DOKUZ EYLUL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DESIGN AND ANALYSIS OF A MATERIAL FEEDING ROBOT FOR AN ALUMINIUM DIE CASTING SYSTEM

by
Kerem KANTAR

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IZMIR

DESIGN AND ANALYSIS OF A MATERIAL FEEDING ROBOT FOR AN ALUMINIUM DIE CASTING SYSTEM

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DESIGN AND ANALYSIS OF MATERIAL FEEDING ROBOT FOR AN ALUMINUM DIE CASTING SYSTEM"** completed by **KEREM KANTAR** under supervision of **PROF. DR. HİRA KARAGÜLLE** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Prof.Dr. Hira KARAGÜLLE

Supervisor

Doç.Dr. Hasan ÖZTÜRK	Yrd. Doç. Dr. Tolga Sürgevil
(Jury Member)	(Jury Member)

Prof.Dr. Mustafa SABUNCU

Director

Graduate School of Natural and Applied Sciences

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DESIGN AND ANALYSIS OF A MATERIAL FEEDING ROBOT FOR AN ALUMINIUM DIE CASTING SYSTEM

ABSTRACT

Today, robots are used at many industrial fields due to their flexibility, efficieny and accuracy. It is possible for man to increase quality of life by using robots for dangerous, dirty and hard labor jobs instead of human. For some production processes, it is not possible to be done by human because of its extreme enviroment conditions or sometimes accuracy of human is not enough. If introduced correctly, industrial robots can improve the job quality and cost savings thanks to their operation efficiency.

It is great importance that right material is chosen and that work is determined correctly for industrial robots to be effective. Therefore for reliability of this kind of applications, it is of great importance that engineers involved follow up all design steps and analyse well obtained data. Basicaly, robots consist of two main units which are the mechanical and the control system. In this study, design of mechanical units of robot application will be discussed.

In this study, principles to be considered for robot application were determined. A material feeding robot in order to be used at an aluminum die casting system is designed and analyzed. At the design process, environment and work conditions were considered and according to these data, appropriate modules were selected. Static and frequency analysis were handled through the use of Ansys and Solidworks. Results obtained from analyses were evaluated and design was updated.

Keywords: material feeding robot, cartesian robot, linear module, selecting actuators, kinetic analysis, static analysis, dynamic analysis.

ALÜMİNYUM DÖKÜM TEZGAHLARI İÇİN METAL BESLEME ROBOTU TASARIMI VE ANALİZİ

ÖZ

Günümüzde esneklikleri, verimlilikleri ve doğrulukları nedeni ile robotlar birçok endüstriyel alanda tercih edilmektedir. Ağır, kirli ve teklikeli işlerde insan yerine robotların kullanılması insan yaşam kalitesini arttırmaktadır. Hatta bazı üretim proseslerinde, zorlu çevre şartları nedeni ile ya da insan kabiliyetinin proses için yeterli olmadığı proseslerde insane çalışması mümkün değildir. Eğer robotlar uygun şekilde etkili olarak kullanılırsa, iş kalitesini arttırırlar ve operasyonel verimlilikleri nedeni ile maliyet iyileştirmesine yardımcı olurlar.

Endüstriyel robotların etkili olabilmeleri için, doğru malzeme seçimi ve için doğru tanımlanması son derecce öneme sahiptir. Bu edenle bu tür uygulamaların güvenilirliği açısından, ilgili mühendislerin tüm dizayn adımlarını takip etmeleri ve elde edilen verileri iyi bir şekilde analiz etmeleri son derece öneme sahiptir. Temel olarak robotlar mekanik sistem ve kontrol sistemi olmak üzere iki ana birimden oluşmaktadır. Bu çalışmada robot uygulamasının mekanik dizaynı ele alınacaktır.

Bu çalışmada, uygulanacak olan robot için dikkat edilmesi gereken prensipler belirlenmiştir. Aluminium enjeksiyon tezgahı için malzeme besleme robotu tasarımı yapılmış ve analizleri gerçekleştirilmiştir. Dizayn sürecinde; çalışma ve çevre şartları belirlenmiş ve bu bilgiler doğrultusunda uygun modül seçimi yapılmıştır. Statik ve frekans analizleri Ansys ve Solidworks programları ile yapılmıştır. Kinematik analizleri doğrultusunda uygun aktüatörler seçilmiştir. Analizlerden elde edilen sonuçlar değerlendirilmiş ve tasarımda gerekli güncellemeler yapılmıştır.

Anahtar sözcükler: malzeme besleme robotu, kartezyen robot, lineer modül, actuator seçimi, kinetic analiz, dinamik analiz, static analiz.

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CHAPTER ONE
INTRODUCTION

The first die casting by pressure injection was invented in mid of 1800’s. In 1849, the first patent was granted for manually operated machine for casting printing type. In 1885, Otto Mergenthaler invented the linotype machine, an automated type casting device which became the prominent type of equipment in the publishing industry. By end of 1800’s, production for various parts began (The North American Die Casting Association, 2010)

Thanks to die casting’s cost improvement for mass production, other applications grew rapidly and made affordable the production of intricate parts in high volumes. Die casting systems have capacity which changes between a few grams to 25kg.

Nowadays, it is a necessity for industries to keep up to developing technology, to meet the quality necessities in order to compete and grow. Robotic applications and automation solutions help to reduce manufacturing costs, eliminate variety due to human handling, and increase the capacity by reducing cycle time. Robots are used in many fields such;

a. Industrial Robots: Industrial robots are fully automatic and semi-automatic welding processes, particularly in the automotive industry, spot welding, MIG/MAG, TIG and plasma welding, casting industry, spray painting tasks, furniture industry, white goods industry.

b. Operational Robots: This type of remote-controlled robots have been designed in general or special-purpose such as loading of machine tools, packaging, and exterior cleaning of aircraft, bomb disposal, mining, space exploration, studies conducted under the sea, in search and rescue after earthquakes and studies for military purposes.

c. Medical and Health Robots: Orthopedic and prosthetic limbs help people to move by detecting electrical tensions by brain sensors in order to control limbs by piezzo manipulators. In addition to today's medical operations, surgery robots allow surgeons to execute operations through continents. (Desmond Jeffery Will, 2004)

For die casting industries, main quality issues result from lack of quantity of molten material and insufficient lubrication at dies. It is of great danger for human to handle hot material manually. Adapting a material feeding robot to an aluminum die casting system helps industries to reduce their cost, increase operation efficiency, and maintain same quality for each cycle. It becomes a necessity for industries to apply a material feeding robot to an aluminum die casting system.

CHAPTER TWO
DIE CASTING MACHINES

2.1 Classification of Die Casting Systems

Depending on the type of metal being cast, die casting systems can be classified as hot-chamber die casting system or cold-chamber die casting system. Casting material determines the type of system. Table 2.1 shows typical die temperatures for various cast material.

Table 2.1 Die and cast temperatures of cast materials. Schrader, George F.; Elshennawy, Ahmad K.; Doyle, Lawrence E. (2000)

	Zinc	Aluminium	Magnesium	Brass (Leaded Yellow)
Die Temperature (°C)	218	288	260	500
Casting Temperature (°C)	400	660	760	1090

2.1.1 Hot-Chamber Die Casting Systems

Vinarcik describes hot-chamber machines, as gooseneck machines; rely upon a pool of molten metal to feed the die. Cycle stars with back movement of hydraulic piston and fills gooseneck with molten material. Hydraulic piston pushes out molten material out of gooseneck to the die. Graphical presentation of hot chamber die casting systems is shown that at Figure 2.1. The hot-chamber die casting systems offer users fast cycle times and opportunity to melt material in the die casting machine. But reaching to high-melting points is not not possible and aluminum cannot be used because it picks up some of the iron while in the molten pool. Due to this, hot-chambered machines are primarily used with zinc, tin and lead based alloys. (Edward J. Vinarcik, 2002)

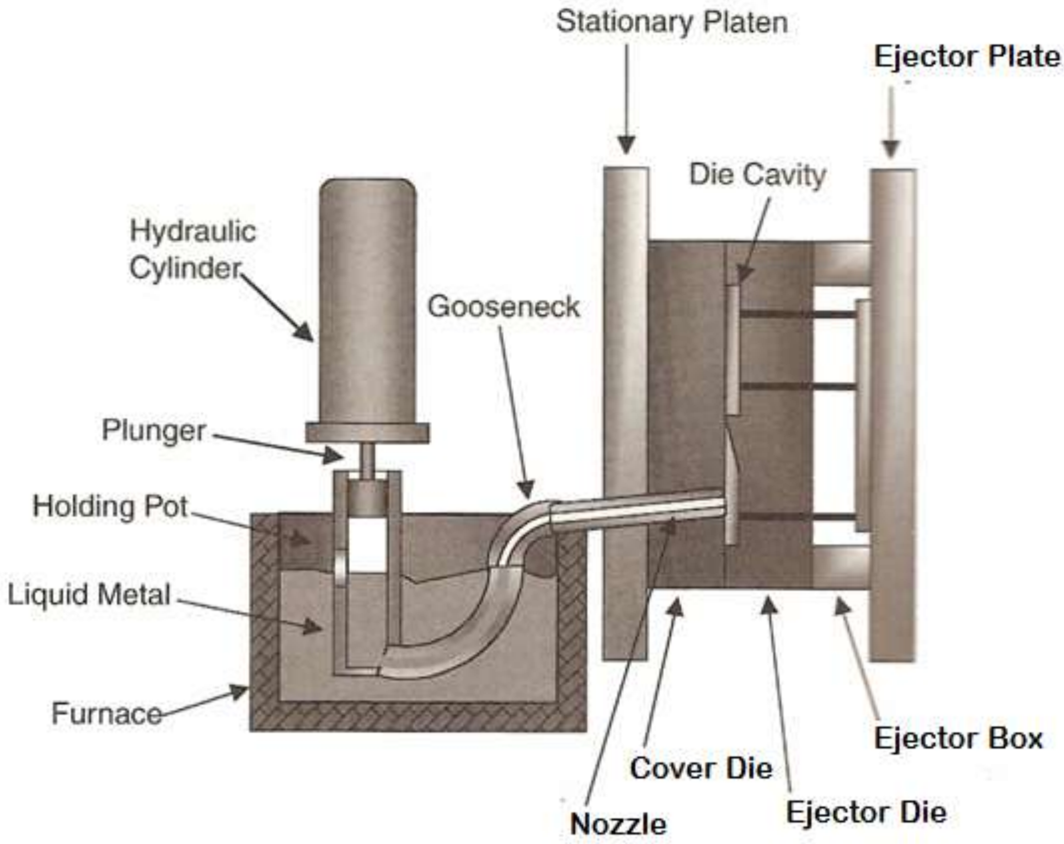


Figure 2.1 Hot-Chamber Die Casting Machine (Edward J. Vinarcik, 2002)

2.1.2 Cold-Chamber Die Casting Systems

Cold chamber die casting systems are preffered when aluminum, zinc alloys with a large composition of aluminum, magnesium and copper will be used as the casting alloy. Melting metal in a special furnace is the first step of this process. Then a precise amount of molten metal must be transported to the machine. Normally molten material is transported via a ladle to the cold-chamber machine A hydraulic or mechanical pistons feeds materal to the die. Graphical presentation of cold chamber die casting systems is shown that at Figure 2.2. Because of manual transportation of molten material from furnace to the die, cycle time gets increase. This is biggest disadvantage of this system (Edward J. Vinarcik, 2002).

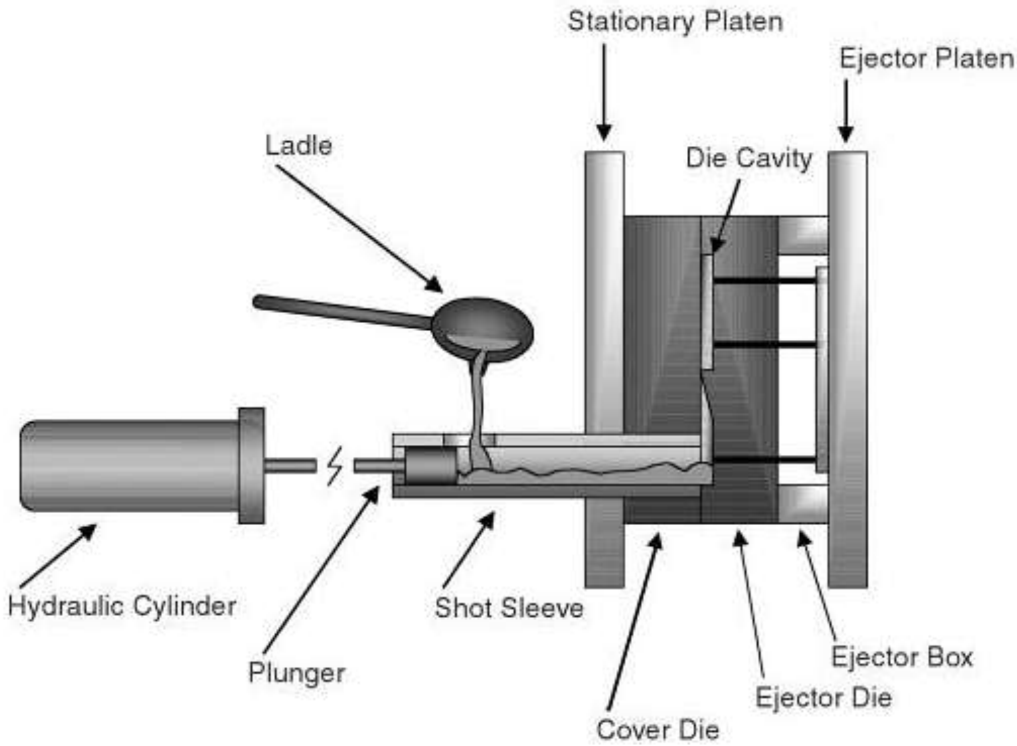


Figure 2.2 Cold-chamber die casting machine (Edward J. Vinarcik, 2002)

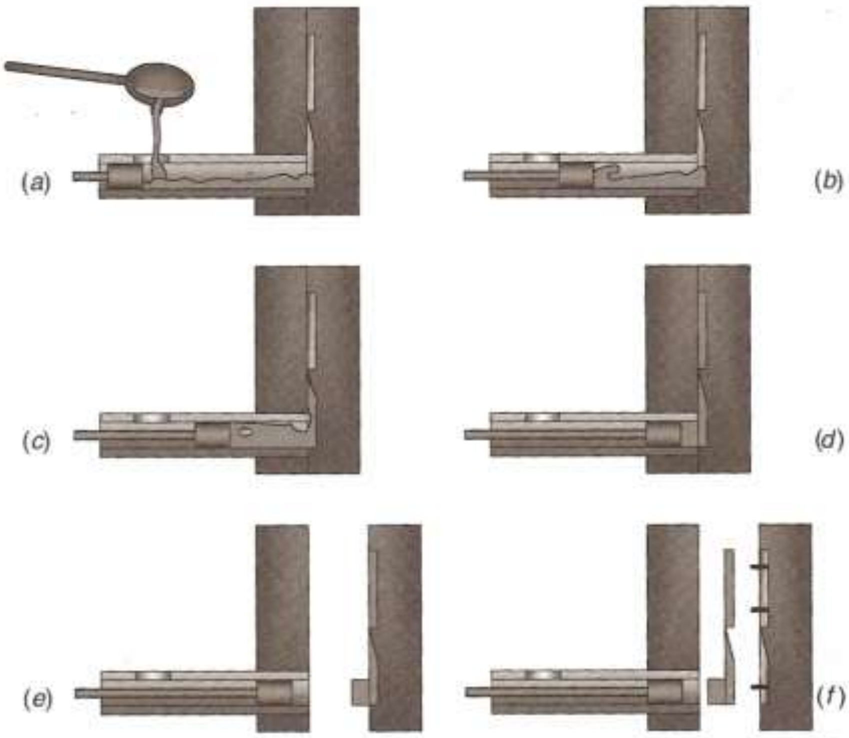


Figure 2.3 Casting cycle for cold-chamber die casting machine. (Edward J. Vinarcik, 2002)

Casting cycle for cold-chamber die casting machine consists of transportation of molten metal from furnace, filling, injection of molten material to die, cooling and discharging material from die. The process of cold-chamber die casting is shown in Figure 2.2 and Figure 2.3. Transportation of molten metal from furnace is of great risk for human health; also it affects cycle time and quality. Most of quality problems at die casting process are caused by lack of material and insufficient lubrication of mold.

CHAPTER THREE
INDUSTRIAL ROBOTS

3.1 Definition of Industrial Robots

According to the definition of International Standards Institute (ISO), the robot is the manipulator used in industrial applications, having three or more programmable axes, automatic-controlled, reprogrammable, multi-purpose, fixed or movable.

Today, robot applications are preferred in many fields for various tasks. Robotic applications can be divided according to their applications. Allonrobots Company describes robots types such; industrial robots, domestic robots, medical and military robots.

“a) Industrial robots - Industrial robots are robots used in an industrial manufacturing environment. Usually these are articulated arms specifically developed for such applications as welding, material handling, painting and others. If we judge purely by application this type could also include some automated guided vehicles and other robots.

b) Domestic or household robots - Robots used at home. This type of robots includes many quite different devices such as robotic vacuum cleaners, robotic pool cleaners, sweepers, gutter cleaners and other robots that can do different chores. Also, some surveillance and telepresence robots could be regarded as household robots if used in that environment.

c) Medical robots - Robots used in medicine and medical institutions.

d) Military robots - Robots used in military. This type of robots includes bomb disposal robots, different transportation robots, reconnaissance drones. Often robots initially created for military purposes can be used in law enforcement, search and rescue and other related fields. “(Allonrobots, 2012).

Robots can be classified as serial or parallel robots according to their joint orientation. There are two different joint orientations which are parallel and serial. A parallel orientation manipulator can be simply defined as a mechanical system that uses several computer-controlled serial chains to support a single platform, or end-effecter. Serial robots are designed as a series of links connected by motor-actuated joints that extend from a base to an end-effecter. They are the most common industrial robots.

