may not be strong enough to hold vertical load. Taking that into consideration, the ball screw model of actuator was selected for door operation. A stroke length of 420 mm is needed for position as seen in 3D model of system. Based on the load, a model LEFS 25 B-500B-S31N3 was selected from digital catalogue. More details about the actuator can be found from digital catalogue provided by supplier. (SMC Product catalogue n.d.).

6.2 Transfer system with linear and rotary actuator

This mechanism includes linear actuator with rotary actuator and a gripping tool available commercially. Rotary actuator is a 180 degree rotating actuator, it will rotate the specimen along with gripper so the specimen can be placed in die without gripping tool having to pass through it. In this mechanism, a shorter linear actuator is used as the length of travel for linear actuation is confined within oven and die. Figure 21 shows the initial idea for this mechanism.

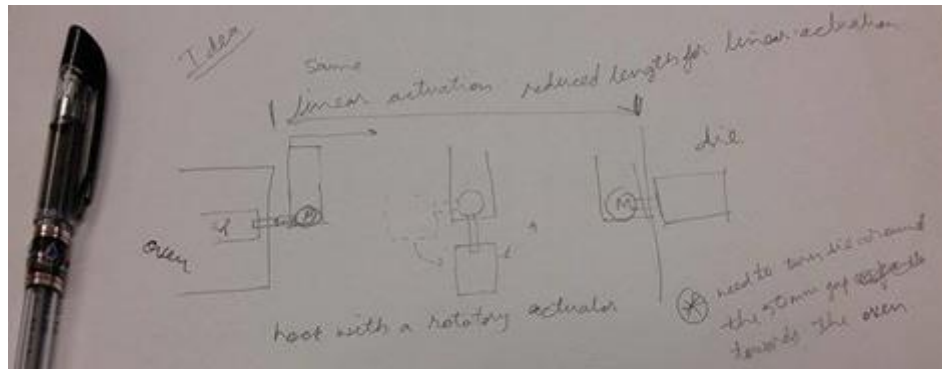


Figure 21 Initial idea sketch for the mechanism.

Since the specimen is gripped, there is no need of a sliding base like in the manual mechanism. The handle rod of oven door also does not interrupt the motion in any way as there is no need of a sliding base for the specimen to be dragged on. Removal of the sliding base also eliminates the surface to surface contact between hot specimen and base, thus eliminating the cooling of specimen by conduction. Here, cooling only occurs by conduction which is through gripper. Since gripping is only on a side and constrained to a very limited area, the heat loss is significantly lower than in manual mechanism. Arm represented by a blue coloured bar stays in its home position between the oven and die during heating of the specimen. When desired temperature is achieved, the oven door opens and arm moves to oven, then gripping tool grips the specimen. Arm then moves towards die, when specimen is completely outside the oven, rotary actuator activates and rotates specimen along with gripper by 180 degrees. The specimen reaches die and is placed there to be pressed and processed for the research. The arm moves to the home position after leaving the specimen to specific spot on die. Figure 22 demonstrates each step and the locations of specimen during the transfer.

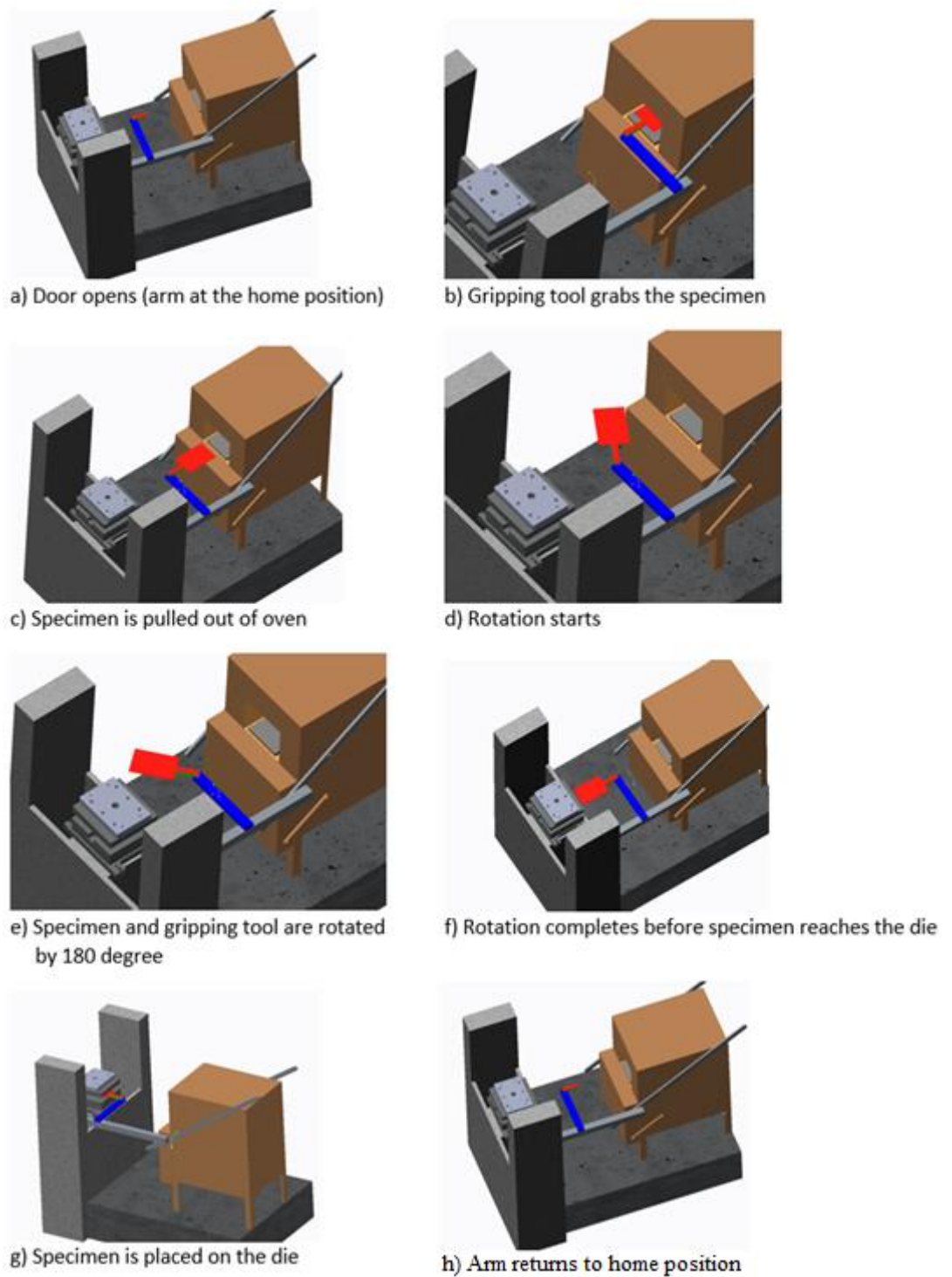


Figure 22 Steps in automated system with rotation of specimen.

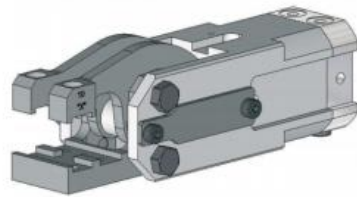
For the system to run, actuators must be selected respective to the specimen properties.

6.2.1 Gripping tool

A commercial work holding tool readily available and suitable for the purpose was selected to be used as gripper. Selection of gripping mechanism and ideas proposed are explained in chapter 7.3. Specialized sheet metal

work holding tools manufactures by DESTACO are also available in Finland, hence those were chosen for the project.

Series 84A2-1 Product Overview



Model	Opening angle
84A2-110000000	72°
84A2X110000000	30°
84A2Y110000000	45°

Model	Clamping force at 5 bar ~N [lbs]	Piston Ø mm [in]	Air consumption per double stroke at 5 bar dm³ [ft³]	Weight ~ Kg [lbs]	Min Opening speed for max. opening sec.	Min Closing speed for max. opening sec.
84A2-11*****	580 [130]	25 [0.98]	0,3 [0.01]	0,6 [1.32]	0,2	0,2

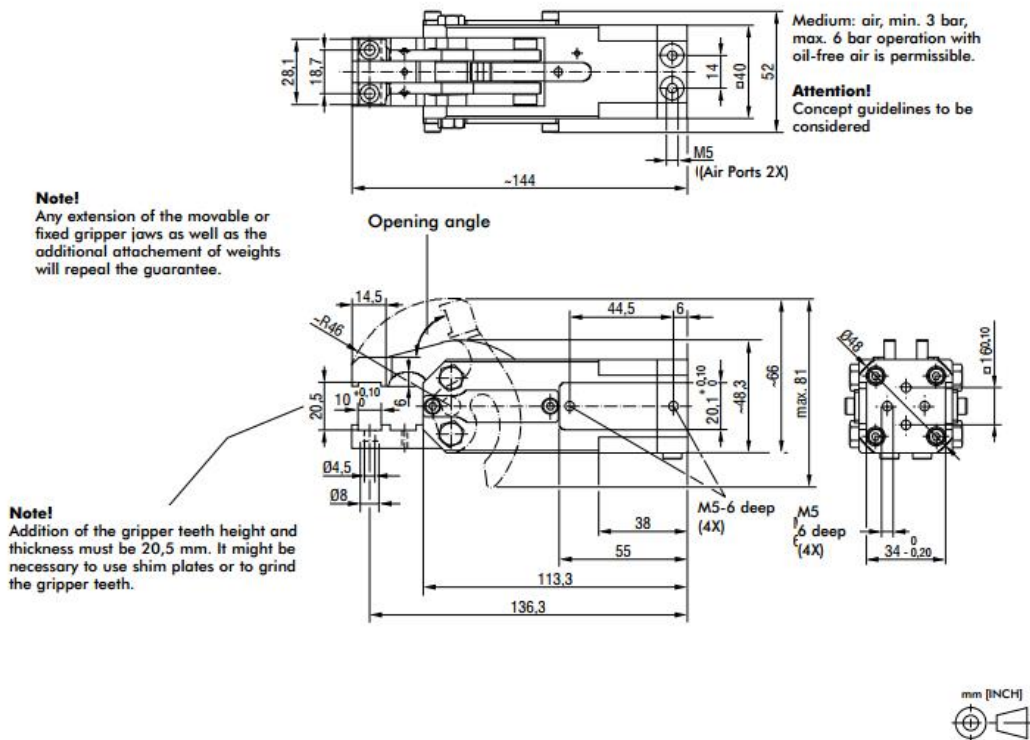


Figure 23 Pneumatic sheet metal gripper (DE-STA-CO Sheet Metal Grippers n.d.).

Selection of work holding tool was only based on its gripping force and in this case, weight of the gripper was also needed to be as low as possible. Since the specimen load is small, all the grippers available had enough gripping capacity and hence, the smallest with lowest weight was chosen. Dimensions and specification of the product is described in Figure 23.

6.2.2 Rotary actuator

A horizontal rotary actuator was selected for rotation of specimen and gripping tool. The rotary actuator is described in chapter 7.4. Its selection was based on the combined weight of specimen, gripper and connecting medium between gripper and rotary actuator. The bending moment and reaction force on the rotor are used to select the component. Following figure shows a schematic diagram of the rotary actuator, gripper and specimen subassembly with approximate maximum load and dimensional values.

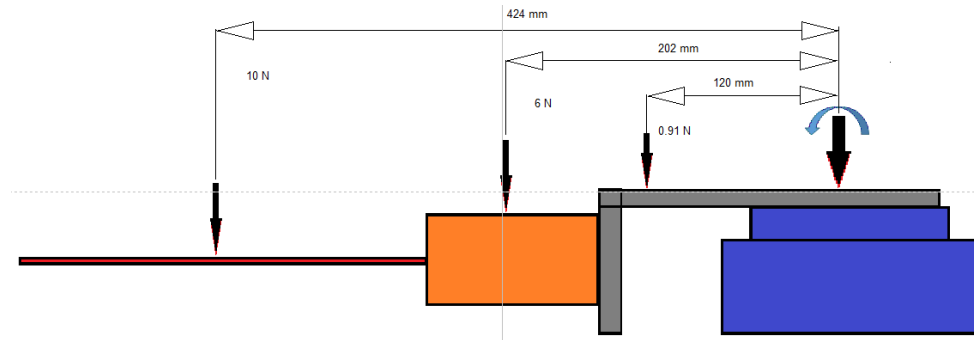


Figure 24 Selecting the rotary actuator.

Here,

The weight of gripper is 0.6 kg

Approximate weight of the aluminium connector based on 3D modelling in CREO 2.0 is 0,091 kg

The distance of centre of masses of each component from centre of rotation are as shown in Figure 24.

Applying statics, load values can be transformed horizontally by adding moment as compensation for transferred distance.

Vertical force on the rotor is $10+6+0.91 = 16.91$ N

Moment on the rotor is,

$$10\text{N}\cdot 424\text{mm} + 6\text{N}\cdot 202\text{mm} + 0.91\text{N}\cdot 120\text{mm} = 5.561\text{N}\cdot\text{m}$$

From the digital catalogue, standard size 50 rotary actuator of MSQ model with high energy shock absorber was selected as presented in Figure 53 in chapter 7.4. The product code according to digital catalogue is MSQ B 50 H 2. Minimum time for 180 degree rotation with this actuator as stated in catalogue is 0.4 seconds. The rotation speed can be adjusted from 0.4 to 2 seconds for 180 degrees rotation. It will be adjusted according to the time taken by linear actuator to transfer specimen from oven to die.

6.2.3 Arm design

All of the above mentioned actuators work closely to the specimen and will be carried towards oven by linear actuator. An arm was needed to connect all the actuators and specimen to linear actuator. Since the arm in this system does not need to pass through the dies, there are not much constrains

except it has to be as light weight as possible. Arm can be designed so that a commercial profile can be used. There are several hollow tube profiles with adequate strength and stiffness available commercially. Among most common materials available locally, aluminium profile delivers all the mechanical properties in a light weight package. Arm has to support weight of specimen, gripper and rotary actuator along with the connections between them. Estimation of bending and stresses can be done with data collected from digital catalogues, specimen and model for connection between gripper and rotary actuator. Arm has to sustain a combined weight of actuator, gripper, connection and specimen calculated to be 40.61 N and moment on arm due to gripper, connection and specimen weight is 5,56 Nm. Load on arm is demonstrated in Figure 25 and 26.

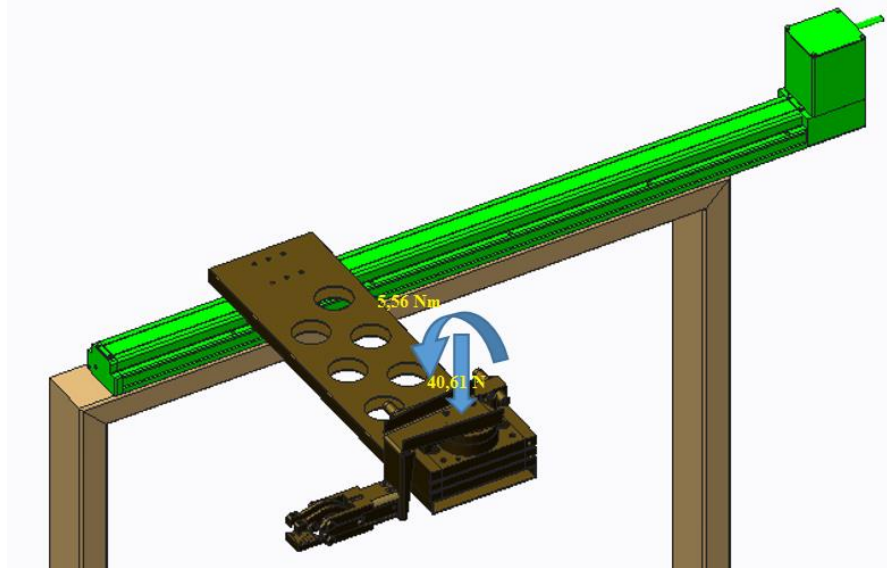


Figure 25 Linear actuator with its payload.

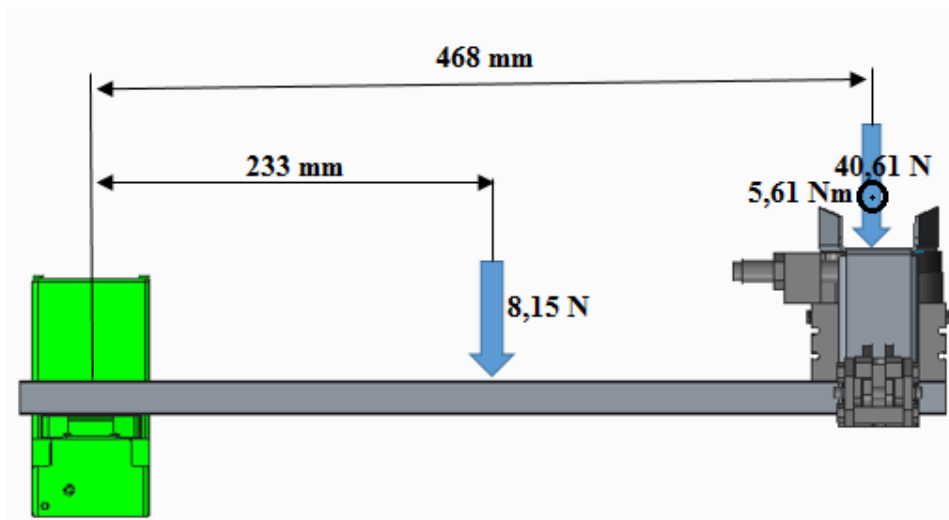


Figure 26 Load diagram for linear actuator selection.

Usually, the beam profile selection process starts with load determination. All the loads and their locations as well as necessary length of beam are identified. Based on given loads, maximum bending moment is calculated. With modulus of elasticity E , allowed stresses δ , and height of profile h , second moment of area I_{tot} can be calculated. Depending on profile cross

section, there are different equations for I_{tot} calculation. For a hollow rectangular cross section, it can be simply calculated by subtracting second moment of area of inner hollow rectangle from second moment of area of outer rectangle. The equation can be formulated as follows,

$$I_{tot} = \frac{b \cdot h^3}{12} - \frac{(b - 2t)(h - 2 \cdot t)^3}{12}$$

After getting a numerical value of I_{tot} , it is compared with those of commercial profiles from catalogue provided by supplier and a profile with slightly higher second moment of area is chosen based on weight and required dimensions of desired profile. Then applicable stresses are checked in the profile with stress equations as follows,

$$\delta = \frac{M_b}{I_{tot}} \cdot h$$

If they are below allowed stress values the profile is considered suitable for application, if not, further calculations of similar fashion are carried out until suitable profile is found.

