DESIGN, CONSTRUCTION AND IMPLEMENTATION OF AN AUTOMATED ASSEMBLY MACHINE TO PRODUCE THE FURNITURE RAILS

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DECEMBER 2022

ÇANKAYA UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEPARTMENT OF MECHATRONICS ENGINEERING

MASTER'S THESIS IN

MECHATRONICS ENGINEERING

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ABSTRACT

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Master of Science in Mechatronics Engineering

Supervisor: Prof. Dr. Can ÇOĞUN
December 2022, 59 Pages

The scope of this thesis is the design, production and implementation of an Assembly Machine to assemble the cage product, which is one of the products of Samet A.Ş. The machine was integrated into the production line after its preliminary performance tests. The slider systems, unit fittings, the transfer mechanism table and drive plate thickness, and other material properties used in the assembly machine were analyzed and determined using the finite element method. The design of the Vibrator Feeding units of the machine, the production of the designed parts and the software used in the machine operation were carried out within the company. The assembly machine, where the preliminary tests were completed, works successfully in the production line with 80 products/min speed.

Keywords: Cage of hidden rail, assembly machine, finite element analysis, design, production, implementation

ÖZ

MOBİLYA RAYLARI ÜRETMEK İÇİN OTOMATİK MONTAJ MAKİNASI TASARIMI, ÜRETİMİ VE UYGULAMASI

GEDİK, Muhammed Ali
Mekatronik Mühendisliği Yüksek Lisans

Danışman: Prof. Dr. Can ÇOĞUN
Aralık 2022, 59 Sayfa

Bu tez kapsamında Samet A.Ş. firmasının bir ürünü olan ve Slidea marka gizli rayın bir parçası olan kafes ürününün montaj makinasının tasarımı, üretimi ve denemeleri yapılmıştır. Montaj makinası ilk denemeler sonrasında üretim hattına eklenmiştir. Montaj makinasında kullanılan maça sistemleri, transfer mekanizması tablasının ve tahrik lamasının kalınlığı , piston bağlantı sistemi ve diğer malzeme özellikleri sonlu elemanlar yöntemi kullanılarak analiz edilmiş ve belirlenmiştir. Makinanın Vibratör Besleme Üniteleri, tasarımı yapılan parçaların üretimi ve makinanın çalışmasında kullanılan yazılım firma bünyesinde gerçekleştirilmiştir. Üretim hattında denemeleri yapılan montaj makinası halen 80 ürün/dak hızında başarı ile üretim hattında çalışmaktadır.

Anahtar Kelimeler: Gizli ray kafesi, montaj makinası, sonlu elemanlar analizi, tasarım, üretim, uygulama

ACKNOWLEDGEMENT

I want to thank Samet A.Ş. for sponsoring my design and I also would like to thank our R&D Manager and my teammates for sharing their experiences with me during the design phase.

Special thanks to my supervisor Prof. Dr. Can ÇOĞUN, for the excellent guidance and for providing me with an excellent atmosphere to conduct this research. My special gratitude to the rest of the thesis committee for the encouragement and insightful comments.

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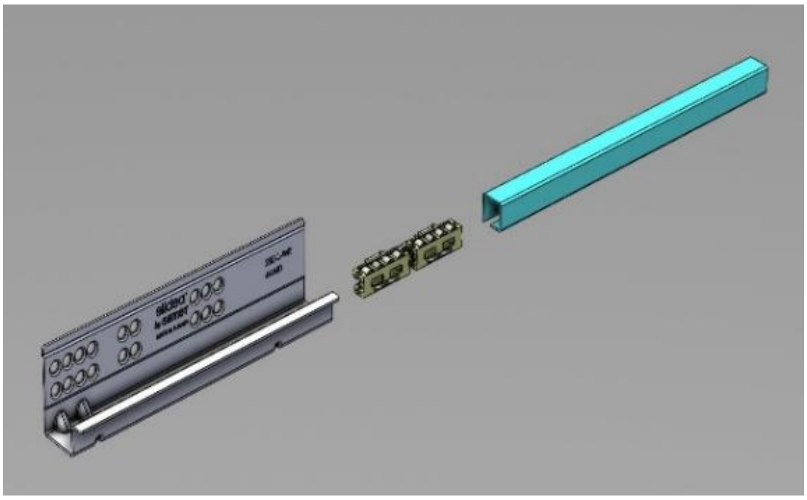
LIST OF ABBREVIATIONS

PLC	**:** Programmable Logic Controller
EDM	**:** Electrical Discharge Machining
AU	**:** Assembly Unit
QCM	**:** Quality Control Mechanism
QCC	**:** Quality Control Check
TM	**:** Transfer Mechanism

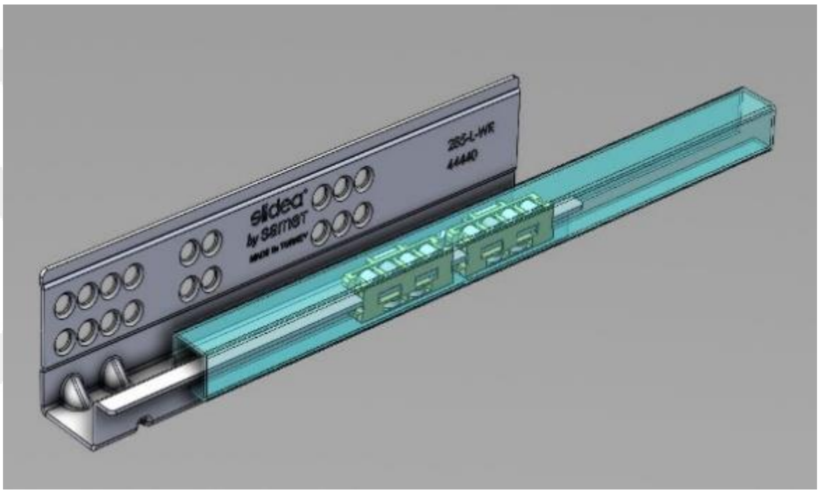
CHAPTER I
INTRODUCTION

Furniture rails are used in furniture drawer systems. The rails allow the drawer to be opened and closed. Rails usually consist of inner and outer rails. The manufacturers standardize the rail systems for use all over the world. One of these rail systems, named the “hidden rail systems”, consists of an inner and outer rail (Figure 1-a) [9]. The inner rail is mounted inside the furniture. The outer rail is fixed to the drawer. When the drawer is opened, the movement between the outer and inner rail is made by a ‘’cage’’ system. The length at which the cage is displaced determines the opening length of the rail. The cage is trapped inside the rail, and this prevents the rail from being disassembled (Figure 1-b). Cage systems can be made of metal and plastic. The cage of Samet A.Ş. consists of six Ø6 mm rollers, two Ø9 mm rollers and an empty cage (Figure 2). Since the cage has small rollers and an empty cage made of plastic, it is not easy to produce and requires a long time to assemble these parts manually. The cages, in which a person can assemble four to five products per minute, can be assembled by a machine at a speed of 80 products/min. Therefore, it is imperative to automate the assembly process.

Samet A.Ş. has an assembly machine for Slidea rail (Figure 1), which can assemble 15 products/min. Each of these parts is arranged in assembly units with different vibrator feeding units. The transfer units transport the empty cages to the assembly machine and quality control unit. At the end of the assembly process, it is decided whether the product has been correctly assembled. Similar machines can do quality control with laser or color sensors. However, these systems can only control the location of the plastic parts. In cases where the diameter of the plastic part is small, the rollers may come away from their position later.

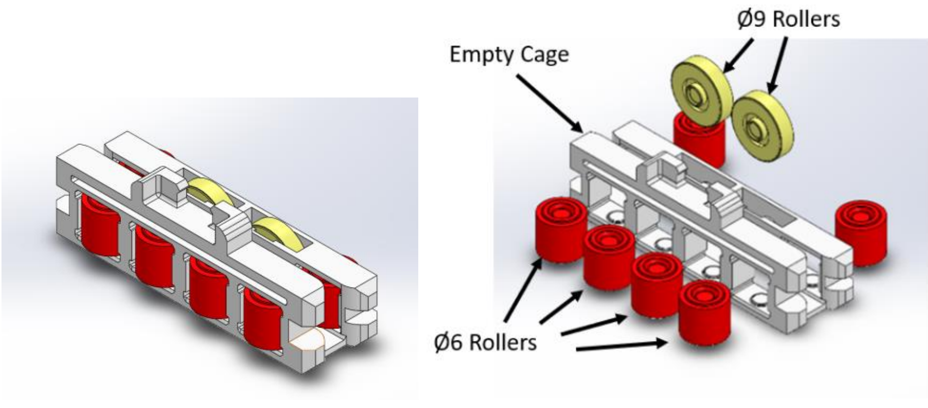


(a)



(b)

Figure 1: Samet A.Ş Slidea Hidden Rail, Case and Inner &Outer Slides a) Disassemble, b) Assembly



(a) (b)

Figure 2: a) Assembled Cage, b) Disassembled Cage

In this thesis, the design, production and implementation of a fully automated assembly machine, which works at a higher speed than the one available in the company, to assemble the cage of the rail systems produced by Samet A.Ş., is mentioned. The aim is to increase the assembly speed of the machine together with the maximum number of correct cages (i.e., maximum yield).

CHAPTER II
DESIGN, PRODUCTION AND IMPLEMENTATION OF THE ASSEMBLY MACHINE

2.1 WORKING PRINCIPLES OF THE MACHINE

The machine consists of four main groups, which are vibrators, assembly units [4], quality control mechanism and transfer mechanism [3]. The plastic parts to be assembled are arranged in the magazines of the machine using vibrators. The parts arranged in the magazine are assembled into empty cages carried by the transfer system consisting of pneumatic pistons and sliders. The assembled cages are controlled by control units, including pistons and slider systems and separated as correct or incorrect.

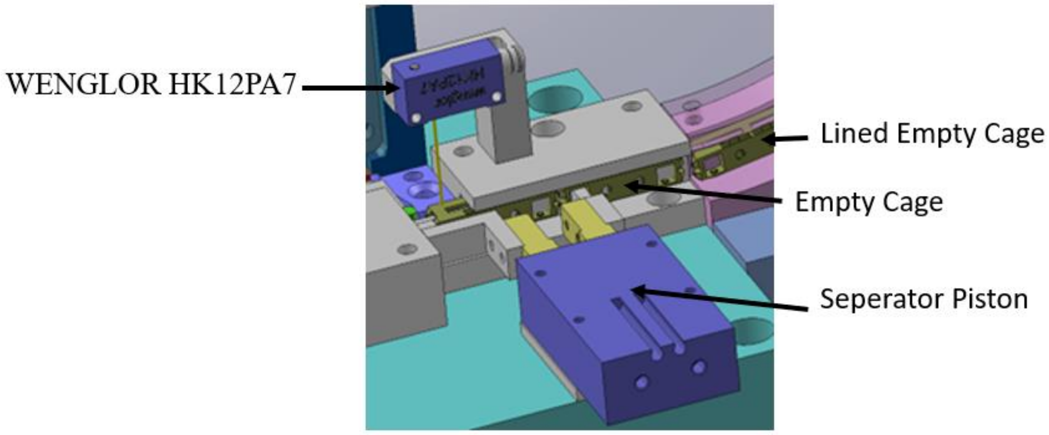


Figure 3: Separator Unit Images

The empty cages were lined with a magazine via a big vibrator. An empty cage was separated by SMC MIW 12/12D model separator piston (Figure 3) to the magazine's end and the TM's beginning. In this step, a laser sensor WENGLOR HK12PA7 detected the cage, and the separator pistons' back arm went into the space of the cage (Figure 3). The empty cage held by the piston was located in the TM fork (Figure 4) and moved to the next stage (Figure 5). Ø6 mm rollers lined up from a vibrator with four outlets are lined up in a special hose. The rollers that fall into the magazine by gravity from the hose are placed in the unit slider guide. The slider guide is moved by FESTO DSNU 25/50 Model piston.

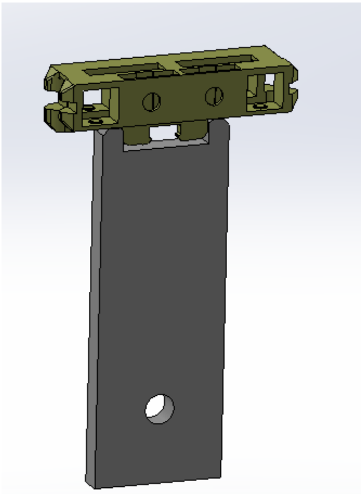


Figure 4: Fork of Transfer Mechanism and Cage

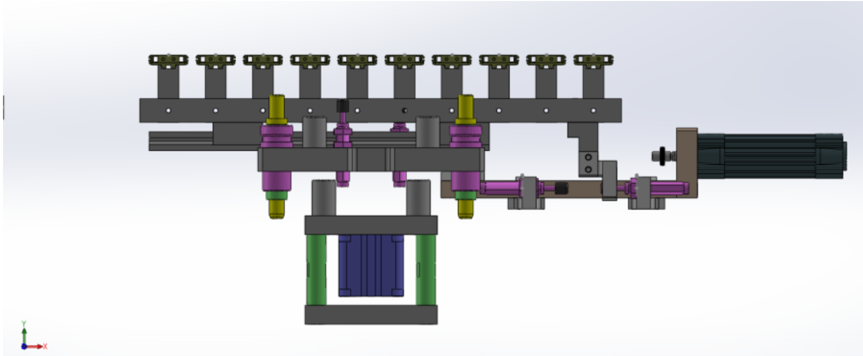


Figure 5: Pistons of the Transfer Mechanism

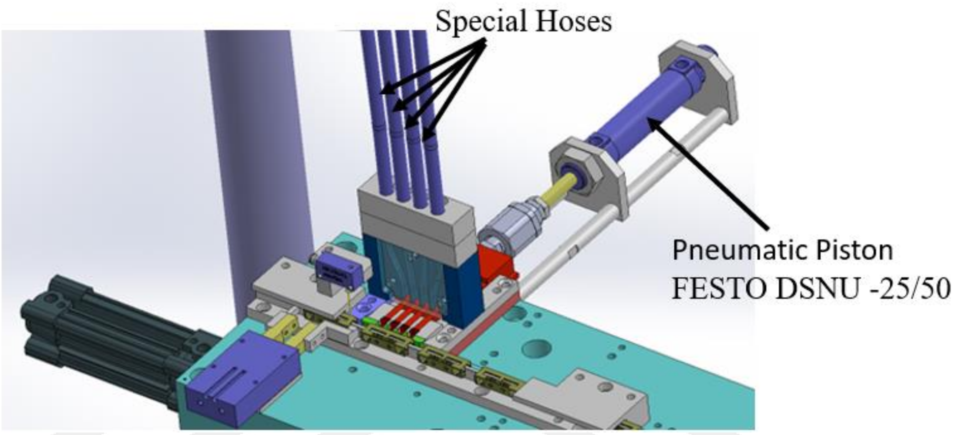
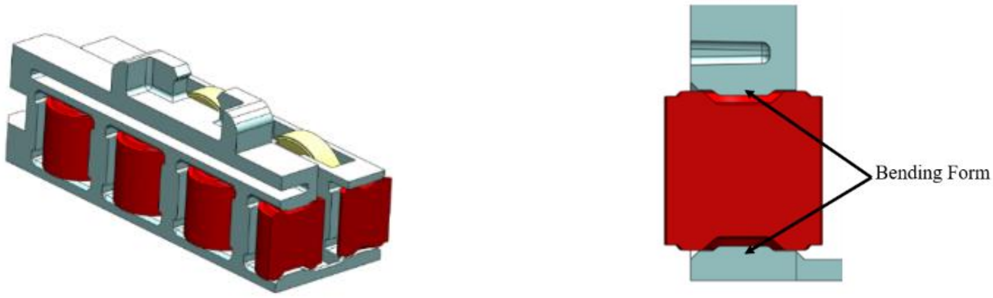
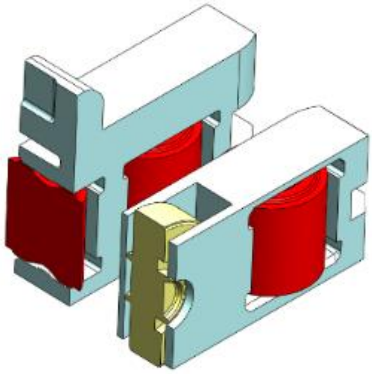


Figure 6: Design of 1st Ø6 mm Rollers Assembly Unit

Four Ø6 mm rollers are assembled into the cage by the movement of the slider guide (Figure 6). The pneumatic piston supplies the 6 N force needed for assembling rollers. During the rollers' assembly, the cage holes were bent, enabling the rollers to place into the cage (Figure 7). After the assembly of the four rollers, the cage is transferred to the next station for the first quality control check (QCC). In this unit (Figure 8), it is checked whether the assembly of the four rollers is successful or not. The control slider is moved by A SMC C85N 16/20 Model piston. The endpoint of the slider touches the assembled rollers with the stroke of the piston. The other piston, located vertically, was used to detect whether the assembly was completed by touching the slider's hole (Figure 8). After PLC read product completion data, the TM moved to the next stage to assemble the two Ø6 mm rollers. This assembly unit (Figure 9) had a very similar working principle to the four Ø6 mm rollers, except that the two rollers assembly unit had two roller compartments on the insert slider.