Industrial robots can be classified in five categories by joint types.

a. Cartesian
b. Cylindrical,
c. Spherical (or Polar),
d. Jointed (or Revolute)
e. SCARA

3.1.1 Cartesian Robot

Figure 3.1 Cartesian robots

Cartesian coordinate robots consist of three linear axes, therefore they also colled as linear robot. Because of their linear axes, they move in a straight line rather than rotate. Graphical presentation of Cartesian robots is shown in Figure

3.1. The biggest advantage of these kinds of robots is coming from its simple design of its linear axes. Programming of Cartesian robots is much easier than other types. Having a linear axis of control is an advantage because it greatly simplifies the robot's arm solution. Linear calculations are far easier to calculate, because the programmer can perform these calculations in a closed form using basic trigonometric principles. (Wisegeek, 2012).

Prof. Vishal B. BHAGWAT has listed advantages and disadvantages of Cartesian robots at laboratory manual of which subject is robots.

Advantages of Cartesian robots;

- Ability to do straight line insertions into furnaces.
- Easy computation and programming
- Most rigid structure for given length.

Disadvantages of Cartesian robot;

- Requires large operating volume
- Exposed guiding surfaces require covering in corrosive or dust enviroments.
- Can only reach front of itself
- Axes hard to seal

Cartesian robots are commonly used for;

- Pick and place work
- Assembly operations
- Handling machine tools
- Arc welding

3.1.2 Cylindrical Robot

Figure 3.2 Cylindrical robots

Cylindrical robots can be basically described as robots which have one rotary joint at the base and linear joints to connect to wrist. This configuration consists of two prismatic joints and a rotary joint and the axes creates a cylindrical coordinate system (Wisegeek, 2012). Graphical presentation for cylindrical robots is shown in Figure 3.2.

Prof. Vishal B. BHAGWAT has listed advantages and disadvantages of cylindrical robots at laboratory manual of which subject is robots.

Advantages of cylindrical robots;

- Can reach all around itself
- Rotational axis easy to seal
- Relatively easy programming
- Rigid enough to handle heavy loads through large working space
- Good access into cavities and machine openings

Disadvantages of cylindrical robots;

- Can not reach above itself
- Linear axis is hard to seal
- Won’t reach around obstacles
- Exposed drives are difficult to cover from dust and liquids

Cylindrical robots are commonly used for;

- Handling at die-casting machines
- Assembly operations
- Handling machine tools
- Spot welding

3.1.3 Polar Robot

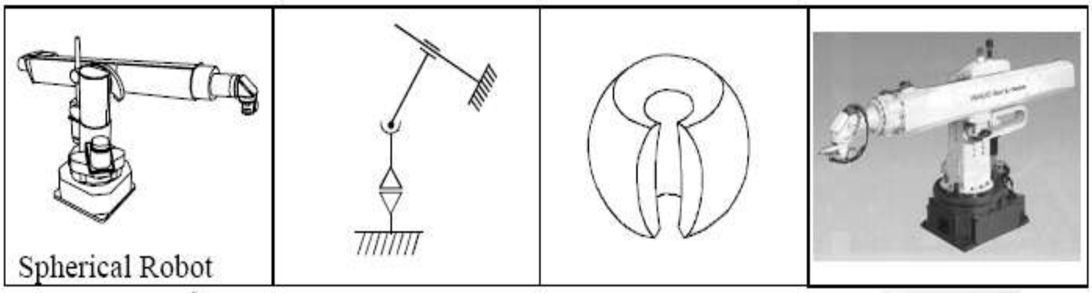


Figure 3.3 Polar Robots

The designation of arm for this configuration can be TRL or TRR (T:twisting joint, R: rotary joint, L: linear joint). A spherical shaped work space is created through the use of these joint combinations. Those with the designation TRR are also called articulated robots. An articulated robot more closely resembles the human arm (Prof. Vishal B. BHAGWAT,2011).

Prof. Vishal B. BHAGWAT has listed advantages and disadvantages of polar robots at laboratory manual of which subject is robots.

Advantages of polar robots;

- Can reach all around itself
- Rotational axis easy to seal
- Relatively easy programing
- Rigid enough to handle heavy loads through large working space

- Good access into cavities and machine openings

Disadvantages of polar robots;

- Can not reach above itself
- Linear axes is hard to seal
- Can not reach around abstacles
- Exposed drives are difficult to cover from dust and liquids

3.1.4 Jointed Robots

The jointed-arm is a combination of cylindrical and articulated configurations. The arm of the robot is connected to the base with a twisting joint. The links in the arm are connected by rotary joints. Many commercially available robots have this configuration. Articulated robots has at least three rotary joints (Prof. Vishal B. BHAGWAT,2011).

Prof. Vishal B. BHAGWAT has listed advantages and disadvantages of jointed robots at laboratory manual of which subject is robots.

Advantages;

- All rotary joints allows for maximum flexibility
- Any point in total volume can be reached.
- All joints can be sealed from enviroment.

Disadvantages;

- Extremely difficult to visualize, control and program.
- Restricted volume coverage.
- Low accuracy.

Commonly used for;

- Assembly operations
- Welding
- Weld sealing
- Spray painting
- Handling at die casting or fettling machines

3.1.5 SCARA Robots

The SCARA (Selection Compliance Assembly Robot Arm) is also known as a horizontal articulated arm robot. Some SCARA robots rotate about all three axes, and some have sliding motion along one axis in combination with rotation about another. By virtue of the SCARA's parallel-axis joint layout, the arm is slightly compliant in the X-Y direction but rigid in the 'Z' direction, hence the term: Selective Compliant. This is advantageous for many types of assembly operations, i.e., inserting a round pin in a round hole without binding. (Prof. Vishal B. BHAGWAT,2011).

Prof. Vishal B. BHAGWAT has listed advantages and disadvantages of scara robots at laboratory manual of which subject is robots.

Advantages;

- High speed
- Height axis is rigid
- Large work area for floor space
- Moderately easy to program

Disadvantages;

- Limited applications

- Two ways to reach point
- Difficult to program off-line
- Highly complex arm

Commonly used for;

- Pick and place work
- Assembly operations

One of the most appropriate types for this application is Cartesian robot. Cartesian robots consist of three prismatic joints. They are commonly used for positioning tools, such dispensers, drivers, cutters and routers.

Design of material feeding robot for an aluminium die casting system consist of following steps:

a) Determination of working space
b) Determination of maximum axis loads:
c) Determination of maximum axis speeds:
d) Choosing of linear modules
e) Determination of the Motor Forces of the Axis
f) Choosing of appropriate motors.

CHAPTER FOUR
DESIGN OF MATERIAL FEEDING ROBOT

In this study, a material feeding robot is designed and analysed. At the design and analysis process, some certain steps are followed. These steps are given in the flow diagram shown in Figure 4.1.

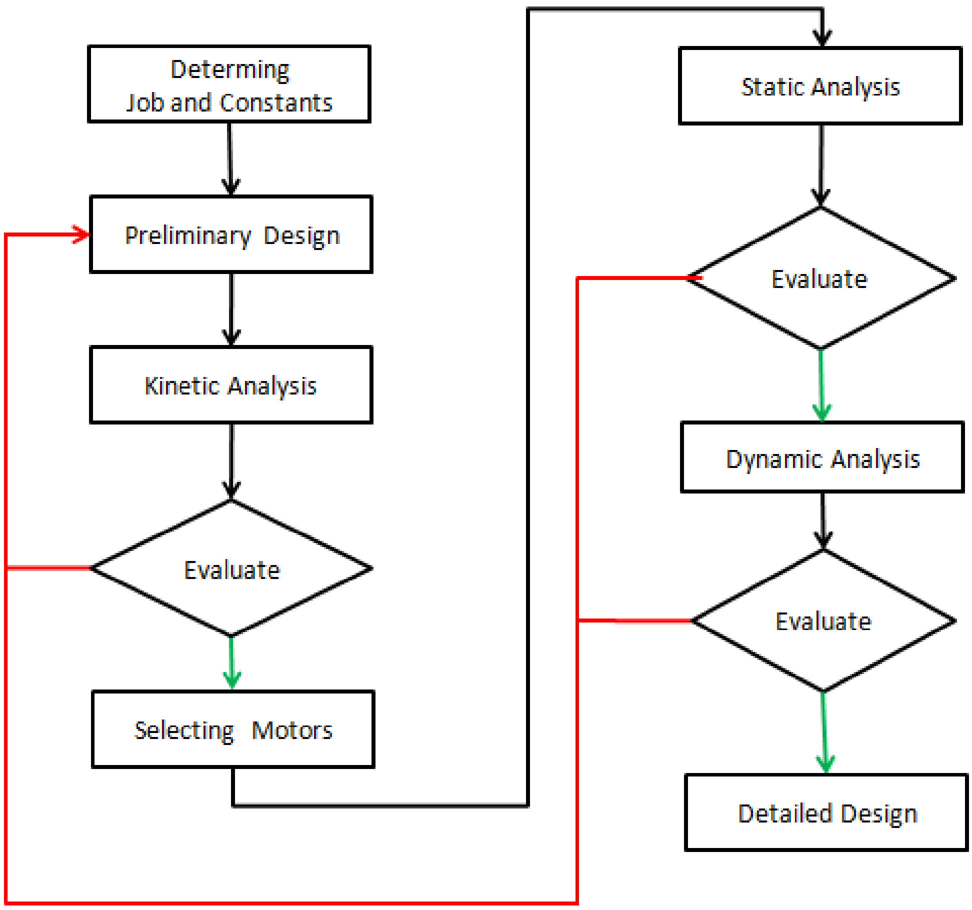


Figure 4.1 Flow diagram of design process

4.1 Determining Job and Environment Constants

In this study, die casting machine model MP-550 of metal press company will be discussed as aluminium die casting machine. During design process of material feeding robot, workspace and job requirements must be considered. The characteristics of die casting machine at issue are shown in Table 4.1. Figure 4.2 indicates the position of furnace against machine.

Table 4.1 Machine specifications

Clamping force	550 Tons
Moving platen stroke	750 mm
Die height	300-900mm (min-max)
Platen dimensions	1150x1150 mm
Distance between tie bars	715x715 mm
Tie bar diameter	145 mm
Ejector stroke	180mm
Ejector force	280 kN
Injector stroke	530 mm
Max shot weight	7000 gr
Max. casting area	1570 cm^2
Driving motor	45kW
Machine weight	24000 kg

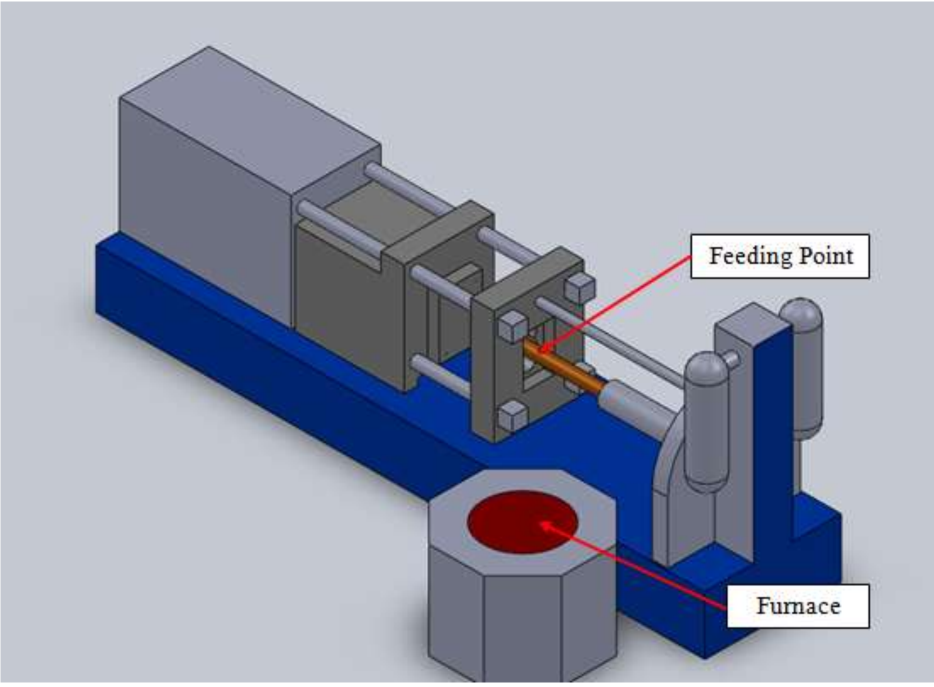


Figure 4.2 Layout of MP-550 and furnace

Job requirements are as follows;

*Molten material must be transfered from furnace to the machine's drop point and horizontal distance for transfer is 3000mm.

*Material feeding robot must be able to reach to the bottom of furnace. The stroke of vertical axis should be 1500mm.

*Approximate temperature at furnace is 680^{o}C. All material and equipments should be selected with the consideration of heat affect.

* Estimated cycle time for material feeding robot is 17 sec.

* Material feeding robot should be able to handle 5kg molten metal.

In order to select appropriate robot design we should evaluate robot types. Articulated robot must have large arms to reach all points of workspace and it should have more capacity than we need for this application. Cartesian robot is more appropriate for these kind of workspace and it is easy to program.

In order to have complete automation of die casting machine, three units which are automatic lubrication system, automatic feeding system and extraction robot must be applied. Figure 4.3 shows whole automation system of die casting machine and automation units are pointed out.

A: Die casting machine

B: Extraction robot

C: Lubrication system

D: Material feeding system

E: Drop point of die casting machine

F: Furnace

According to enviromental conditions, ball secrew driven linear module is choosen instead of tooth belt driven linear module. Our first constants are distance and cycle time. Layout of machine and furnace are presented in Figure 4.3 and Figure 4.4, which represents the workspace which material feeding unit should have according to layout shown in Figure 4.3. Linear modules will be selected with the consideration of axis strokes and velocities and preliminary design will be created for analysis in the following chapters.

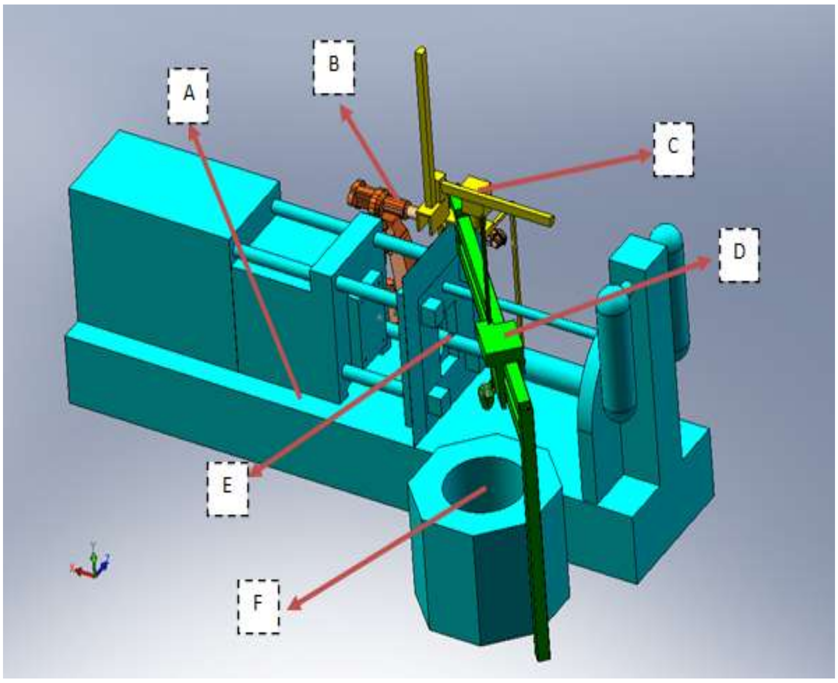


Figure 4.3 Complete automation of die casting machine

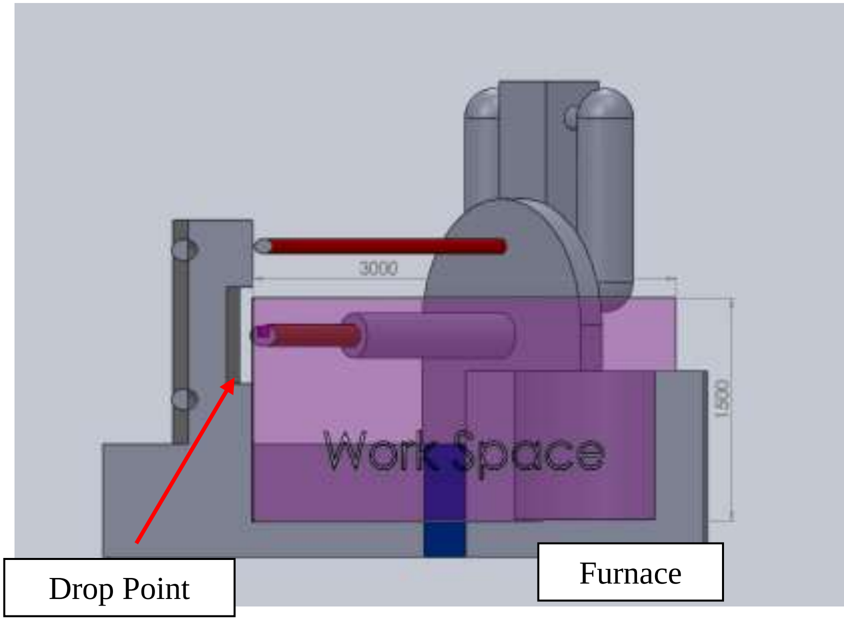


Figure 4.4 presentation of work space

4.2 Establishing the Loads and Calculating the Bearing Forces

We need axis loads and forces of bearing impact caused by loads in addition to information on stroke in order for appropriate linear modules to be chosen in application of Cartesian robot designed as seen in Figure 4.5.

According to module's unit mass values, mass is calculated for determined vertical and horizontal axes. Preliminary design is created through the use of Solidworks cad program. It is ensured that first design has same mass properties with the linear modules which are selected in order to simulate real model.

Kinetic analysis is designed according to total cycle time. Total cycle time of die casting process is approximately 160sec. for four kg cast. Process cycle time consists of four main steps such; feeding molten material, casting, and extraction of cast from die and lubrication of die. Job combination table for process with manual operations is given in Table 4.2. The capacity of machine is 400 cycle per day with 21 hours per day and %85 operation efficiency.