In this case however, there were constrains regarding profile dimensions. Width of profile depended on slider dimensions from linear actuator and height was to be less than 30 mm. So, a profile of adequate dimensions was first selected and then its applicability was verified with calculations using a programme written in Mathcad. A Mathcad file named “palkki1De” from Finite Element Methods course with program for a continuous beam to calculate nodal displacements U , deflection $v(x)$, bending moment $M(x)$ and shear force $Q(x)$ was used. Numerical values regarding dimension of beam and its load were inputted and calculations were done by program. The results showing deflections, bending moments and stresses is attached as appendix. (Murtola 2015, lectures)

A profile of 150 mm × 30 mm × 2 mm was selected to accommodate the 150 mm wide rotary actuator. Calculations regarding deflections and stresses were done using Mathcad. For the given load, all values including bending moment, shear stresses, normal stresses and deflection were under safety limits with large margin. Aluminium profile has lower mass per length compared to more common steel structure, to further reduce weight circular cut outs were made on the arm as illustrated in Figure 25.

6.2.4 Linear actuator

The electric linear actuator was selected for its controllability. The LEFB linear electric actuator with slider type belt drive was selected for the reasons explained later in chapter 7.2.3. Length of actuator, its size and other parameters were chosen from the digital catalogue. Manufacturer also supplies the controller and necessary electrical components for the linear actuator. There were two motor options available, servo and step motor. Servo motors are better suited for high speed operations but step motor was selected as servo motors were not available for the chosen size. The slider of actuator can be stopped in several points with position repeatability of ±0.02 mm.

Controller details and assembly are described in the features catalogue available online. Controlling the actuator as desired can be done by programming into the controller or by using teach pendant as described in user manual of linear actuator provided by the supplier. There is a better suited option called program less controller in which actuator is taught to work without using PC or teaching box. The slider has to stop in three points in this case, one to pick up the specimen, one to drop the component in die and other point in between oven and die where it rests as a home position. The home position should be further from oven to allow opening and closing of door as there is a handle rod in oven door. Since the points to work are less, it is economical to use program less control in this case.

As it was with rotary actuator, there were various size of linear actuator available. The selection of preferred size was based on the actuation length and load.

Based on the catalogue, size 25 actuator could handle 5 kg payload but for enhanced safety, we selected size 32 actuator which can handle a payload of 14 kg horizontally. As seen in Figure 27, the LEF32 model can handle a payload of 5 kg in a distance more than 750 mm in the rolling direction and a maximum acceleration of 3000 mm/s². All other cases allows distances more than 2000 mm. In our case the maximum distance of load is 468 mm hence is safe.

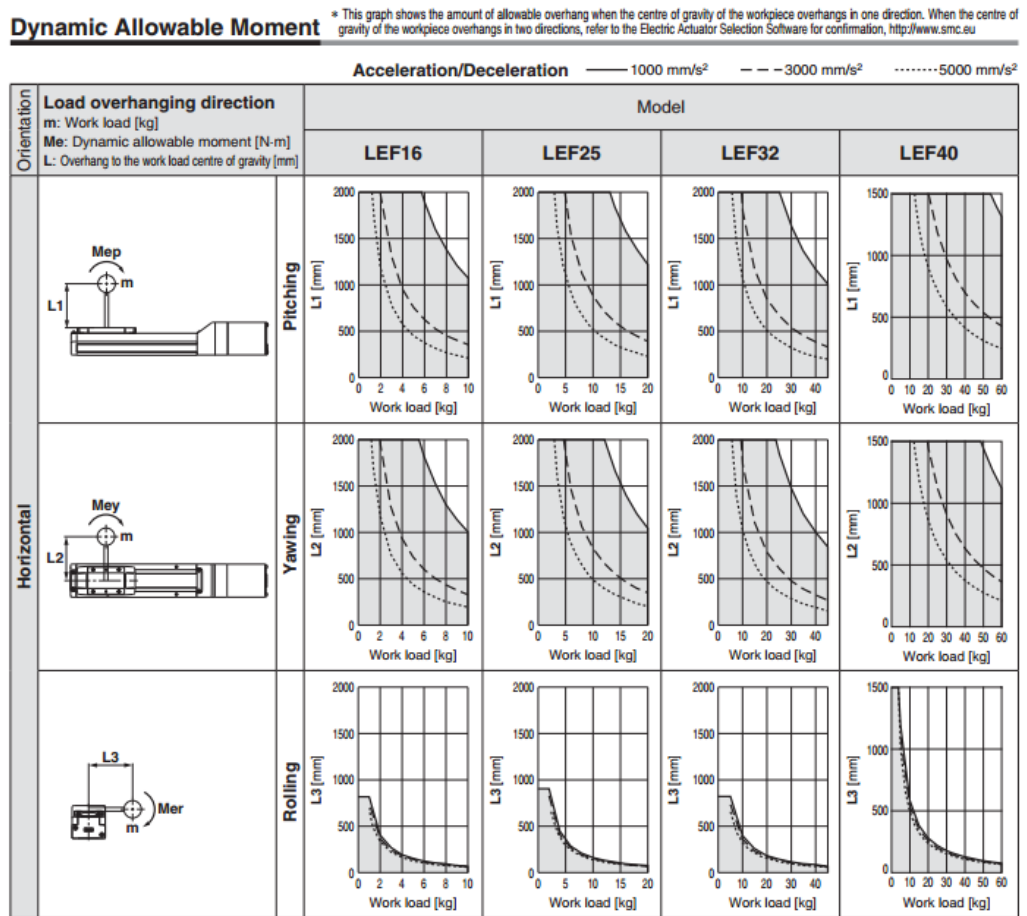


Figure 27 Dynamic allowable moment for linear actuator (SMC Electric actuator n.d.).

Maximum allowed speed to drive the payload can also be graphically determined from the digital catalogue as demonstrated in Figure 28. Maximum allowed speed for LEFB32 actuator as selected above for 5 kg payload is 900 mm/s. With these information of allowed speed and acceleration, the time needed to transfer specimen can be calculated.

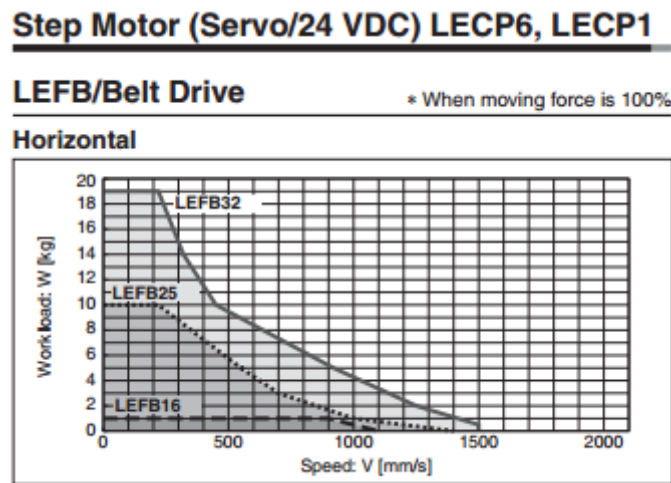


Figure 28 Workload vs speed graph for linear actuator (SMC Electric actuator n.d.).

6.2.5 Transfer time

Transfer in this system takes place in steps as described in Figure 22 in section 6.2. When door opens, gripper travels to specimen, gripper grips and linear actuator moves towards die. During motion, rotary actuator rotates the specimen by 180 degree and it is dropped in die when the gripper opens. Total time of transfer is calculated from the moment oven door is open. It includes travel time to specimen, gripper closing time, travel time to die and gripper opening time. The time taken to rotate the specimen overlaps with the linear transfer time so is not added to calculate total time. However, the rotation time, if long, increases the linear transfer time of linear actuator itself hence, it affects the total time.

The time of transfer of linear actuator is calculated in three parts, acceleration time, constant speed time and deceleration time as described in Figure 29.

Calculating the cycle time

Calculate the cycle time using the following calculation method.

Cycle time:

T can be found from the following equation.

$$T = T1 + T2 + T3 + T4 \text{ [s]}$$

- T1: Acceleration time and T3: Deceleration time can be obtained by the following equation.

$$T1 = V/a1 \text{ [s]} \quad T3 = V/a2 \text{ [s]}$$

- T2: Constant speed time can be found from the following equation.

$$T2 = \frac{L - 0.5 \cdot V \cdot (T1 + T3)}{V} \text{ [s]}$$

- T4: Settling time varies depending on the conditions such as motor types, load and in positioning of the step data. Therefore, calculate the settling time with reference to the following value.

$$T4 = 0.2 \text{ [s]}$$

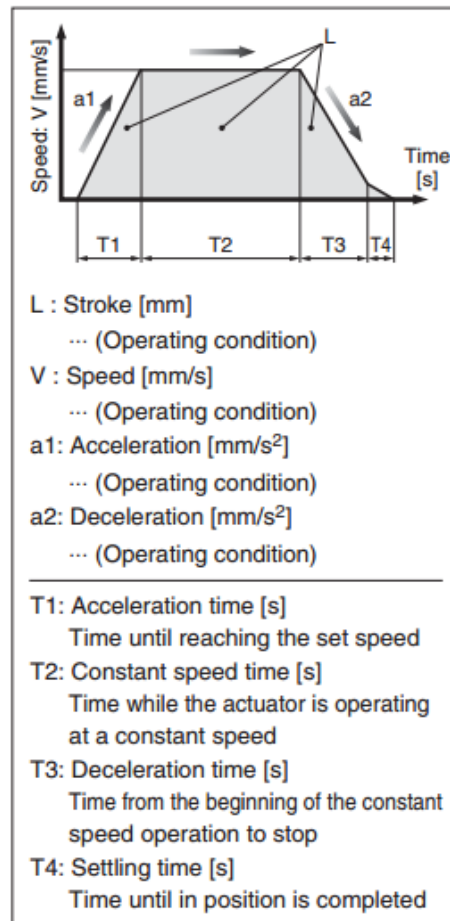


Figure 29 Cycle time calculation for linear actuator (SMC Electric actuator n.d.).

Here, the maximum allowable velocity for the actuator with 5 kg payload is 900 mm/s and maximum allowable acceleration is 3000 mm/s².

Now,

$$a1 = 3000 \frac{\text{mm}}{\text{s}^2} \quad a2 = 3000 \frac{\text{mm}}{\text{s}^2}$$

$$L = 955 \text{ mm} \quad V = 900 \frac{\text{mm}}{\text{s}}$$

Now, time for linear transfer from oven to die is,

$$T1 := \frac{V}{a1} = 0.3 \text{ s} \quad T3 := \frac{V}{a2} = 0.3 \text{ s}$$

$$T2 := \frac{L - 0.5 \cdot V \cdot (T1 + T3)}{V} = 0.761 \text{ s}$$

$$T4 := 0.2 \text{ s}$$

$$T := T1 + T2 + T3 + T4 = 1.561 \text{ s}$$

This time is the minimum time taken by actuator to carry specimen from oven to die after gripping is done. When the oven door opens, the gripper is

in its home position. Time taken by it to travel up to the specimen is calculated in similar fashion and found to be 1.0 seconds. The gripper takes 0.2 seconds to close as well as open while gripping the specimen as stated in its catalogue. Rotation can be controlled and takes 0.4 to 2.0 seconds for 180 degrees of rotation. The linear transfer time with gripper action 1.96 seconds so rotation time can be optimized accordingly to execute rotation within the linear transfer. If we take arm arriving time from home position into account, it would add one second to the calculated linear transfer time. Hence, total time of transfer is now 2.96 seconds or approximately 3.00 seconds.

The 3D model of system with rotation is completed using CREO and is available in its own format. Figure 30 demonstrates the sheet metal transfer system with rotary actuator.

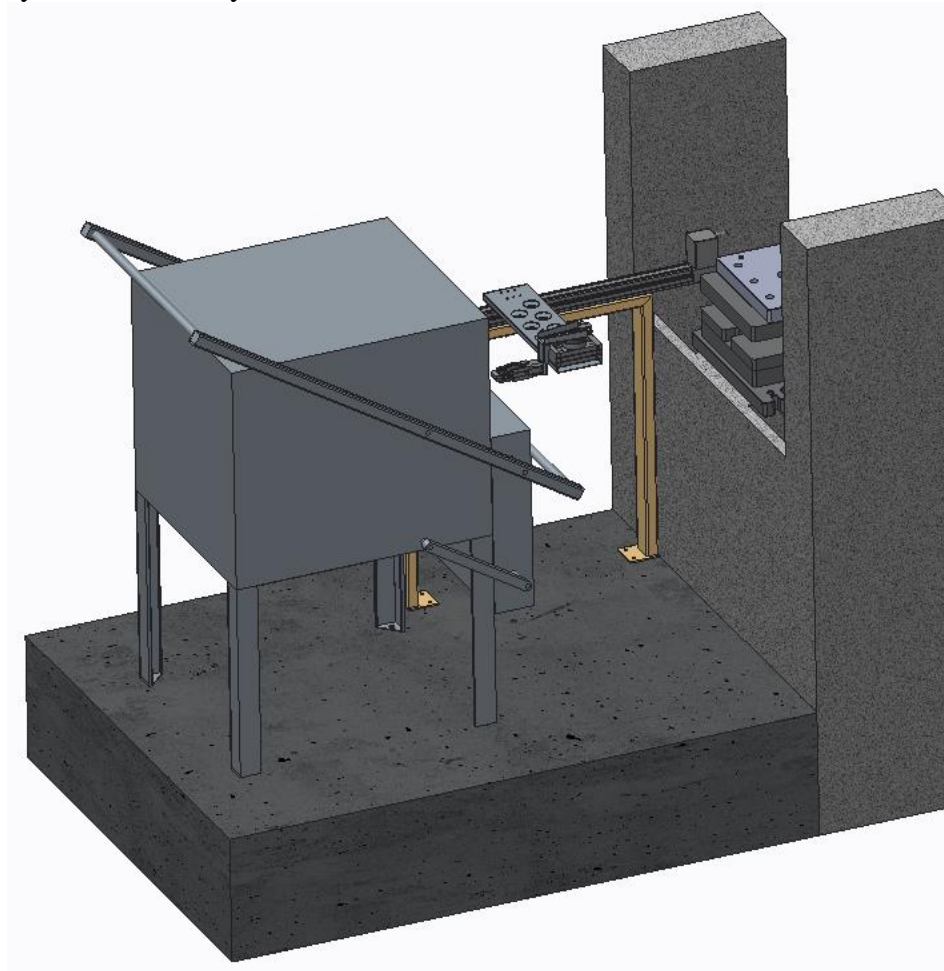


Figure 30 Transfer system with rotation.

6.3 Transfer system with linear motion only

This is simpler mechanism and has less processes or steps during transfer. Here, the specimen is gripped and transferred straight to the die without any rotation or other forms of motion whatsoever. In this system, the arm carrying specimen and gripper has to travel through the die along with the specimen which demands longer stroke length of linear actuator. Die separation allows limited width of gripper to pass through, a maximum height of 30 to

45 mm. Commercial solutions being larger than the allowed dimension, a special gripping solution has to be designed for this system. Designing and manufacturing a component takes longer time. It is expensive compared to the readymade commercial solutions, hence previous system is better in terms of time to complete the system and economic reasons. Despite the benefits, the previous system incorporates a rotation of hot specimen that may have safety related issues. If gripping action fails, the specimen may fly off due to centrifugal force during rotation which is hazardous. On the other hand, if gripper fails in this system, the specimen would drop vertically to the floor which is inaccessible in everyday use and hence is safer. For this vary reason this system with only linear motion of specimen is preferred despite the expenses and time delay inevitable with new design of gripping tool.

In this simpler system, the specimen travels in a straight path and rests in the die with exactly same orientation as it was in oven. A gripper grabs the specimen from oven and carries it through the separation of upper and lower die plates. After reaching the predefined fixed point, the gripper opens and specimen drops. Figure 31 demonstrates the steps of transfer in this system.

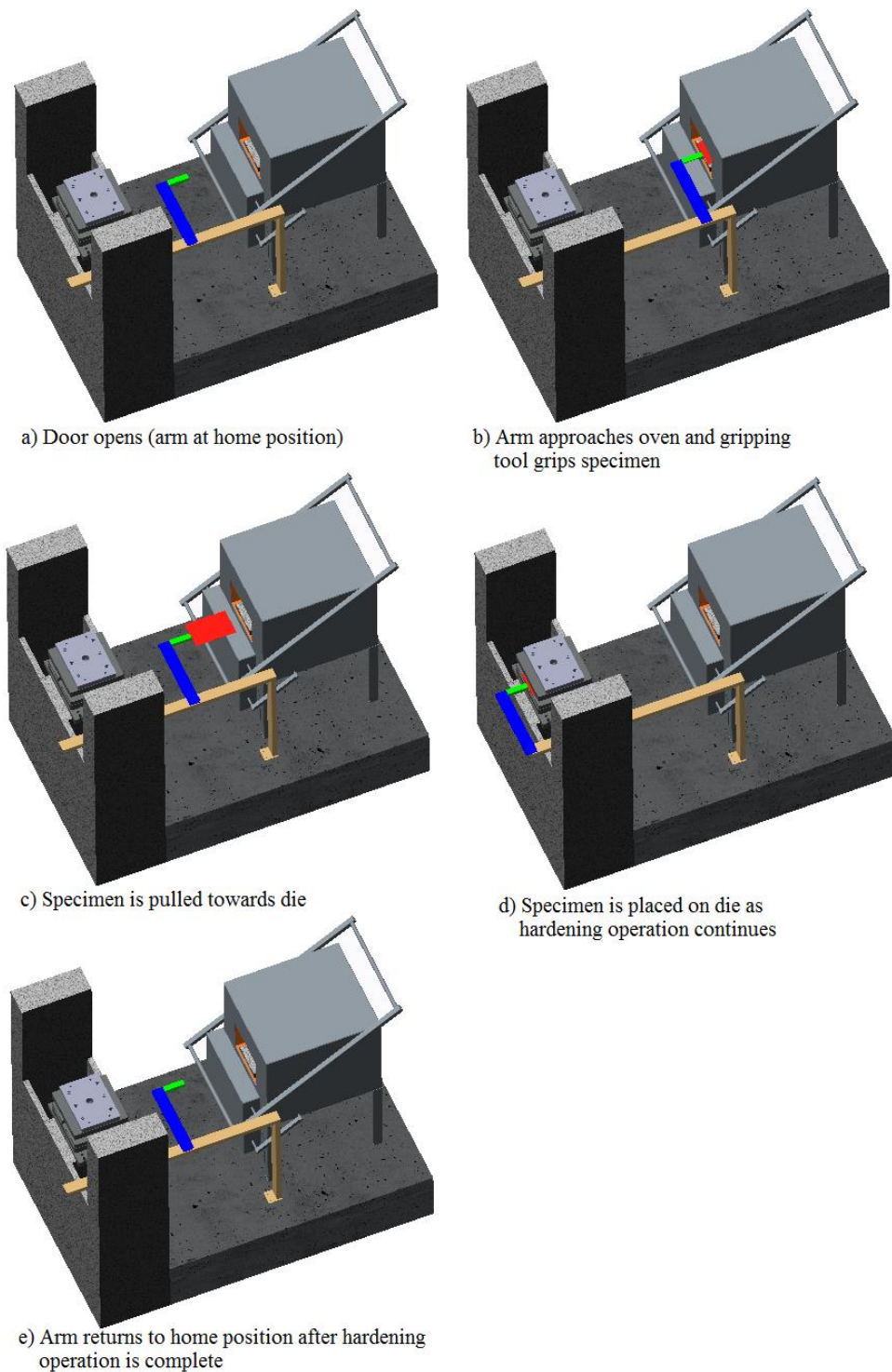


Figure 31 Steps of transfer in automated system without rotation.