(a)



(b)

Figure 7: Section View a) Ø6 mm Rollers, b) Ø9 mm Roller

The next unit is the assembly unit of the Ø9 mm roller. In this unit, unlike other assembly units, the rollers are assembled on the vertical axis, not on the horizontal axis. Moreover, the vibrator unit of Ø9 mm rollers was actuated by gravity (Figure 10). The slider guide moved by the piston FESTO DSNU 16/25 pushes the Ø9 mm spool up to the cage. The Ø9 mm roller also stretches the cage as it enters it (Figure 7). After the Ø9 mm roller was assembled, the TM carried the cage to the next station, where the 2nd Ø9 mm roller was placed like the 1st Ø9 mm roller (Figure 11).

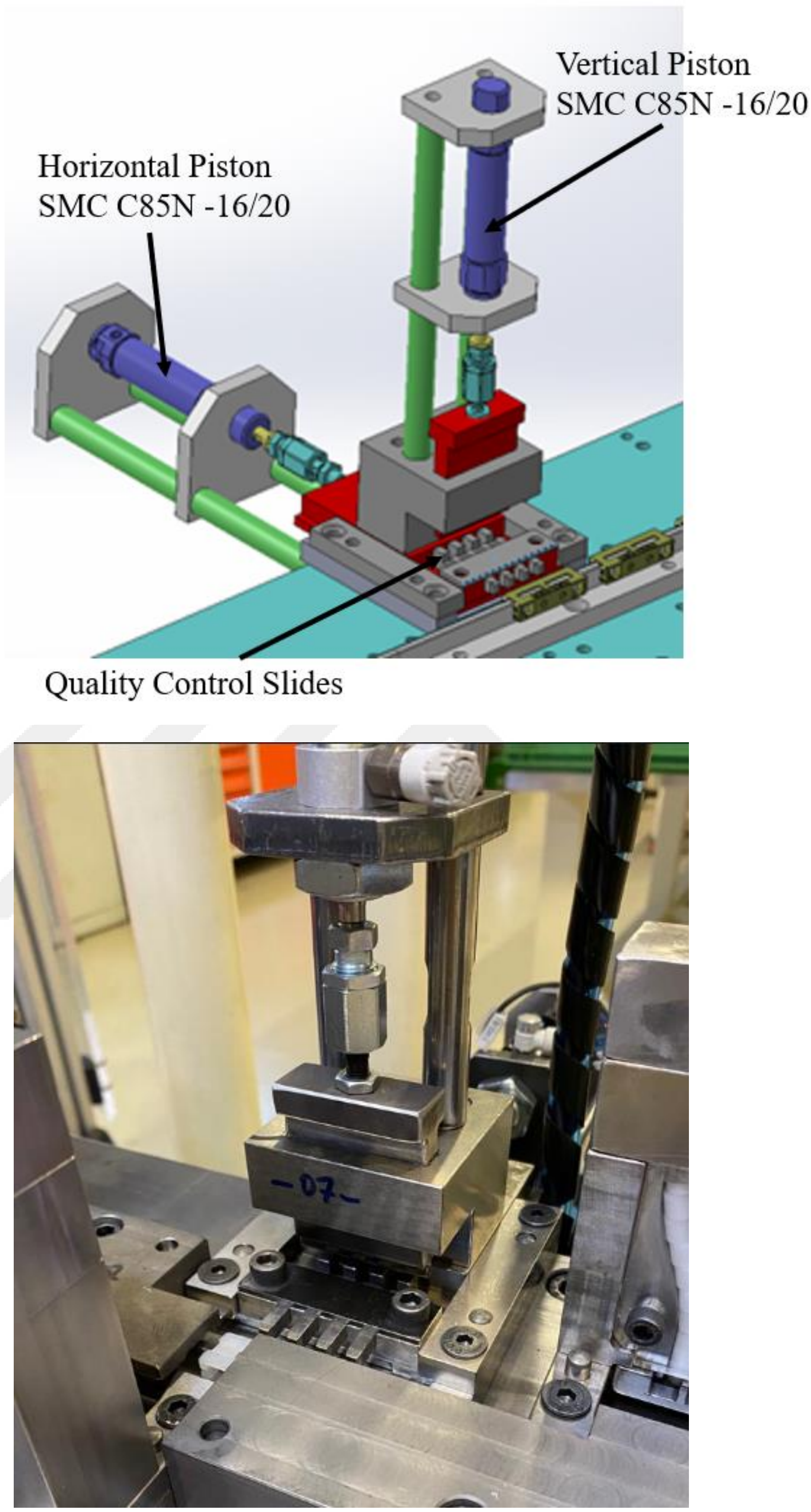


Figure 8: Quality Control Unit of Unit

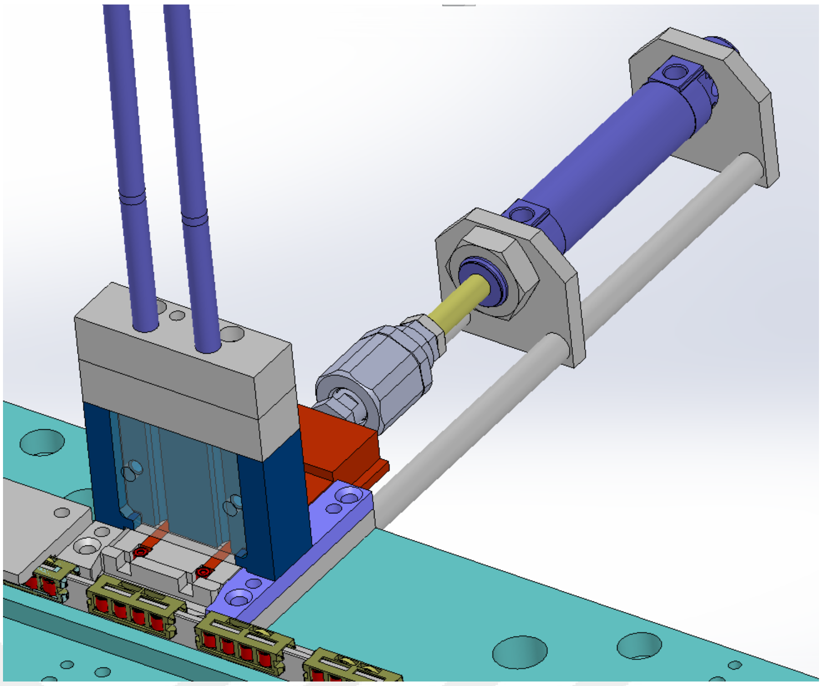
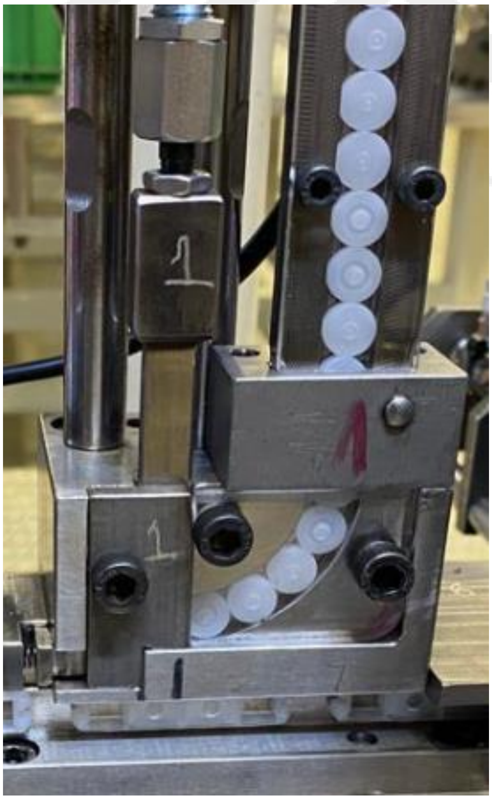


Figure 9: Design of 2nd Ø6 mm Roller Assembly Machine



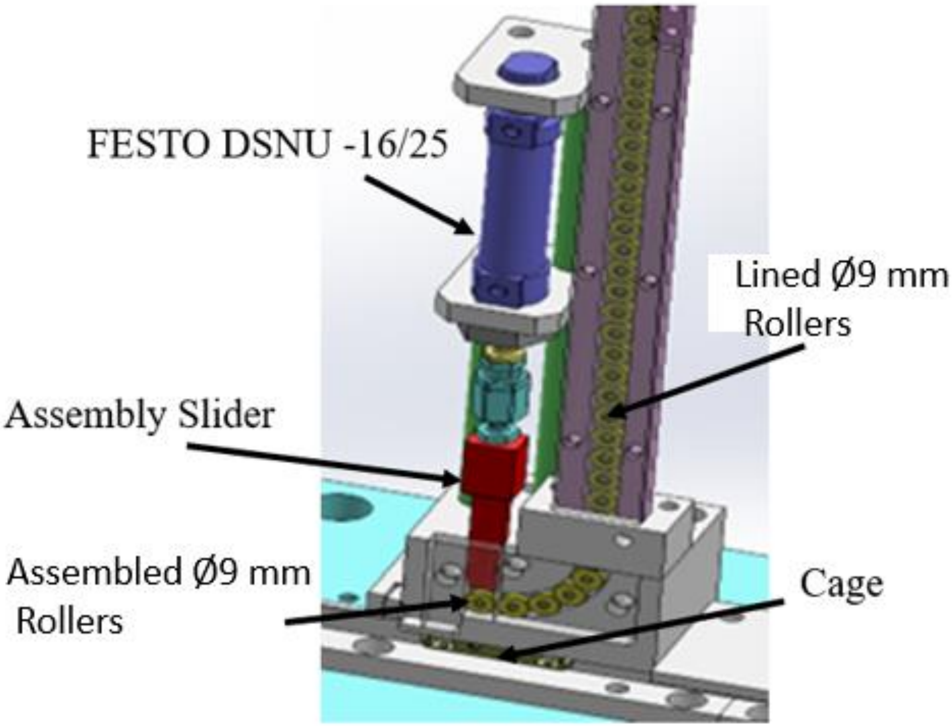


Figure 10: Magazine of Ø9 mm Roller Assembly Unit

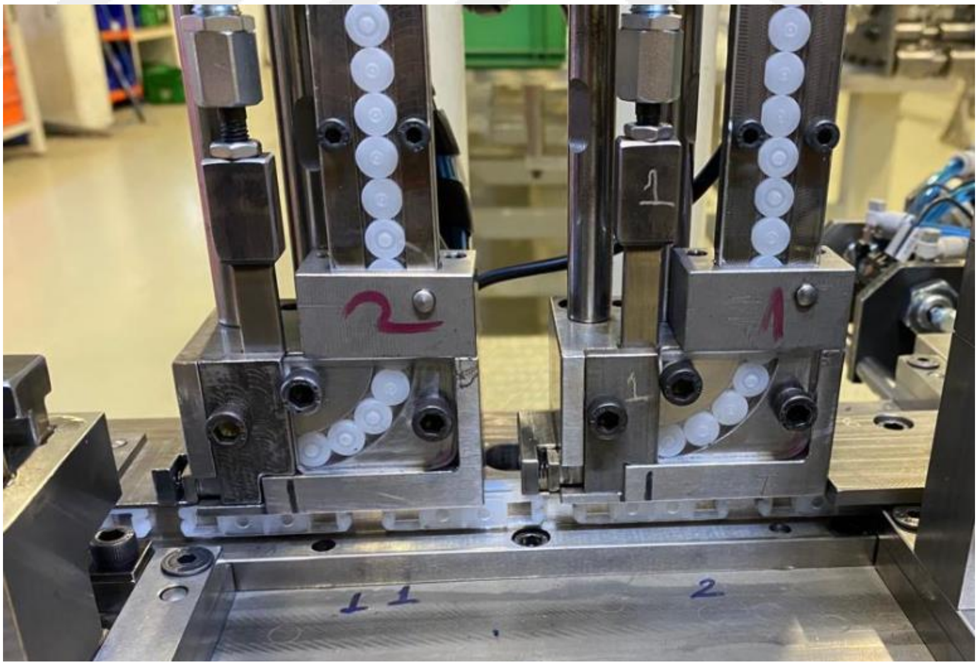


Figure 11: 1st and 2nd Ø9 mm Roller Assembly Units

After the second Ø9 mm roller was assembled, the TM carried the cage to the next unit. The four Ø6 mm rollers in the front were checked. Afterward, two Ø6 mm and two Ø9 mm rollers were checked. The 2nd QCC was performed the same way as the 1st QCC. After the 2nd QCC was completed (Figure 12) in the same way as the 1st QCC, the TM carried the cage to the waiting unit. At this unit, the cage waited for the decision about the box (acceptable or reject) to be directed. If the product is assembled correctly, it falls directly into the box from the gutter. If the product was assembled incorrectly, the FESTO DSNU 12/20 model piston pushed the cage into the defective product box (Figure 13).