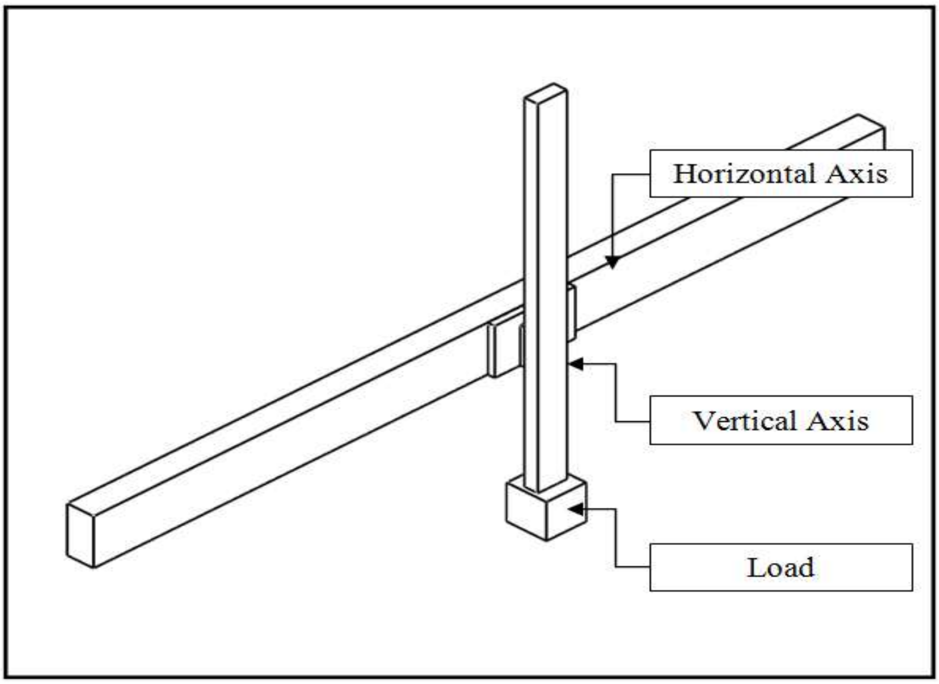


Figure 4.5 Preliminary Design

Automatic systems help to decrease cycle time. Improved cycle time is given in Table 4.3. It is estimated that cycle time is 20 seconds for automatic lubrication. By implementing automatic systems, cycle time of operation is reduced from 160 seconds to 115 seconds. The increased capacity of machine is 558 cycle per day with 21 hours per day and %85 operation efficiency. There is % 39 improvements at the capacity of machine through the use of automatic applications.

Table 4.2 Job Combination Table with Manual Operatios

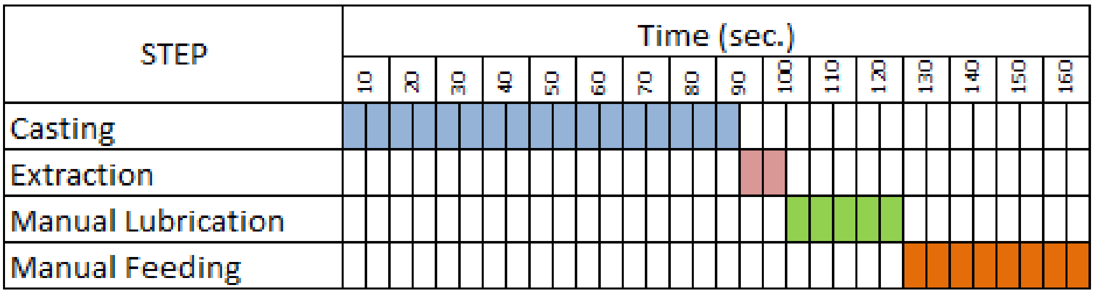
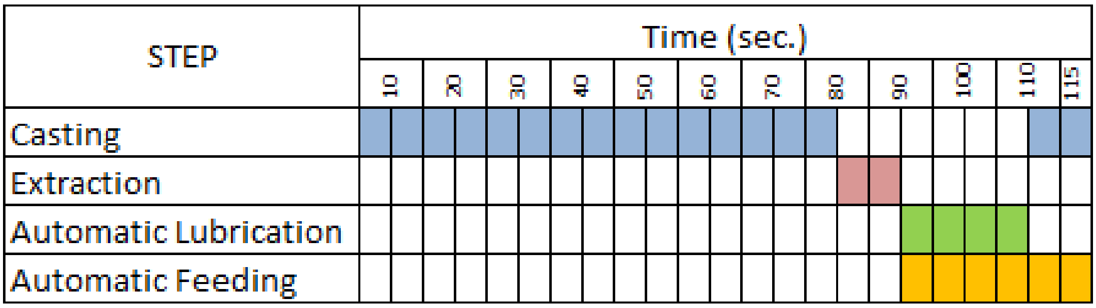


Table 4.3 Job Combination Table with Automatic Lubrication and Feeding System



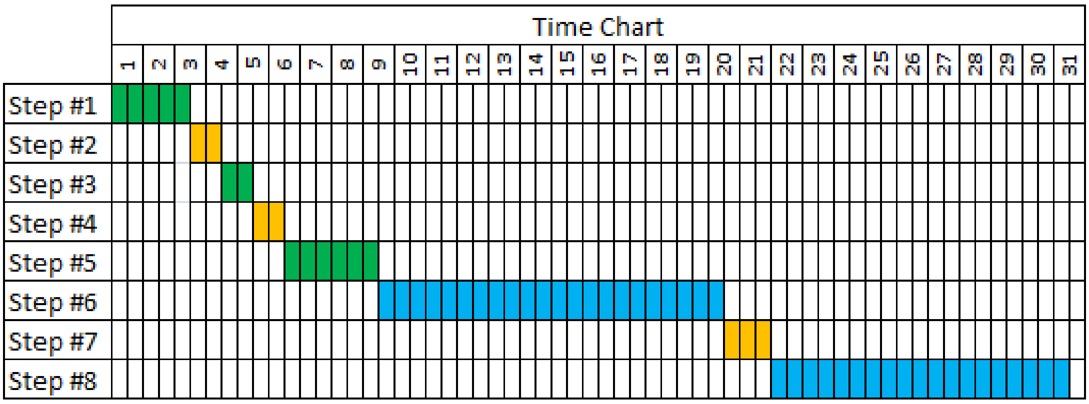
Cycle time for feeding is determined as 30,5 sec. Complete cycle consists of 8 steps. These eight steps are as follows;

- Step 1: Moving axis into furnace
- Step 2: Waiting for ladle to fill with material.
- Step 3: Raising to the amount adjusting position
- Step 4: Rotating ladle to correct position to adjust material amount
- Step 5: Moving to the upper position
- Step 6: Transfer to the machine.
- Step 7: Drop to the machine.
- Step 8: Move back to the initial position.

Total cycle time is divided for each step and kinetic analysis are made according to these predetermined times. Detailed cycle time is shown in Table 4.4. At the Table 4.4, green cells indicate the movement at vertical axis which is called axis #1 in following chapters, blue cells shows the movement at horizontal axis #2 and yellow ones are for rotational axis #3.

For this application, linear modules of Bosch Rexroth Company will be used. Specifications of modules are shown in Table 4.5. The values shown in Table4.5 are obtained from catalogue of Bosch Rexroth Company for linear modules. Permissible loads and velocities are show in the following Figures and tables.

Table 4.4 Time Chart of Feeding Robot



According to Table 4.4, cycle times of steps are as follows;

- Step 1: Moving axis into furnace:	2.5	sec
- Step 2: Waiting for ladle to fill with material:	1.0	sec.
- Step 3: Raising to the amount adjusting position:	1.0	sec.
- Step 4: Rotating ladle to correct position:	1.0	sec.
- Step 5: Moving to the upper position:	3.0	sec.
- Step 6: Transfer to the machine:	11.0	sec.
- Step 7: Drop to the machine:	1.5	sec.
- Step 8: Move back to the initial position:	9.5	sec.

Table4.5 Module specifications from Bosch Rexroth catalogue.

Size	Number of carriages	Ball Screw	Dynamic load capacity C (N)			Dynamic Moments		Max. lenght	Moved Mass
			Guide way	Ball Screw	Fixed Bearing	Mt (Nm)	ML (Nm)	Lmax (mm)	Mb (kg)
CKK 12-90	1	12x2	4620	2240	6900	125	16	750	0,36
		12x5		3800					
		12x10		2500					
	2	12x2	7500	2240	6900	200	240		0,59
		12x5		3800					
		12x10		2500					
CKK 15-110	1	16x5	15600	12300	13400	515	80	1500	0,52
		16x10		9600					
		16x16		6300					
	2	16x5	25340	12300	13400	835	1075		0,86
		16x10		9600					
		16x16		6300					
CKK 20 - 145	1	20x5	37600	14300	17000	1650	255	1800	1,21
		20x20		9100					
		20x40		14000					
		25x10		15700					
	2	20x5	61080	14300	17000	1650	255	1800	2,06
		20x20		9100					
		20x40		14000					
		25x10		15700					
CKK 25-200	1	32x5	55000	21500	26000	5800	7810	2200 (With SPU 5500)	3,18
		32x10		31700					
		32x20		19700					
		32x32		19500					
	2	32x5	89340	21500	26000	5800	7810	2200 (With SPU 5500)	5,2
		32x10		31700					
		32x20		19700					
		32x32		19500					

Table 4.6 Weight calculation table for linear modules from Bosch Rexroth catalogue

Size	Ball screw	Number of carriages	Weight (kg)
CKK 12-90	with	1	$0.0055 \cdot L + 0.9$
		2	$0.0055 \cdot L + 1.2$
CKK 15-110	with	1	$0.0092 \cdot L + 1.6$
		2	$0.0092 \cdot L + 2.0$
CKK 20-145	with	1	$0.0178 \cdot L + 3.0$
		2	$0.0178 \cdot L + 3.9$
CKK 25-200	with	1	$0.0299 \cdot L + 6.7$
		2	$0.0299 \cdot L + 8.7$

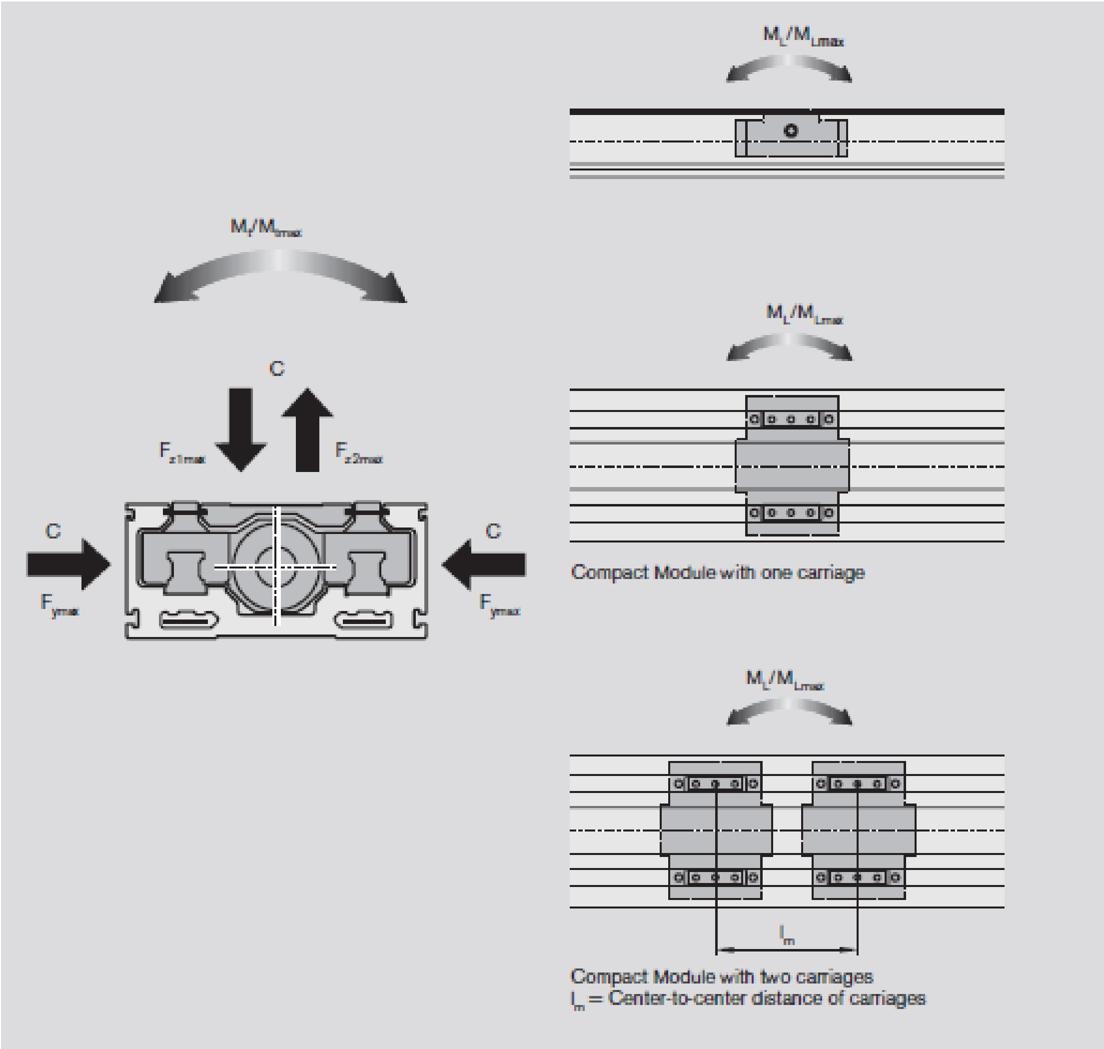


Figure 4.6 Force and moment which acting on modules from Bosch Rexroth catalogue

Table 4.7 Maximum permissible loads from Bosch Rexroth linear catalogue

Size	Number of carriages	Maximum permissible forces (N)			Maximum permissible moments (Nm)	
		F_{z1max}	F_{z2max}	F_{ymax}	M_{tmax}	M_{Lmax}
CKK 12-90	1	4 620	4 620	2 490	125	16
	2	7 500	7 500	4 050	200	240
CKK 15-110	1	12 000	6 000	3 480	198	31
	2	19 490	9 740	5 650	322	414
CKK 20-145	1	29 000	14 500	8 410	638	100
	2	47 110	23 550	13 660	1 030	1 180
CKK 25-200	1	42 200	21 100	12 230	1 372	209
	2	68 550	34 270	19 880	2 228	2 999

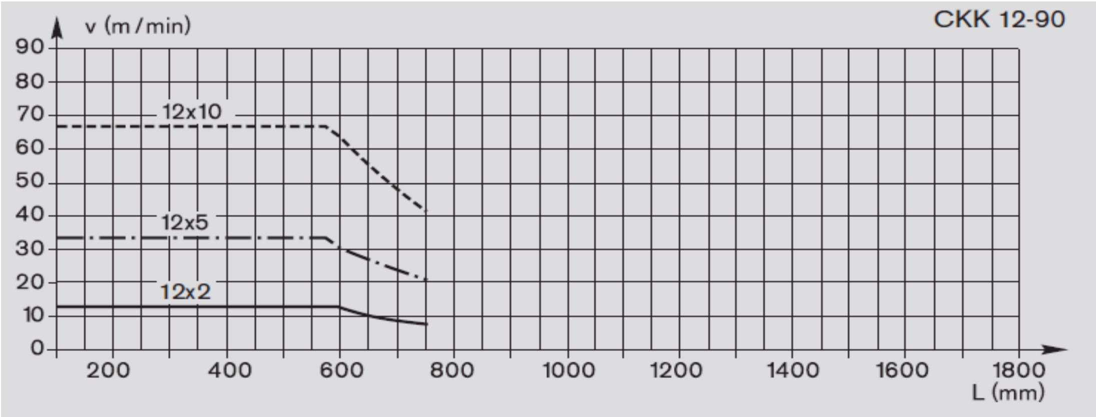


Figure 4.7 Permissible velocities for CKK 12-90 from Bosch Rexroth linear module catalogue

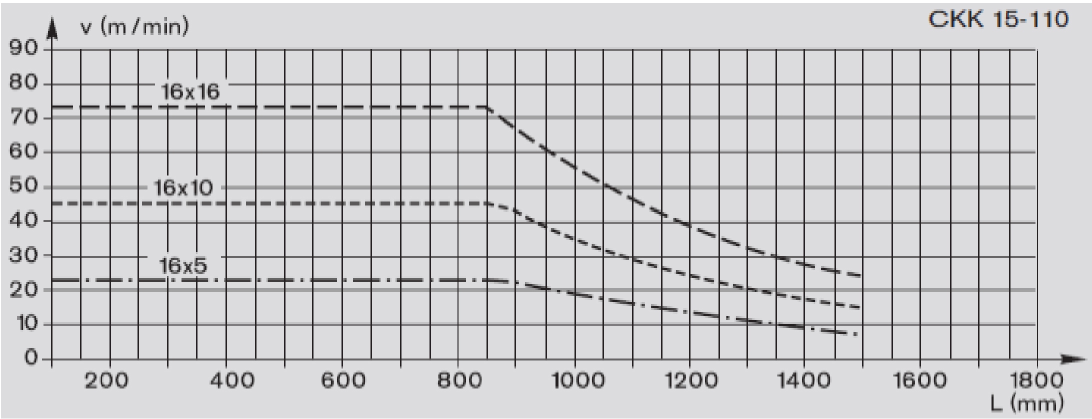


Figure 4.8 Permissible velocities for CKK 15-110 from Bosch Rexroth linear module catalogue