Just like previous system, this system also needs to a linear actuator to move the specimen. Here a gripper needs to be designed as there are no commercially available gripper of required size.

6.3.1 Gripping tool

Gripper is needed to be designed with a maximum height being less than 45 mm. The mechanism used in concept design along with proposed ideas for gripping mechanism are described in chapter 7.3.4. Height of gripper is the

primary constrain in this design. There are two power supplies available at site: pneumatic and electric. We can design gripper based on either of the power supply. First the pneumatic system was designed, a simple mechanism described in Figure 51 of chapter 7.3.4 can be implemented in the design. A cylinder structure with allowable dimensions attached to moving arm with its rod can act as an actuator when pneumatic pressure is applied. The system however is expensive to manufacture as the piston needs to be airtight and needs high precision manufacturing. Pneumatic valves and connection ports are also complex structure to produce. Figure 32 shows the mechanism in action. While the yellow coloured piston rod extends, the gripper opens and due to the geometry of connection between piston rod and upper jaw, when it retracts it pulls the jaw along with it. The gap between upper and lower jaws can be compensated by adding corresponding inserts on the jaw according to the plate thickness.

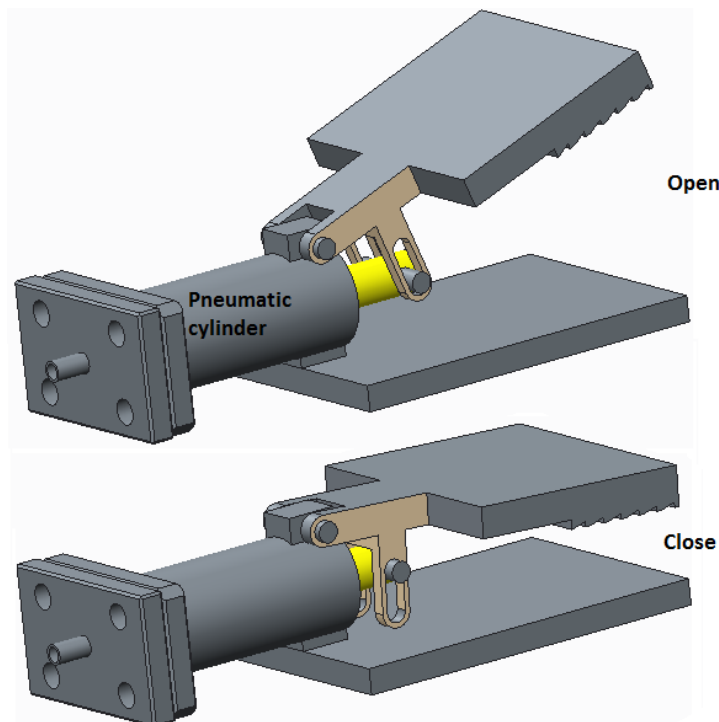


Figure 32 Custom designed pneumatic gripper.

Electric gripper are easier to produce as there is no need of airtight components and tight tolerances. Heat susceptible motor can be kept in a distance and power transmission can be introduced with a power screw that not only transmits power but also performs the actuation. The gripper however, was discussed to be a concept design for its mechanism only and will be further developed in succeeding project afterwards. As a result, two mechanisms, one for each power type were introduced.

Having all the actuations with same power supply gives easier compatibility for controlling applications so electric system is preferred over pneumatic. Pneumatic mechanism was omitted after discussion with customer during review meetings. During development of the gripping tool, steel has to be used instead of aluminium as aluminium has lower melting point. The length of gripping tool also has to be extended to reach centre of oven where

specimen is placed for best heating results. The length of gripper determines the place where specimen will be kept during heating. It should be considered depending on the preferred placement of specimen and so, a gripper with length of 150 mm to 200 mm should be designed while designing the gripper.

3D models of gripper were designed to demonstrate the mechanism which would be the base for following project to develop the gripping tool. Figure 33 demonstrates open and close positions of electric gripper with scissor mechanism. The mechanism itself is described in chapter 7.3.4 and Figure 52. One end of scissor connection is allowed to move in horizontal direction, it is attached to a rectangular bracket which consists of a threaded standard hole compatible with the power screw. When screw rotates, the screw pushes and pulls the bracket hence operating the scissor mechanism. In this case also, gap is kept in between upper and lower jaw to accommodate removable insert which will grip the specimen.

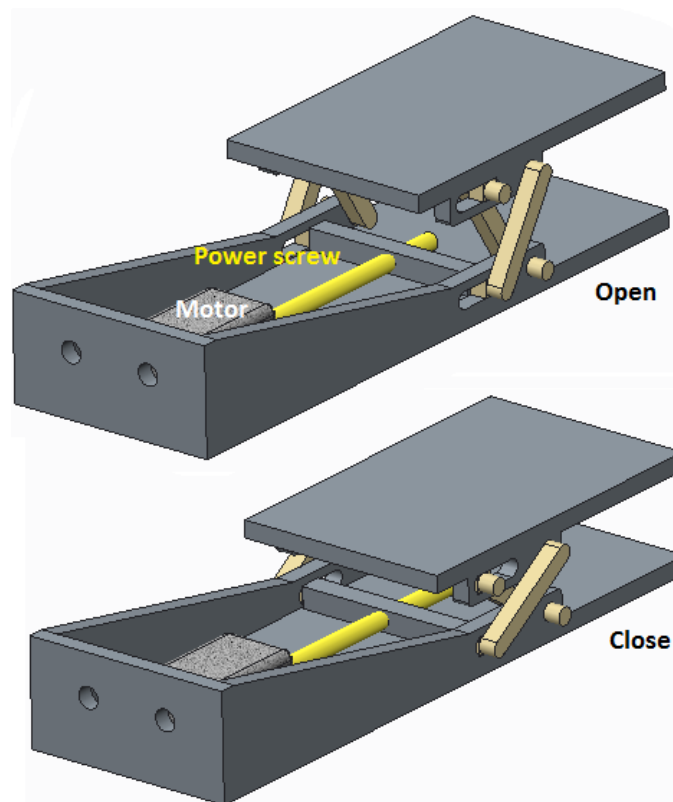


Figure 33 Custom designed electric gripping mechanism.

6.3.2 Arm design

The connecting component and supporting structure for gripper and specimen is arm, which was needed to be designed as a light weight and stiff structure. Unlike previous arm, this arm does not have to hold weight of rotary actuator hence, loads acting on it are even smaller. Also, the gripper could be directly fixed to arm and required no connector in between. The arm however has to show minimum deflection after loading and to ensure that, mechanical analysis were needed to be executed. Beam profile was selected from online catalogue and material for the profile is EN AW-6063

T5 as commercialized by Purso. Figure 34 shows the information about material properties from datasheet.

Mechanical, physical and chemical characteristics of aluminium extrusion alloys

Identifier	EN AW-6060				EN AW-6063				
Chemical identifier	EN AW-Al MgSi				EN AW-Al Mg0.7Si				
Temper designations	T4	T5	T6	T66	T4	T5	T6	T66	
Strength requirements	Ultimate tensile strength R_m (min) MPa (N/mm ²)	120	140	170	195	120	160	195	225
	Yield strength $R_{p0.2}$ (min) MPa (N/mm ²)	60	100	140	150	65	110	160	180
	Ultimate tensile strain A min ($A_{50\%}$ min) PURSO	16 (14)	8 (6)	8 (6)	8 (6)	10-14 (10-12)	7-10 (5-6)	8-10 (6-8)	8-10 (6-8)

Figure 34 Datasheet for aluminium alloy EN AW-6063 T5 (Purso profile design manual, 2014).

Beam selection was based entirely on the geometrical requirements of system and load due to gripper with specimen on it. Considering the new gripper to have weight of 0.6 kg just as previous one, we could proceed with arm design. The length of arm was same as before which was 560 mm but with different profile.

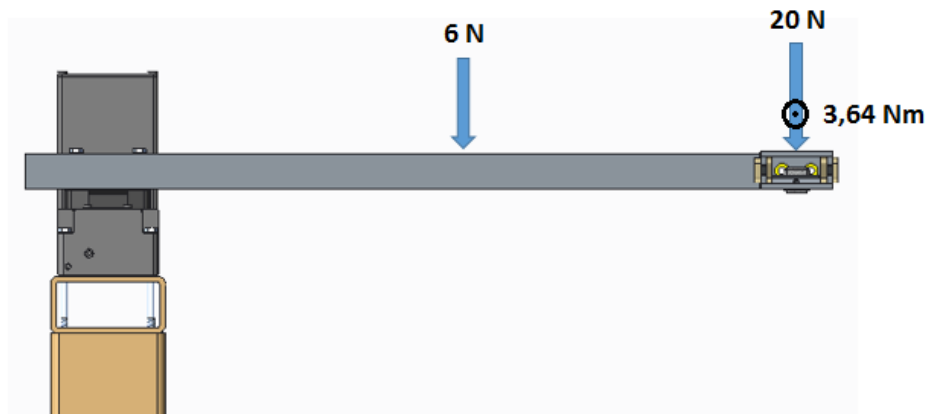


Figure 35 Load for arm in system without rotary actuator.

Without rotary actuator, load is reduced by a significant amount. The weight of beam itself is low as the profile is smaller. During calculations for beam profile, the load due to its own weight also is needed to be considered and was found to be 1.08 kg/m from commercial catalogue. The selected beam can be made even lighter by removing material, cutting circular hole patterns on the beam makes it lighter without having significant effect on its stiffness as load is light. For the length of 560 mm, weight is 0.6 kg but with holes it is reduced to 0.527 kg. Mass analysis was done with CREO as shown in Figure 36. It is not important to reduce mass since the difference

is very small, but it is always recommended to have lighter profiles. Furthermore, making big size holes demands machining so can be neglected for minimum improvement in results.

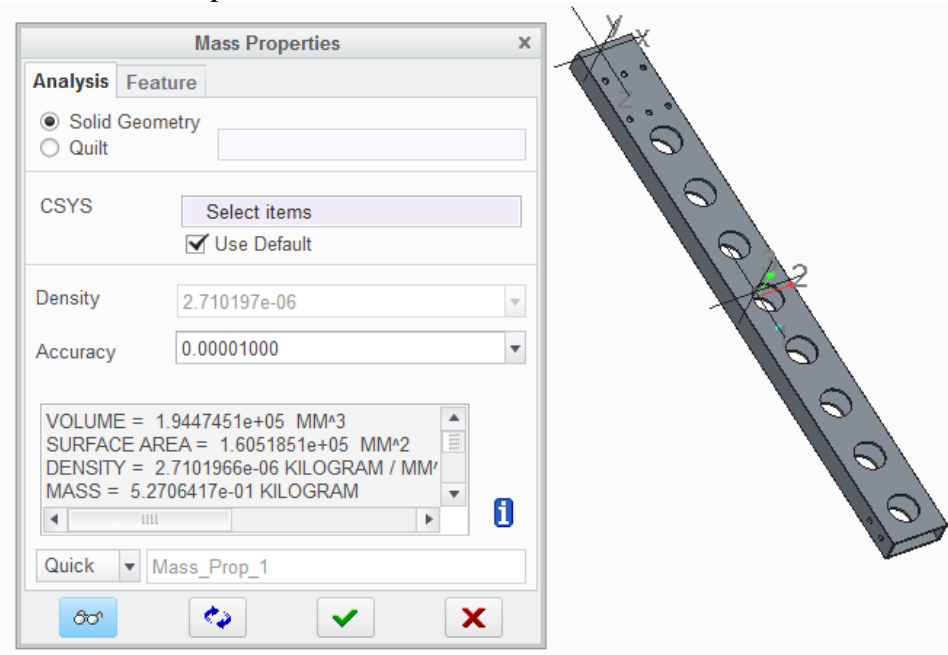
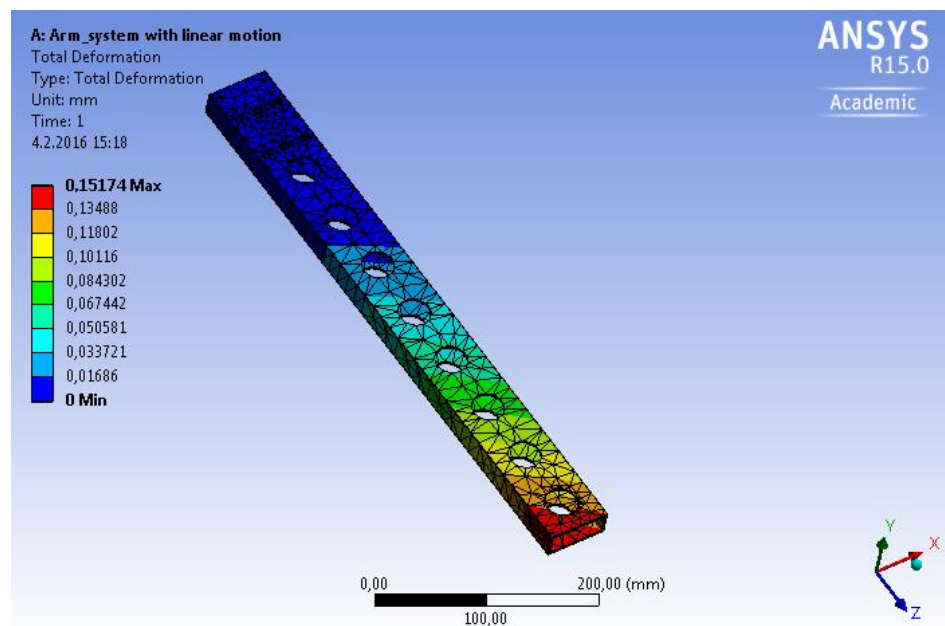


Figure 36 Mass properties of arm after holes were created to reduce mass.

The width of 6 threaded holes on the slider are distributed in a plane of 48 mm × 60 mm area, since the arm is to be assembled on those holes, the width of arm should be larger than that. A rectangular profile of 60 mm × 25 mm × 2.5 mm was selected and calculations regarding stresses, forces and deflection as well as bending moment were executed. Beam profile selection was done with Mathcad and the calculations from Mathcad are attached as appendix. 3D analysis software ANSYS was used to check possible deflections as presented in following figures. Maximum deflection was found to be 0.15 mm only. The technical drawings of arm are attached as appendix for further use.



6.3.3 Linear actuator

Electric linear actuator same as explained in chapter 6.2.4 was used. Here, with reduced load, actuator of lower capacity could be used but for enhanced safety and possibility to accommodate either systems, same actuator was used. The actuator length however will be longer since the slider has to pass through die separation. Required stroke length is 1385 but standard sizes of actuator available is with 1500 mm stroke length. The linear actuator LEFB32T-1500-R31N3 is chosen for the stroke length.

6.3.4 Supporting structure for actuator

The linear actuator needed a base to be assembled on. There are standard 5.5 mm holes on linear actuator dedicated to assembly of the component on a fixed base. A frame structure with hollow rectangular tubes with necessary holes was designed to make base platform for the linear actuator. A profile of 80 mm × 40 mm × 4 mm was selected in order to accommodate the actuator. 3D model was created along with the system and necessary drawings for manufacturing are attached as appendix.

6.3.5 Transfer time

Transfer time in this system also can be calculated as explained in chapter 6.2.5 above. With lower payload in this system, the actuator can use higher transfer speed. Along with specimen, the payload is 26 N as shown in Figure 35. Comparing the payload for LEFB32 using workload vs speed graph for linear actuator mentioned in Figure 28, a maximum speed of 1100 m/s could be used for payload of 30 N. Also, acceleration of 5000 mm/s² could be used for the case.

Now,

$$a_1 = 5000 \frac{\text{mm}}{\text{s}^2} \quad a_2 = 5000 \frac{\text{mm}}{\text{s}^2}$$

$$L = 1380\text{mm} \quad V = 1100 \frac{\text{mm}}{\text{s}}$$

Now, time for linear transfer from oven to die is,

$$T_1 := \frac{V}{a_1} = 0.22\text{ s} \quad T_3 := \frac{V}{a_2} = 0.22\text{ s}$$

$$T_2 := \frac{L - 0.5 \cdot V \cdot (T_1 + T_3)}{V} = 1.035\text{ s}$$

$$T_4 := 0.2\text{ s}$$

$$T := T_1 + T_2 + T_3 + T_4 = 1.675\text{ s}$$

This time is the minimum time taken by actuator to carry specimen from oven to die after gripping is done. When the oven door opens, the gripper is in its home position. Time taken by it to travel up to the specimen is calculated in similar fashion and found to be 0.83 seconds. Even if the gripper takes 1 second to close and open, the linear transfer time with gripper action will be 3.5 seconds, opening of gripper in die can happen along with pressing. But if gripper is made to operate as fast as previous one, the transfer time including travelling to oven from home position and gripping/dropping the specimen at die will be 2.9 seconds which is as fast as previous system. Hence, depending on gripper operating time, total time of transfer from home position to oven to die will be from 2.9 seconds to 3.5 seconds.