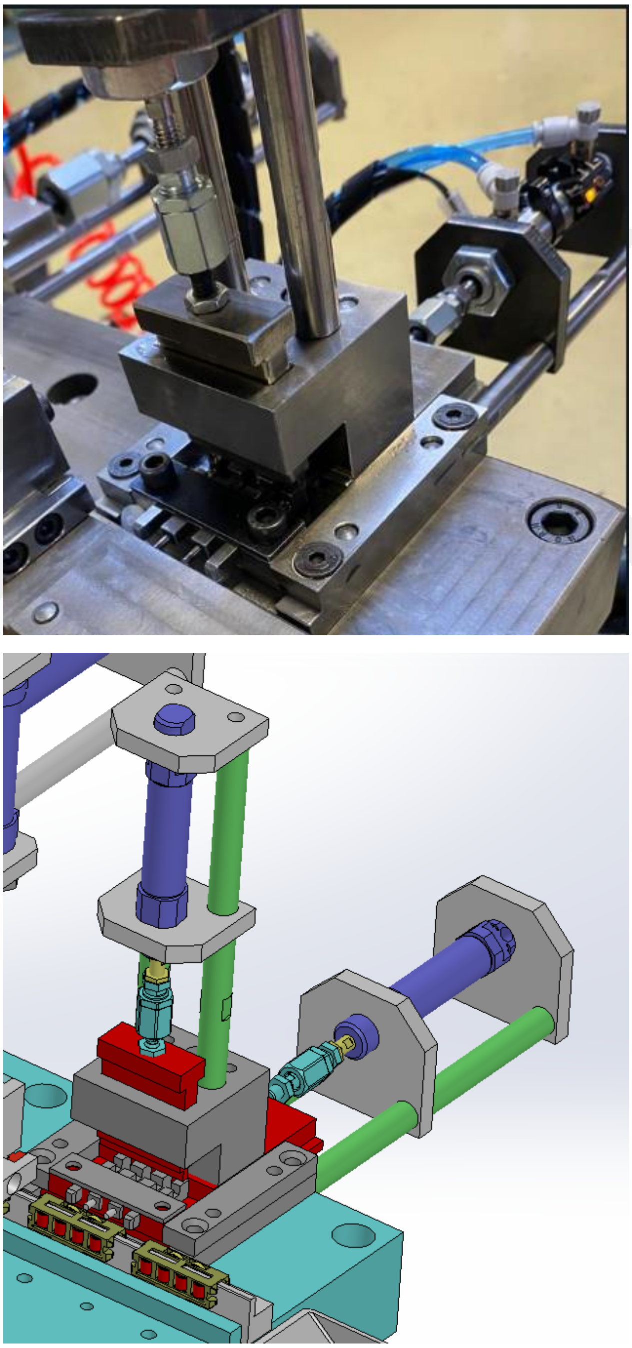


Figure 12: Design of 2nd Quality Control Check Unit

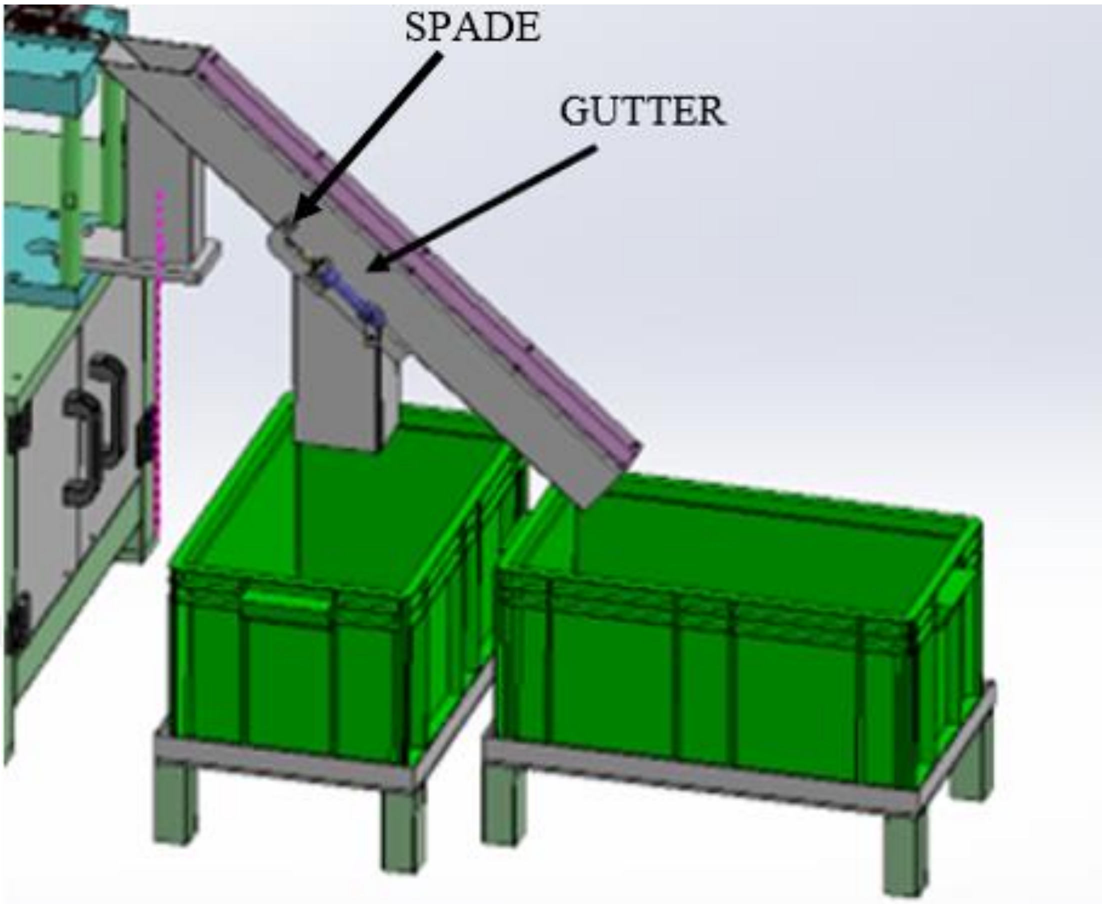
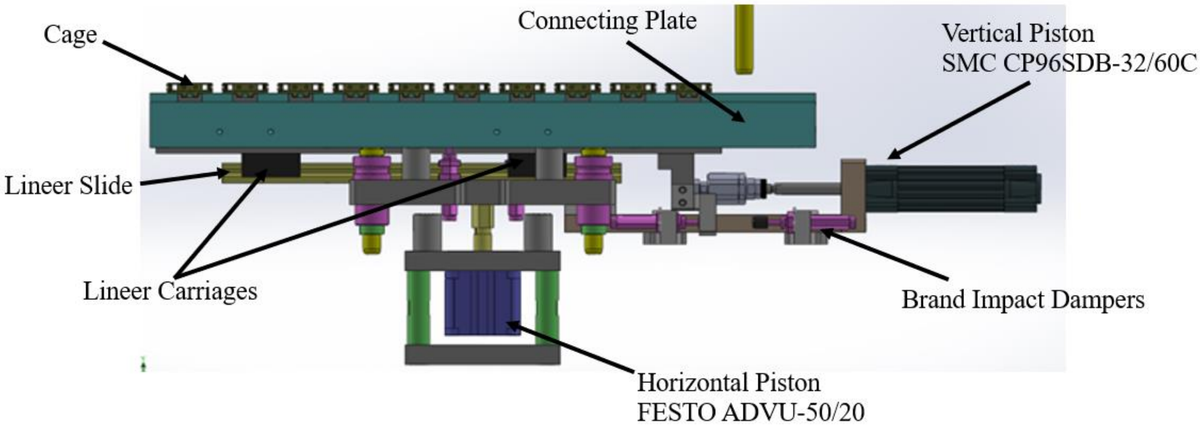


Figure 13: Gutter and Boxes

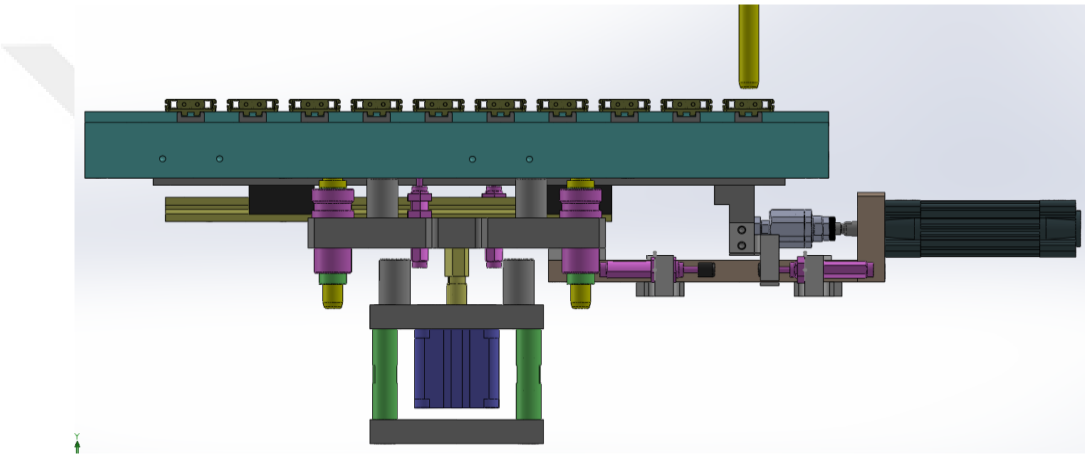
2.2 SUPPORTING SYSTEMS OF THE MACHINE

2.2.1 Transfer Mechanism

In the system, two pneumatic pistons work in the horizontal forward direction SMC CP96SDB 32/60C and the vertical FESTO ADVU 50/20 (Figure 14). A spade, in the form of a fork, holds the cage. The cage placed on the fork was moved to the next unit by the movement of the horizontal piston. The vertical piston ensures the separation of the roller from the forks. After the forks go down, the horizontal piston returns to its original position. When the vertical piston activates again, the forks catch the roller. In this way, the fork catches the previous cage. The cages are moved to the next station by the same way.



(a)



(b)

Figure 14: TM Positions, a) Forward Position, b) Zero Position

One linear slide and two linear carriages are fixed to the connecting plate of the forks (Figure 14). In this way, the forks move to the targeted position without any vibration and friction during the movement of the horizontal piston. Two SMC RBC1412 M14x1.5 Brand Impact Dampers relieve the contraction during the piston movements and reduce the impact force created by the piston in the first and last stroke. The position of these impact dampers can be adjusted according to the stroke of the horizontal piston. The two bolts are used to adjust the closing stroke of the shock absorbers. In the forward position, the bolt and shock absorber are connected in parallel (Figure 15). They are connected in parallel in the reverse position. These dimensions also set the distance between the units in the transfer system.

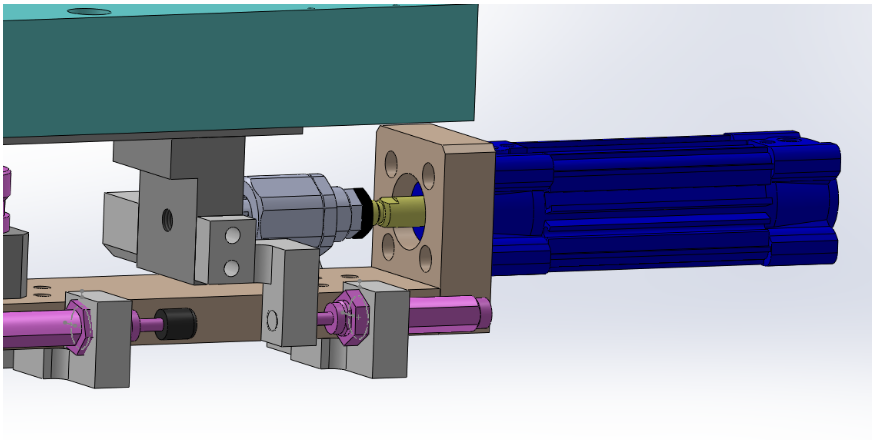


Figure 15: Stroke of Transfer System with Shock Observers

In the first and last strokes of the pistons, the large shaft inside the piston hits the wall of the outer piston (Figure 16). The abrasion of this inner shaft, which constantly strikes its front and rear walls in the first and last stroke positions, determines the piston's life. However, when the first and last strokes are not used, air remains in the forward and backward position of the piston. This feature ensures no collision of the piston inside the mill to the walls and, thus, a longer lifetime.

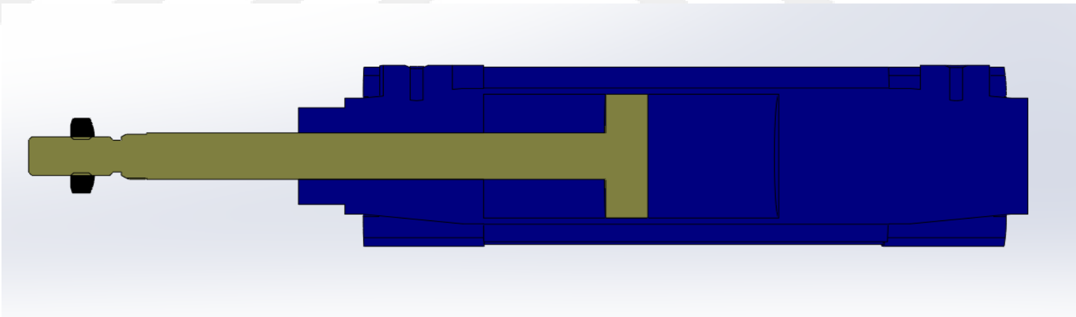


Figure 16: Cross-Sectional View of Pneumatic Piston

The piston connection plate is connected to the transfer mechanism table with four bushings to prevent axial misalignment. The height and back position of the fork on the vertical axis is set with shock absorbers. The stroke of the horizontal piston is set to 50 mm since there is 50 mm between each fork. The vertical piston stroke is limited by 10 mm. As the horizontal piston, the first and the last 5 mm and the stroke of the vertical piston are not functional.

2.2.2 Assembly Unit

The machine has four assembly units; two assemble the Ø6 mm rollers, and the remaining two assemble the Ø9 mm rollers. The first assembly unit is moved by FESTO DSNU 25-50 model piston. This piston drives the slider guide [2]. The transport slider is the size of the roller fed by four magazines.

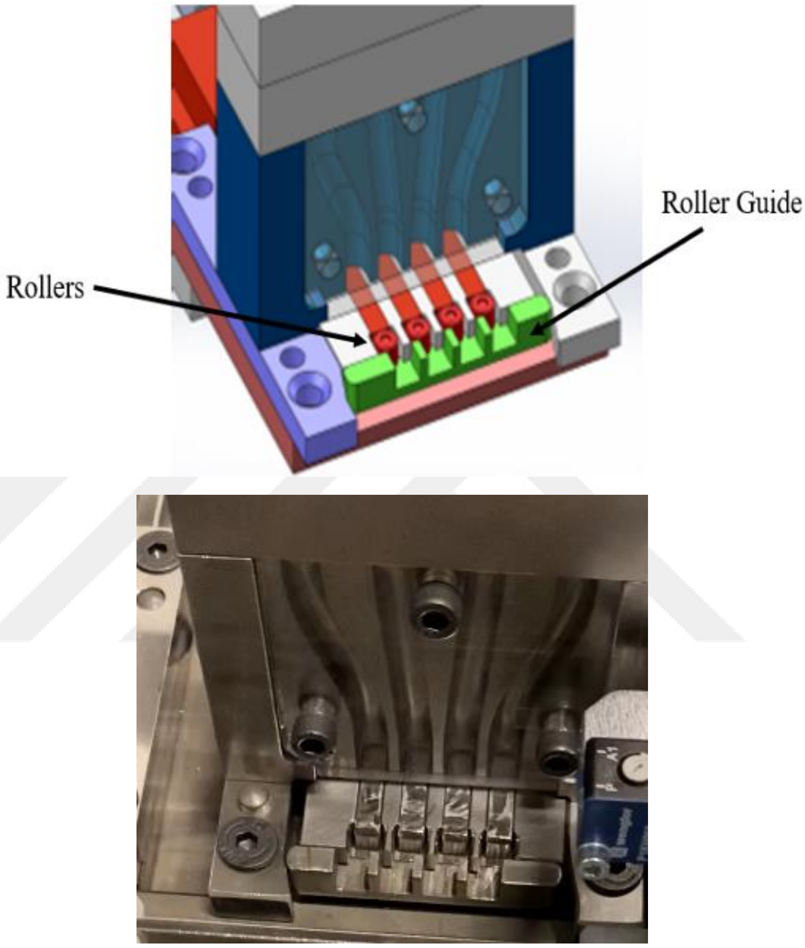


Figure 17: Design of Slide Form and Roller Guide

A roller guide prevents the products from falling from the magazines. The design, which prevents the product from coming out from vibrators at first, moves together as the slider guide moves and is oriented according to the design of the side sheets. When the piston pushes the slider guide to the end of the stroke, this does not impede the rollers, and the rollers will enter the cage (Figure 17). The second Ø6 mm roller assembly unit has two magazines (Figure 18) and operates as the first unit.

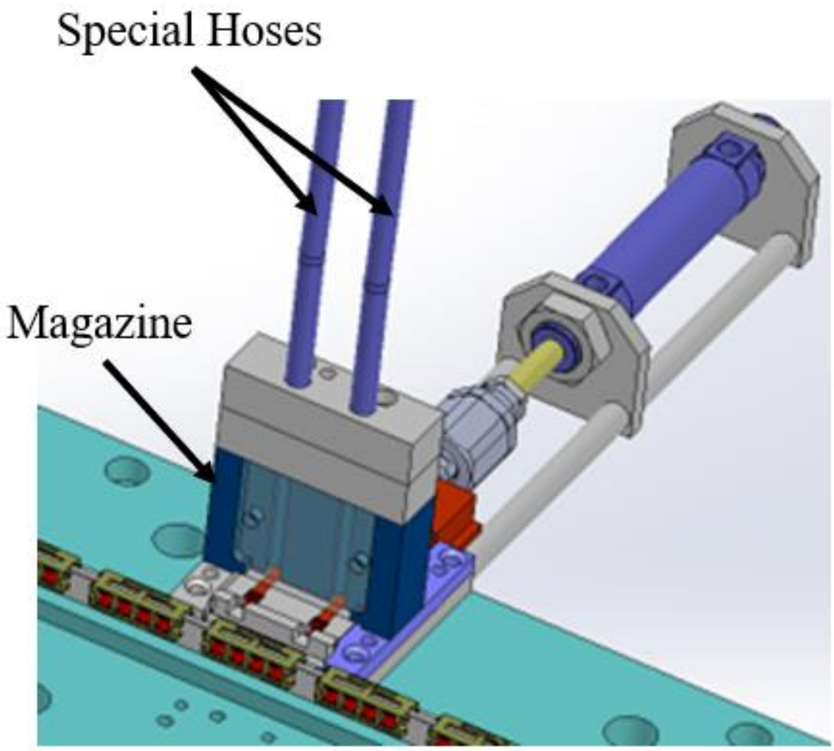


Figure 18: Design of 2nd Roller Assembly Unit

The Ø9 mm roller assembly unit is different from the others. FESTO DSNU 16/25 model piston was used for this process. The rollers line vertically and follow a quarter-circle path to enter the system (Figure 19). It is ensured that the products do not fall from the assembly unit with a simple spring-slider guide system. The compression spring keeps the free slider in the forward position. When the vertical piston pushes the insertion slider, the slider overcomes the spring force. When the piston reaches its final position, it pushes the Ø9 mm slider into the cage. The slider's geometry prevents other rollers from entering the system.