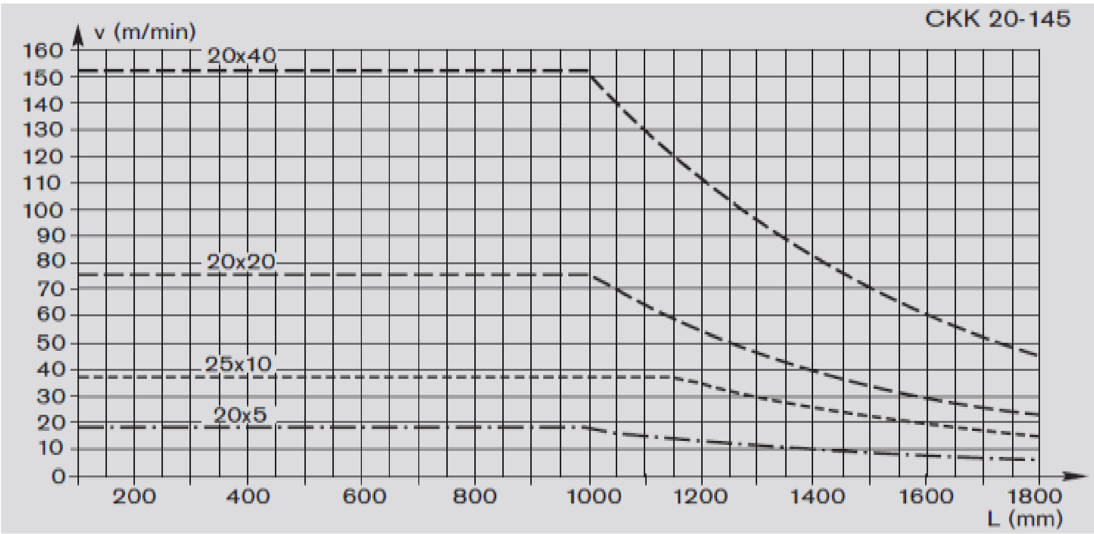


Figure 4.9 Permissible velocities for CKK 20-145 from Bosch Rexroth linear module catalogue

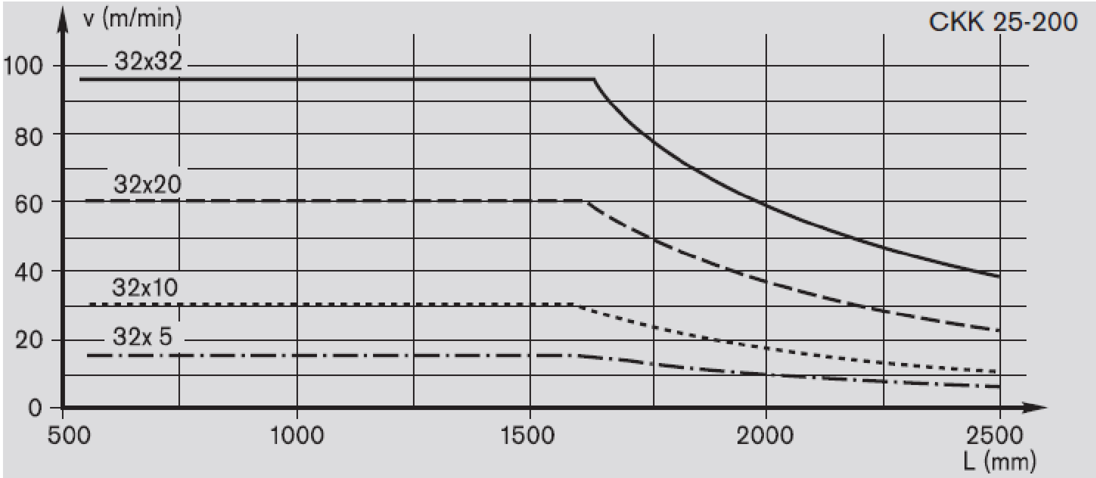


Figure 4.10 Permissible velocities for CKK 25-200 from Bosch Rexroth linear module catalogue

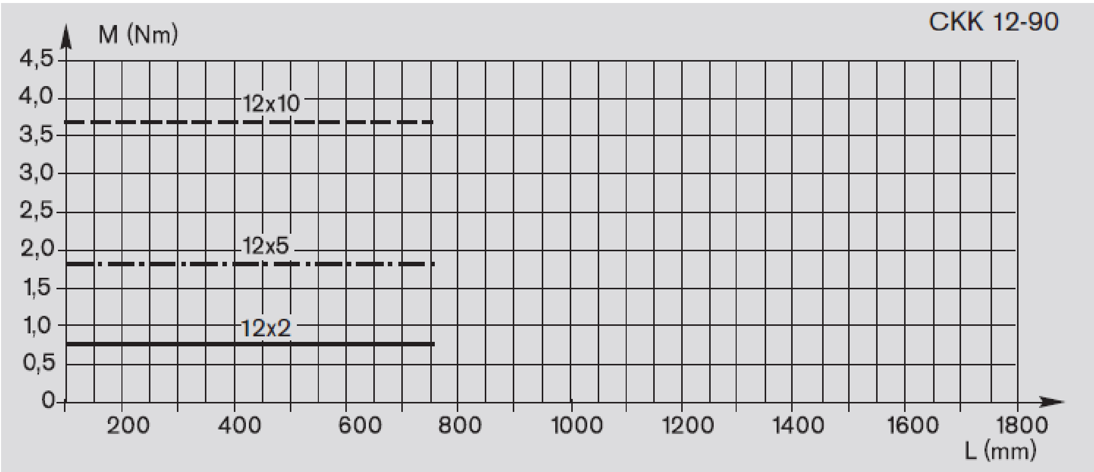


Figure 4.11 Permissible moment for CKK 12-90 from Bosch Rexroth linear module catalogue

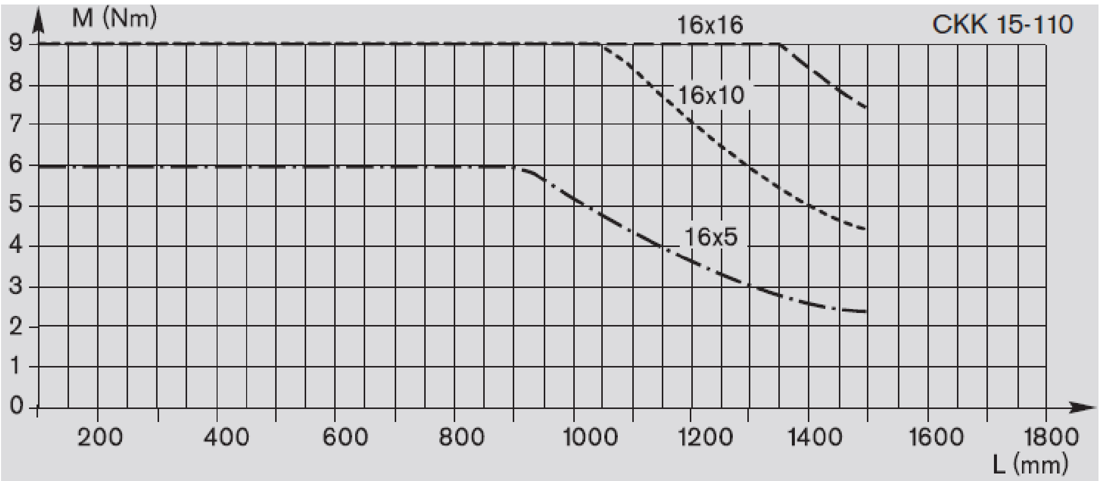


Figure 4.12 Permissible moment for CKK 15-110 from Bosch Rexroth linear module catalogue

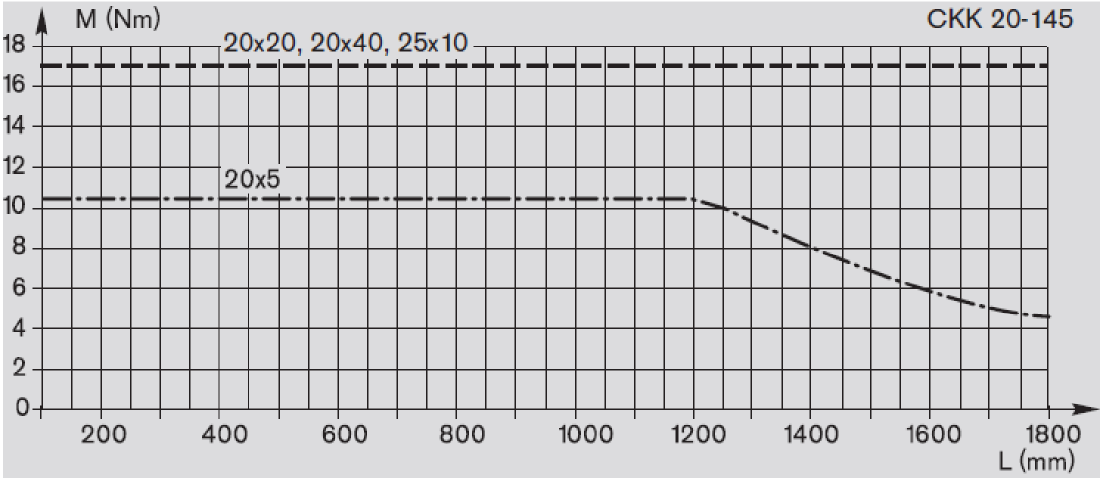


Figure 4.13 Permissible drive moment for CKK 20-145 from Bosch Rexroth linear module catalogue

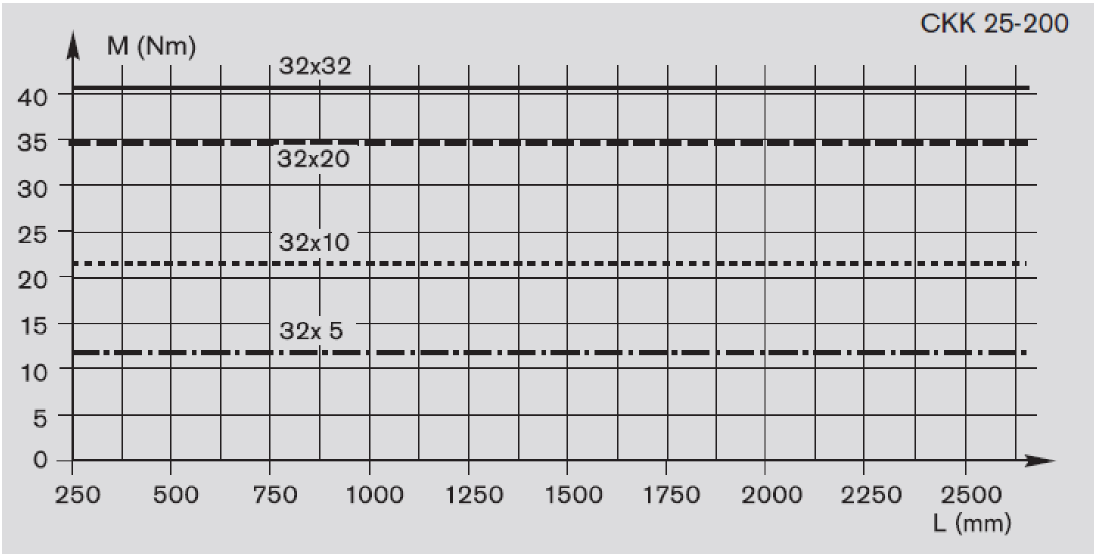


Figure 4.14 Permissible moment for CKK 25-200 from Bosch Rexroth linear module catalogue

4.2.1 Determining Linear Module for Vertical Axis

Job requirements are determined in Section 4.1. The distance to be reached is 1500 mm and it is shown that time for step#1 is determined as 2.5 seconds in Table 4.4. According to Table 4.5 which is obtained from linear module catalouge of Bosch Rexroth Company, CKK 12-90 is not appropriate for vertical axis because of its maximum permissible length. The next module CKK 15-110 has appropriate length.

Required velocity for vertical axis is 30 m/min. According to Figure 4.8, it is obvious that CKK15-110 is not able to reach required velocity at determined length. CKK 20-145 is selected for vertical axis. CKK 20-145 with one carriage is selected and mass of module is calculated as 29,7 kg according to Table 4.6. The mass of molten material is determined as 5 kg at section 4.1 and mass of arm, which creates rotational movement of ladle is 7,5 kg.

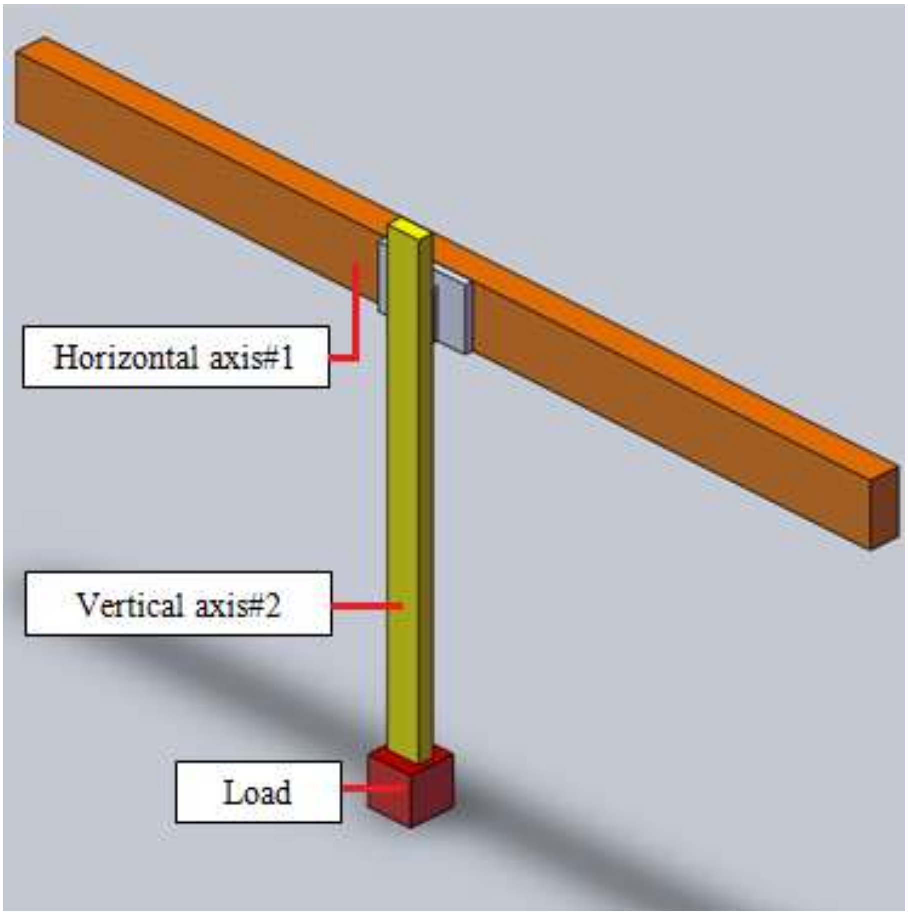


Figure 4.15 Basic design

In compliance with above mentioned design data, kinetic model is created. Data obtained from analysis held on CosmosMotion will be compared with the values from module catalogue which is shown in Table 4.5 and Figure 4.16 shows directions of moments and forces which are mentioned in Table 4.5.

As shown in the y-axis of the robot to create free-body diagram.

F_{x1}, F_{y1}, F_z1 = impact force due to load

F_{xr1}, F_{yr1}, F_{zr1}= bearing reaction force

m_{axis}= own weight of the axis module

M_{x1}, M_{y1}, $M_{z}1$= external moments acting on the axis

M_{xr1}, M_{yr1}; M_{zr1}= moments acting on the bearings

$\Sigma F_x=0, \Sigma F_y=0, \Sigma F_z=0, \Sigma M_x=0, \Sigma M_y=0, \Sigma M_z=0$

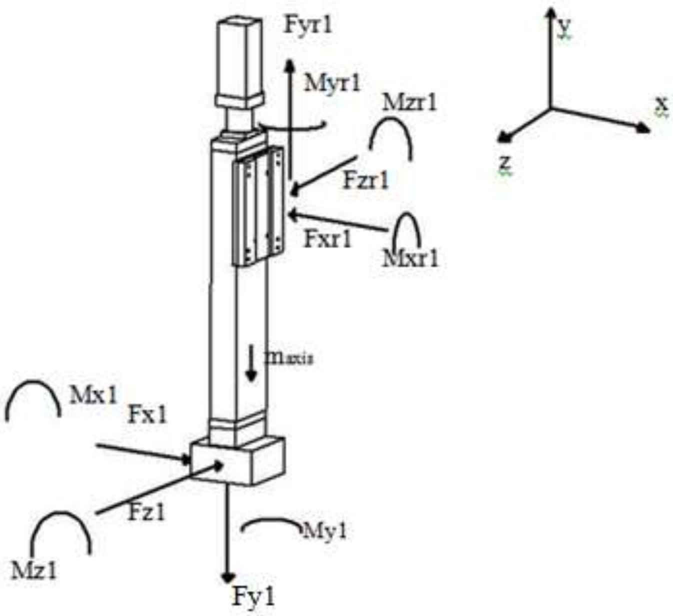


Figure 4.16 Axis#1 free-body diagram

We can find the reaction forces and moments in the axes bearings by applying total force and total moment equations. Basic model was created and loads were applied to this model throught the use of SolidWorks. Gravity is taken into account for kimetic model and in addition to 5kg molten material; 7.5kg load is added for ladle mechanism. Vertical distance determined from workspace which is given Figure 4.4 at previous chapter. All velocities are determined as same as in Table 4.3. Reaction forces and moments are calculated based on these data and given in Figure 4.17.

V_{max} = 900mm/sec (Figure 4.17-b) (4.1)

a_{max} = 48448mm/sec^2 (Figure 4.17-a) (4.2)

M_t = 41.87 Nm (Figure 4.17-d) (4.3)

$M_L \quad = \quad 19.33Nm \qquad \text{(Figure 4.17-f)} \qquad\qquad (4.4)$

All forces and moments are compared with catalogue values which are given in Table 4.7. Moments obtained from CosmosMotion shows that selected CKK 20-145-1 with 20x40 screw module is suitable for designed system.