The necessary parts were designed and drawings of necessary parts as well as assemblies are attached as appendix. An assembly tree of complete system including all commercial and new designed parts is also attached as appendix 20. A complete model of the designed sheet metal transfer system is presented in Figure 38.

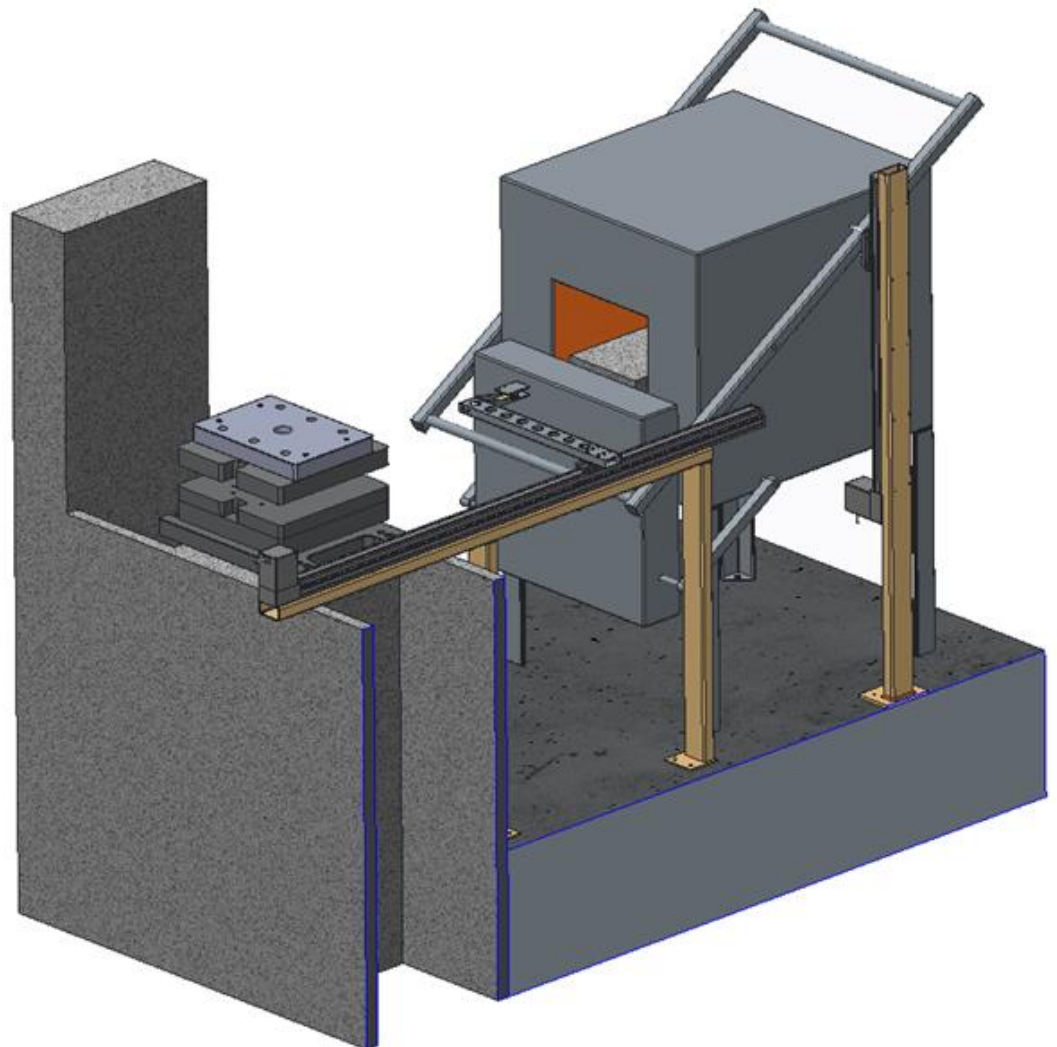


Figure 38 A section view showing complete model of transfer system.

7 PROPOSED IDEAS

The development of any process or mechanism includes ideation phase as one of the most important step where multiple ideas are generated and gathered for further processing. This topic describes all the ideas proposed for all the individual mechanisms that are needed in the system. Idea generation was assisted by group discussion with customer and supervisor. Multiple ideas for the new automated mechanism were gathered and proposed to the client.

7.1 Position of moving components

The linear actuators and all the mechanism including moving components should be positioned in place with minimum human interference for safety purposes. It is be carrying hot sheet metal at high velocity and has to be kept as far from user or other clients as possible. The side of oven closer to the wall settles the requirement as there is almost none interfering. The movement of actuator is linear and position of the moving component is represented by a green rectangular bar in the Figure 39.

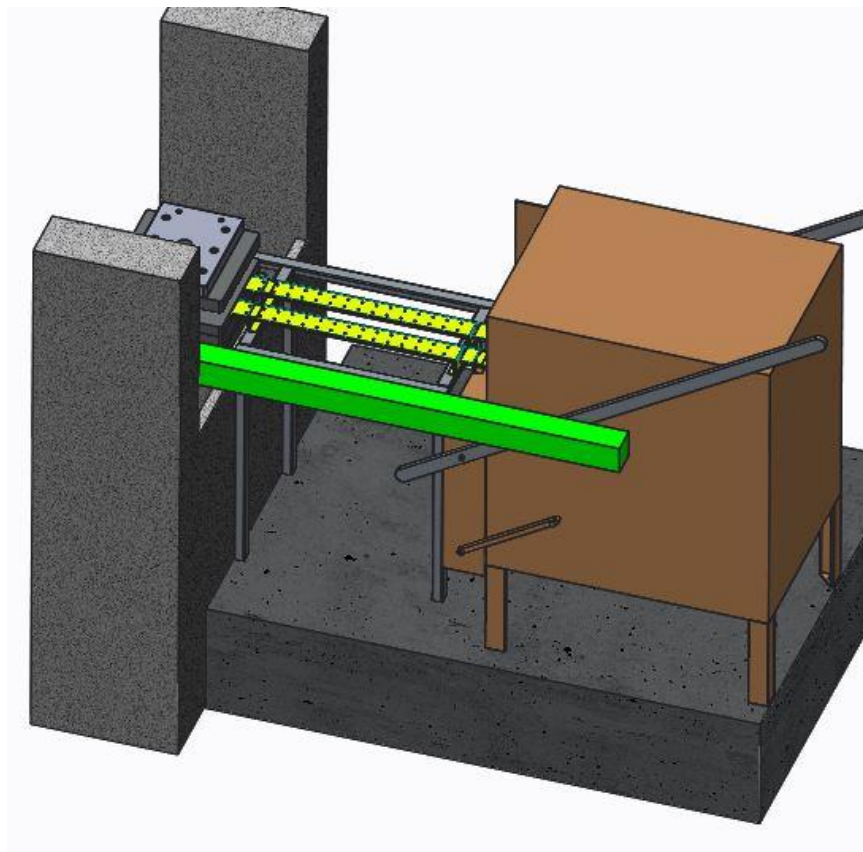


Figure 39 Position of linear actuator.

7.2 Linear actuation

Transfer of specimen in this arrangement takes place in a straight horizontal path, so a linear actuator has to be used for the transfer. There are multiple ways of linear actuation. An actuator is a device that can be operated by an

external energy source such as electric current, hydraulic pressure or pneumatic pressure. Actuator is used to convert the external energy into desired motion. It is necessary not only to create motion but also to control the action using different control mechanisms.

7.2.1 Pneumatic cylinder and guide rail

Pneumatic actuators are widely used in industrial applications that demand high speed and light weight components. A pneumatic cylinder uses power of compressed gas or vacuum to produce linear motion. In pneumatic systems there is at least one pressurised air tank or an air compressor as power source and the actuators are connected to it via pipelines and control valves. HAMK Sheet Metal Centre has pneumatic system and pneumatic pressure is supplied to working site via already constructed pipelines.

Pneumatic cylinders and hydraulic cylinders have similar construction consisting of a piston rod in a cylinder barrel. A piston at the end of rod helps in actuation upon the action of pressure and whole arrangement packed by two end caps with necessary ports. A cutaway model in Figure 40 below reveals the key features of a cylinder.

Pneumatic cylinders are of different types but most of them can be classified as single acting, double acting and multi-stage or telescopic cylinders based on their modes of actuation. The single acting cylinder produces force in only one direction and returning to the initial state is facilitated either by springs or external load. The double acting cylinders can produce motion in both directions and so is useful in this case. Telescopic ones are either single or double-acting. It has a piston rod assembled within a series of hollow cylinders of increasing diameter. When pressurized, the piston rod and each succeeding cylinder "telescopes" out as a segmented piston. This arrangement gives a noticeable benefit of space and so are used in places where large stroke length are necessary from a small storage length.

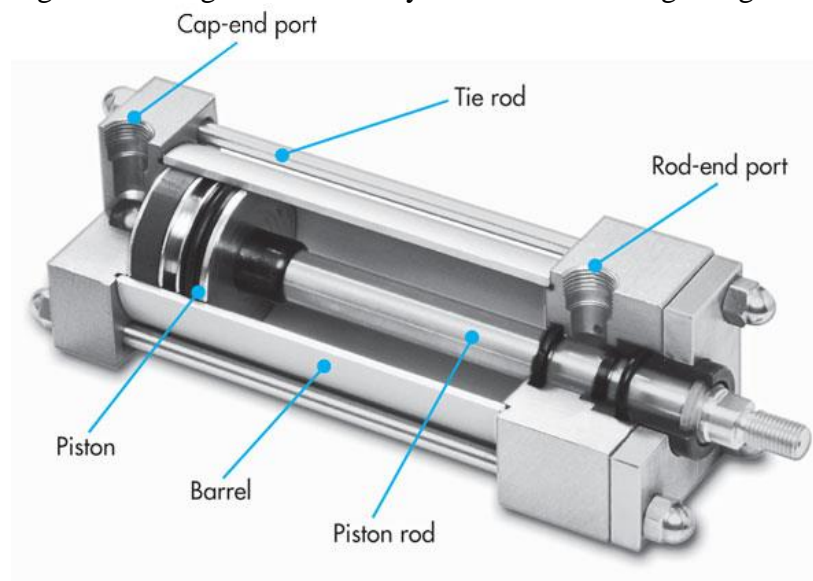


Figure 40 A section model of a double acting pneumatic cylinder (Hitchcox, Hydraulics & Pneumatics, 2013).

This linear actuating feature of a pneumatic system could be used in this project for the linear transportation of specimen. A long double acting pneumatic cylinder with needed stroke length can be fixed on a side of oven. Guide rail for the cylinder rod with a holder for specimen can slide along the length between oven and die as shown in Figure 41. The guide rails would prevent bending of rod as well as make path of motion for the process.

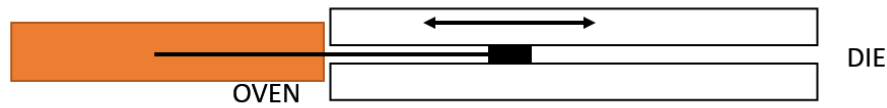


Figure 41 Schematic illustration of application of pneumatic cylinder and guide rails.

7.2.2 Rodless pneumatic cylinder

The pneumatic cylinder and guide rail assembly as mentioned in above idea is an economical solution but requires extra space to keep the cylinder and when larger stroke length are needed, the cylinder themselves get longer in dimension. The transfer process is also sensitive to large vibrations which can cause dropping of specimen and guide rails in above mentioned idea needs precise assembly and manufacturing to resolve that. As explained in manual transfer system above, the guide rails will also have to face a large friction as there are no elements to minimize friction which causes more vibration and rough movement.

Rodless pneumatic cylinders, which are also available commercially, already have a sliding platform for the load and hence would not need any guiding rails. They have easier mounting option consisting of standard holes on the product which can be mounted on a support structure used for placement of the actuator. They are better suited for longer stroke applications as they are protected from bending, piston bending and irregular seal wear. A schematic diagram of the product is described in Figure 42.

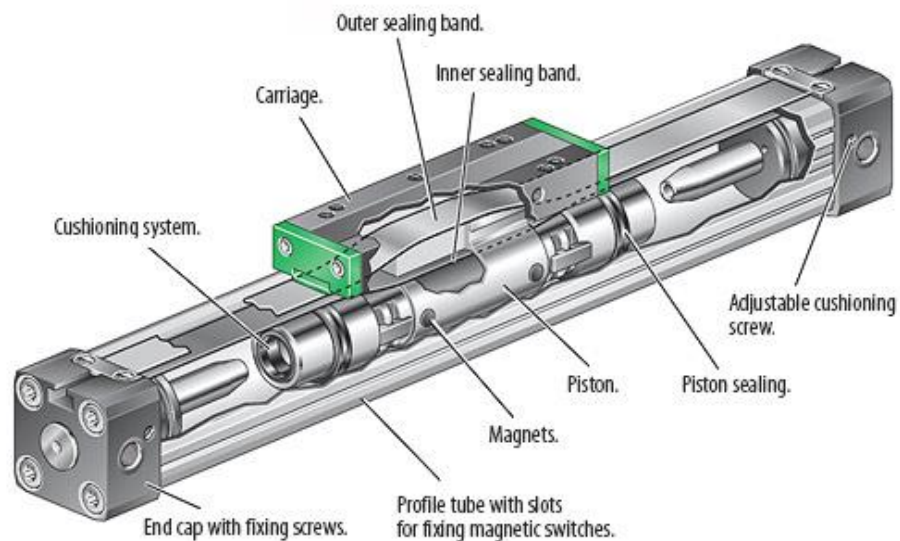


Figure 42 A section view of rodless pneumatic cylinder (RLF Rodless Cylinder n.d.).

Below in Figure 43 is a commercially available rodless cylinder. Mounting options can vary according to the model of cylinder and so does the pneumatic input and output ports. They can be selected based on the needs in industrial applications.



Figure 43 A commercial rodless pneumatic cylinder (Rodless cylinders n.d.).

7.2.3 Belt driven linear actuator

Above mentioned actuation systems are suitable for a normal operation but in this project the specimen being transferred is a hot sheet metal plate. Specimen is to be picked up from oven and placed in the die precisely. Pneumatic system acts fast and smooth as well as cools itself during its operation but due to the compressibility of gas, the precise control of the position of specimen can be difficult.



Figure 44 An electric actuator, belt drive (SMC, Product catalogue n.d.).

A belt driven linear actuation system is a promising solution for the case. The picture in Figure 44 is an electric belt drive actuation system manufactured by SMC Corporation. It is also a commercially available solution for linear actuation in which there is a slider mounted on the top of a sliding base or platform that guides the motion. The slider moves by the help of a belt which is driven by electric motor, hence called belt drive.

Slider in the system consists of 6 standard size holes which can be used to mount the apparatus that holds the specimen. Similarly, sliding base, which is also the body of this actuator has multiple standard holes that are to be used to mount the actuator on a rigid base. Figure 45 shows slider on top of electric belt actuator manufactured by SMC Corporation.

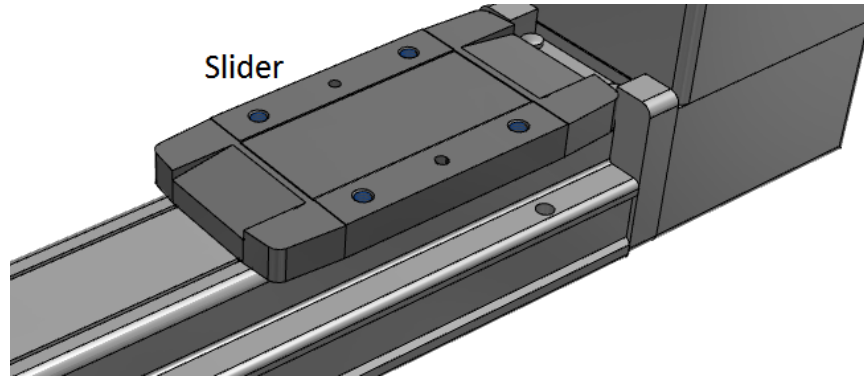


Figure 45 Slider on the linear actuator.

A controlled linear motion which is fast and reliable is attainable using the electric belt drive in the sheet metal transfer system. Also, the electric power source is available easily in the facility hence this idea was preferred for the project.

Table 2 Idea selection matrix for linear actuation mechanism.

Evaluation criteria	Importance rating (5)	Pneumatic cylinder and guide rail	Rodless pneumatic cylinder	Belt driven linear actuator
Product dimensions	3	4	5	5
Ease of operation	5	3	3	4
Ease of assembly	2	3	4	4
Power supply compatibility	4	2	2	5
manufacturability	4	4	5	5
	total	57	66	83

Table 2 above shows the weight of ideas and plays an important role in idea selection. The idea selection matrix, as in table above, were created for each mechanism with multiple ideas of actuation. Essential features that influence the design and function of product are listed as evaluation criteria and are ranked from one to five considering their influence over the other features. The feature with minimum importance gets one point and that with highest influence in selection gets five points. After that, all the ideas are evaluated for those respective features and ranked comparing with each other. Finally, the points of each feature for an idea is multiplied with its importance rating and are added to get total points. Idea with highest total points is the best idea and proceeds for further development. Similar method is applied in idea selection matrixes mentioned in table 3 and 4 in later topics. Here, the belt driven system has highest points and is preferred over

others for flexibility in operation, ease of assembly and power supply compatibility.

7.3 Work holding mechanism

A hot sheet metal at about 880°C - 950 °C cannot be hooked and unhooked manually by hands. The extreme heat and radiation due to high temperature makes the plate itself and its surrounding hazardous to work with. Special arrangement should be made for hooking and unhooking of the sheet metal. High temperature also changes material properties of the plate. Creeping is a major issue in elevated temperatures and can play role in failure of mechanism. A long term loading on a material induces slow flow or deforming of the material also known as creep. Metals used in construction show extremely low creep compared to polymer materials at elevated temperature of 880°C - 950 °C. Due to such properties, metal should be used in design of gripping tool.

Furthermore, separation between the dies in the stamping press is limited to 30 mm which can be extended to a maximum of 45 mm. If the sheet metal work holding tool is designed to pass through the die during operation, the separation dimension must be considered while designing and selecting the work holding tool. Multiple ideas were generated during ideation and are described below.