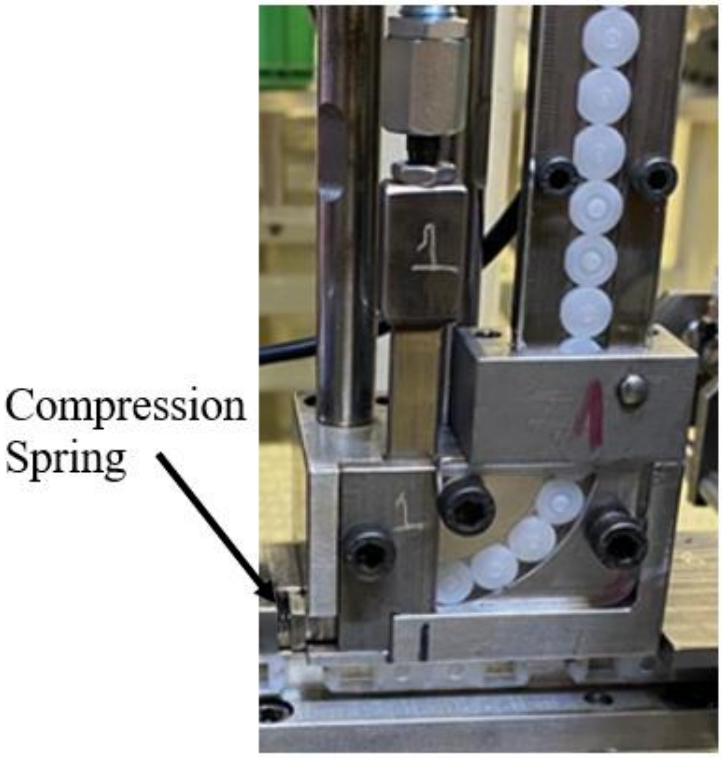
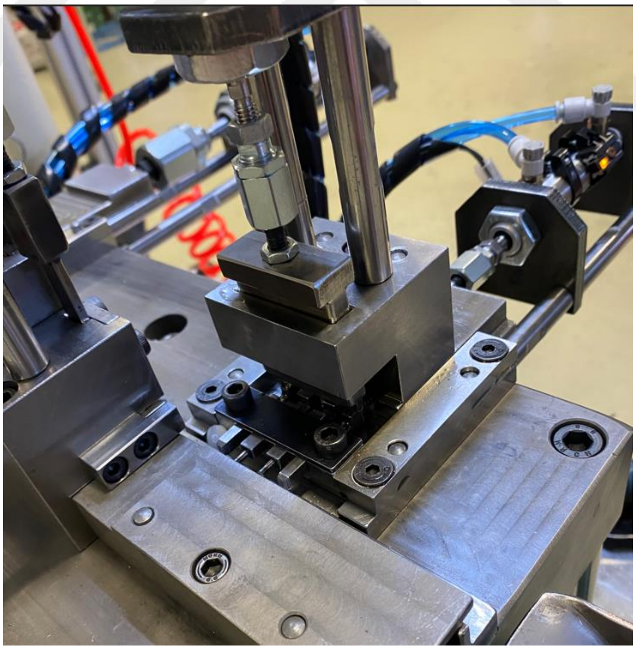


Figure 19: Magazine of Ø9 mm Roller

2.2.3 Quality Control Mechanism

There are two QCCs in the machine. The units are almost identical, except that the product they control differs. Therefore, the slider guides' design differs (Figure 20). The first QCC controls four Ø6 mm rollers. The second QCC controls two Ø6 mm and two Ø9 mm rollers. The QCC units consist of one SMC C85N-16/20 piston in the horizontal position and one SMC C85N 16/20 model piston in the vertical position. The vertical piston moves the slider that comes into contact with the products at the last stroke of the slider. The vertical piston controls whether the products are assembled or not.

(a)



(b)

Figure 20: The QQCs, a) the 1st QC, b) the 2nd QCC

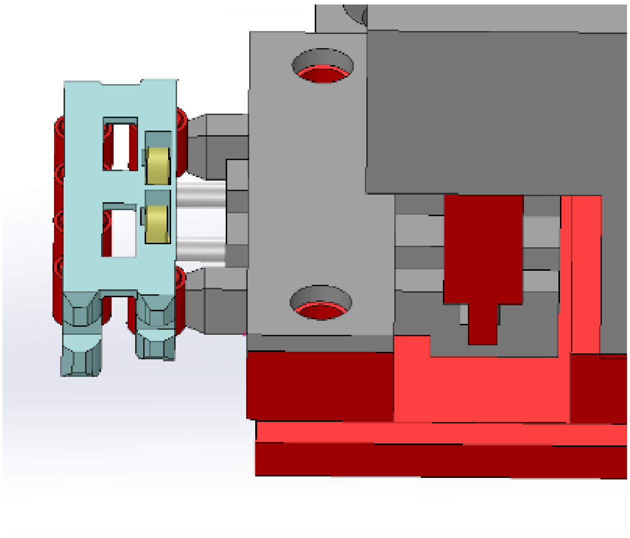


Figure 21: The QCC of the Correctly Assembled Cage

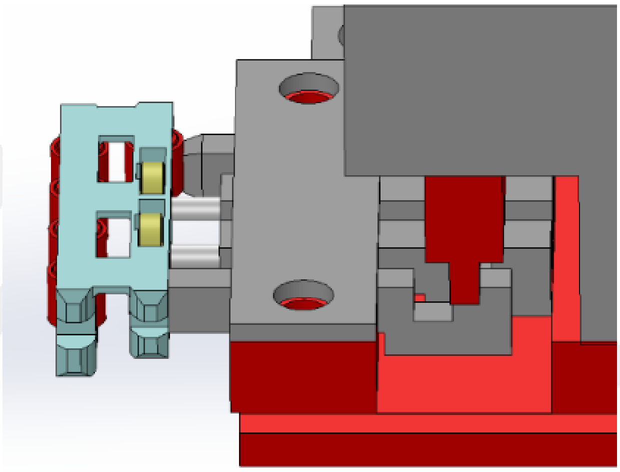


Figure 22: The QCC of the Mis-Assembled Cage

Four independent springs and sliders are connected to the horizontal piston. All four sliders will be aligned if a product is in the cage. When the vertical piston reaches its final stroke, the piston slider will enter the space of the four horizontal sliders. If the position sensor on the piston reads the value, the product passes QCC(Figure 21). If one or more roller(s) is not assembled, the independent slider(s) will enter the space of the roller (Figure 22). So, the vertical piston will not read a value in the stroke sensor (a rejected cage).

2.2.4 Vibrators

There are five vibrators in the assembly machine; two are for Ø6 mm rollers, two are for Ø9 mm rollers, and one is for the cage (Figure 23). Vibrators also act as

Quality Control units. The defective rollers (generally undesirable burrs and distorted shapes) cannot pass through the channels of the vibrator.

Figure 23: Vibrators of The Assembly Machine

2.3 MATERIALS SELECTION AND FEA OF THE SYSTEM COMPONENTS

2.3.1 The Meshing Of The Components

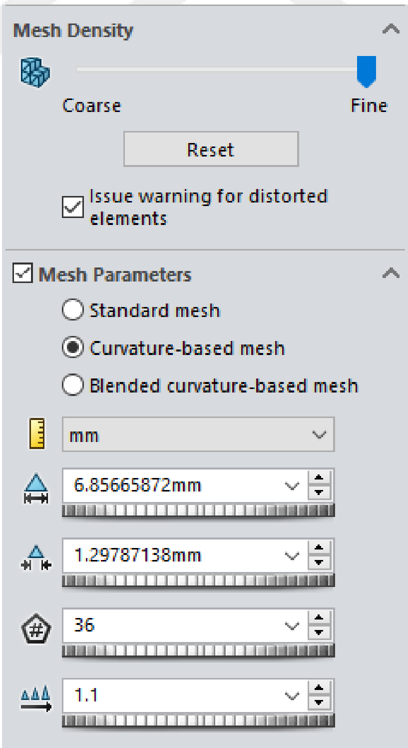


Figure 24: Mesh Parameters of Analysis

For the meshing process, the SolidWorks Simulation Software provides three user interfaces for mesh options. These are standard mesh, curvature-based mesh and blended curvature-based mesh (Figure 24). The curvature-based mesh is selected to precisely calculate the results by performing a more concentrated mesh on asymmetric and cylindrical surfaces. As the number of meshes increases, the analysis's precision also increases. However, the performance of the computer on which the meshing process is done needs to be satisfactory in handling the task. The minimum number of elements is a maximum of 36. On the other hand, the element size growth rate can be between 1.1 and 3. During the analysis in this chapter, 36 element numbers and the lowest rated element size growth (1.1) were selected to seek out the most realistic results.

2.3.2 Slider And Slider Guide

The 3D drawing and contact surfaces (red colored) of the slider system (Figure 25) of the Ø6 mm rollers mounting unit are shown in Figure 24. The force required to insert a roller into the cage is 6 N. So, the four rollers require 24 N for mounting. 300 N force capacity piston is used in the assembly machine. The force can be changed by changing the air pressure supplied to the piston. A piston with a diameter of 25 mm exerts a force of about 300 N at 6 bar pressure [5]. The critical issue to consider when choosing a piston is its force and application duration. Samet A.Ş. works with companies such as SMC and FESTO. The smallest tube diameter pistons produced by these companies are 12 mm. The force of this piston at 6 bar is 67 N. This piston seems sufficient for the assembly of these four rollers. Still, it is necessary to consider factors such as the friction force between the slider-slider guide systems, the production tolerance of the plastics to be mounted, and the burrs that form when the plastic comes out of the injection molding. Therefore, a "force multiplication factor (safety factor)'' is required when choosing a piston. SMC Company recommends this factor through an interface program [12]. The piston recommended by the program is a 20 mm tube diameter, and the force applied by this piston is 180 N. This piston was tested in the assembled system, and the machine's operating speed was 45-50 products/minute. A 25mm tube piston, which exerts a maximum 300N force on the slider-slider guide system, is used to increase the speed. According to this force, the slider guide structure was modified. The stress on the slider guide system and the safety factor were calculated based on this force value (Figure 26).

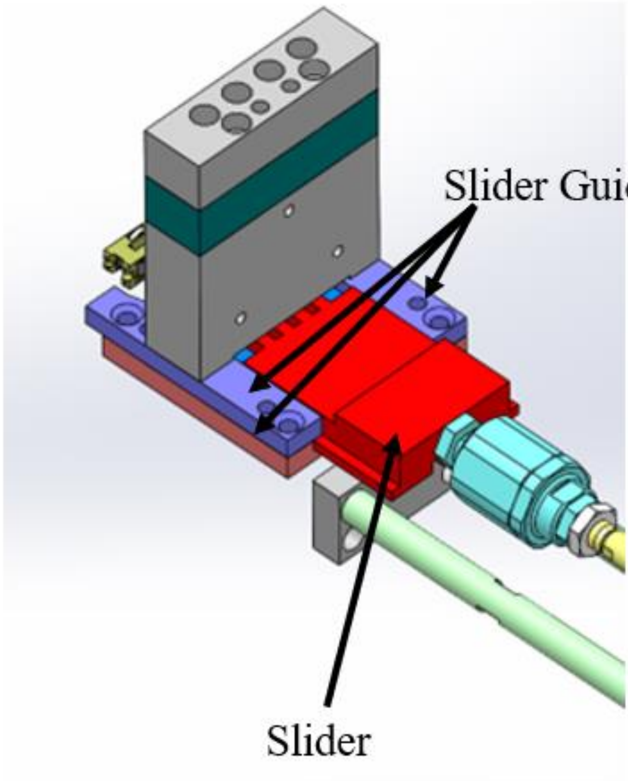


Figure 24: Slider & Slider Guide System

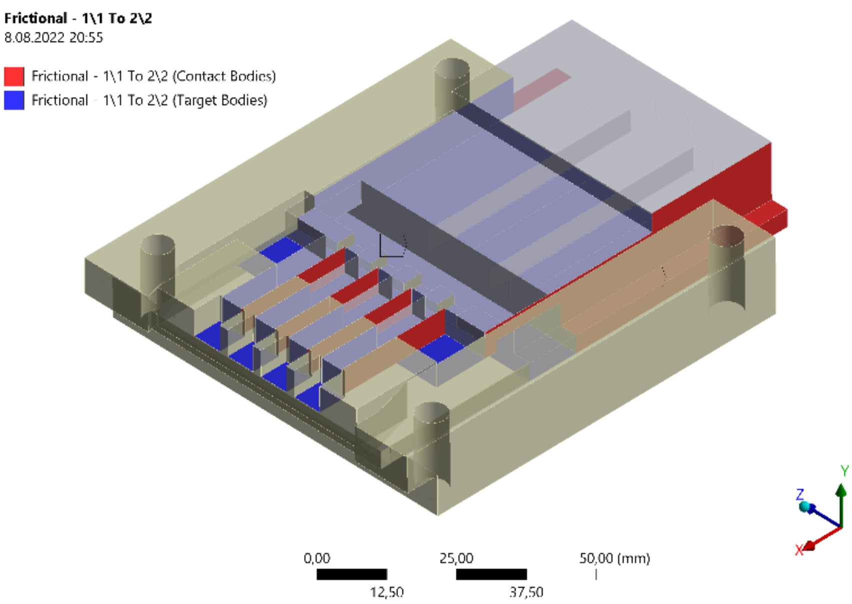


Figure 25: Contact Surface Between Slider and Slide Guide

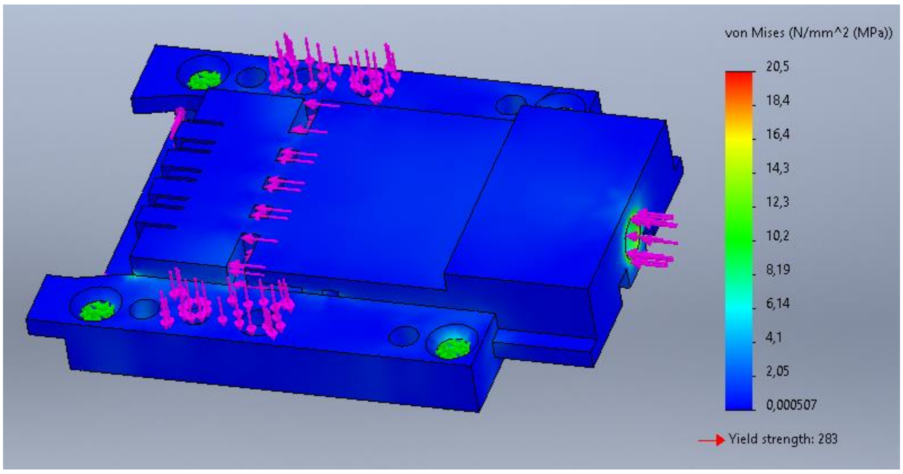


Figure 26: Von Mises Stress Analysis of Slider Guide

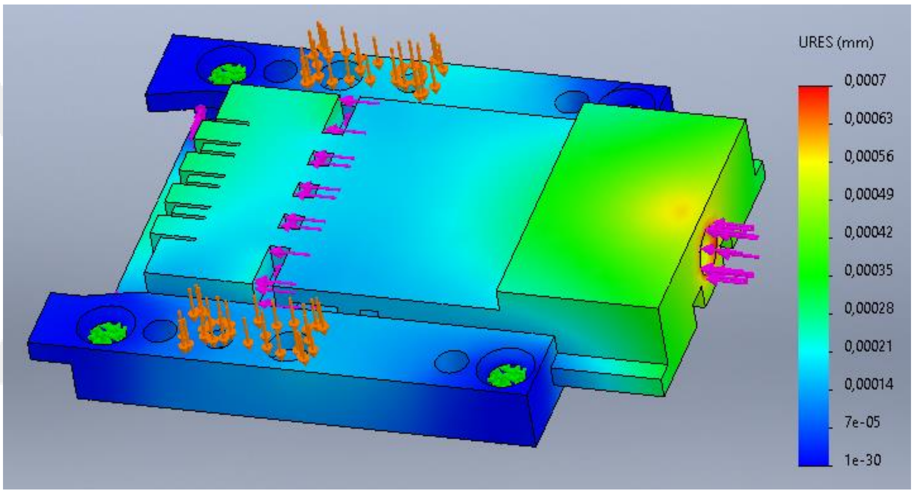


Figure 27: Resultant Displacement Analysis of Slider Guide

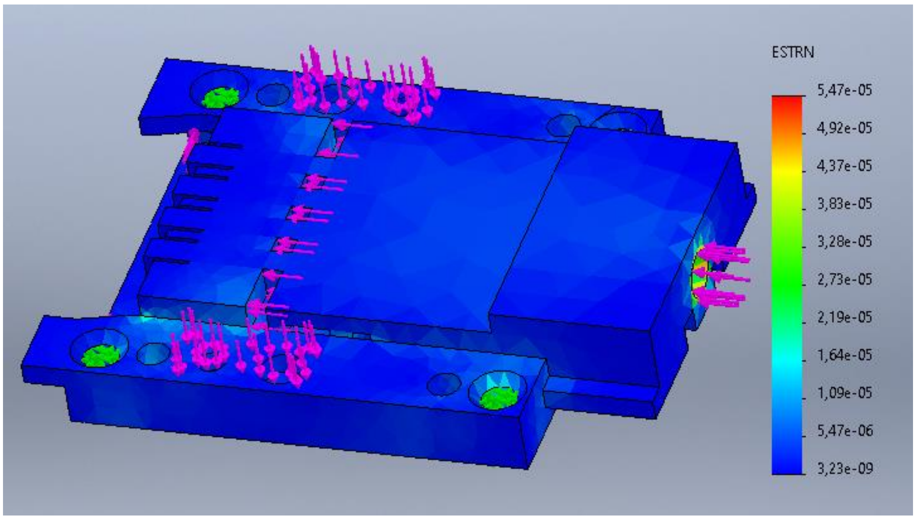


Figure 28: Equivalent Strain Analysis of Slider Guide

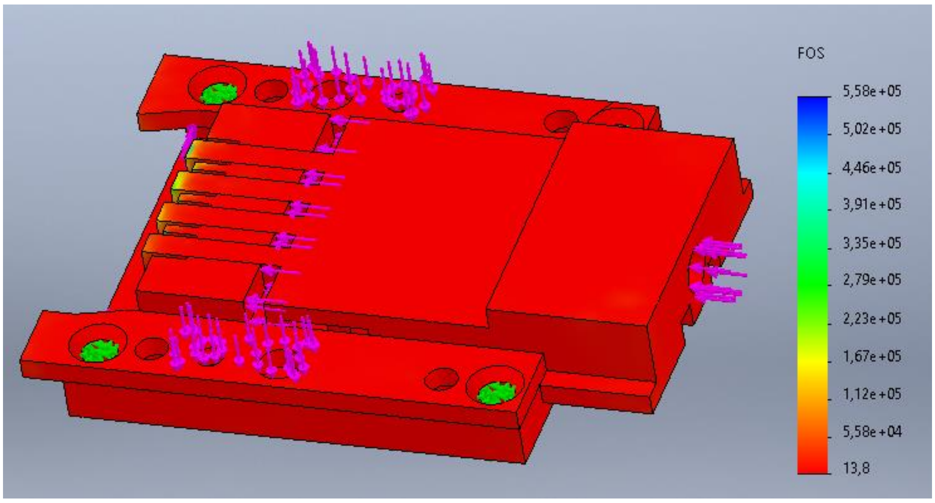


Figure 29: Von Mises Factor of Safety Analysis of Slider Guide System

Table 1: Material Properties of SAE 1023 Carbon Steel [13]

PROPERTY	VALUE
Elastic Modulus (N/mm^2)	$204\ x\ 10^3$
Poisson's Ratio (N/A)	$29x\ 10^{-2}$
Shear Modulus (N/mm^2)	$80\ x\ 10^3$
Mass Density (N/mm^3)	$7{,}858\ x\ 10^3$
Tensile Strength (N/mm^2)	425
Yield Strength (N/mm^2)	282
Thermal Expansion Coefficient (1/K)	$1.2\ x\ 10^{-5}$
Thermal Conductivity (W/m.K)	52
Specific Heat (J/kg.K)	486

The slider guide's static force analysis was made using the SolidWorks Static Simulation Analysis 2020 Program package. The SAE1023 material strength properties (Table 1) and the applied force were used in the FEA. The Maximum Von Mises stress value was 20.5 MPa at the piston force-acting region (Figure 26). The displacement in this region is approximately $7x10^{-3}$ mm (Figure 27). The stress on the contact surface between the parts is approximately 5 MPa. Figure 27 reveals that the displacement on the contact surfaces is about $21x10^{-5}$ mm. When the 300 N piston force and 2 kg weight of the feeding unit are considered, the slider guide is exposed to the highest stress in the assembly unit. The Von Mises factor of the safety of the weakest section of the system is 13.8 (Figure 29). As explained above, the slider guide FEA for the static force reveals the safety of the design. Moreover, SAE 2312 and SAE

2379 steels with high abrasion resistance were used as slider materials. The caps on the slider guide are made of SAE 2312. Nitriding (hardening) heat treatment was applied to the caps to improve the hardness and abrasion resistance.