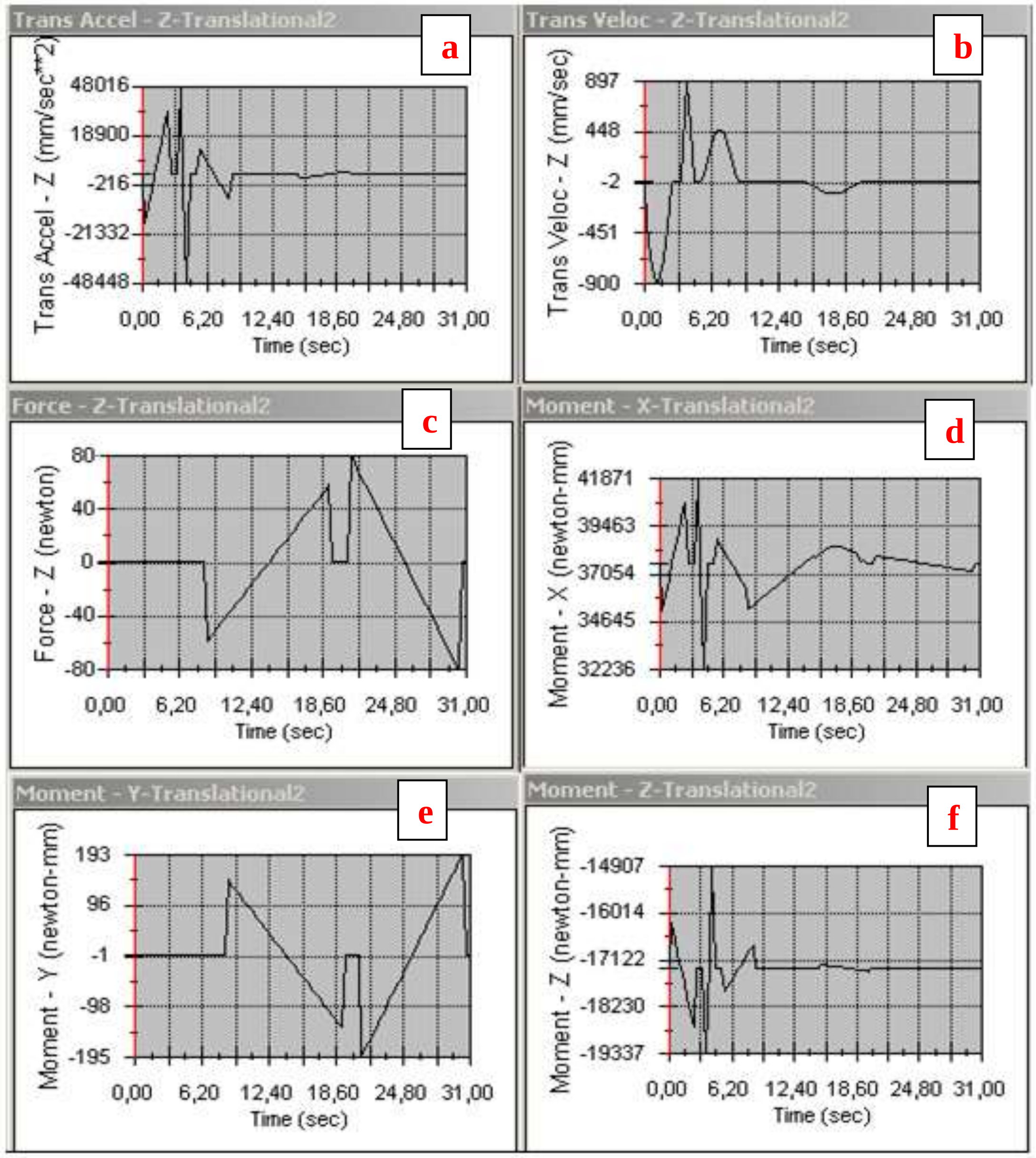


Figure 4.17 Moment diagrams obtained from kinetic analysis of vertical axis

4.2.2 Determining Linear Module for Horizontal Axis

Job requirements are determined in Chapter 4.1. The distance to be reached is 3000 mm and it is shown that time for step#8 is determined as 9,5 seconds in Table 4.4. According to Table 4.5 which obtained from linear module catalouge of Bosch Rexroth Company, CKK 25-200 has appropriate length. CKK 25-200 with one carriage is selected and mass of module is calculated as 96,4 kg according to equations given in Table 4.6. Basic kinetic model is created at Solidworks cam program and job requirements which are defined in Chapter 4.1 are applied to the basic model. The reaction forces and reaction moment values are obtained from kinetic analysis. Reaction force and moment curves are given in Figure 4.18.

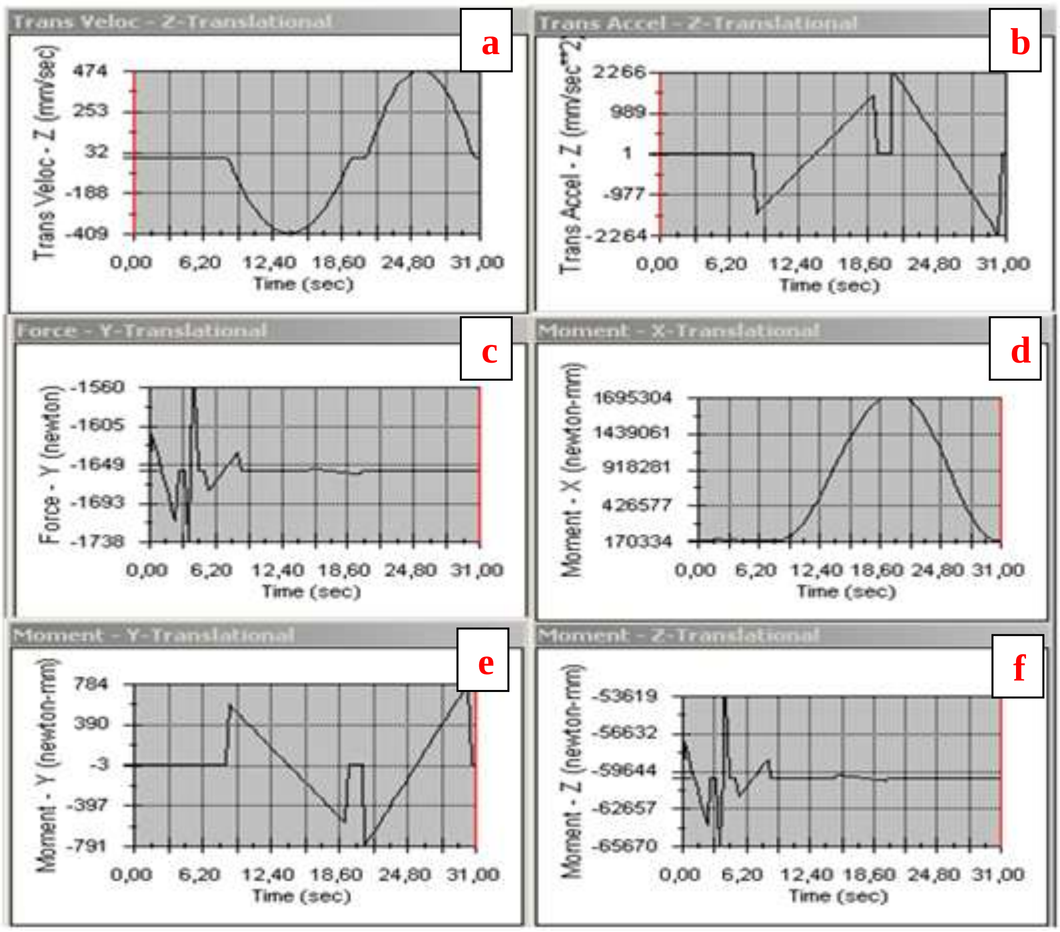


Figure 4.18 Force and Moment diagrams obtained from kinetic analysis of horizontal axis

V_{max}= 474 mm/sec (Figure 4.18-a) (4.5)

a_{max}= 1226 mm/sec^2 (Figure 4.18-b) (4.6)

M_t= 1695 Nm (Figure 4.18-d) (4.7)

M_L= 65 Nm (Figure 4.18-f) (4.8)

According to kinetic analysis results, reaction forces exceed the maximum permissible loads which are given in Table4.7 for CKK 25-200 with one carriage. The linear module with two carriages is selected for horizontal axis. New mass of linear module is calculated as 98,4 kg. It is not necessary for kinetic analysis to be repeated with this new mass value. Because horizontal axis is not a movable mass, so it has no affect on reaction forces. CKK25-200 with secrew 32x20 and with two carriages is selected for horizontal axis.

4.2.3 Design of ladle arm

In order to select material for ladle arm, enviromental conditions should be studied. The temperature of molten material has 660°C heat. Molten aluminum spreads around at drop point of machine. All material should have resistance to these environmental conditions. Due to these conditions 100Cr6 material will be used for moveble parts of ladle arm.

During die casting process, amount of molten material in the pot always changes. The distance between ladle and molten material must be measured to approach it safely at every cycle. Two electrodes will be implemented to ladle arm in order to determine the distance between ladle and molten material. These electrodes will contact molten metal before ladle. After determining level of material, vertical translation of ladle will get slow and will enter molten aluminum with a pre-determined angle.

In order to adjust amount at ladle, ladle must be rotated to pre-defined angle. All electronic equipment and motors should be preserved against heat, dust and molten material. To keep safe the motor which provides rotational movement of ladle, servo motor must be placed in safe zone. An arm mechanism is designed for motor to rotate ladle from safe zone. Figure 4.19 shows three positions of ladle. First position is for entering to molten material and filling the laddle up. Second position is for translation of molten material from furnace to machine's drop point. Third position is for discharging at drop point.

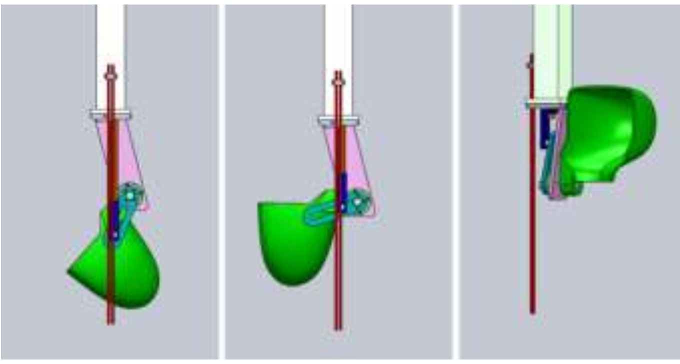


Figure 4.19 Positions for ladle

According to time chart which is shown in Table 4.4, the ladle arm was simulated at Cosmos Motion and rotary motion generator moment curve was obtained from SolidWorks Cosmos Motion program. It was considered that ladle is full of 5kg molten material. Entrance angle of ladle cup to go in the molten material is to be of highly importance because of oxidation. During movement, it shouldn't be allowed the molten material to mix with air. In accordance with these information, it was determined as 60° for entrance to the molten material for filling the ladle up, 15° for adjusting amount to 5 kg, and -80° degree for droping molten material to the feeding point of machine. The curves which are obtained from Cosmos Motion for he motion of ladle cup are shown in Figure 4.20

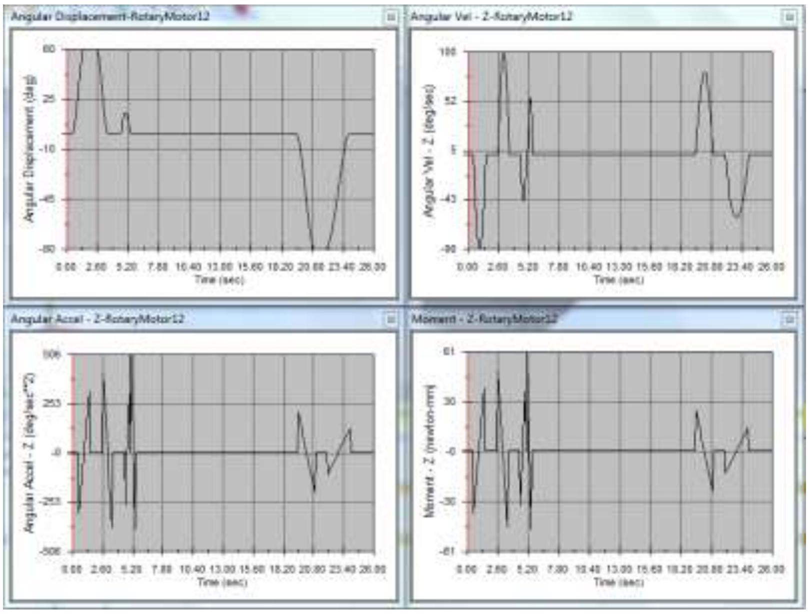


Figure 4.20 Curves obtained from CosmosMotion for the motion of ladle cup

4.2.4 Selecting Motors for Compact Modules

In order to select servo motor for horizontal axis, necessary power must be calculated. According to kinetic analysis, CKK25-200 with secrew 32x20 is selected.

Necessary power is calculated from following equations;

$$n = \frac{stroke}{p \; x \; t} x60 \qquad (4.9)$$

$$M_{ta} = \frac{F \; x \; p}{\eta \; x \; \pi \; x \; 2000} \qquad (4.10)$$

$$Pa = \frac{M_{ta} \; x \; n}{9550} \qquad (4.11)$$

M_{ta} = Drive torque (Nm) (4.12)

F = Operating load (N) (4.13)

$\eta \approx 0.9$ (4.14)

n = Rotary speed (min-1) (4.15)

Pa = Drive power (kW) (4.16)

t = Time spend to reach maximum stroke (sec) (4.17)

Also just to compare and validate operating load which is calculated by Cosmos Motion, operating load can be calculated below given equation.

F= m x a (4.18)

m = mass of movable parts (kg) (4.19)

a = inertia of movable parts (m/sec^2) (4.20)

Horizontal axis

$$n = \frac{3000}{20\ x\ 9.5} x60 = 947\ min^{-1} \tag{4.21}$$

$$M_{ta} = \frac{80\ x\ 20}{0.90\ x\ \pi\ x\ 2000} = 0.28Nm \tag{4.22}$$

$$Pa = \frac{0.28\ x\ 947}{9550} = 27\ W \tag{4.23}$$

Pa = 27 W (Horizontal Axis) (4.24)

F= 35 x 2.266=79.31 N (4.25)

Vertical axis:

$$n = \frac{1500}{40\ x\ 3.5}\ x\ 60 = 642\ min^{-1} \tag{4.26}$$

$$M_{ta} = \frac{1738\ x\ 40}{0.90\ x\ \pi\ x\ 2000} = 12.29\ Nm \tag{4.27}$$

$$Pa = \frac{12.29\ x\ 642}{9550} = 0.82\ kW \tag{4.28}$$

Pa = 0.82 kW (Vertical Axis) (4.29)

F= 35 x 48.448=1695.68 N (4.30)

Ladle Motor:

$$n = \frac{100x60}{360} = 16.66\ min^{-1} \tag{4.31}$$

According to above calculations servo motors can be selected. Servo motors are selected from catalogue of Omron Company. SGMAH–A5A is selected for horizontal axis. SGMGH-13D is selected for vertical axis. SGMAH-A3A is selected for ladle motion. It is necessary to use reductor to reach drive torque for motors which are chosen for both vertical and horizontal axis. Reductor VRSF-3B-100 of Shimpo Company is selected for horizontal axis. Reductor VRSF-3B-400 of Shimpo Company is selected for vertical axis. The rates of both reductors are 1/3. Maximum rotary speed is 1000rpm. Through the use of reductors, SGMAH-A5A can provide 0.477N.m torque; SGMGH-13D can provide 25.02N.m torque.

Table 4.8 Servo Motor Properties

Sigma-II rotary servo motor				
	Voltage	**Rated torque**	**Capacity**	**Model**
SGMAH (3000 min^{-1}) 	230 V	0.0955 N.m	30 W	SGMAH-A3A□
		0.159 N.m	50 W	SGMAH-A5A□
		0.318 N.m	100 W	SGMAH-01A□
		0.637 N.m	200 W	SGMAH-02A□
		1.27 N.m	400 W	SGMAH-04A□
		2.39 N.m	750 W	SGMAH-08A□
	400 V	0.955 N.m	300 W	SGMAH-03D□
		2.07 N.m	650 W	SGMAH-07D□
SGMPH (3000 min^{-1}) 	230 V	0.318 N.m	100 W	SGMPH-01A□
		0.637 N.m	200 W	SGMPH-02A□
		1.27 N.m	400 W	SGMPH-04A□
		2.39 N.m	750 W	SGMPH-08A□
		4.77 N.m	1500 W	SGMPH-15A□
	400 V	0.637 N.m	200 W	SGMPH-02D□
		1.27 N.m	400 W	SGMPH-04D□
		2.39 N.m	750 W	SGMPH-08D□
		4.77 N.m	1500 W	SGMPH-15D□
SGMGH (1500 min^{-1}) 	400 V	2.84 N.m	0.45 kW	SGMGH-05D□
		5.39 N.m	0.85 kW	SGMGH-09D□
		8.34 N.m	1.3 kW	SGMGH-13D□
		11.5 N.m	1.8 kW	SGMGH-20D□
		18.6 N.m	2.9 kW	SGMGH-30D□
		28.4 N.m	4.4 kW	SGMGH-44D□
		35.0 N.m	5.5 kW	SGMGH-55D□
		48.0 N.m	7.5 kW	SGMGH-75D□
		70.0 N.m	11 kW	SGMGH-1AD□
		95.4 N.m	15 kW	SGMGH-1ED□

4.3 Analysis and Results

4.3.1 Static Analysis

Basic model which is created for kinetic analysis is not sufficient for this kind of anaysis. Basic model is created to demonstrate mass and velocity of linear modules. In order to run static analysis on basic model, it must contain material properties and moments of inertia. Real sections of modules are given in Figure 4.21. It is not easy to create mesh at these types of complicated structures. Therefore, basic sections that have same moments of inertia which are given at Bosch Rexroth Compact Module Catalogue are created to simulate real module. Visual basic program is used to calculate section and draw beam at solidworks. The program which is shown in Figure 4.22 creates sections by iteration. Program code is given in Appendix A. Equivalent sections of beams are given at Figure 4.23.