7.3.1 Hook based solution

A hook based solution is the simplest solution to transfer sheet metal from a place to other linearly. In this idea, a set of hooks would fit into holes made in the specimen as shown in Figure 46. The mechanism would work exactly as in manual system explained before. Hooks assembled to an arm would rotate through few degrees to facilitate the mechanism.

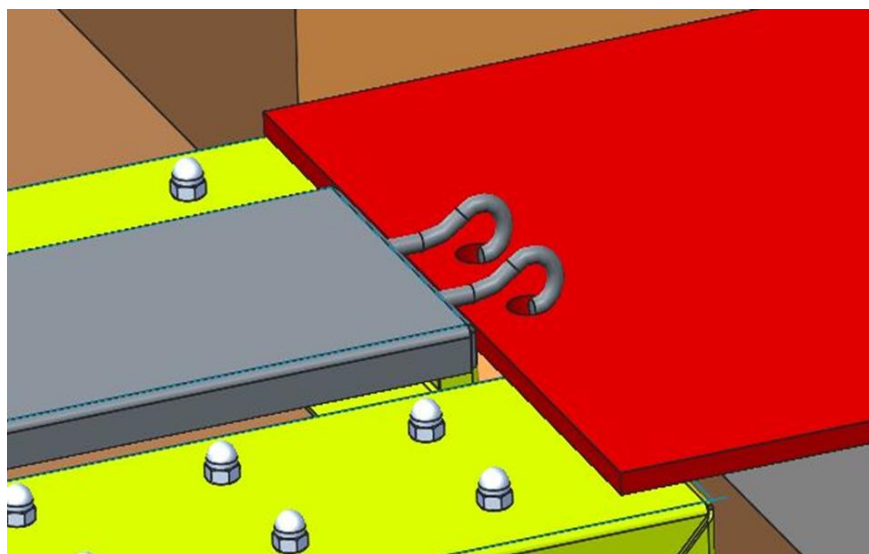


Figure 46 Hooks for specimen holding.

Though this is an economical solution, the open end of hook is dangerous to work with hot sheet metal specimen. During transfer, the specimen and hooks should have relatively same acceleration and velocity so that specimen would not fly off the hook in between the transfer. The inevitable friction that acts during transfer causes vibration which would aid to unhooking of the specimen during transfer and heated sheet metal would be a safety hazard in such situations. Apart from that, surface contact in between the sheet metal and dome shaped guiding platform still accounts for heat loss from specimen which is not recommended.

7.3.2 Magnetic gripper

During tests of oven and specimen, there have been multiple manual transfer attempts using hand tool. The hot sheet metal was grabbed by manual pliers as illustrated in Figure 47 and successfully transferred. This method has been used multiple times and has been effectively executing the task.



Figure 47 Manual sheet metal grabbing pliers.

In this idea, similar mechanism of gripping and holding the sheet metal can be used, the jaws of pliers can be assembled with electromagnets. When activated, they grip the specimen and when deactivated, they drop it. Springs can be used in opening of the jaws as described in Figure 48.



Figure 48 Magnetic grippers.

Instead of permanent teeth to grip the specimen, removable inserts can be used so that if welding occurs or any other damage happens, the teeth can be replaced with new ones without changing anything else.

7.3.3 Commercial work holding gripper

Commercially existing work holding grippers can be used for the task with slight modification in the transfer path. There are various commercially available electric, hydraulic as well as pneumatic grippers.

Electric grippers are available in small profiles just as required. They are fast, precise and have good control systems. They have easier mounting as well but the functional parts are sensitive to heat. Electric grippers has motor that creates the motion and the electromagnet in motors are sensitive to heat exposure hence is highly risky to be used. Figure 26 shows an electric gripper manufactured by SCHUNK GmbH & Co. KG.



Figure 49 Electric 2 finger parallel gripper (Schunk n.d.).

Hydraulic grippers need hydraulic power supply which is not available in the working site hence is not economical to use.

Pneumatic grippers are fast acting and some of them have self-locking feature that locks the closing and opening of the gripper as a safety measure in case of power failure. Having a pneumatic power supply readily available at site makes it preferred over all other options. Hence, pneumatic commercial grippers are clearly the best solution here.

Specialized grippers for sheet metals are manufactured by a company called DE-STA-CO, A Dover Company. The grippers are light weight and have full metal body that can be used in high temperature environments as well. They have multiple mounting options which makes assembly easier and high gripping forces which makes sure that the specimen will not fly away during its operation. Grippers of various size and dimensions are available to choose from. Figure 50 shows an example of a pneumatic sheet metal gripper.

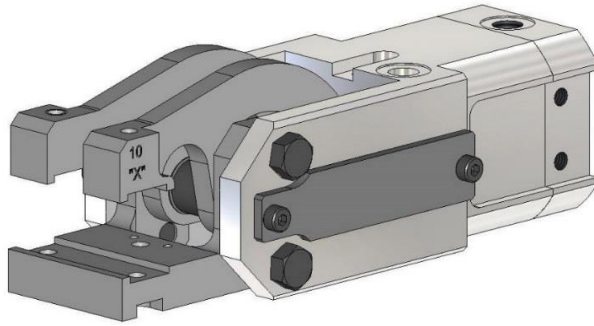


Figure 50 Pneumatic sheet metal gripper (DE-STA-CO Sheet Metal Grippers n.d.).

7.3.4 Designing a new gripper; a concept design

All the grippers mentioned above can be used in this project and are better than previous ones for the reasons mentioned above. Pneumatic sheet metal gripper being fast, reliable and useable in high temperature is comparatively better solution than others. Despite all the benefits, lowest height available for the product is 48.3 mm which exceeds the limits of die separation and hence cannot be used to pull the specimen through the die. Introducing a rotatory motion in the travelling path of specimen solves all the issues using pneumatic sheet metal gripper as described in chapter 6.2, but for higher safety of operation, a thinner gripper can be designed that could pass through the die separation removing the rotating step of the hot specimen.

To design a new gripper, a mechanism has to be decided. A simple mechanism as shown in Figure 51 below can be used to design the gripper.

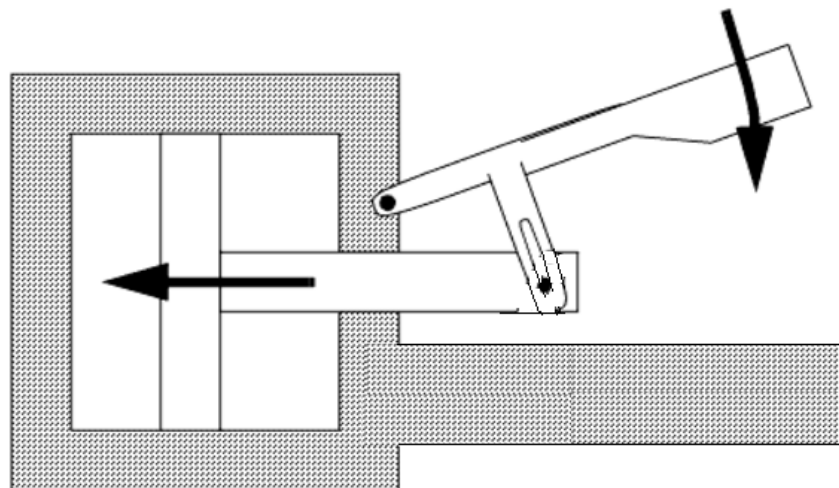


Figure 51 Gripping mechanism for new gripper design.

Here, pneumatic actuation of piston creates angular movement of the jaws which grabs the specimen. The gripping force is proportional to the pneumatic pressure and the area of piston. Large gripping area makes the holding more stable and lessens the chances for specimen to deform hence, the grabbing area or the area of jaw can be extended. It can be made flat and wide like the gripping part of the manual plier demonstrated in Figure 47.

An alternative mechanism is scissor mechanism as described in Figure 52, found usually in scissor lifts. Scissor lifts are used as aerial work platform to access higher workplaces. One end of the rod at base can be arranged to have linear motion with help of electric motor which will push the top up or down as required. This can be used to grip the sheet metal. A model of conceptual gripper was prepared with CREO 2.0 and was presented in chapter 6.3.1.

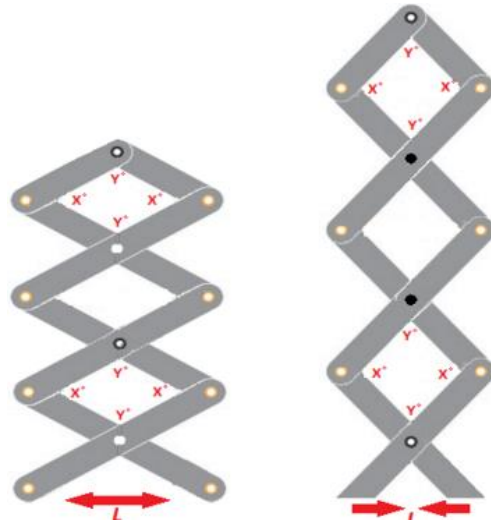


Figure 52 Scissor mechanism (Scissor lifts information n.d.).

Transfer system without rotation using costume design grippers is an alternative for the main idea for elevated safety levels in the working site.

Table 3 Idea selection matrix for work holding mechanism.

Evaluation criteria	Importance rating (5)	Hook based solution	Magnetic gripper	Commercial work holding tool	Custom designed gripper
Product dimensions	5	4	3	3	5
Ease of operation	4	3	3	4	5
Light weight structure	2	5	3	5	4
Power supply compatibility	4	4	2	4	5
manufacturability	4	4	3	5	4
	total	74	53	77	89

An idea selection matrix was created to compare most important features as illustrated in Table 3. Custom designed gripper gives the best results followed by commercial pneumatic gripper as discussed above.

7.4 Rotary actuator

There are two final automated systems described in this thesis. One of them has rotational motion implemented to allow use of commercial grippers. Grippers available commercially are larger in dimension than the separation of dies so cannot pass through. Using a rotary actuator would eliminate that requirement and any rotary actuator could be used regardless of its dimensions. Here, the gripper and specimen are to be rotated through 180 degrees for the specimen to be placed on die. A rotary table available as MSQ model can be used to achieve the requirement.

Rotary actuators are available with all types of power sources. Electric rotors have multiple delicate components and cannot be used near intense heat, hydraulic actuators need dedicated pumping system which is not economical. Here in the design with rotary actuator, the system uses a pneumatic gripper dedicated to sheet metal gripping and so the rotary actuator is also selected to be pneumatic. The company that provides linear actuator mentioned above also manufactures pneumatic components. A pneumatic rotary actuator model that allows easy mounting and enough rotation was selected from the catalogue and is shown in Figure 53 and 54.

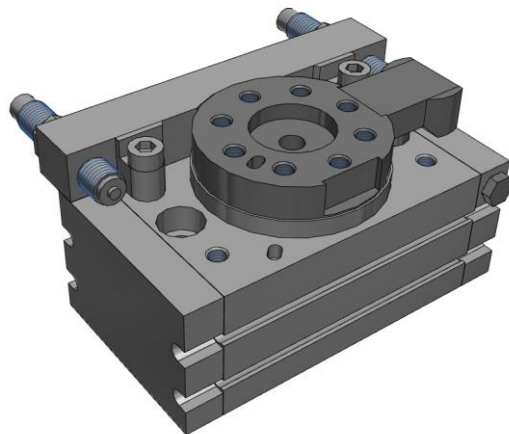


Figure 53 3D model of the rotary actuator (SMC digital catalogue n.d.).

Easy mounting of work piece.

- Table I.D./O.D tolerances
Basic type: **MSQB H9/h9**
High precision type: **MSQA H8/h8**
- Positioning pin hole
- Hollow axis
Accommodates wiring and piping for equipment mounted on the table

Table inside and outside diameters
For alignment of rotation center and work piece

Positioning pin hole
For position of rotation direction

Hollow axis		1	2	3	7			
Size		1	2	3	7			
Hollow axis		ø3.5	ø3.8	ø5	ø6			
Size		10	20	30	50	70	100	200
Hollow axis		ø6	ø9	ø12	ø13	ø16	ø19	ø24

Large rolling element bearing

3 to 4 times higher axial load
(compared with series CRG)

Rolling bearing

Pivoting angle adjustment range: 0 to 190°

With internal shock absorber
2 to 5 times more kinetic energy
(compared with an adjustment bolt)

Easy mounting of body

- Reference dia: Boss, Hole
- Positioning pin hole
- Mounting from 2 directions

Pin hole

Reference diameter (boss)

Reference diameter (hole)

Pin hole

Movement in direction of table's radial thrust: 0.01 mm or less

By using high precision bearing, the movement in the direction of table's radial thrust is reduced.

Piping from 2 directions (front and side) is possible

Piping position can be selected to accommodate mounting conditions

Front direction

Side direction

High precision type

High precision bearing

Basic type **MSQB**

High precision type **MSQA**

Features 1

SMC

Figure 54 Rotary actuator MSQ model (Rotary Table / Rack-and-Pinion Type n.d.).

7.5 Oven door mechanism

Electric oven for this project has a vertically opening door that operates by circular motion of handle rod. During opening and closing, the door not only moves in vertical line but also in horizontal direction because of the circular opening path. An actuator that allows both rotation and linear motion has to be used to automate the oven door operation. The pin connection of door handle is illustrated in Figure 55.



Figure 55 Rotating connection of door handle.

7.5.1 Pneumatic cylinder

Pneumatic cylinder can be used to allow rotation as well as linear motion when assembled with pin connection on both ends. The lower joint of oven door which is connected to handle can be attached to rod of pneumatic cylinder with a pin connection to allow rotation. The back cover or the base of cylinder can be assembled to oven top of front wall with an external bracket. As described in Figure 56, a simple bracket that allows rotation can be bolted on the top corner of front wall and cylinder can be assembled. A cylinder with minimum length of 200 mm and a maximum length of 600 mm would be required. Due to limited space, a maximum cylinder diameter of 50 mm can be used.

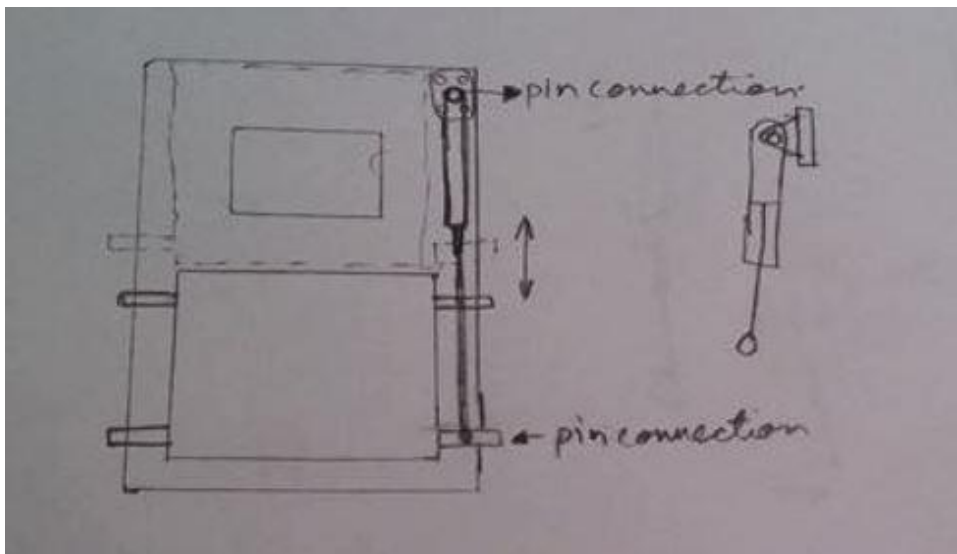


Figure 56 Initial sketch for pneumatic cylinder position in door operation.

7.5.2 Rotary actuator

The operation of door is related to rotation of its handle bar. A rotary actuator can be used to control the rotation of the handle bar which would open and close the door as desired. Commercially available rotary actuator can be assembled on the connection between handle and oven. The concept is demonstrated in Figure 57 where the green square represents rotary actuator.

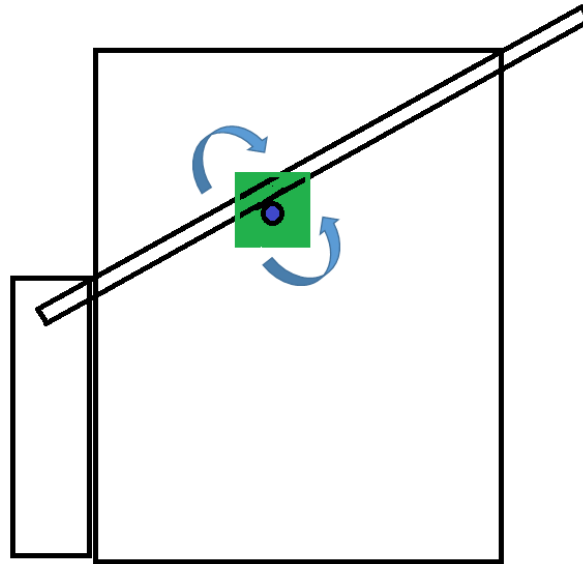


Figure 57 Using a rotary actuator for door operation.

Multiple companies are selling rotary actuators that operates pneumatically or electrically and also hydraulically. Again, hydraulic system needs new power supply so is not economical to use here. Either of electric or pneumatic system can be used. Figure 58 is a pneumatic rotary actuator from a German based automation company Festo.

Swivel modules DSM ★



- Size 6, 8, 10, 12, 16, 25, 32, 40, 63 mm
- Torque 0.15 ... 80 Nm
- Swivel angle 0 ... 270°
- Position sensing
- Adjustable cushioning.

★ DSM

Figure 58 Rotary actuator from Festo (Semi-rotary actuators with rotary vane n.d.).

7.5.3 Custom designed actuator

Both ideas above works well satisfying the needs of the case but they demand modification in the oven itself and with the first idea, the cylinder being slender, there is high risk of buckling. A solution that allows rotation

and linear motion can be manufactured to operate the oven door. A holding bracket with rotating rods can be made for the handle that allows angular change of the handle beam of oven and assembled with any linear actuator. As it moves up and down, it drags handle along with it, closing and opening the door.