2.3.3 Drive Plate

The drive plate is one of the parts exposed to the highest force in the machine. A piston force of approximately 1200 N at 6 bar is applied to the plate. At the same time, the force of the piston, which moves the transfer system on the horizontal axis, also acts on this part. Since it is connected to the table with four rods, the piston force of 1200 N (Figure 14, FESTO ADVU-50/20) acts on the system from these four rods (Figure 30). The drive plate with 5 mm and 8 mm were manufactured and tested in the manufacturing and testing stages of the assembly machine. The tests revealed the excessive vibration and motion instability (causing the seizure of the transfer system movements) of the drive plate for a 5 mm thick plate. So, in the design stage of the drive plate, cold-drawn steel with 8 mm thickness was selected. The material properties of the cold-drawn steel are given in Table 2.

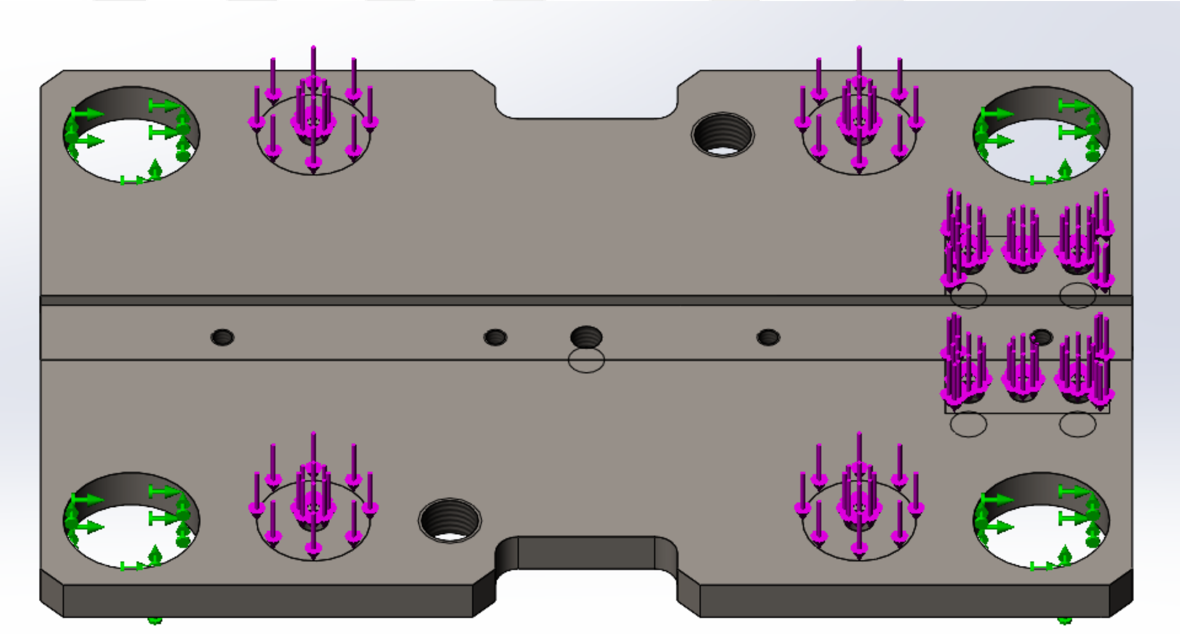


Figure 30: Force Directions and Fixed Places of the Drive Plate

Table 2: Material Properties of SAE 1015 Cold-Drawn Steel [13]

PROPERTY	VALUE
Elastic Modulus (N/mm^2)	$205\ x\ 10^3$
Poisson's Ratio (N/A)	$29x\ 10^{-2}$
Shear Modulus (N/mm^2)	$80x10^3$
Mass Density (N/mm^3)	$7{,}870\ x\ 10^3$
Tensile Strength (N/mm^2)	385
Yield Strength (N/mm^2)	325
Thermal Expansion Coefficient (1/K)	$1.2\ x\ 10^{-5}$
Thermal Conductivity (W/m.K)	49.8
Specific Heat (J/kg.K)	486

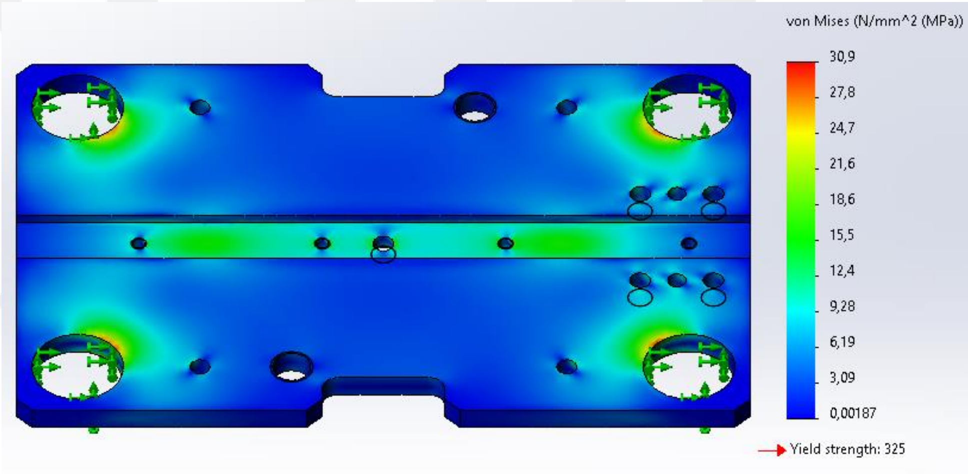


Figure 31: Von Mises Stress Analysis of Drive Plate

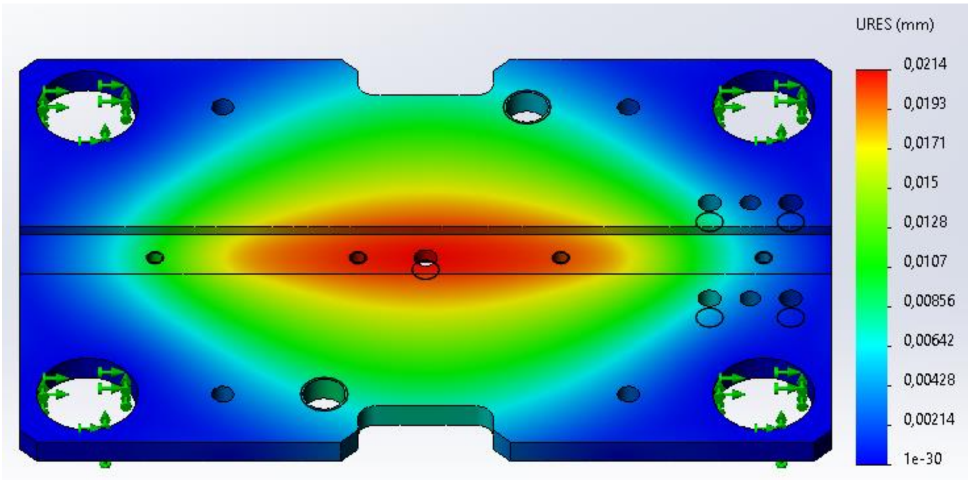


Figure 32: Resultant Displacement Analysis of Drive Plate

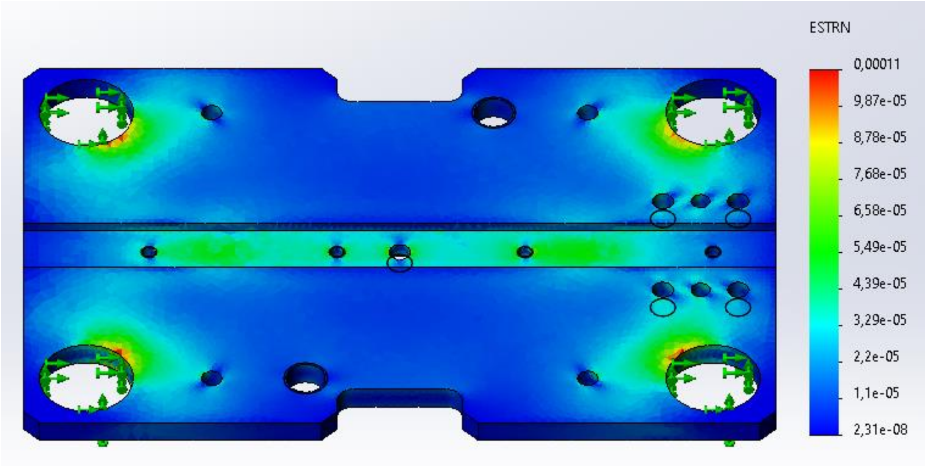


Figure 33: Equivalent Strain Analysis of Drive Plate

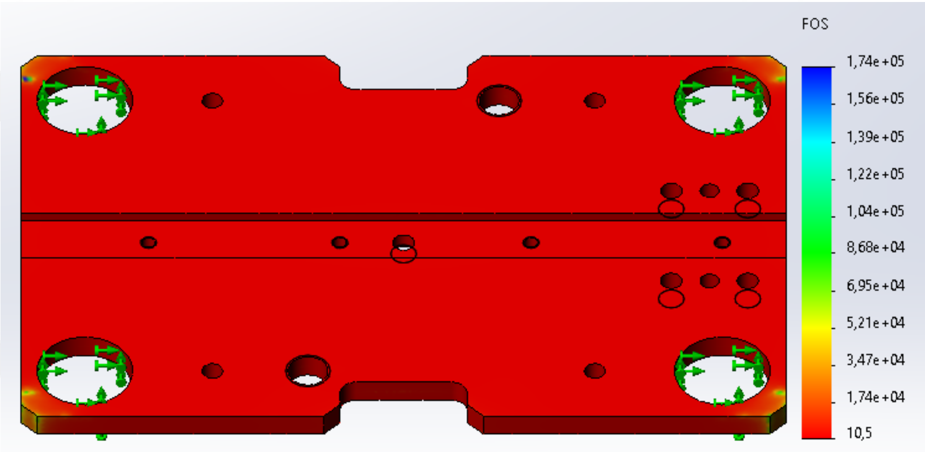


Figure 34: Von Mises Factor of Safety Analysis of Drive Plate

When the 8 mm thickness drive plate is analyzed, the region exposed to the highest Von Mises stress is 30,9 MPa (Figure 31). The bending of the middle of the part resulted in $2x10^{-2}$ mm deflection (Figure 32). The Von Mises stress factor of fafety of the plate is 10,5 (Figure 34). The above-given results indicate that the design is safe for static loading conditions.

2.3.4 Unit Fittings

Unit Fittings are used to fix the piston, which drives the assembly units' slider to the machine body (Figure 35). A self align quick coupling is used between the piston and the slider to compensate the elongation and vibration of the system. Al 6082 is used as the material of the mounting parts due to its good machinability, low weight and high corrosion resistance. The cylindrical rods (12 mm diameter) mounting the

Piston Connection Plates (Figures 35 and 36) are made of DIN 670 Steel (Table 3). It has good abrasion resistance, good machinability and shock-absorbing characteristics. The analysis of the unit was performed for the largest diameter piston force of 300 N.

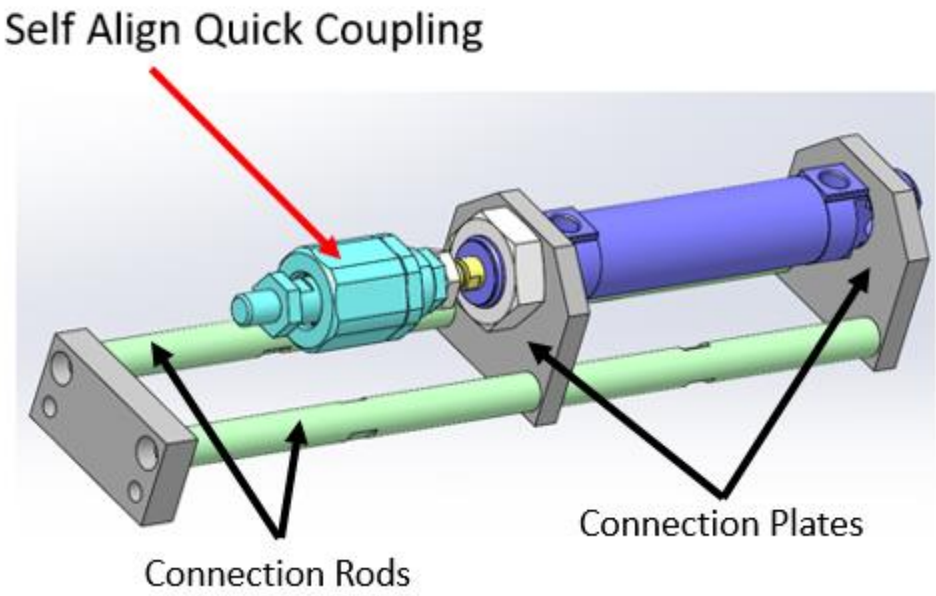


Figure 35: Design of Assembly Unit Fittings Elements

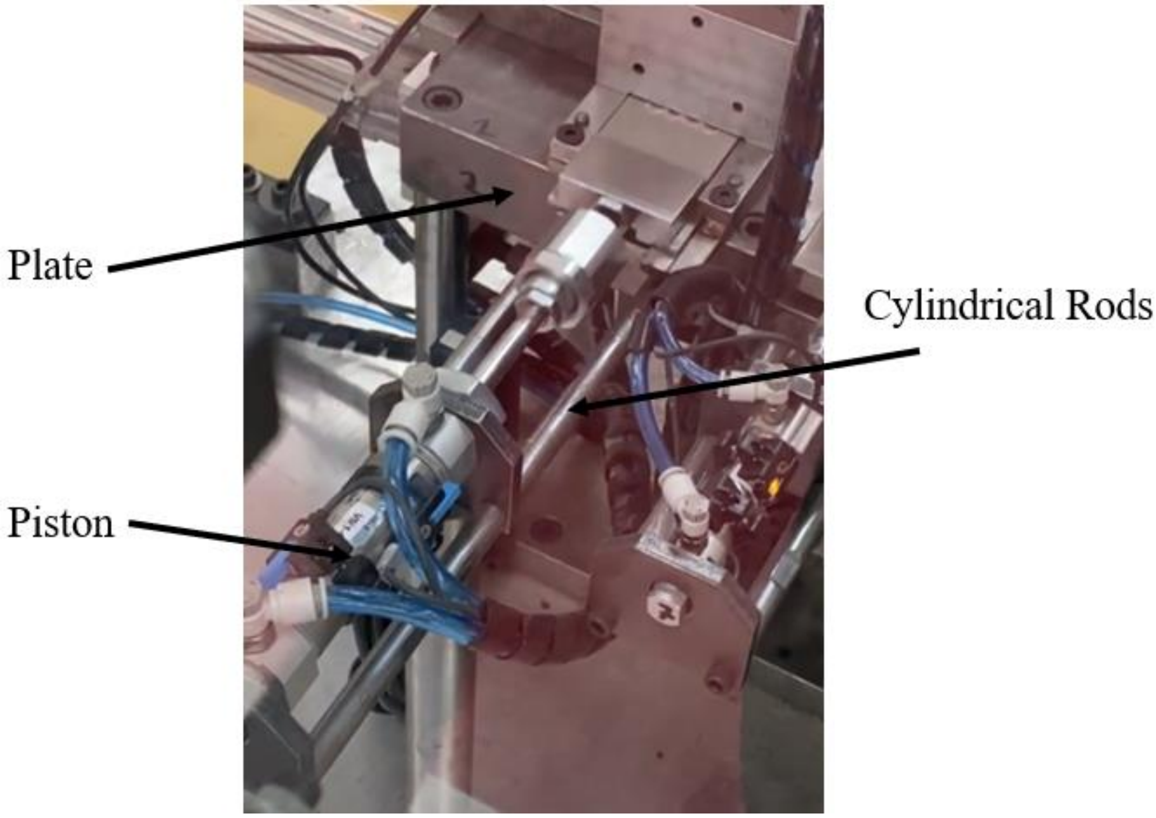


Figure 36: Assembly Unit Unit Fittings Elements

Table 3: Material Properties of DIN 670 Steel [13]