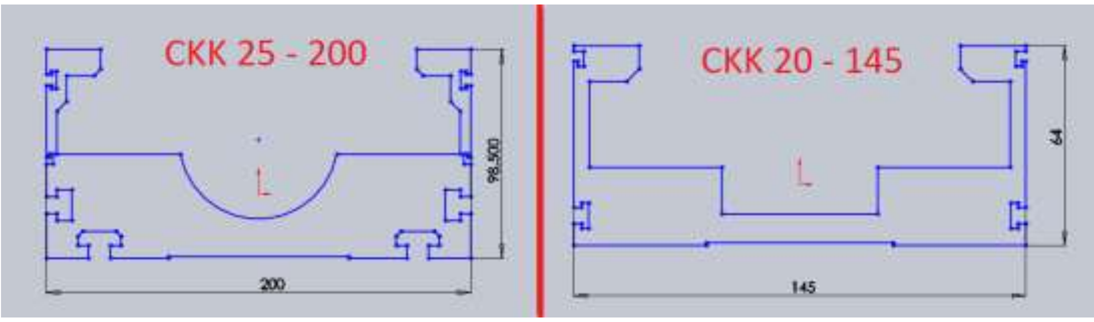


Figure 4.21 Real Sections of Compact Modules

For compact module CKK 20 -145, it is given that Iy moment of inertia is 114.1 cm^4 and Iz is 986.4 cm^4. For compact module CKK 25 - 200, it is given that Iy moment of inertia is 612 cm^4 and Iz is 3008 cm^4. Through the use of Visual basic, equivalent sections are created automatically and 3D cad model of linear modules created. Modulus of elasticity for compact modules is given is catalogue as $70000N/mm^2$.

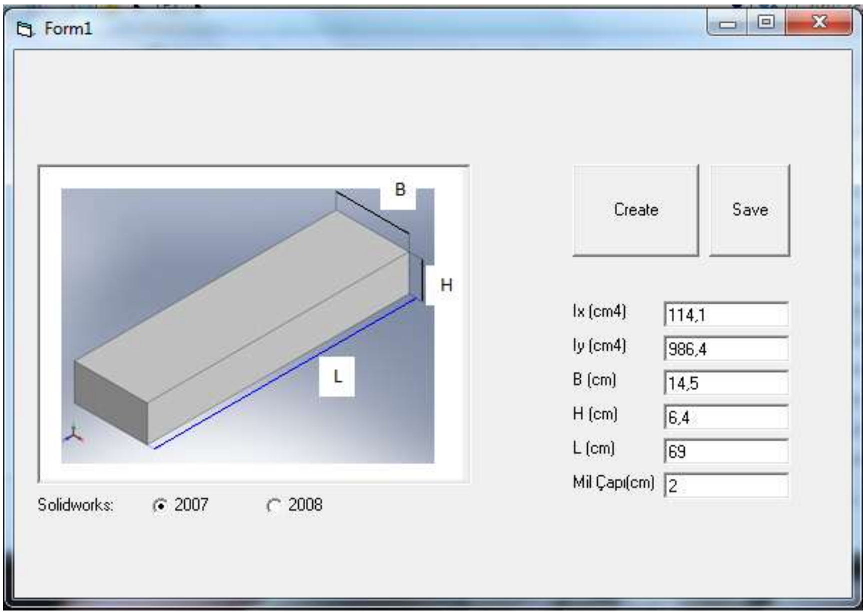


Figure 4.22 Software to Create Equivalent Sections

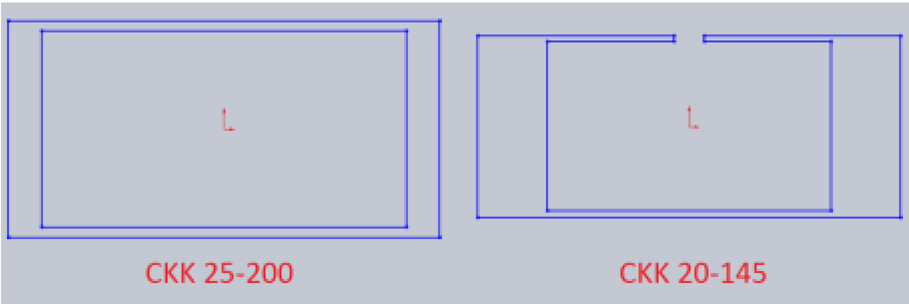


Figure 4.23 Equivalent Beam Sections

Calculated moment of inertia of equivalent CKK 25-200

$$Iy = 611{,}83 \text{ cm}^4 \quad (4.32)$$

$$Iz = 3007{,}42 \text{ cm}^4 \quad (4.33)$$

Calculated moment of inertia of equivalent CKK 20-145

$$Iy = 114.10 \text{ cm}^4 \quad (4.34)$$

$$Iz = 987.62 \text{ cm}^4 \quad (4.35)$$

With equivalent sections, analysis model is created. Mass, gravity and constraints are applied to basic model.

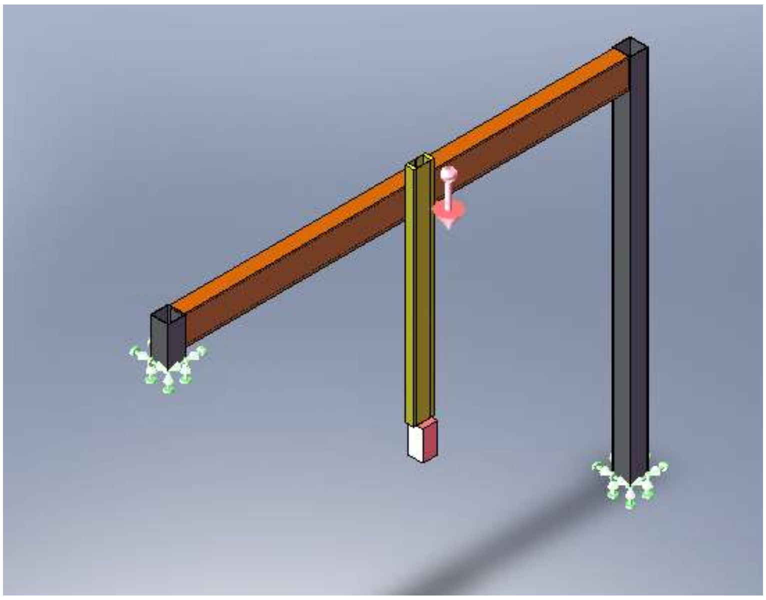


Figure 4.24 Design of Static Analysis Model

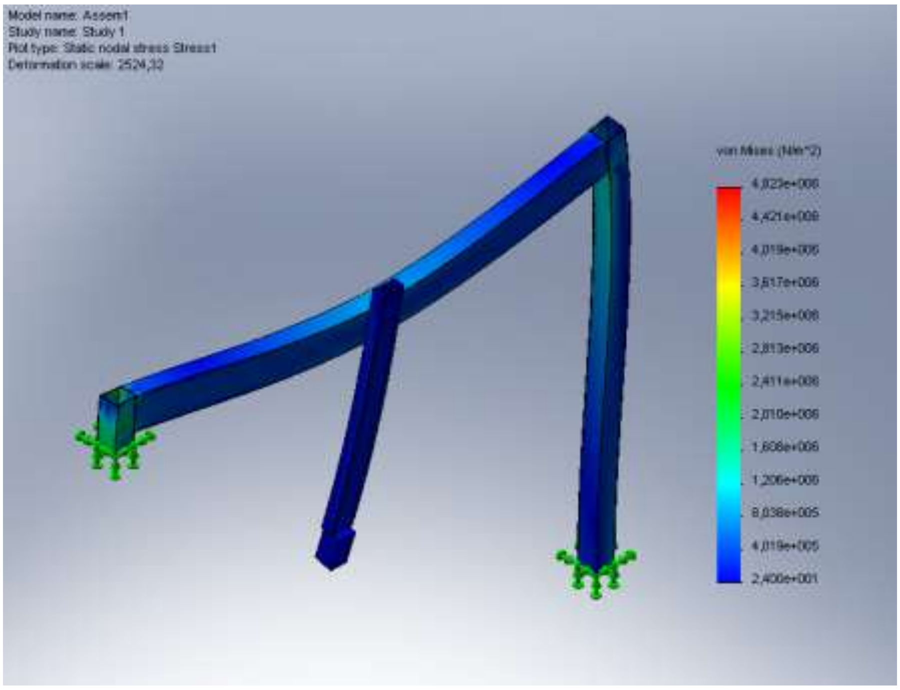


Figure 4.25 Stress Result

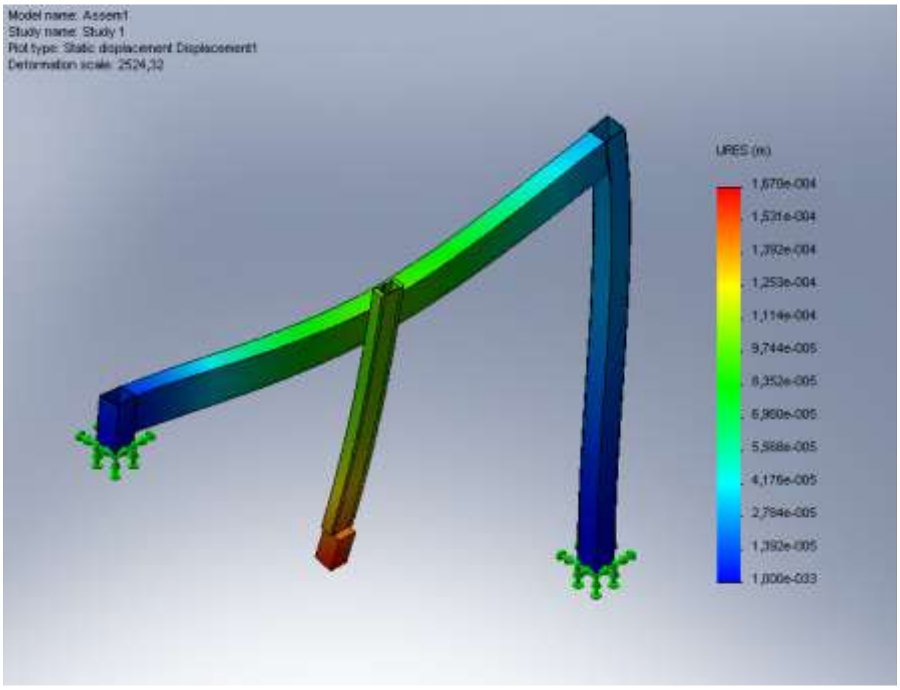


Figure 4.26 Deformation Results

4.3.2 Dynamic Analysis

To run dynamic analysis, real sections of each part are created at solidworks. Real model is created at Ansys workbench through the use of work station at Dokuz Eylül University Batul Lab. Four main positions are decided to run test. Axis positions are given at Table 4.9. First fifteen frequencies are calculated and structural deformations are given in Figure 4.27-4.36.

Table 4.9 Vertical and Horizontal Axis Positions

	Position			
	1	2	3	4
Vertical Axis	0	665	665	1500
Horizontal Axis	0	1500	3100	3100

Natural frequencies are shown in Table 4.10 for aforementioned determined positions.

Table 4.10 Frequencies for determined positions

Position	Frequency (Hz)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	6,33	8,71	14,30	14,49	15,54	26,93	37,39	38,89	39,23	39,63	43,36	52,09	69,81	77,71	78,25
2	7,15	12,60	19,68	28,15	30,30	41,84	52,04	55,51	57,67	58,01	74,56	88,70	91,04	103,65	112,34
3	7,69	13,18	14,43	14,72	24,53	28,26	39,68	39,82	42,64	43,02	63,94	78,33	78,81	87,00	90,41
4	7,61	13,81	14,43	14,72	24,05	29,74	39,54	39,62	39,73	40,59	44,96	47,43	62,92	68,41	78,35

Figures are given below for structural frequencies.

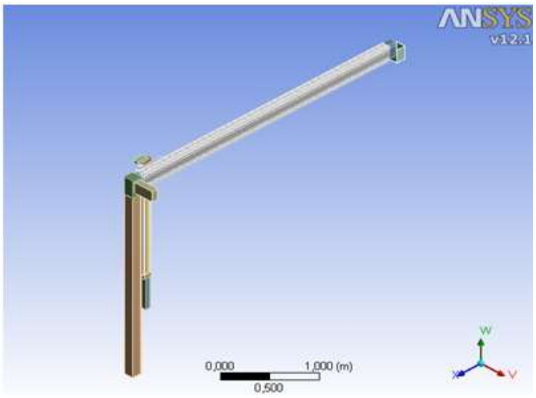


Figure 4.27 Test Position for First Position

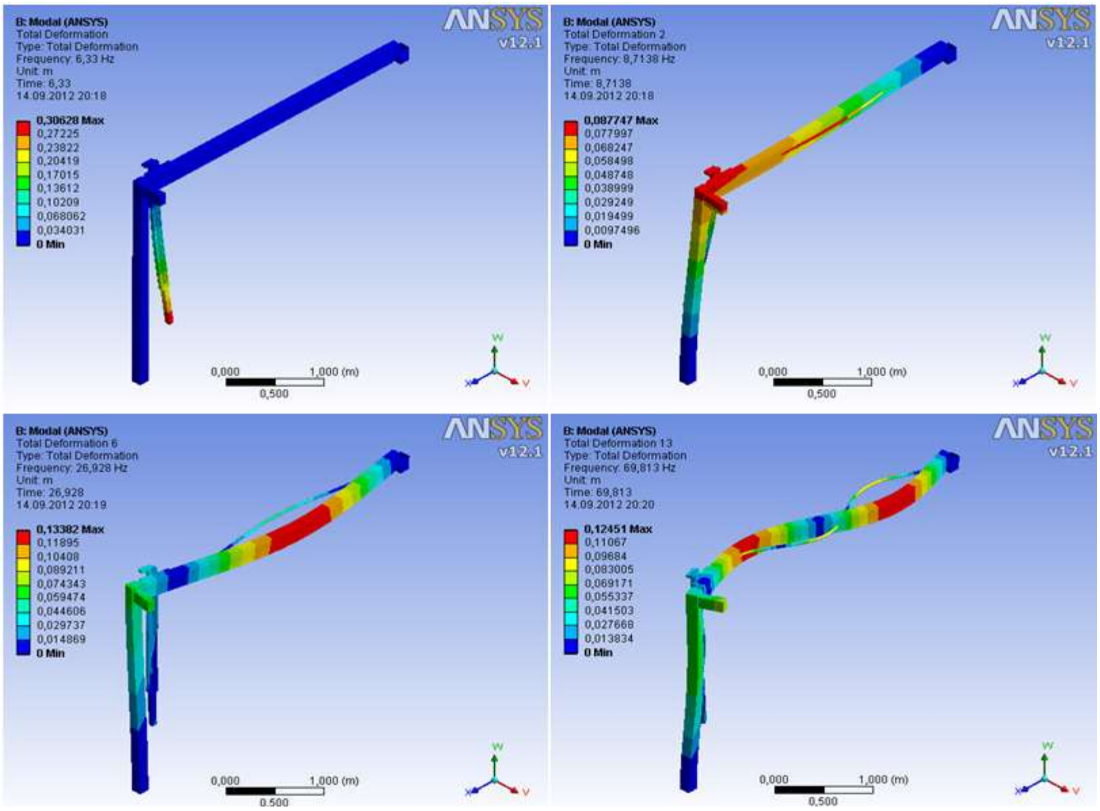


Figure 4.28 Dynamic Test Results for First Position

Second Position;