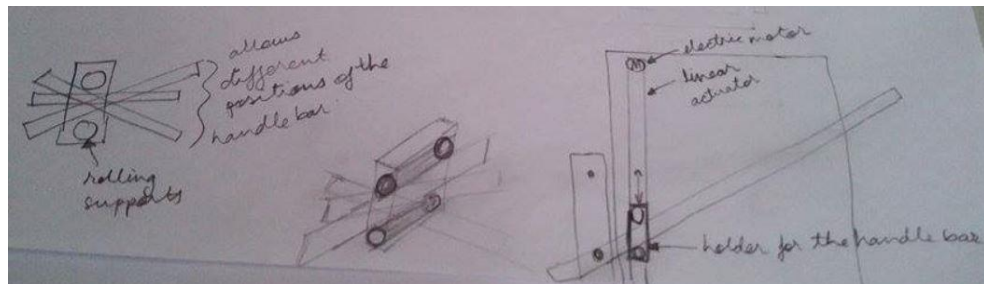


Figure 59 Idea sketch for connection between handle rod and actuator.

Figures 59 and 60 demonstrate the working of the door operating mechanism, it is simple and easy to manufacture as well. Using a cylinder is economical solution in this case but due to complications in controlling the operation, electric actuator is preferred and was decided to be used in meeting with customer.

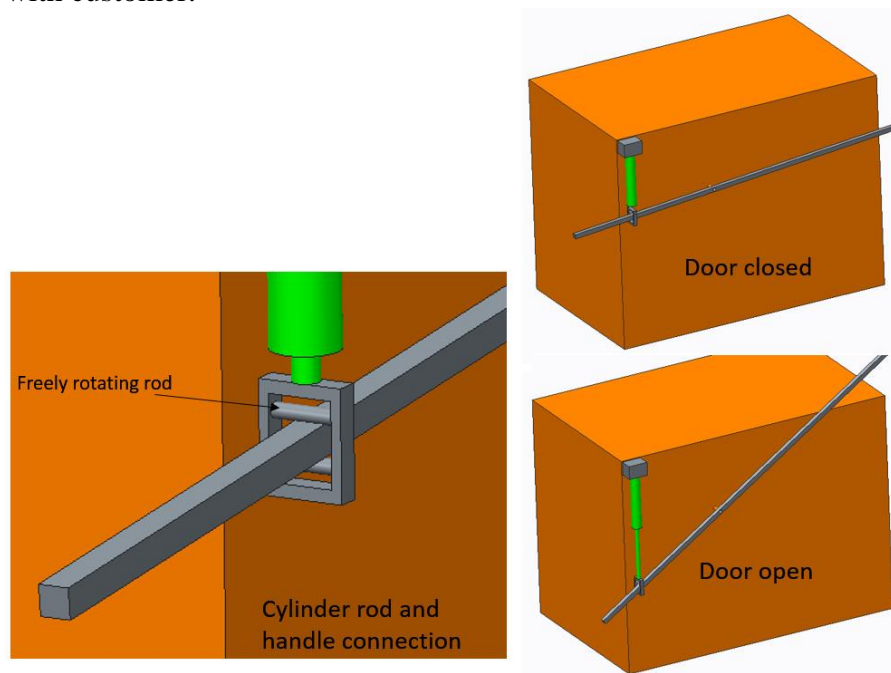


Figure 60 Mechanism for custom design actuator.

Oven door mechanism demands modification in oven structure. The rotary actuator needs to be fixed in joint of handle rod and cylinders need a pin connection on handle. These modification to oven itself may cause harm to door operation as well, so, it is preferred to use mechanism which eliminates this risk. Table 4 compares ideas for oven door mechanism.

The custom designed actuator can be designed to eliminate any modifications to oven itself. It uses electric power supply which is easier to assemble as other actuations also share same power supply.

Table 4 Idea selection matrix for oven door mechanism.

Evaluation criteria	Importance rating (5)	Pneumatic cylinder	Rotary actuator	Linear electric actuator with custom designed bracket
Product dimensions	5	4	4	5
Ease of assembly	4	3	2	4
Light weight structure	2	3	3	3
Power supply compatibility	4	2	2	5
	total	46	42	67

8 OPERATION

Each system explained above is designed combining multiple components that performs multiple tasks through series of steps. These steps need to be operated in certain predefined sequence for the operation to be successful. Operating the linear motion of arm has three stopping points or stations: home position, picking point and dropping point. Position of these stations are based on the dimensions of gripping tool. The gripping tool is not completely developed yet so these positions cannot be decided precisely yet. However, an estimation of where these points exist is demonstrated in Figure 61.

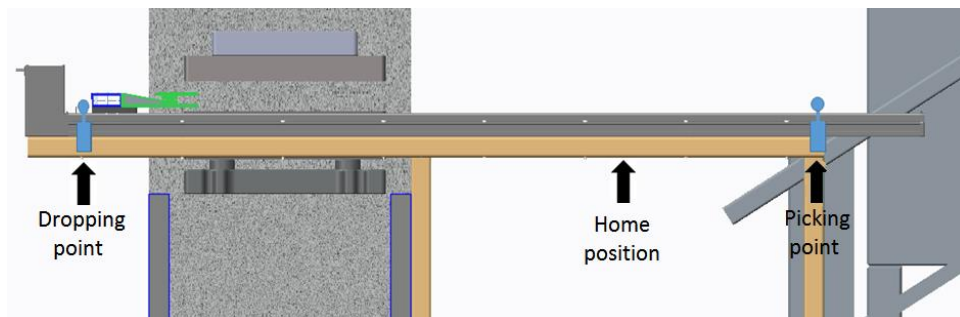


Figure 61 Location of home position, picking and dropping points.

8.1 Control system

Both transfer systems explained above use similar linear actuator, controller for linear actuator is supplied by the manufacturer. The slider in actuator needs to stop in 3 points as explained above, home position where it rests, pickup position near the oven from where specimen is picked and drop position near the die where it is dropped. The exact coordinates of these points depend directly on the gripper dimensions and so are to be determined during development of the gripper in later project. Selecting these positions and controlling motion of slider is explained in user manual also provided by the manufacturer.

Gripper in electric system is operated by electric motor, the opening and closing of gripper can be controlled by electric switch that changes the rotating direction of motor. Two limit switches can be installed in each ends of picking and dropping positions of actuator, so that the slider physically pushes them and activates respective operations. Limit switches that operates when pushed to certain angle are available commercially. A limit switch manufactured by Omron and available commercially in YEInternational is illustrated in Figure 62. YEInternational is distributing store that sells electronic and other components. Position of switch, as indicated by light blue structure in figure below, depends on the stopping position of slider on each end. It can be assembled after installing the linear actuator.

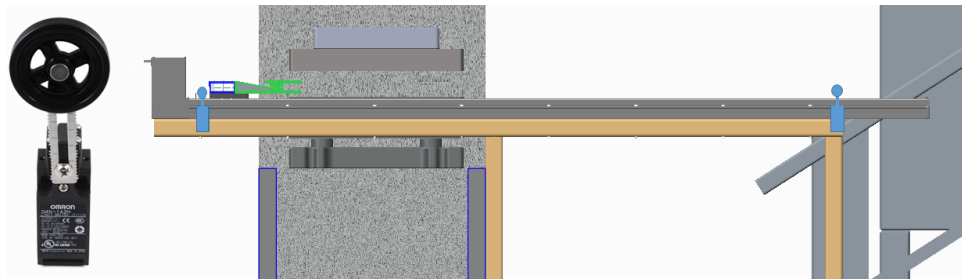


Figure 62 Limit switch (left) and its positions (YEInternational n.d.).

8.2 Operation sequence

Initially, the arm will be resting at home position, the oven door will open. For the system without rotation, operating steps after door is opened are as explained in chapter 7.2. With application of proper timing and sequence, the whole operation is executed with these steps. First the slider moves to oven and stops at picking point, when it activates limiting switch the gripper grips specimen. Then slider moves to die. Here, to allow proper gripping, a predefined waiting time has to be set in controller of linear actuator. Waiting time depends on the gripping closing and opening time of gripper. Similarly, the specimen is dropped at dropping point when other limit switch is activated. The machined gap of $50 \text{ mm} \times 50 \text{ mm}$ on dies will allow gripper to stay at dropping point but a small separation between die and gripping tool is recommended. Arm assembly along with gripper will stay outside the dies during press hardening is carried out.

Depending on the number of tests and complexity of programming steps in linear actuator, the arm can be programmed later to carry specimen into the oven from that position and then return to home position. During later meetings with customer, the system with rotation and pneumatics was omitted for its dual power supply system and safety issues regarding rotation of hot specimen. Hence, the development of control mechanism for that system was suspended during the project.

9 MAINTENANCE AND SAFETY

Work safety and reliability of system is a primary concern in every mechanical design. Sheet metal transfer system has multiple mechanisms and needs

maintenance after certain period of use. During operation, the insert used in grippers to grip hot specimen might deform or get attached to specimen due to intense heat. It needs to be replaced when damaged and can be done without disassembling the gripper itself. The commercial linear actuator needs to be checked externally and internally in every 6 months. The lubrication in moving parts need to be inspected and belt needs to be replaced after 2000 km of use. The detailed maintenance and mounting information are provided in digital catalogue of the product. (SMC, Product catalogue n.d.)

Transporting a hot sheet metal specimen at high speed can result in various safety hazards if not considered early. Since the later system omits rotation of specimen, it enhances safety compared to first system. The moving components of system are designed to reside towards wall of test site where there is minimum or almost none human interference to avoid possible risks. External physical stoppers are recommended near the end of die plates to stop specimen movement if gripper fails. Worker will stay behind walls of stamping press which will prevent direct exposure to oven and hot specimen in its motion. In case of exhibitions or multiple workers nearby, it is recommended to build a physical barrier on the opposite side of wall. Figure 63 below shows the position of complete system in test site. Working and public access area are shown as green colour region and position for recommended physical fence as well as external stopper near die in yellow box.

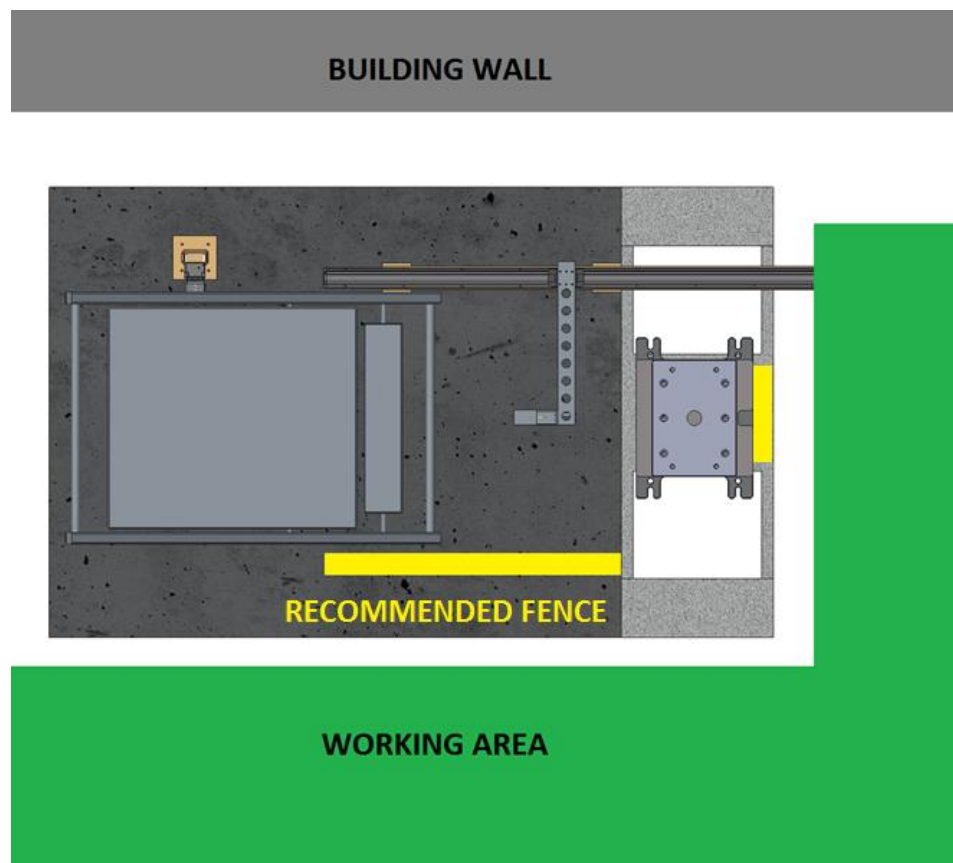


Figure 63 Sheet metal transfer system and surrounding.

During use, daily visual inspection of cables passing through arm is highly recommended. In case of system failure, the oven should be switched off

and specimen should be left to cool down before taking any repair and maintenance measures.

High temperature of specimen and oven can cause burns and rashes, in case of accident, cold water should be applied in burnt areas. Depending on severity of burn, the wounded area should be kept soaked in cold water or ice water for 5 to 15 minutes before applying skin care products such as aloe vera cream or antibiotic ointment. Bandage soaked in cold water can be applied on burnt area and patient should be taken to doctor for further treatment. Third degree burns are those where burned skin looks white or charred due to damage in all layers of skin. Third degree burns may cause little or no pain at all as the nerves and tissue in the skin are damaged. Soaking in water and applying ointments should not be done in such severe case, the patient should be rushed to hospital immediately. (First aid: Burns, 2012.)

It is highly recommended to work in pair or in presence of another worker nearby to enhance safety and first aid in case of safety hazards.

10 RESULTS AND CONCLUSION

The hardening research that is being conducted at Sheet Metal Centre of HAMK is important for the development of safety measures in public transportation. Hardening is dependent on cooling rate and initial specimen temperature, hence, the facility that is to be developed should be swift and safe. At early meetings with the customer, basic requirements were discussed and the design process was initiated. During follow up meetings, there were several modifications made to the design and new acquired ideas as well. The meetings and discussions with all parties involved were helpful and essential for the development of the project satisfying all the needs. A system with rotation was developed to compensate the limited space in between the dies as products of smaller dimensions were not found. Later, it was discussed to use a system with longer stroke and no rotation of specimen for enhanced safety. A mechanism and its implementation in the design of the gripper was discussed, designed and modelled. This concept design is to be the foundation for following design projects dedicated in development of gripping tool. As a result, a completely electromechanical system as desired by the customer was designed.

An earlier project regarding the development of a manual transfer system during summer led to the realization of the importance of automation in the system for product consistency. The design and manufacturing of a manual mechanism as a prototype was the background of this thesis project and the automated system is a developed version of that manual system to achieve higher safety and better results during hardening research.

The design process in this thesis project included many brainstorming sessions and group discussions with the supervisor and the customer. Multiple ideas were created and replaced during the course of development and the selection was made during these discussion sessions. The development of this system implanted a realization of the continuous progression cycle in

research and development process of the engineering world. Products are designed for certain purposes and are perfected for the time being by the designer and his team, but later, there will always be possibilities of improvement leading to the next generation of design and product families. The ideas generated initially were considered reasonable but later, issues regarding their function, usability and compatibility with the system were realized resulting in modifications of ideas and a generation of new automation methods. The design of the transfer system without rotation is one example of a better and safer version of automation as described above. Time being one of strongest limiting factors, this development was finalized to initiate the assembly of the system at the working site. There may still be fields in this design that can be improved, modified and even eliminated based on the development of new commercial components and changes in customer requirements. These possibilities will be considered during the next projects of gripper design by the designer who will carry on the project continuing the loop of research and development in a quest to achieve a better system.

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MILESTONE MEETINGS

S.N.	Milestone	Objective	Result
1	Thesis review meeting 1	Thesis topic orientation in Sheet Metal Centre Hämeenlinna	Passed
2	Thesis review meeting 2	Idea/Concept discussion	Passed
3	Thesis review meeting 3	Detailed design review/prototype review	Passed
4	Thesis review meeting 4	Final design review	Passed

Thesis review meeting 1:

Thesis topic was discussed in customer site. The requirements for the thesis were explained and discussed. General ideas of how the project could be done were discussed and dimensions of oven was measured for future tasks.

Thesis review meeting 2:

Idea generation was done after first review meeting. The gathered ideas were discussed about their potential and drawbacks. Functional ideas regarding transfer of specimen and opening of door were accepted and some were rejected. Further development of idea was discussed.