PROPERTY	VALUE
Elastic Modulus (N/mm^2)	$20\ x\ 10^3$
Poisson's Ratio (N/A)	$28x\ 10^{-2}$
Shear Modulus (N/mm^2)	$79x10^3$
Mass Density (N/mm^3)	$8\ x\ 10^3$
Tensile Strength (N/mm^2)	600
Yield Strength (N/mm^2)	400
Thermal Expansion Coefficient (1/K)	$1{,}1\ x\ 10^{-5}$
Thermal Conductivity (W/m.K)	14
Specific Heat (J/kg.K)	440

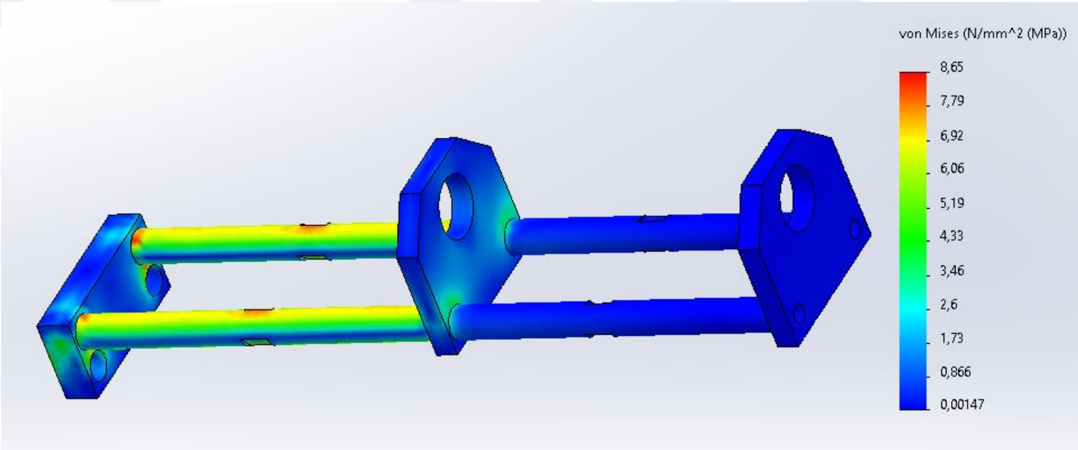


Figure 37: Von Mises Stress Analysis of Unit Fittings

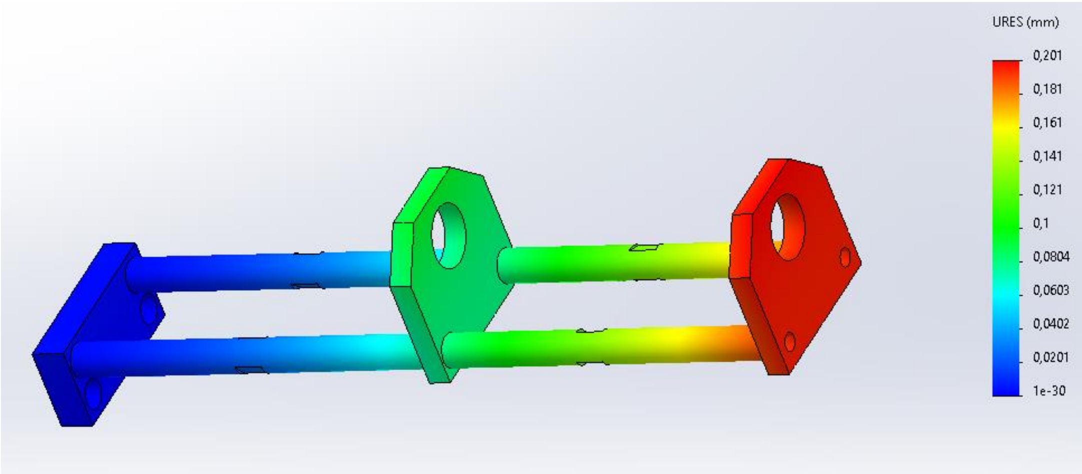


Figure 38: Resultant Displacement Analysis of Unit Fittings

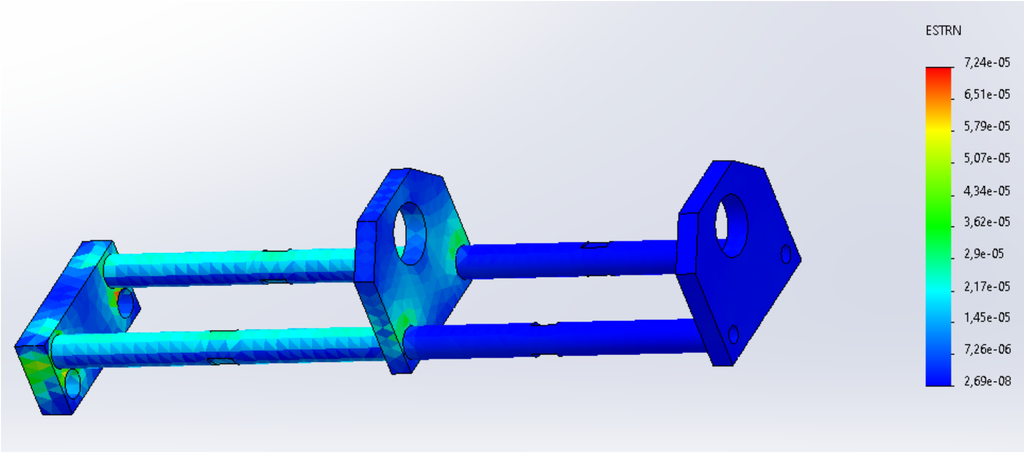


Figure 39: Equivalent Strain Analysis of Unit Fittings

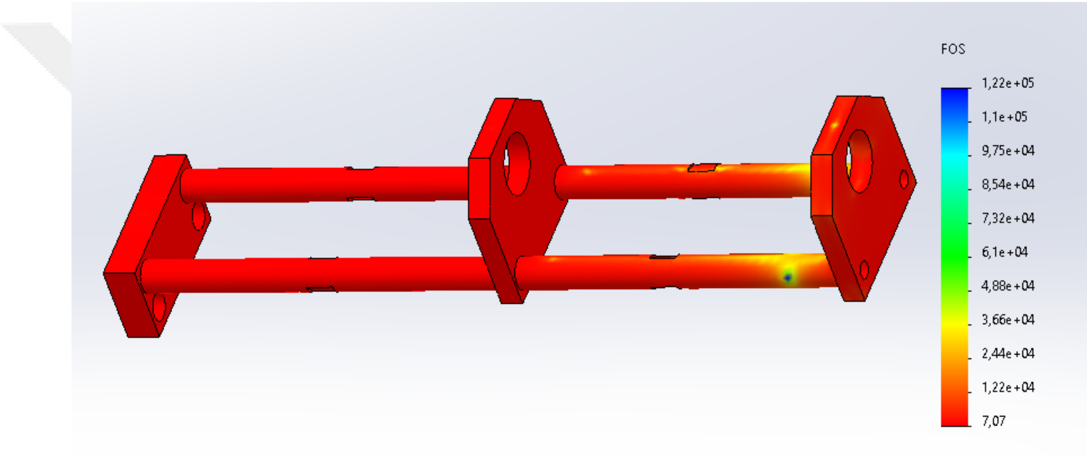


Figure 40: Von Mises Factor of Safety Analysis of Unit Fittings

The maximum Von Mises stress value was 8.65 MPa when the piston was under operation (Figure 37). The system's overall (resultant) elongation under 300 N piston load was 0.2 mm (Figure 38). The equivalent strain of the system is generally less than $2x10^{-5}$ (Figure 39). The factor of safety of the overall assembly is about 7 (Figure 40). The above-given results indicate that the design is safe for static loading conditions.

2.3.5 Carrier Plate (Table)

The assembly and QCC units are mounted to the Carrier Plate (Figure 41 and 46). The carrier plate is made of nitrided and ground SAE 2312 steel (Table 4) with 25 mm thickness.

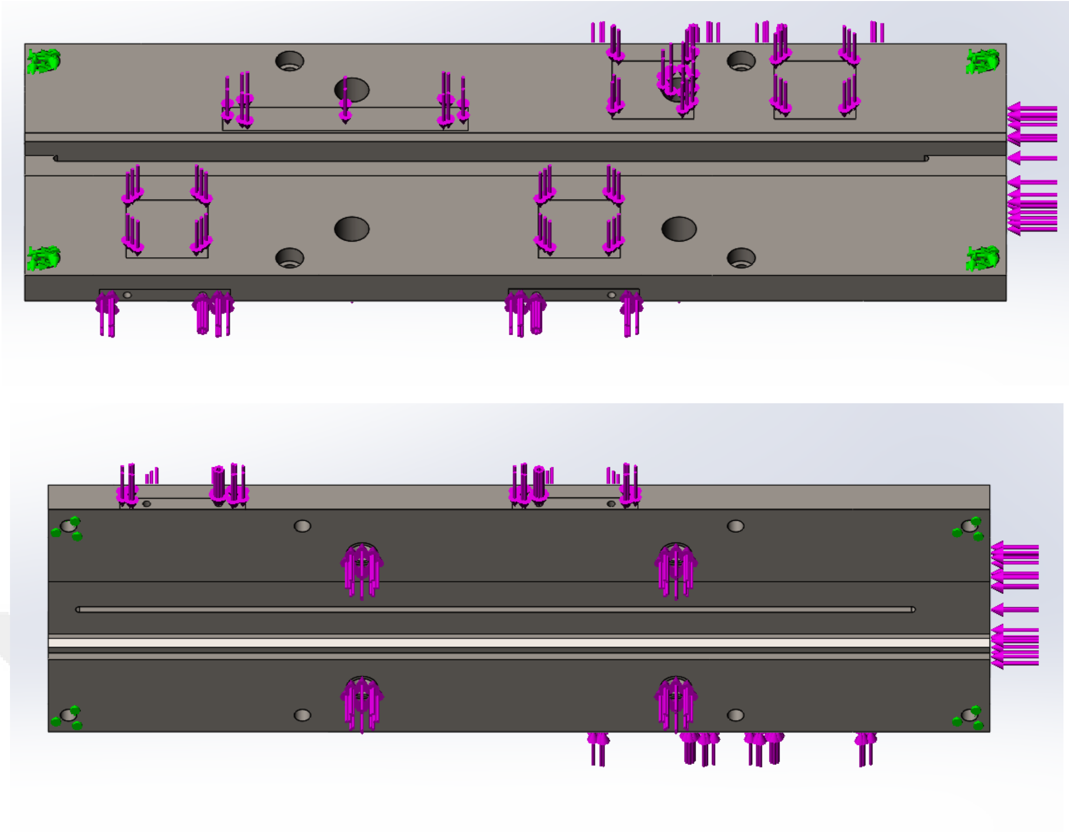


Figure 41: Forces Acting on Carrier Plate

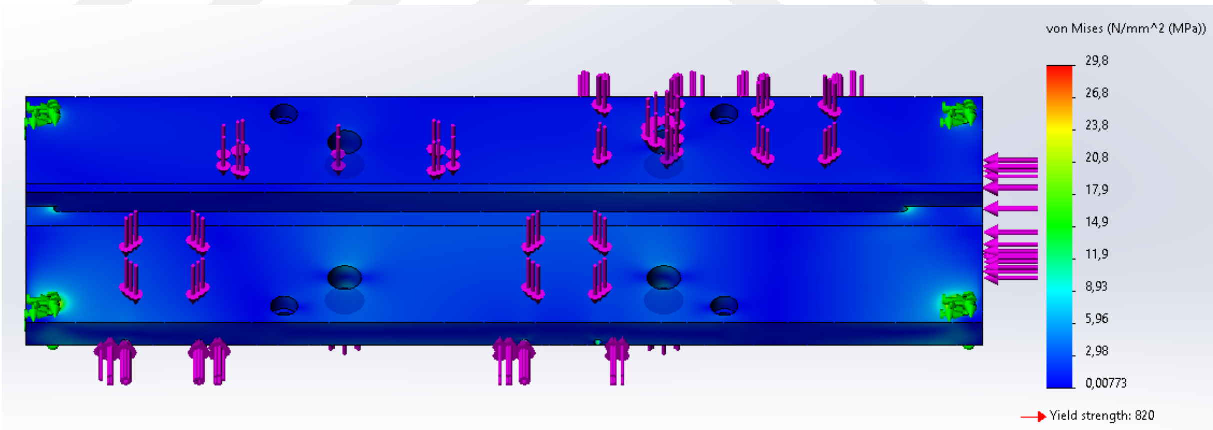


Figure 42: Von Mises Stress Analysis of Carrier Plate

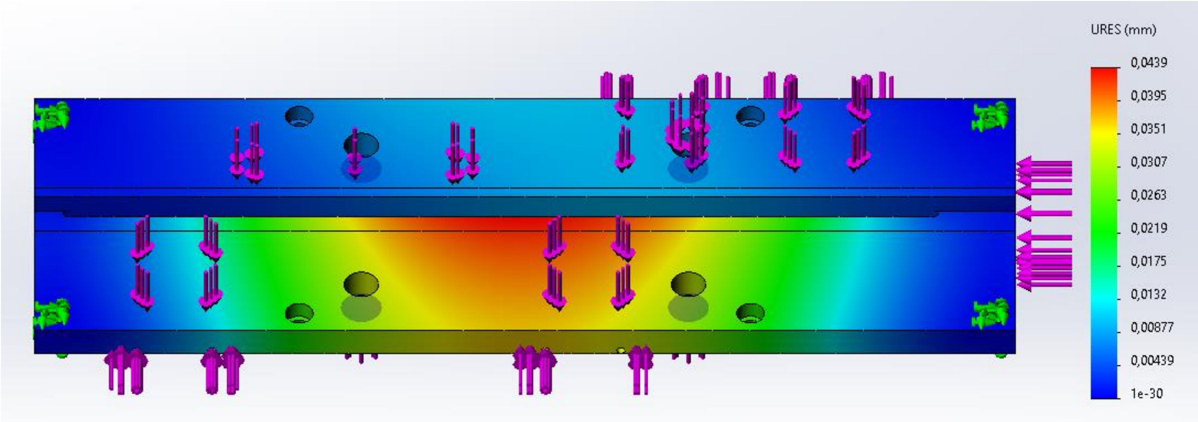


Figure 43: Resultant Displacement Analysis of Carrier Plate

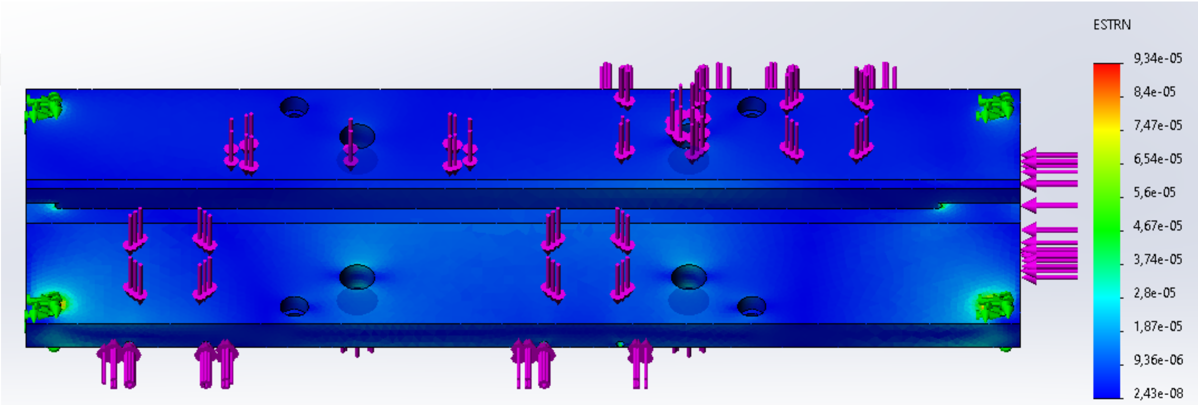


Figure 44: Equivalent Strain Analysis of Carrier Plate

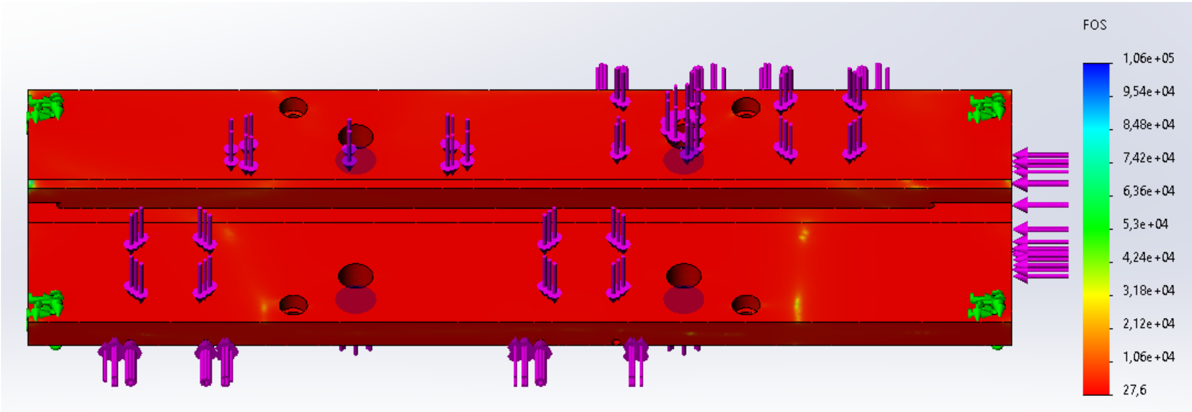


Figure 45: Factor of Safety Analysis of Carrier Plate

Table 4: Technical Properties of SAE 2312 [13]