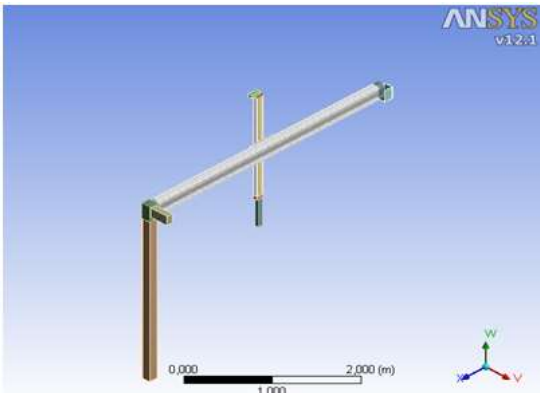


Figure 4.29 Test Position for Second Position

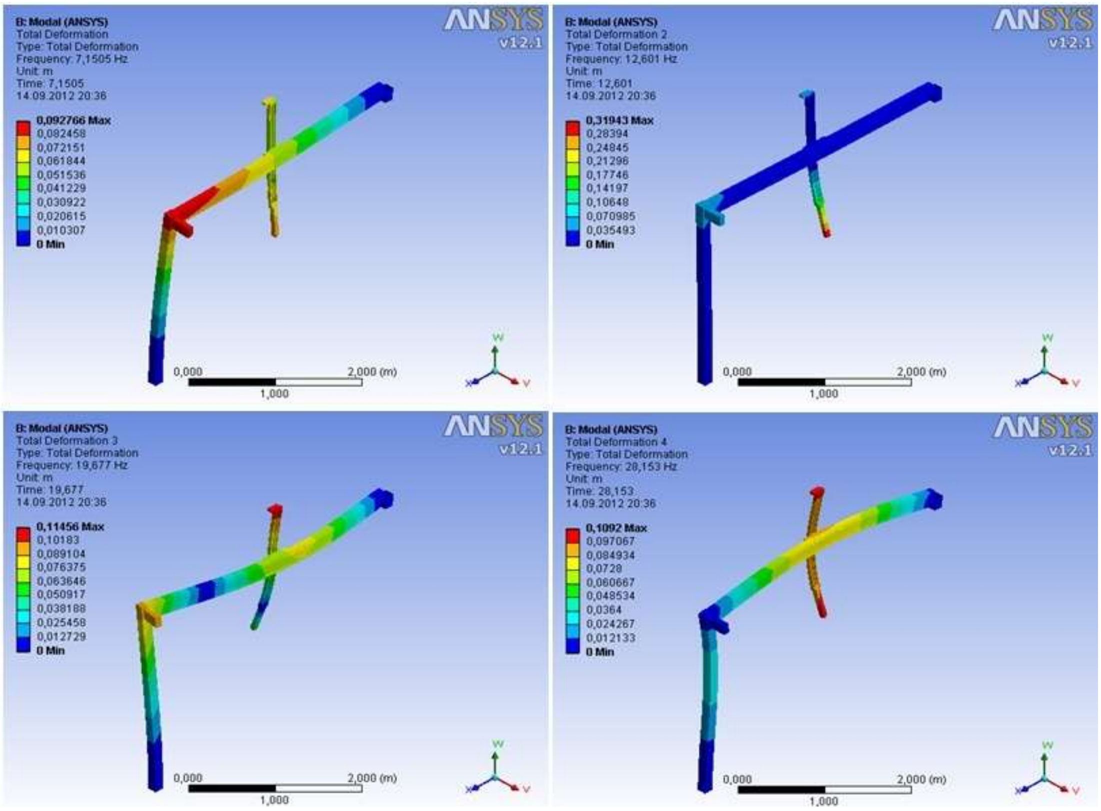


Figure 4.30 Dynamic Test Results for Second Position

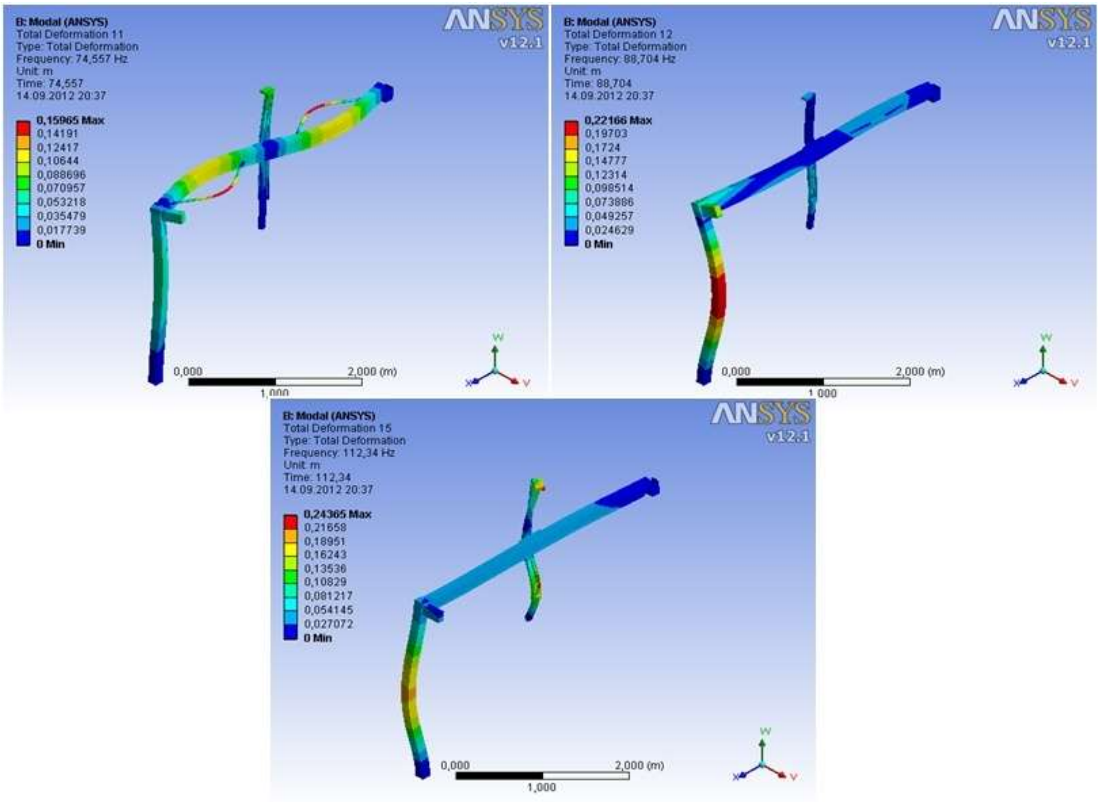


Figure 4.31 Dynamic Test Results for Second Position

Position 3

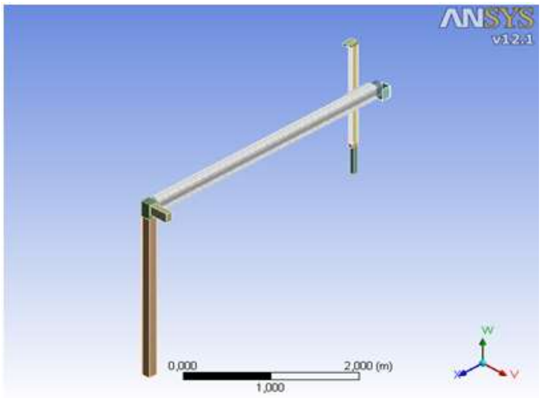


Figure 4.32 Test Position for Third Position

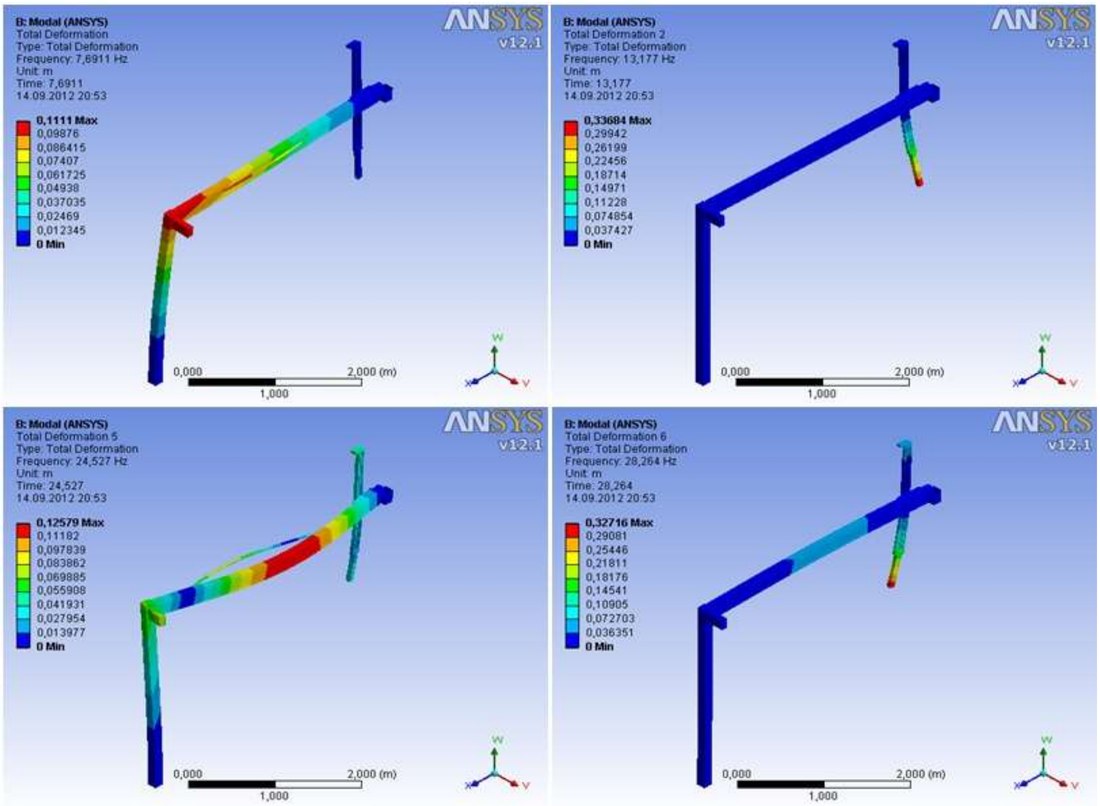


Figure 4.33a Dynamic Test Results for Third Position

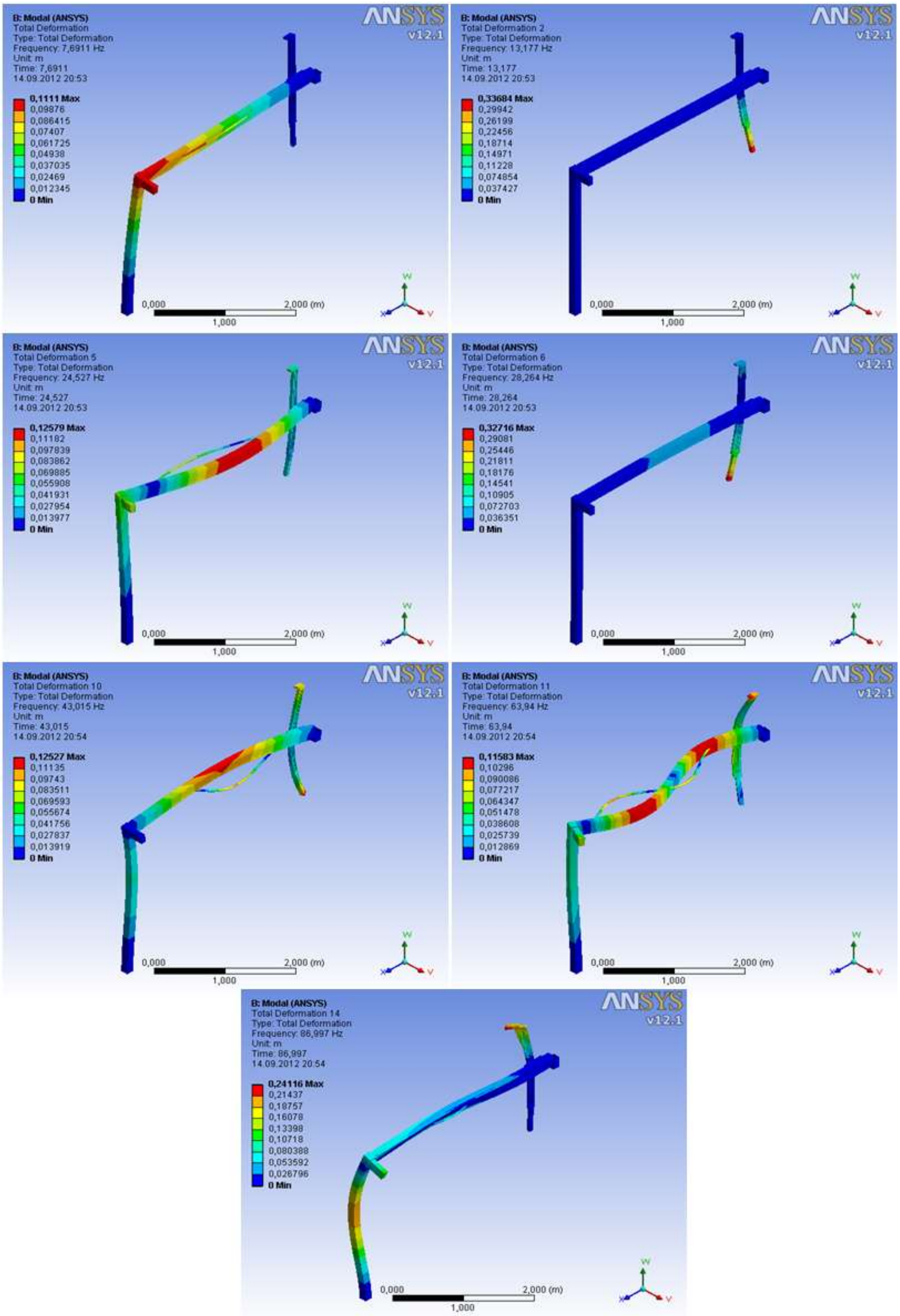


Figure 4.33b Dynamic Test Results for Third Position

Position 4;

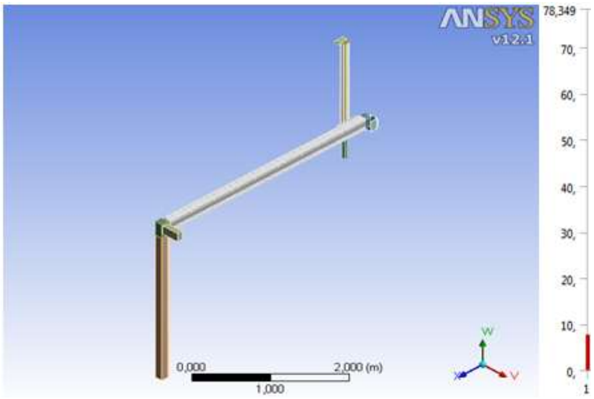


Figure 4.34 Test Position for Forth Position

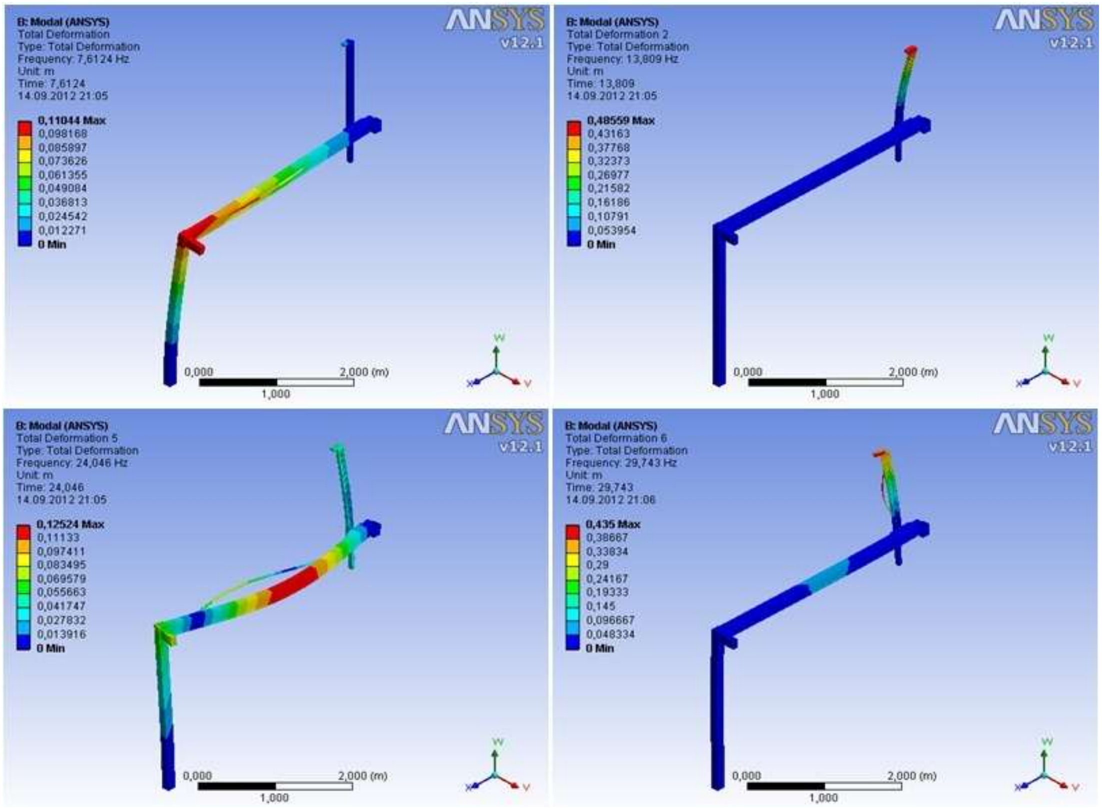


Figure 4.35 Dynamic Test Results for Forth Position

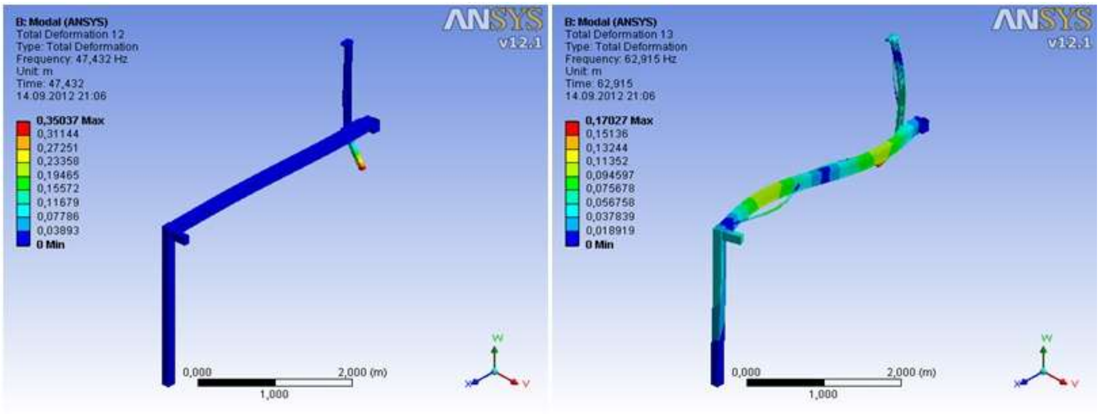


Figure 4.36 Dynamic Test Results for Forth Position

Following Tables 4.11a and 4.11b shows specifications of designed material feding robot for metal press MP-550 die casting machine.

Table 4.11a Characteristics of Designed Material Feeding Robot

Spesifications of Material Feeding Robot	
Vertical Stroke (mm)	1500
Horizontal Stroke (mm)	3000
Cycle Time (sec)	30.5
Load Capacity (kg)	5
Vertical Axis	
Linear Module	Bosch - CKK 20-145-1
Stroke of Linear Module (mm)	1500
Diameter of Screw (mm)	20
Pitch of Screw (mm)	40
Max Speed (m/min)	70
Max Moment (N/m)	17
Motor	Omron - SGMGH 13D
Motor Power (kW)	1,3
Motor Speed (min^{-1})	1500
Rated Motor Torque (N.m)	8.34
Reductor / Reductor Rate	Shimpo - VRSF-3B-400 / 3/1
Horizontal Axis	
Linear Module	Bosch - CKK 25-200-2
Stroke of Linear Module (mm)	3000
Diameter of Screw (mm)	32
Pitch of Screw (mm)	20
Max Speed (m/min)	35
Max Moment (N.m)	35
Motor	Omron - SGMAH A5A
Motor Power (kW)	0.050
Motor Speed (min^{-1})	1500
Rated Motor Torque (N.m)	0.159
Reductor / Reductor Rate	Shimpo - VRSF-3B-100 / 3/1

Table 4.11b Characteristics of Designed Material Feeding Robot

Rotary Axis for Ladle	
Motor	Omron - SGMAH A3A
Motor Power (kW)	30
Motor Speed (min^{-1})	3000
Rated Motor Torque (N.m)	0.0955

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

In the present study, die casting machines and material feeding robots were examined as thesis subject. Criteria that should be paid importance in setting Cartesian robot systems were established. Based on the criteria considered, linear movement modules used in the Cartesian systems were chosen properly. Software was created in order to create equivalent module to make analysis easily. Through this software created, it is possible to create similar sections of which physical properties are known.