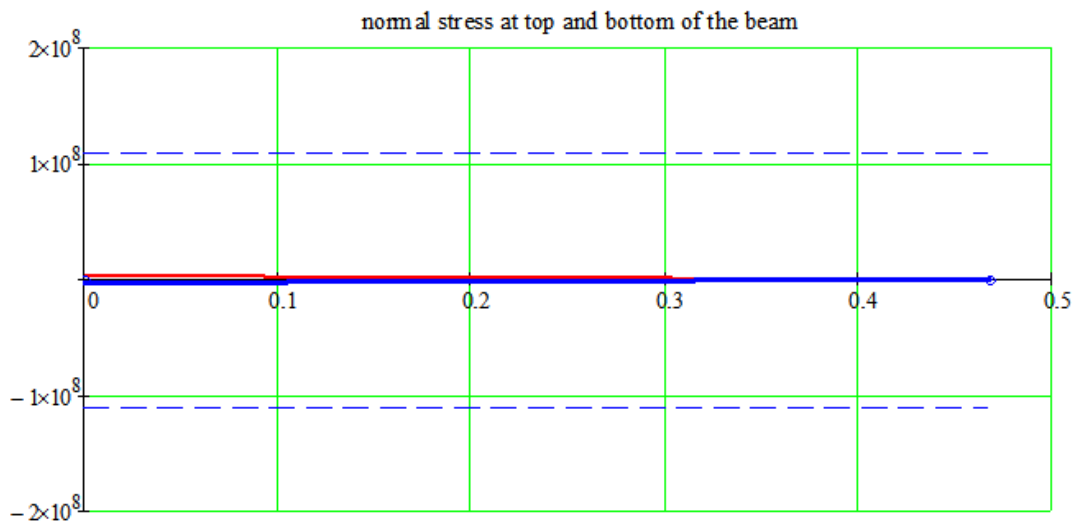
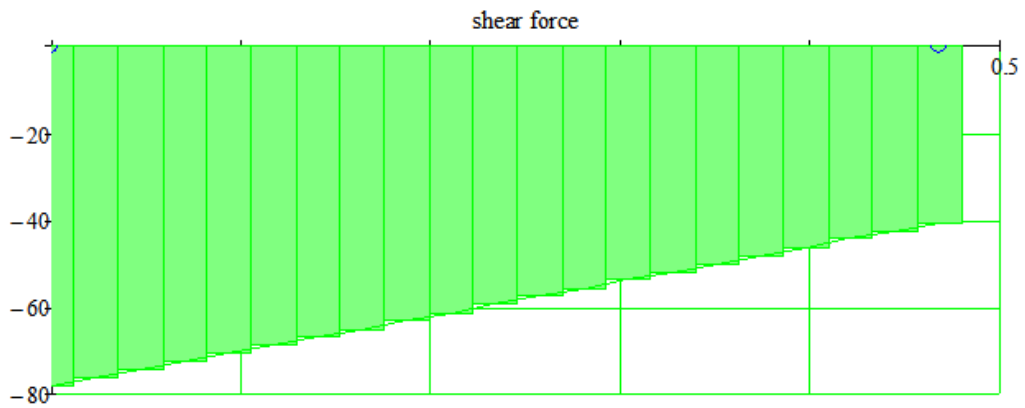
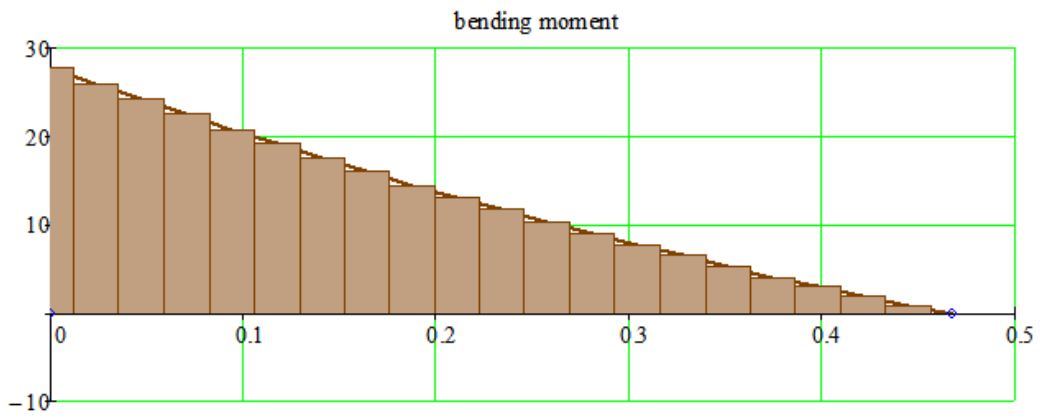
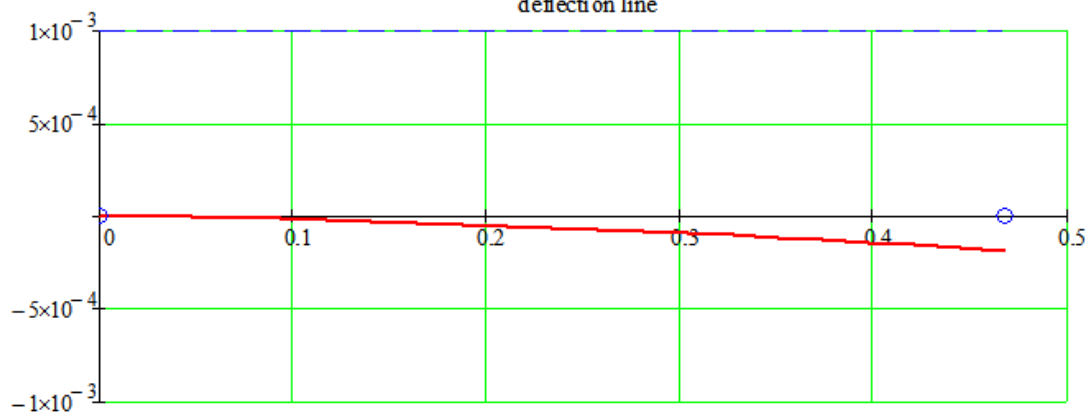
Thesis review meeting 3:

Functional specs were updated and approved. Components selected were approved as well as possibility of new system without rotary actuator was discussed and proposed by customer for further development.

Thesis review meeting 4:

Latest 3D models, parts and commercial components are presented and discussed for any further update. Functional demonstration of process was done and approved. Final concept was accepted and permitted for further development and manufacturing in customer site.

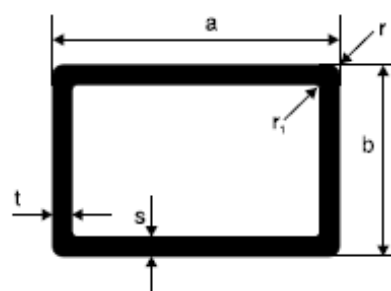
BEAM PROFILE CALCULATIONS RESULTS FOR SYSTEM WITH ROTATION



34

Suorakaide- putket 2

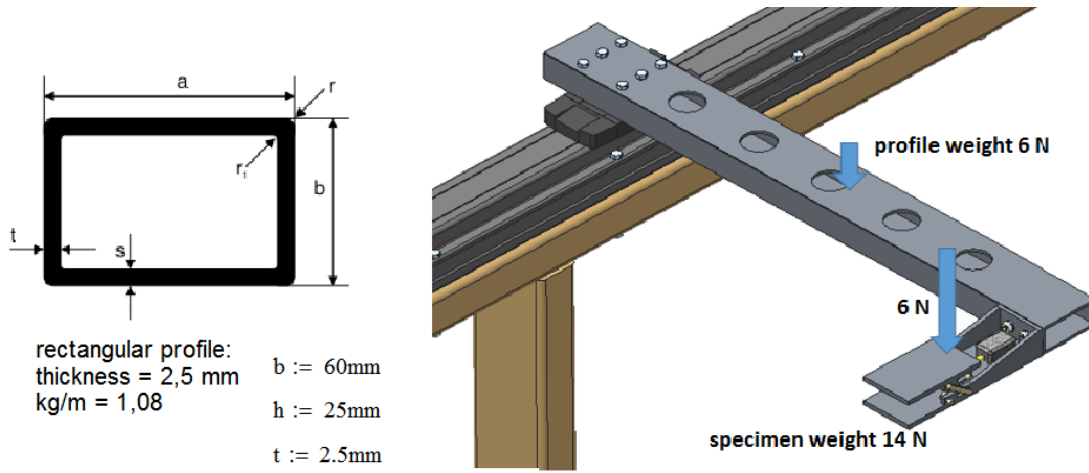
Rectangular tubes 2



Merkintätapa: Suorakaideputki $a \times b \times s \times t$. Marking: Rectangular tube $a \times b \times s \times t$.

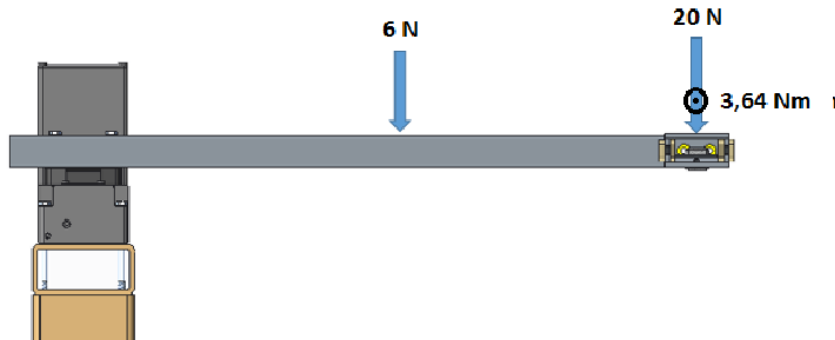
a mm	b mm	s mm	t mm	r mm	r ₁ mm	kg/m	numero number
50	30	2	2	0,5	—	0,82	4496
50	30	2,5	2,5	0,5	0,5	1,01	3898
50	30	3	3	0,5	0,5	1,20	1570
50	35	2	2	1,5	—	0,88	2355
50	35	2,55	2,55	3,0	3,0	1,099	9726
50	40	2,5	2,5	1,0	0,5	1,15	3106
50	40	4	4	0,5	0,5	1,78	4790
60	20	2	2	0,5	—	0,82	500
60	25	2,5	2,5	0,5	0,5	1,08	17725
60	25	3	3	0,5	0,5	1,28	1460
60	30	2	2	2,5	0,5	0,93	3277
60	40	1,5	1,5	2,0	0,5	0,79	1555
60	40	2	2	1,0	0,5	1,04	4015
60	40	3	3	—	—	1,52	331
60	40	3	3	3,0	—	1,51	3150
60	55	2	2	—	—	1,20	1286
65	30	2,5	2,5	1,0	0,5	1,21	5045
70	42	3	3	1,0	0,5	1,71	4817
70	50	4	4	0,5	3,0	2,44	2277
70	60	3	3	5,0	2,0	1,97	705
70	60	4	4	3,0	2,0	2,62	5213
71	61	3,5	3,5	5,0	1,5	2,31	1825
75	25	1,5	1,5	0,5	0,5	0,81	5260
75	25	3	3	2	0,5	1,515	16355
75	30	4	4	0,5	—	2,10	854
80	40	2	2	1,0	0,5	1,25	4014
80	40	3	3	—	—	1,85	1580
80	40	3	3	2,0	1,0	1,85	873
80	40	4	4	2,0	0,5	2,408	9266
80	40	4	4	2,0	1,0	2,411	9161
80	40	4	4	0,5	0,5	2,42	1461
80	40	5	5	0,5	—	2,97	1305
80	50	2,5	6,5	0,5	1,0	2,660	8532
80	60	3,5	3,5	5,0	1,5	2,46	706
80	60	4	4	2,0	1,0	2,85	252
90	42	4	4	2,0	1,0	2,67	3609
90	50	4	4	0,5	3,0	2,87	1262
100	20	2	2	—	—	1,25	942
100	25	2	2	4,0	5,0	1,326	7289
100	35	2	2	0,5	—	1,41	1944

RESULTS OF ARM BEAM SELECTION CALCULATION FOR TRANSFER SYSTEM WITHOUT ROTATION



rectangular profile:
 thickness = 2,5 mm b := 60mm
 kg/m = 1,08 h := 25mm
 t := 2.5mm

$$I := \frac{b \cdot h^3}{12} - \frac{(b - 2t)(h - 2 \cdot t)^3}{12} = 4.146 \times 10^{-8} \text{ m}^4$$



RESULTS

To accommodate the slider screws, larger profile than required was used.

Used profile:
 $I = 4.146 \times 10^{-8} \text{ m}^4$

Needed second moment of area

$$v_m := \max(\max(V), -\min(V))$$

$$I_{tarv} := \frac{v_m}{v_{max}} \cdot I_1$$

$$I_{tarv} = 10.67 \times 10^{-9}$$

$$\max(|\vec{M}|) = 10.52 \times 10^0$$

$$\max(|\vec{Q}|) = 24.958 \times 10^0$$

$$\max(|\vec{\sigma}|) = 3.172 \times 10^6$$

$$\max(|\vec{v}|) = 257.352 \times 10^{-6} \text{ m} = 0.257\text{mm}$$

Maximum bending moment

Maximum shear force

Maximum normal stress

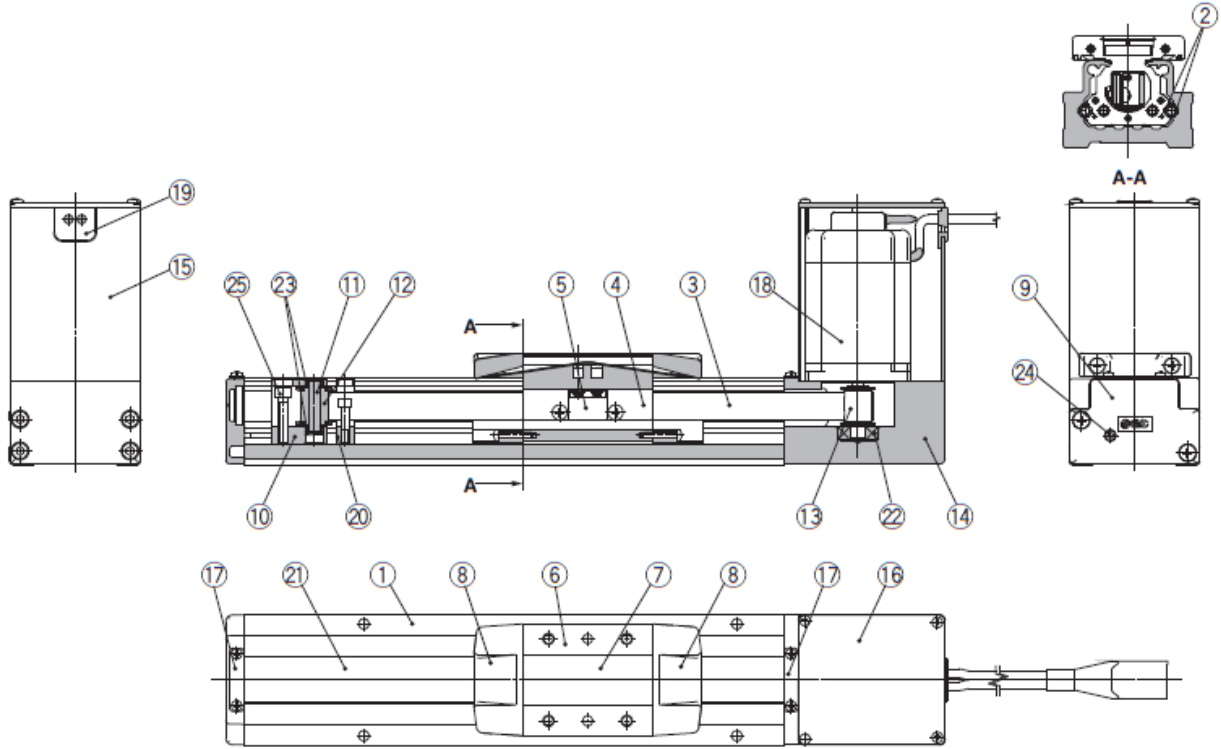
Maximum displacement

[Arm beam selection calculation from Mathcad for transfer system without rotation are excluded from public version]

TECHNICAL DRAWINGS OF LINEAR ACTUATOR FOR HORIZONTAL ACTUATION

Construction

Series LEFB

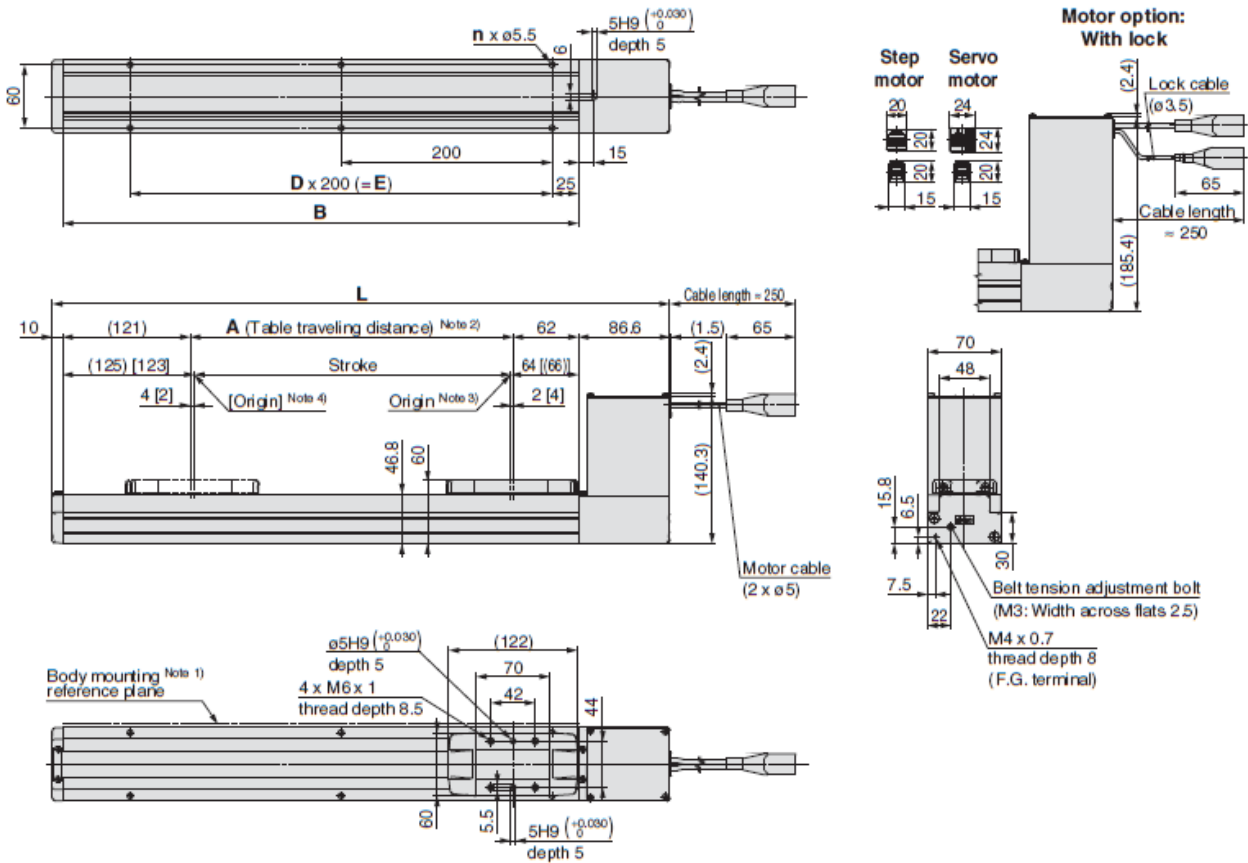


No.	Description	Material	Note
1	Body	Aluminium alloy	Anodised
2	Rail guide	—	
3	Belt	—	
4	Belt holder	Carbon steel	Chromating
5	Belt stopper	Aluminium alloy	Anodised
6	Table	Aluminium alloy	Anodised
7	Blanking plate	Aluminium alloy	Anodised
8	Seal band stopper	Synthetic resin	
9	Housing A	Aluminium die-cast	Coating
10	Pulley holder	Aluminium alloy	
11	Pulley shaft	Stainless steel	
12	End pulley	Aluminium alloy	Anodised
13	Motor pulley	Aluminium alloy	Anodised
14	Motor mount	Aluminium alloy	Anodised
15	Motor cover	Aluminium alloy	Anodised
16	End cover	Aluminium alloy	Anodised
17	Band stopper	Stainless steel	
18	Motor	—	
19	Rubber bushing	NBR	
20	Stopper	Aluminium alloy	
21	Dust seal band	Stainless steel	
22	Bearing	—	
23	Bearing	—	
24	Tension adjustment bolt	Chromium molybdenum steel	Chromating
25	Pulley fixing bolt	Chromium molybdenum steel	Chromating