PROPERTY	VALUE
Elastic Modulus (N/mm^2)	$205\ x\ 10^3$
Poisson's Ratio (N/A)	$28x\ 10^{-2}$
Shear Modulus (N/mm^2)	$79\ x\ 10^3$
Mass Density (N/mm^3)	$7{,}850\ x\ 10^3$
Tensile Strength (N/mm^2)	440
Yield Strength (N/mm^2)	820
Thermal Expansion Coefficient (1/K)	$1.1\ x\ 10^{-5}$
Thermal Conductivity (W/m.K)	14
Specific Heat (J/kg.K)	440

A total of 500 N piston force from the Ø9 mm assembly unit of the quality control unit was exerted on the plate (Figure 10, FESTO DSNU-16/25). At the same time, a force of 480 N acted in the x-direction from the transfer unit to the table (Figure 14, SMC CP96SDB-32/60C). A piston force of 1200 N in the vertical direction acts on the part (Figure 14, FESTO ADVU-50/20). Although, 300 N piston force from the assembly unit acts on the part horizontally (Figure 6, FESTO DSNU-25/50). When the units' weights are considered, the forces acting on the part is shown in Figure 41. The slot required for the movement of the forks is machined in the middle of the part. Therefore, high stress values are observed at the proximity of the slot. The maximum Von Mises stress was about 29,8 MPa around the plate's mounting holes (Figure 42). The deflection of the part in the middle section reached about 0.04 mm (Figure 43). The Von Mises factor of the safety of the weakest section of the plate is 27,6 (Figure 45). The findings indicate that the design is safe for static loading conditions.

2.3.6 Base Plate

The Base Plate (Figure 46), which is the main chassis of the machine, carries the Vibrators, Units and Safety Cabinet. It is made of Al 5083 material due to its good machinability and durability (Table 5). The thickness of the plate is selected over-safe as 20 mm due to possible new unit assemblies on it in the future.

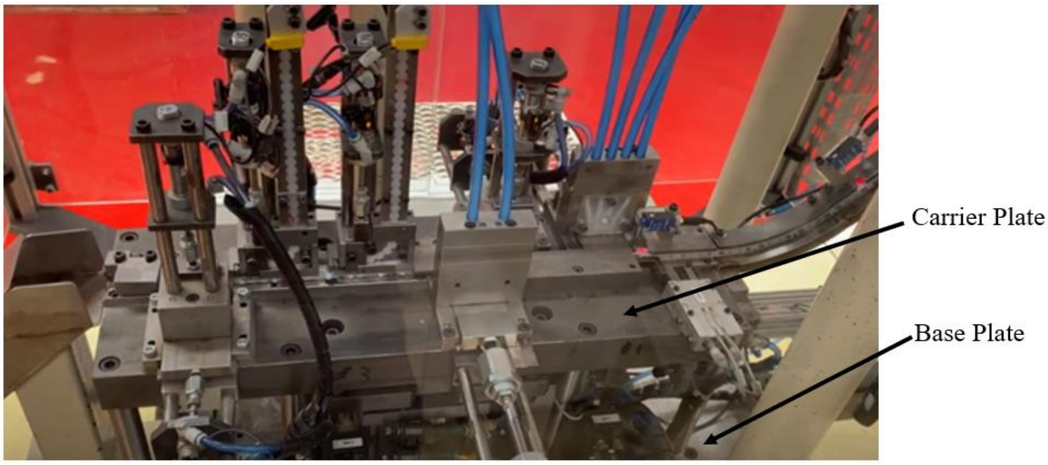


Figure 46: Base Plate

Table 5: Material Properties of Al 5083 [13]

PROPERTY	VALUE
Elastic Modulus (N/mm^2)	$70\ x\ 10^3$
Poisson's Ratio (N/A)	$33x\ 10^{-2}$
Shear Modulus (N/mm^2)	$25{,}9x10^3$
Mass Density (N/mm^3)	$2{,}68\ x\ 10^3$
Tensile Strength (N/mm^2)	275
Yield Strength (N/mm^2)	240
Thermal Expansion Coefficient (1/K)	$2{,}38\ x\ 10^{-5}$
Thermal Conductivity (W/m.K)	127
Specific Heat (J/kg.K)	880

The weight of the plate, the transfer system and the mounting units is 50 kg. The cabin and feeding vibrators weigh 90 kg and 35 kg, respectively. In Figure 47, the areas indicated with the red arrows on the four sides are the mounting zones of the cabins. Those zones carry a total weight of 90 kg. Areas indicated with green arrows are the zones where the vibrators are mounted. Each of those zones carries a weight of 35 kg. The area indicated by a yellow arrow is the zone where the transfer system and plastic mounting units are mounted. The average load in this area is 50 kg.

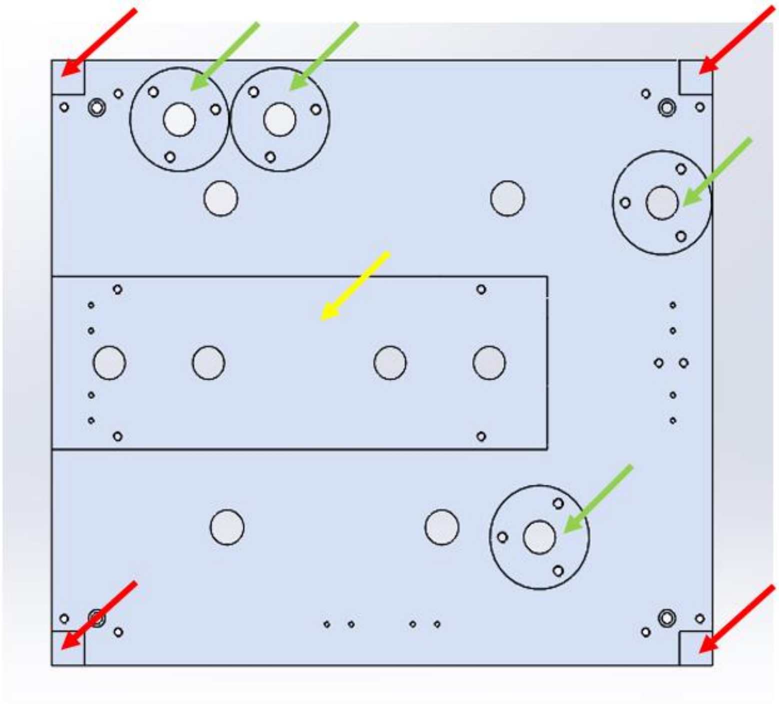


Figure 47: Base Plate Loading Zones

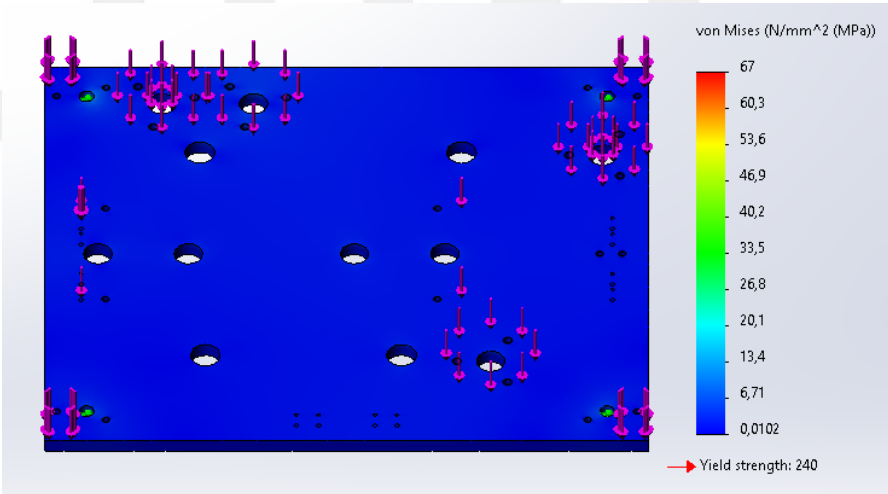


Figure 48: Von Mises Stress Analysis of Base Plate

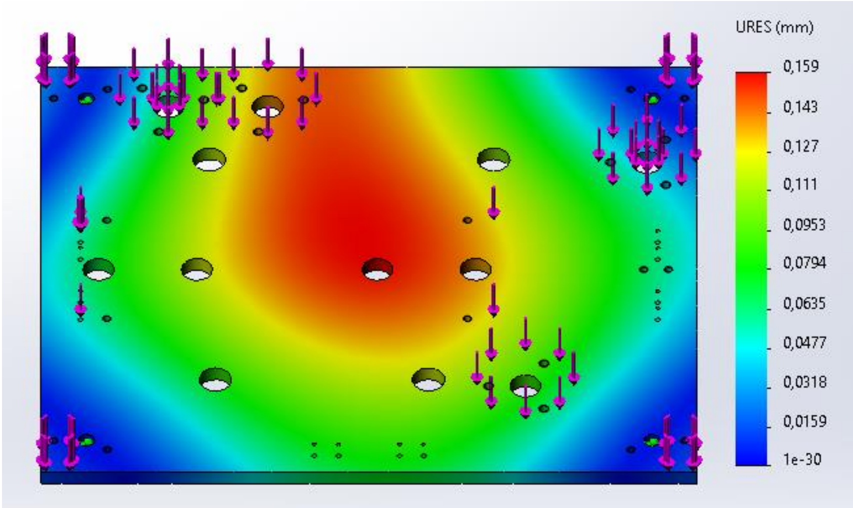


Figure 49: Resultant Displacement Analysis of Base Plate

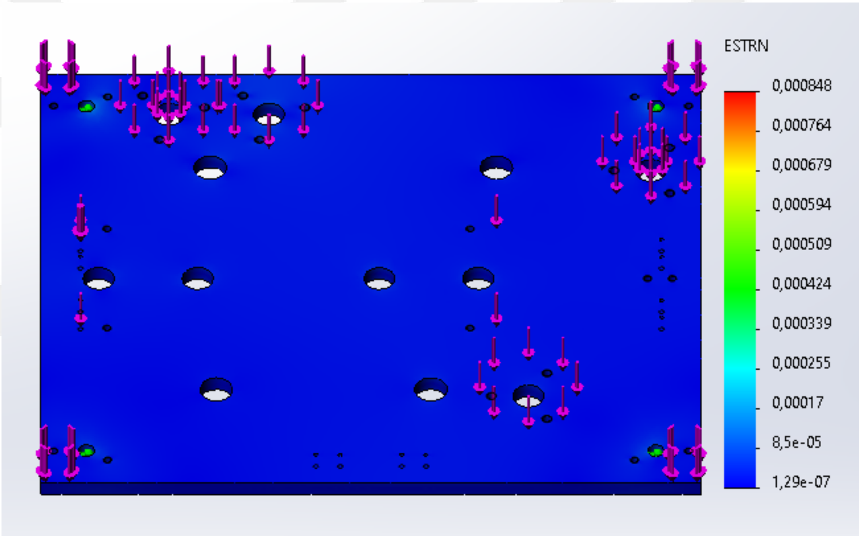


Figure 50: Equivalent Strain Analysis of Base Plate

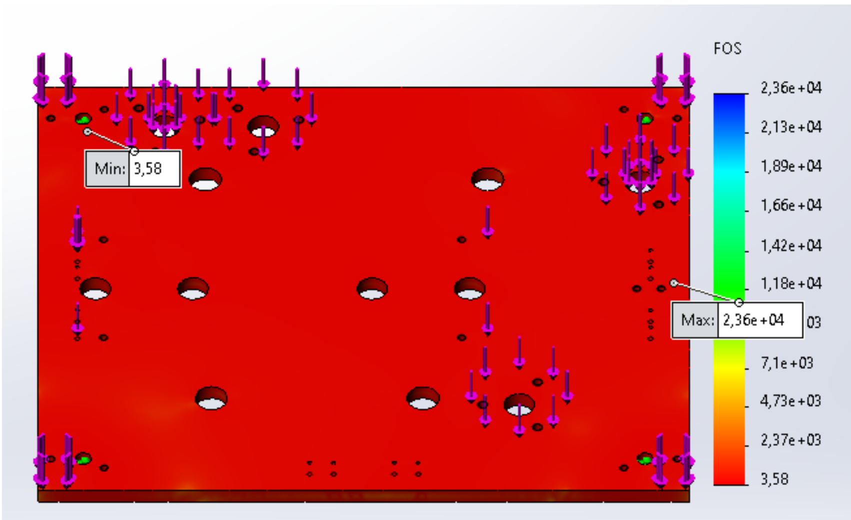


Figure 51: Factor of Safety Analysis of Base Plate

For the 15 mm thick base plate, The Von Mises stress factor of safety was low (about 1.5). However, the deflection was high (0.39 mm at the center). The maximum stress for a 20 mm thick plate is reduced to 69 MPa (Figure 48). Moreover, the displacement of the base plate is reduced to 0.16 mm (Figure 49). The equivalent strain was negligible (less than $8.48x10^{-4}$ mm/mm, Figure 50). Moreover, the Maximum Von Mises Factor of Safety is increased to 3.58 (Figure 51). The FEA results revealed a safe design for a 20 mm thick plate in terms of stress, strain, deflection and safety factor.

2.3.7 Cabin

Sigma profiles and plexiglass closings form the skeleton of the cabinets (Figure 52). The plexiglass closings are supported by a locking mechanism (magnetic type) to prevent its opening while the machine is operative.

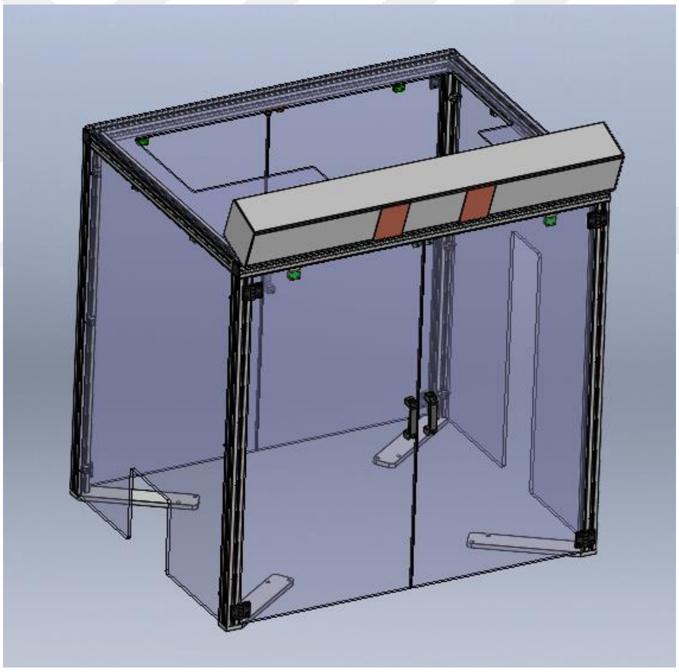


Figure 52: Safety Cabin

2.3.8 Vibrators

It is divided into two groups; the bowl and the understructure(Figure 53). The understructure consists of components that generate vibration [1]. The upper part of the understructure is made of conical- or circular-shaped welded sheets. The other components of the vibrators are electromagnetic suspension springs and the base

(Figure 53). The traps are located through the tracks to prevent the feed of the defective rollers with burr and other types of defects to the assembly stations.