TECHNICAL DRAWINGS OF LINEAR ACTUATOR FOR HORIZONTAL ACTUATION

Dimensions: Belt Drive

LEFB32



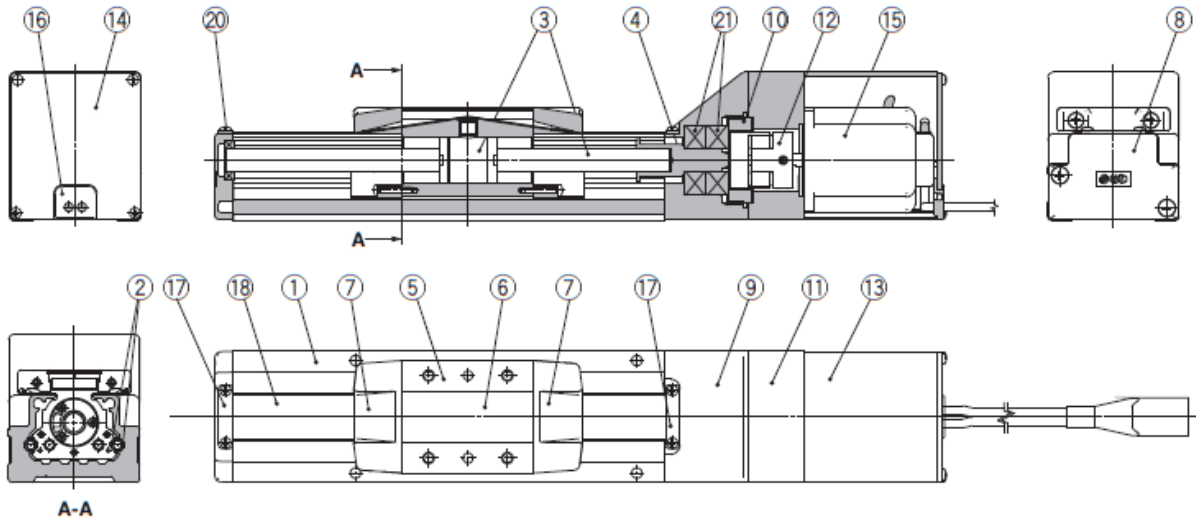
- Note 1) When mounting the actuator using the body mounting reference plane, set the height of the opposite surface or pin to be 3 mm or more because of R chamfering. (Recommended height 5 mm)
- Note 2) Distance within which the table can move when it returns to origin. Make sure a workpiece mounted on the table does not interfere with the work pieces and facilities around the table.
- Note 3) Position after return to origin
- Note 4) [] for when the direction of return to origin has changed.

Model	L	A	B	n	D	E
LEFB32□T-300□	585.6	306	489	6	2	400
LEFB32□T-500□	785.6	506	689	8	3	600
LEFB32□T-600□	885.6	606	789	8	3	600
LEFB32□T-700□	985.6	706	889	10	4	800
LEFB32□T-800□	1085.6	806	989	10	4	800
LEFB32□T-900□	1185.6	906	1089	12	5	1000
LEFB32□T-1000□	1285.6	1006	1189	12	5	1000
LEFB32□T-1200□	1485.6	1206	1389	14	6	1200
LEFB32□T-1500□	1785.6	1506	1689	18	8	1600
LEFB32□T-1800□	2085.6	1806	1989	20	9	1800
LEFB32□T-2000□	2285.6	2006	2189	22	10	2000

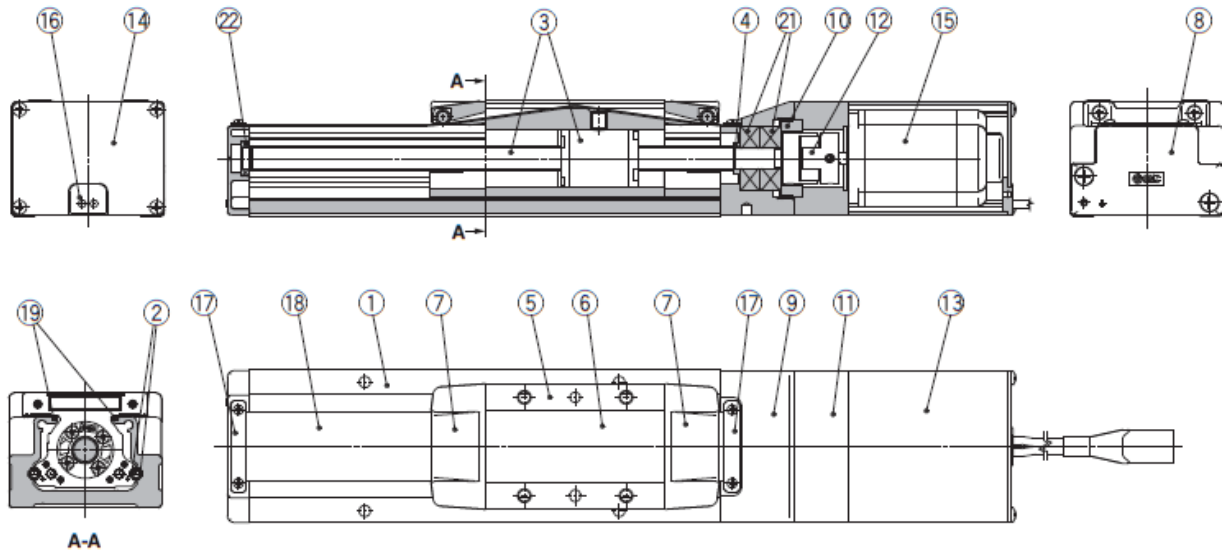
TECHNICAL DRAWINGS OF LINEAR ACTUATOR FOR OVEN DOOR OPERATION

Construction: In-line Motor

LEFS16, 25, 32



LEFS40



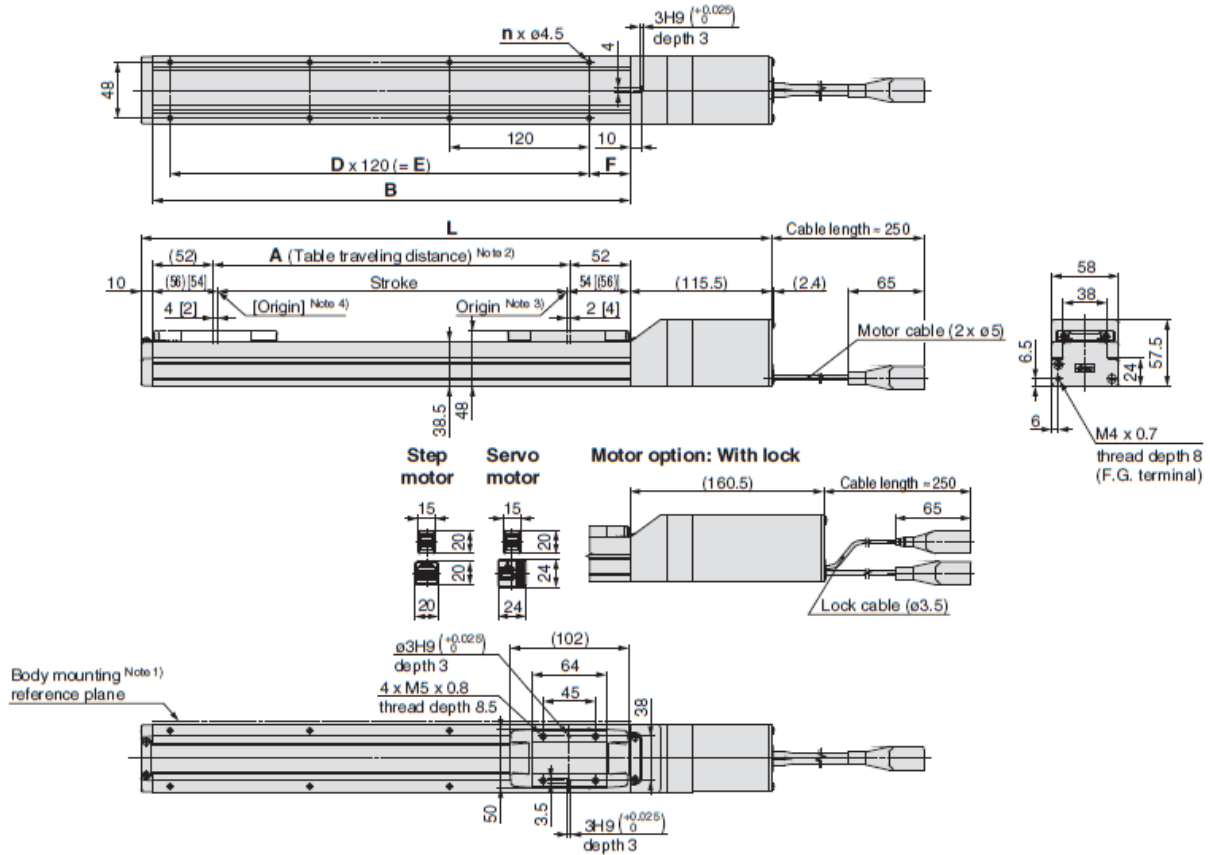
No.	Description	Material	Note
1	Body	Aluminium alloy	Anodised
2	Rail guide	—	
3	Ball screw assembly	—	
4	Connected shaft	LEFS16, 25, 32	
	Spacer	LEFS40	
5	Table	Aluminium alloy	Anodised
6	Blanking plate	Aluminium alloy	Anodised
7	Seal band stopper	Synthetic resin	
8	Housing A	Aluminium die-casted	Coating
9	Housing B	Aluminium die-casted	Coating
10	Bearing stopper	Aluminium alloy	

No.	Description	Material	Note
11	Motor mount	Aluminium alloy	Coating
12	Coupling	—	
13	Motor cover	Aluminium alloy	Anodised
14	End cover	Aluminium alloy	Anodised
15	Motor	—	
16	Rubber bushing	NBR	
17	Band stopper	Stainless steel	
18	Dust seal band	Stainless steel	
19	Seal magnet	—	
20	Bearing	—	
21	Bearing	—	

TECHNICAL DRAWINGS OF LINEAR ACTUATOR FOR OVEN DOOR OPERATION

Dimensions: In-line Motor

LEFS25



- Note 1) When mounting the actuator using the body mounting reference plane, set the height of the opposite surface or pin to be 3 mm or more because of R chamfering. (Recommended height 5 mm)
- Note 2) Distance within which the table can move when it returns to origin. Make sure a workpiece mounted on the table does not interfere with the work pieces and facilities around the table.
- Note 3) Position after return to origin
- Note 4) [] for when the direction of return to origin has changed.

Dimensions

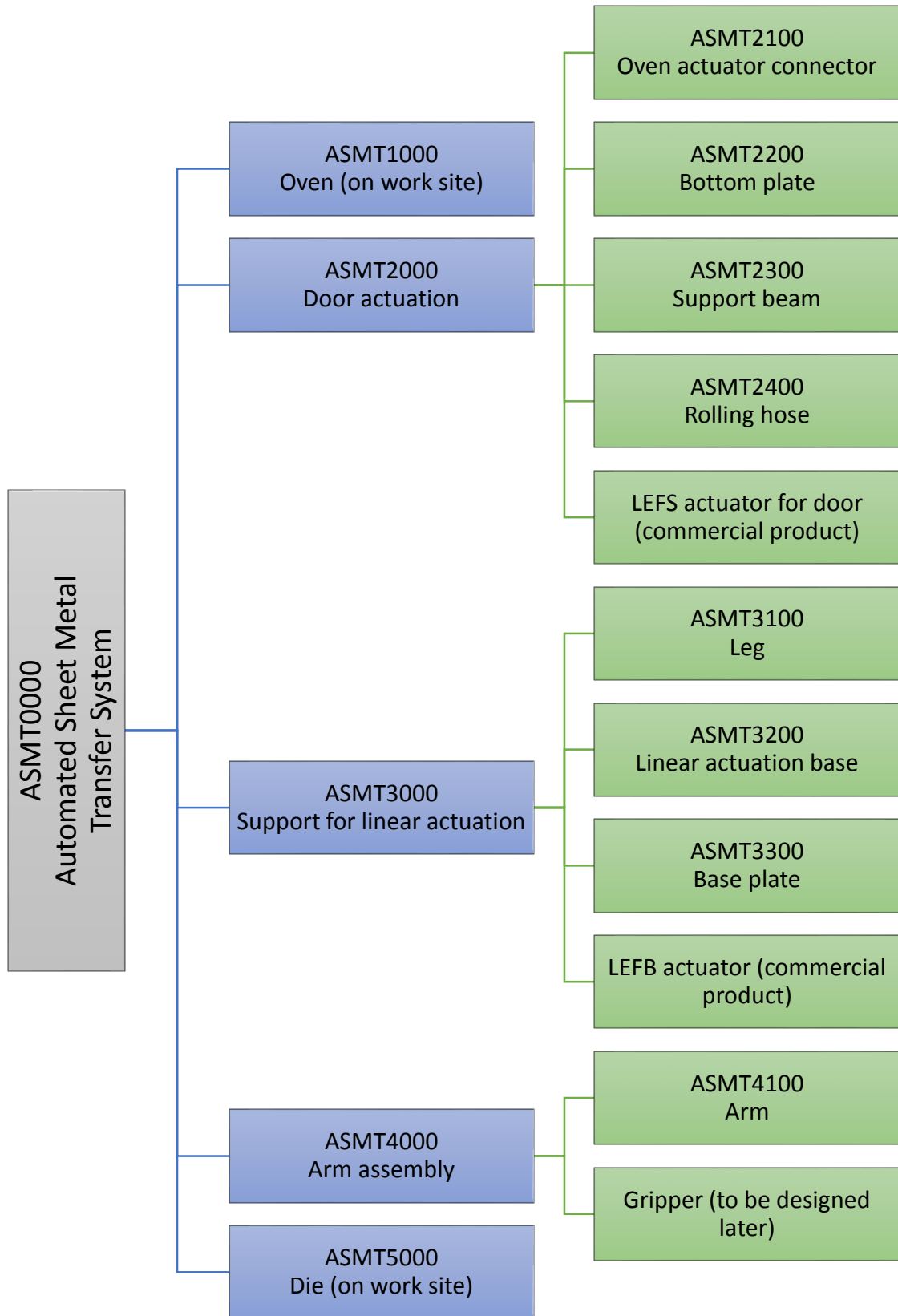
Model	L		A	B	n	D	E	F
	Without lock	With lock						
LEFS25□-50□	285.5	330.5	56	160	4	—	—	20
LEFS25□-100□	335.5	380.5	106	210	4	—	—	35
LEFS25□-150□	385.5	430.5	156	260	4	—	—	
LEFS25□-200□	435.5	480.5	206	310	6	2	240	
LEFS25□-250□	485.5	530.5	256	360	6	2	240	
LEFS25□-300□	535.5	580.5	306	410	8	3	360	
LEFS25□-350□	585.5	630.5	356	460	8	3	360	
LEFS25□-400□	635.5	680.5	406	510	8	3	360	
LEFS25□-450□	685.5	730.5	456	560	10	4	480	
LEFS25□-500□	735.5	780.5	506	610	10	4	480	
LEFS25□-550□	785.5	830.5	556	660	12	5	600	
LEFS25□-600□	835.5	880.5	606	710	12	5	600	
LEFS25□-650□	885.5	930.5	656	760	12	5	600	
LEFS25□-700□	935.5	980.5	706	810	14	6	720	
LEFS25□-750□	985.5	1030.5	756	860	14	6	720	
LEFS25□-800□	1035.5	1080.5	806	910	16	7	840	



Step Motor (Servo/24 VDC) / Servo Motor (24 VDC) | LEFS | LEFB | LECA6 | LECP6 | LEC-G | LEC-P1 | LEC-PA | LEFS | LEFB | LEFS | LECS□ | LEFG | Specific Product Precautions

[13 manufacturing drawings are excluded from public version]

ASSEMBLY TREE FOR AUTOMATED SHEET METAL TRANSFER SYSTEM



PRODUCT PART LIST AND MANUFACTURER OR RESELLER

Table Product part list and manufacturer/reseller.

Manufacturer/reseller	Name	Product code	Quantity
SMC Pneumatics Finland Oy	LEFS actuator for door operation	LEFS 25 B-500B-S31N3	1
SMC Pneumatics Finland Oy	LEFB actuator for linear actuation	LEFB32T-1500-R31N3	1
Purso Oy/local distributor	Aluminium profile	60 mm x 25 mm x 2.5 mm	1000 mm
Check raw material store of HAMK or contact raw material purchaser of HAMK.	Steel profile	80 mm x 40 mm x 4 mm	1580mm x 1pc 1500mm x 1pc 850mm x 2pc
	Hexagonal nut DIN933	DIN933-8.8-M05	10
	Hex screw	DIN933-8.8-M05x18	4
	Hex screw	DIN933-8.8-M05x75	10
	Hex Screw	DIN931-8.8-M05x70	2
	Hexagonal nut	DIN934 - 8.8 - M05	2
	Flat washer	DIN125-A 5	2

Similar hex screws can be used instead of ordering different standard screws. Length of screw are only important dimension.

1. SMC Pneumatics Finland Oy

SMC Pneumatics Finland Oy

Keskus. 0207 513513

Fax. 0207 513595

PL 72 (Tiistinniityntie 4)

Y-tunnus 1650102-9

02231 ESPOO

Sales and technical support contact can be found in link below.

https://www.smc.eu/portal_ssl/WebContent/local/FI/Yhteyshenkilot/Yhteyshenkilot.jsp?tree_options=tree_contact.js&tree_state=0&tree_highlighted_node=6050

2. Purso Oy

Commercial profile can be found in catalogue from webpage of company. But they sell in large quantities only so it is recommended to contact material purchaser of HAMK to buy given profile.

<http://purso.fi/en/products-and-systems/profiilit-ja-komponentit/standard-profiles/>

3. Local distributor or raw material purchaser from HAMK can be contacted for steel profiles. There may be profiles in HAMK material store as well.
4. Blank steel slab 100 x 60 x 10
5. Blank steel slab 100 x 100 x 5
6. Blank steel slab 150 x 150 x 10