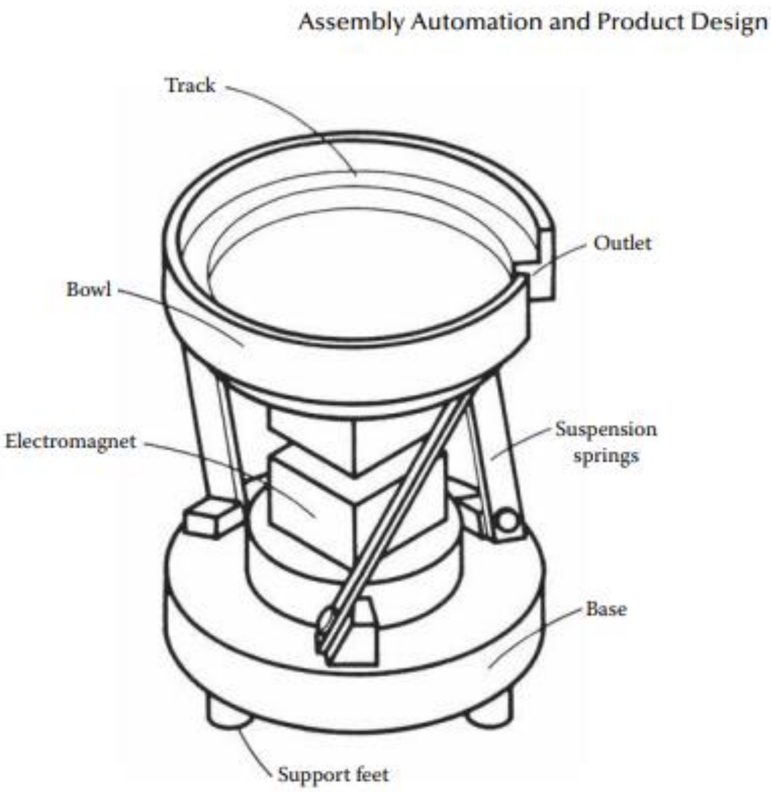


Figure 53: Components of the Vibrator

2.4. OPERATIONS SEQUENCE OF THE MACHINE AND THE PLC SYSTEM

2.4.1 Operation Sequence

The assembly machine's operation sequences are as follows (Figure 55):

1st station (AYIRICI (separator)): The piston loads the transfer unit of the cage.

2nd station (Ø6 mm MAKARA 1 TAKMA (Ø6 mm roller assembly)): The four Ø6 mm rollers are inserted.

3rd station is empty.

4th station (Ø6 mm MAKARA KONTROL (Ø6 mm Roller Control)): The 1st QCC is performed.

5th station (Ø6 mm MAKARA TAKMA (Ø6 mm Roller Assembly)): The two Ø6 mm rollers are inserted.

6th station is empty.

7th and 8th stations (Ø9 mm MAKARA TAKMA (Ø9 mm Roller Assembly)): The two Ø9 mm rollers are inserted.

9th station is empty.

10th station (Ø6 mm MAKARA, Ø9 mm MAKARA KONTROL(the two Ø6 mm and the two Ø9 mm Roller QCC)): The 2nd QCC is performed.11th station: It will be decided whether the cage is assembled correctly or not.

In case of malfunctions in a station, the unit's green color turns red on the screen. The control panel view of the control unit is shown in Figure 55.

2.4.2 Plc

The programming and integration of the PLC software (operational control board) to the assembly machine were performed by the technical personnel of the Samet A.Ş. PLC department.

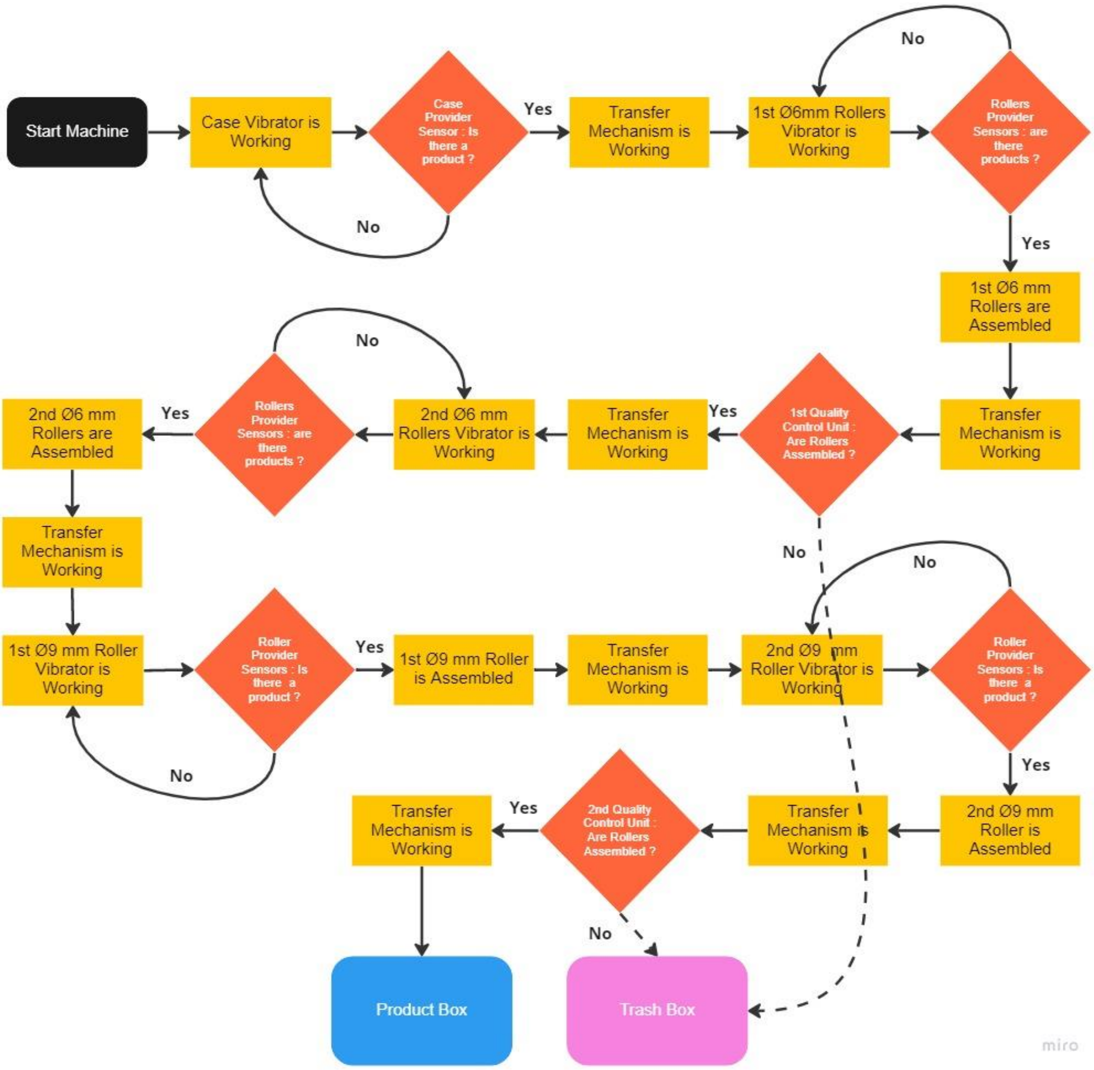


Figure 54: Working Algorithm of the Machine

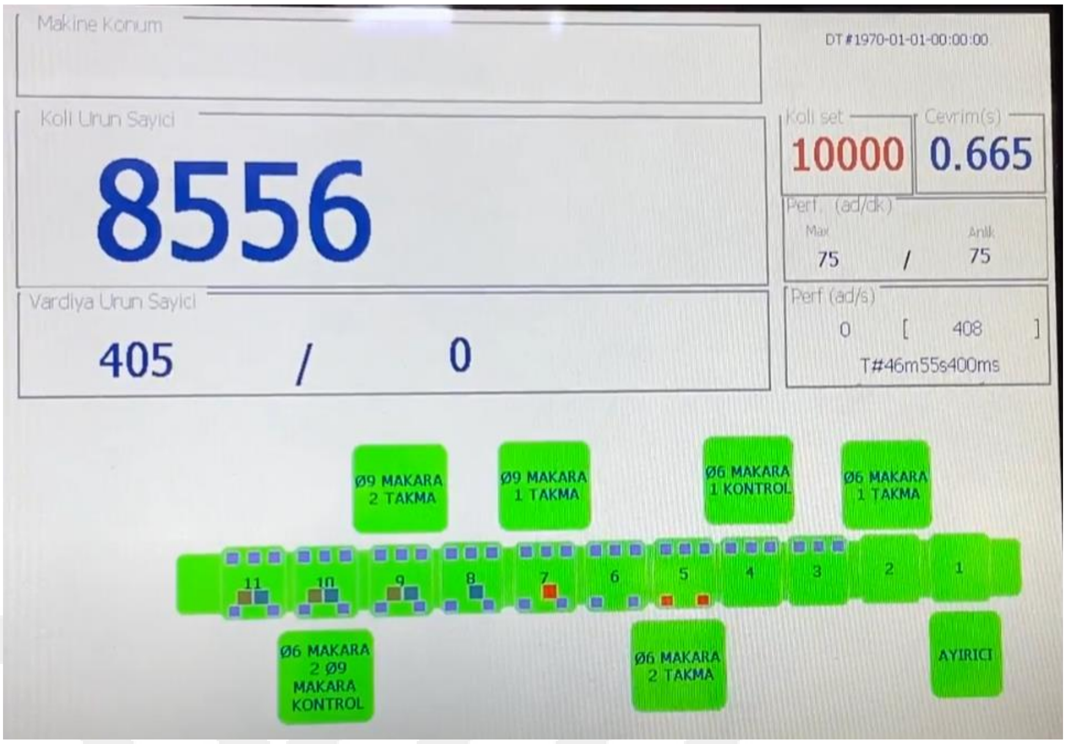


Figure 55: Monitor View of Machine Control Unit

CHAPTER III
PERFORMANCE, ORIGINALITIES AND BENCHMARKING OF THE ASSEMBLY MACHINE

The PLC saves the number of acceptable and rejected cages. The PLC program controls the cycle times and waiting times between commands. The assembling speed of the machine can be set by increasing or decreasing these times.

The targetted speed of the machine was 60 products/min. The testing phase of the machine revealed that the designed and constructed machine achieved 60 products/min speed with 99.9% yield. The machine worked at 99.9% yield at 80 products/min. When the speed was increased to 100 products/min, the yield was reduced to 95%. The reduced yield is attributed to the shorter waiting times of the pistons than that of the falling time of the rollers into the slider bearings. So, 80 products/min is accepted as the machine's working speed, which the production planning department of Samet A.Ş also accepts.

The Vibrators can separate rollers with burrs and other defects. In the QCC units of the machine, the rollers can be detected whether they are mounted or not. However, the diameter tolerances of the rollers cannot be controlled. The last station was planned to check the diameter of the rollers with a camera. However, the plan could not be implemented since the camera's speed was insufficient to monitor and measure the diameter of the roller at the desired speed of 80 products/min (i.e., 640 rollers/min). Due to this reason, QCCs were done mechanically in the machine.

As aforementioned, another assembly machine, the product of another company (IronFT Inc.) in Türkiye, was still operative in SAMET A.Ş. to assemble the cages (Figure 56). This machine assembles the cages with three rollers [6]. The main difference between the two machines was their transfer mechanism. The IronFT design had a rotary table transfer system to assemble the rollers to the cage (Figure 57). The assembly stations were placed on the rotary round table. The cage was transferred between the units by the rotary motion of the round table. In this design, the table's diameter, driving motor power, and motor size were big, causing high costs as the product dimensions increased [8]. The Weiss servo motor, which provides turntable movement, costs 5000-6000 Euros. However, the cost of the pneumatic piston used in the linear table motion is about 400 Euros in the new design. Moreover, linear table systems have a much lower cost than rotary tables. The IronFT machine assembles three rollers fed by vibrators at 10 products/min speed, much less than the new design.

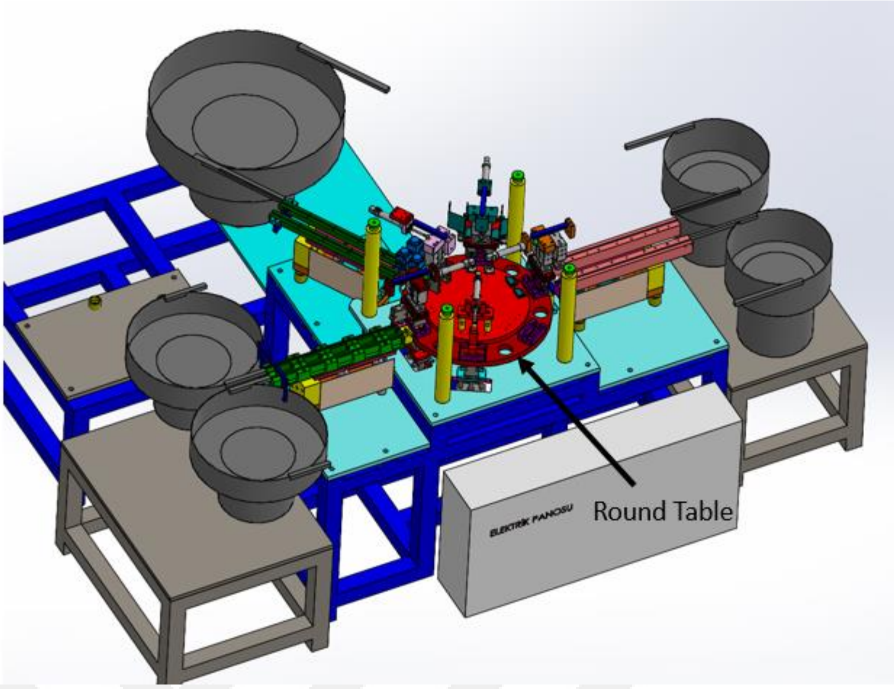


Figure 56: IronFT / Adjustment Group System Machine

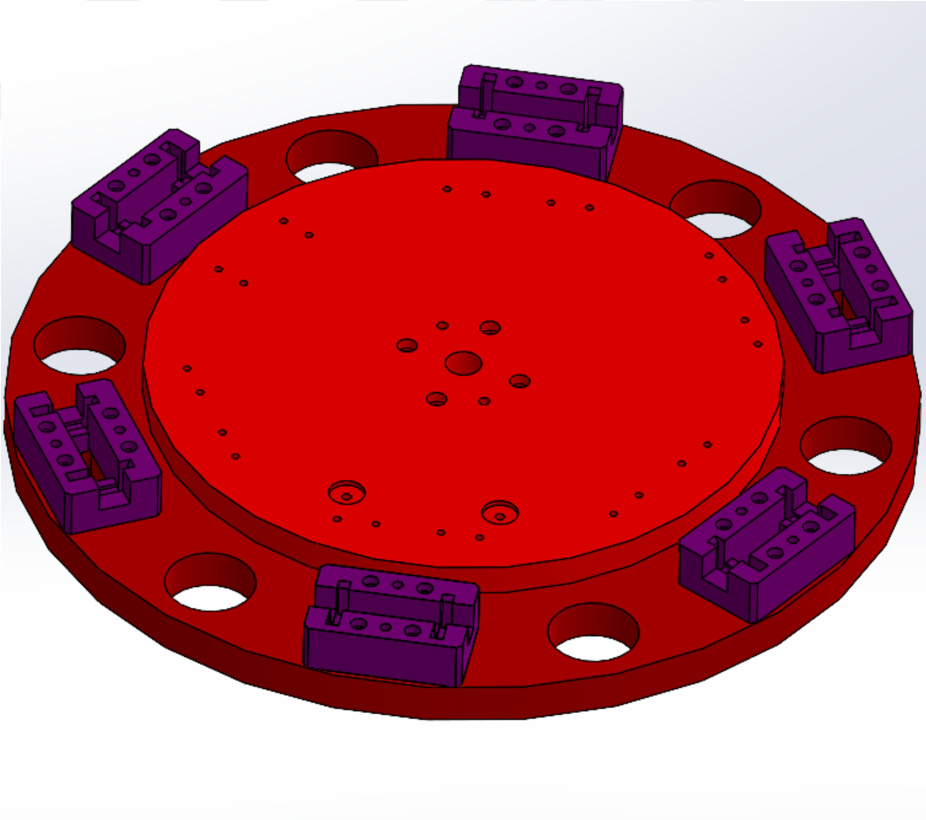


Figure 57: Rotary Table

CHAPTER IV
CONCLUSION

In this thesis, the design, production and implementation of an Assembly Machine to assemble the cage product, which is one of the products of Samet A.Ş., were mentioned. The transfer system, assembly unit and QCC units were designed specifically for the product. The finite element technique was used in static analyses of the critical parts of the machine.

The machine has been working in the company's production line at 80 products/min with a 99.9% yield. The Vibrators can separate rollers with burrs and other defects. In the QCC units of the machine, the rollers can be detected whether they are mounted or not.

Another assembly machine, the product of IronFT Inc., still operative in SAMET A.Ş., had a rotary table transfer system to assemble the rollers to the cage at a much lower speed than the new design. Moreover, the new machine’s linear transfer system costs much less than the IronFT design, considering the costs of the driving motor, table and pistons.

The speed of quality control and the yield rate could be further increased using a high-speed camera and related control software.

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