The static and kinetic analyses are made through the use of Solidworks Cosmos Motion program. But for dynamic analysis, Solidworks which is used at regular computer fails to solve equations and create mesh. Dynamic analyses are made at work station at laboratory and Ansys workbench was used to create an analysis model. The sections of linear modules used in this design were created and dynamic analysis model is created and assembled by software which is developed in laboratory. When results of dynamic analysis are evaluated, it is obvious that the weakest part of structure is the beam which stands ground and holds the end point horizontal axis. First natural frequencies of all three positions show that maximum displacement is at the top of support beam. For further design, it is recommended to increase thickness of beam. For further applications, an experiment should be designed to compare data obtained from analyses with real construction. Stand by position of linear ladle is important for the life of system. Waiting at upper of furnace might cause the linear modules to heat up.

In creating Cartesian systems, selecting the proper modules is important as well as connection parts and precision in these connections during mounting is very important. The parts of which linearity and precision were ignored may affect running of the system and precludes taking desired efficiency from the modules and motors. These topics must be paid attention to during production and mounting.

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APPENDIX A

Codes for Form and Comman

```
Private Sub Command1_Click()
    ix0 = Val(Text1.Text): iy0 = Val(Text2.Text):
    b0 = Val(Text3.Text) / 10: h0 = Val(Text4.Text) / 10: l = Val(Text5.Text) / 1000:
d = Val(Text6.Text) / 10
Form1.Cls
'-----------------------------------------------------------------------------------
'Burda girilen alan atalet momentlerine gore kenar boyları hesaplanır
    'Bilinenler birim cm
'----------------------
b = 2
10
h = ((b0 * h0 ^ 3 - 12 * ix0 + pi * d ^ 4 / 64) / (h0 * b0 ^ 3 - 12 * iy0 + pi * d ^ 4 /
64)) ^ 0.5 * b
iy = (h0 * b0 ^ 3) / 12 - (h * b ^ 3) / 12
If iy > iy0 Then
b = b + 0.001
GoTo 10
End If
x1 = -b0 / 200: y1 = h0 / 200: z1 = 0
x2 = b0 / 200: y2 = -h0 / 200: z2 = 0
x3 = -b / 200: y3 = h / 200: z3 = 0
x4 = b / 200: y4 = -h / 200: z4 = 0
iy = (h0 * b0 ^ 3) / 12 - (h * b ^ 3) / 12
ix = (b0 * h0 ^ 3) / 12 - (b * h ^ 3) / 12
Form1.Print ix0, ix, "-------", iy0; iy, "-------",
If Option1.Value = True Then
Call create2007
End If
If Option2.Value = True Then
```

```
Call create2008
End If
End Sub
Private Sub Command2_Click()
directory = "d:\" + "profil\"
directorys = directory + "profil-b" + Text3.Text + "xh" + Text4.Text + "-Ix" + Text1.Text + "-Iy" + Text2.Text + ".SLDPRT"
'----------------------------------------------------------------------
'Burası kaydedilecek klasörün denetlendiği ve eğer yoksa oluşturulduğu yer
'----------------------------------------------------------------------
v = 0
d0 = directory + "*.*"
a = Dir("d:\*.*", vbDirectory)
Do While a <> ""
   a = Dir$
      If a = "profil" Then
      v = 1
      End If
Loop
If v = 0 Then
   m9 = MsgBox(directory + " klasörü oluşturulacak", , "!") = vbOK
   On Error GoTo 7
   MkDir directory  ' change the path and  name
   m10 = MsgBox("profil klasörü oluşturuldu", , "!") = vbOK
   GoTo son
7
   m11 = MsgBox("Klasör oluşturulamıyor", , "!") = vbOK
   GoTo 8
End If
son:
'----------------------------------------------------------------------
If Option1.Value = True Then
```

```
    Call save2007
End If
If Option2.Value = True Then
    Call save2008
End If
Form1.Print directory
8
End Sub
Private Sub Form_Load()
Label1.Caption = "Ix (cm4)"
Label2.Caption = "Iy (cm4)"
Label3.Caption = "B (mm)"
Label4.Caption = "H (mm)"
Label5.Caption = "L (mm)"
Label6.Caption = "Solidworks:"
Label7.Caption = "2007"
Label8.Caption = "2008"
Label9.Caption = "Mil Çapı(mm)"
Option1.Value = True
Option2.Value = False
Command1.Caption = "Create"
Command2.Caption = "Save"
Text1.Text = "114,1"
Text2.Text = "986,4"
Text3.Text = "145"
Text4.Text = "64"
Text5.Text = "690"
Text6.Text = "20"
pi = 3.1415
End Sub
```

<u>Codes for Module</u>

```
Public swApp As Object
Public Part As Object
Public SelMgr As Object
Public boolstatus As Boolean
Public longstatus As Long, longwarnings As Long
Public Feature As Object
Public directory, d0, directorys As String
Public ix, ix0, d, iy, iy0, b0, h0, b, h, x1, x2, x3, x4, y1, y2, y3, y4, z1, z2, z3, z4, l
As Double
Sub create2007()
GoTo atla
a = Len(d)
For i = 1 To a
If Mid(d, i, 1) = "," Then
d = Mid(d, 1, i - 1) + "." + Mid(d, i + 1, a - i)
End If
Next
a = Len(h0)
For i = 1 To a
If Mid(h0, i, 1) = "," Then
h0 = Mid(h0, 1, i - 1) + "." + Mid(h0, i + 1, a - i)
End If
Next
a = Len(b0)
For i = 1 To a
If Mid(b0, i, 1) = "," Then
b0 = Mid(b0, 1, i - 1) + "." + Mid(b0, i + 1, a - i)
End If
Next
a = Len(b)
For i = 1 To a
If Mid(b, i, 1) = "," Then
```

```
b = Mid(b, 1, i - 1) + "." + Mid(b, i + 1, a - i)
End If
Next
a = Len(h)
For i = 1 To a
If Mid(h, i, 1) = "," Then
h = Mid(h, 1, i - 1) + "." + Mid(h, i + 1, a - i)
End If
Next
a = Len(x1)
For i = 1 To a
If Mid(x1, i, 1) = "," Then
x1 = Mid(x1, 1, i - 1) + "." + Mid(x1, i + 1, a - i)
End If
Next
a = Len(x2)
For i = 1 To a
If Mid(x2, i, 1) = "," Then
x2 = Mid(x2, 1, i - 1) + "." + Mid(x2, i + 1, a - i)
End If
Next
a = Len(x3)
For i = 1 To a
If Mid(x3, i, 1) = "," Then
x3 = Mid(x3, 1, i - 1) + "." + Mid(x3, i + 1, a - i)
End If
Next
a = Len(x4)
For i = 1 To a
If Mid(x4, i, 1) = "," Then
x4 = Mid(x4, 1, i - 1) + "." + Mid(x4, i + 1, a - i)
End If
```

```
Next
a = Len(y1)
For i = 1 To a
If Mid(y1, i, 1) = "," Then
y1 = Mid(y1, 1, i - 1) + "." + Mid(y1, i + 1, a - i)
End If
Next
a = Len(y2)
For i = 1 To a
If Mid(y2, i, 1) = "," Then
y2 = Mid(y2, 1, i - 1) + "." + Mid(y2, i + 1, a - i)
End If
Next
a = Len(y3)
For i = 1 To a
If Mid(y3, i, 1) = "," Then
y3 = Mid(y3, 1, i - 1) + "." + Mid(y3, i + 1, a - i)
End If
Next
a = Len(y4)
For i = 1 To a
If Mid(y4, i, 1) = "," Then
y4 = Mid(y4, 1, i - 1) + "." + Mid(y4, i + 1, a - i)
End If
Next
a = Len(z1)
For i = 1 To a
If Mid(z1, i, 1) = "," Then
z1 = Mid(z1, 1, i - 1) + "." + Mid(z1, i + 1, a - i)
End If
Next
a = Len(z2)
```

```
For i = 1 To a
If Mid(z2, i, 1) = "," Then
z2 = Mid(z2, 1, i - 1) + "." + Mid(z2, i + 1, a - i)
End If
Next
a = Len(z3)
For i = 1 To a
If Mid(z3, i, 1) = "," Then
z3 = Mid(z3, 1, i - 1) + "." + Mid(z3, i + 1, a - i)
End If
Next
a = Len(z4)
For i = 1 To a
If Mid(z4, i, 1) = "," Then
z4 = Mid(z4, 1, i - 1) + "." + Mid(z4, i + 1, a - i)
End If
Next
a = Len(l)
For i = 1 To a
If Mid(l, i, 1) = "," Then
l = Mid(l, 1, i - 1) + "." + Mid(l, i + 1, a - i)
End If
Next
atla:
Set swApp = GetObject(, "sldworks.application")
Set Part = swApp.ActiveDoc
Set SelMgr = Part.SelectionManager
swApp.ActiveDoc.ActiveView.FrameState = 1
boolstatus = Part.Extension.SelectByID2("Front Plane", "PLANE", 0, 0, 0, False, 0,
Nothing, 0)
Part.SketchManager.InsertSketch True
Part.ClearSelection2 True
```

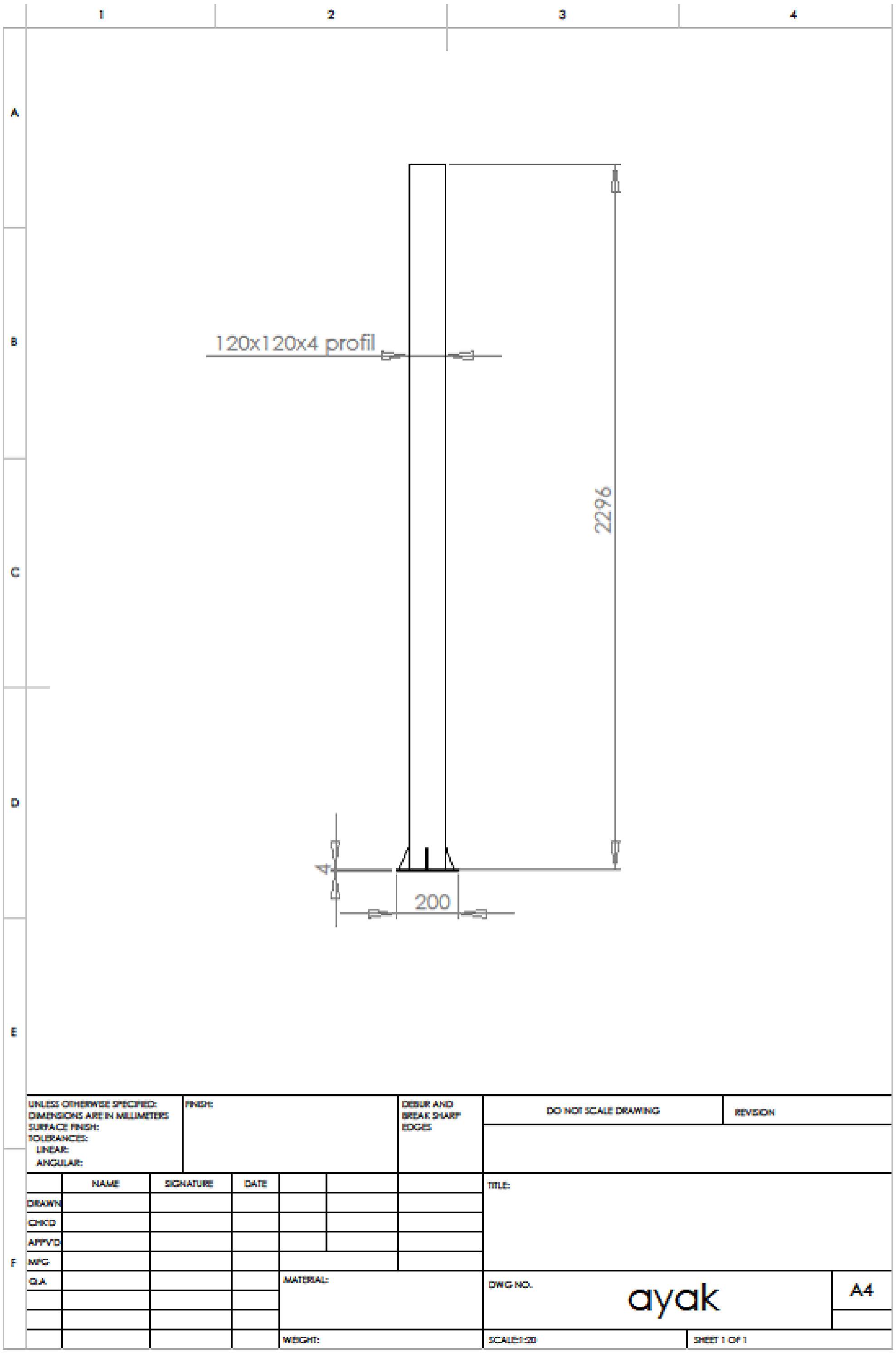
```
'-----------------------------------------------------------------------------------
'Burda dikdörtgenin sol ust ve sağ alt koselerinin koordinalarını (x,y,z) metre cinsinden
If x1 + 0.001 > x3 Then
x3 = x1 + 0.001
x4 = x2 - 0.001
End If
If y1 + 0.0018 > y3 Then
y3 = y1 - 0.0018
y4 = y2 + 0.0018
x3 = x3 - 0.001
x4 = x4 + 0.001
End If
Part.SketchRectangle x1, y1, z1, x2, y2, z2, 1
Part.SketchRectangle x3, y3, z3, x4, y4, z4, 1
Form1.Cls
Form1.Print y1, y2, y3, y4
'-----------------------------------------------------------------------------------
'Burda L boyu kadar extrude yapılır
Set swApp = GetObject(, "sldworks.application")
Set Part = swApp.ActiveDoc
Set SelMgr = Part.SelectionManager
swApp.ActiveDoc.ActiveView.FrameState = 1
Part.ShowNamedView2 "*Trimetric", 8
Part.ClearSelection2 True
Part.FeatureManager.FeatureExtrusion2 True, False, False, 0, 0, l, l, False, False, False, False, 0.01745329251994, 0.01745329251994, False, False, False, False, 1, 1, 1, 0, 0, False
Part.SelectionManager.EnableContourSelection = 0
'-----------------------------------------------------------------------------------
'Burada Mil çizilip extrude edilir
Set swApp = GetObject(, "sldworks.application")
```

```
Set Part = swApp.ActiveDoc
Set SelMgr = Part.SelectionManager
swApp.ActiveDoc.ActiveView.FrameState = 1
boolstatus = Part.Extension.SelectByID2("Front Plane", "PLANE", 0, 0, 0, False, 0,
Nothing, 0)
Part.SketchManager.InsertSketch True
Part.ClearSelection2 True
'----------------------------------------------------------------------------------
'Burda Mil Çizilir
d0 = d / 200
Part.CreateCircle 0, 0, 0, d0, 0, 0
'----------------------------------------------------------------------------------
'Burda Mil Extrude edilir
Set swApp = GetObject(, "sldworks.application")
Set Part = swApp.ActiveDoc
Set SelMgr = Part.SelectionManager
swApp.ActiveDoc.ActiveView.FrameState = 1
Part.ClearSelection2 True
Part.FeatureManager.FeatureExtrusion2 True, False, False, 0, 0, l, l, False, False,
False, False, 0.01745329251994, 0.01745329251994, False, False, False, False, 1, 1,
1, 0, 0, False
Part.SelectionManager.EnableContourSelection = 0
son:
Form1.Cls
Form1.Print x1, x2, x3, x4
End Sub
Sub save2007()
Set swApp = GetObject(, "sldworks.application")
Set Part = swApp.ActiveDoc
Set SelMgr = Part.SelectionManager
swApp.ActiveDoc.ActiveView.FrameState = 1
Part.SaveAs2 directorys, 0, False, False
```

```
End Sub
Sub create2008()
Set swApp = GetObject(, "sldworks.application")
Set Part = swApp.ActiveDoc
Set SelMgr = Part.SelectionManager
Part.SketchManager.InsertSketch True
boolstatus = Part.Extension.SelectByID2("Front Plane", "PLANE", -0.05715727310112, 0.04907139013618, -0.003177264220145, False, 0, Nothing, 0)
Part.ClearSelection2 True
'-----------------------------------------------------------------------------------
'Burda dikdörtgenin sol ust ve sağ alt koselerinin koordinalarını (x,y,z) metre cinsinden
Dim vSkLines As Variant
vSkLines = Part.SketchManager.CreateCornerRectangle(x1, y1, z1, x2, y2, z2)
vSkLines = Part.SketchManager.CreateCornerRectangle(x3, y3, z3, x4, y4, z4)
'-----------------------------------------------------------------------------------
Set SelMgr = Part.SelectionManager
Part.ShowNamedView2 "*Trimetric", 8
Part.ClearSelection2 True
boolstatus = Part.Extension.SelectByID2("Line2", "SKETCHSEGMENT", 0, 0, 0, False, 0, Nothing, 0)
boolstatus = Part.Extension.SelectByID2("Line1", "SKETCHSEGMENT", 0, 0, 0, True, 0, Nothing, 0)
boolstatus = Part.Extension.SelectByID2("Line4", "SKETCHSEGMENT", 0, 0, 0, True, 0, Nothing, 0)
boolstatus = Part.Extension.SelectByID2("Line3", "SKETCHSEGMENT", 0, 0, 0, True, 0, Nothing, 0)
Part.FeatureManager.FeatureExtrusion2 True, False, False, 0, 0, l, 0.01, False, False, False, False, 0.01745329251994, 0.01745329251994, False, False, False, False, 1, 1, 1, 0, 0, False
Part.SelectionManager.EnableContourSelection = 0
Part.ShowNamedView2 "*Isometric", 7
```

```
End Sub
Sub save2008()
Set swApp = GetObject(, "sldworks.application")
Set Part = swApp.ActiveDoc
Set SelMgr = Part.SelectionManager
Part.SaveAs2 directorys, 0, False, False
End Sub
```

APPENDIX B


120x120x4 profil
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4
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
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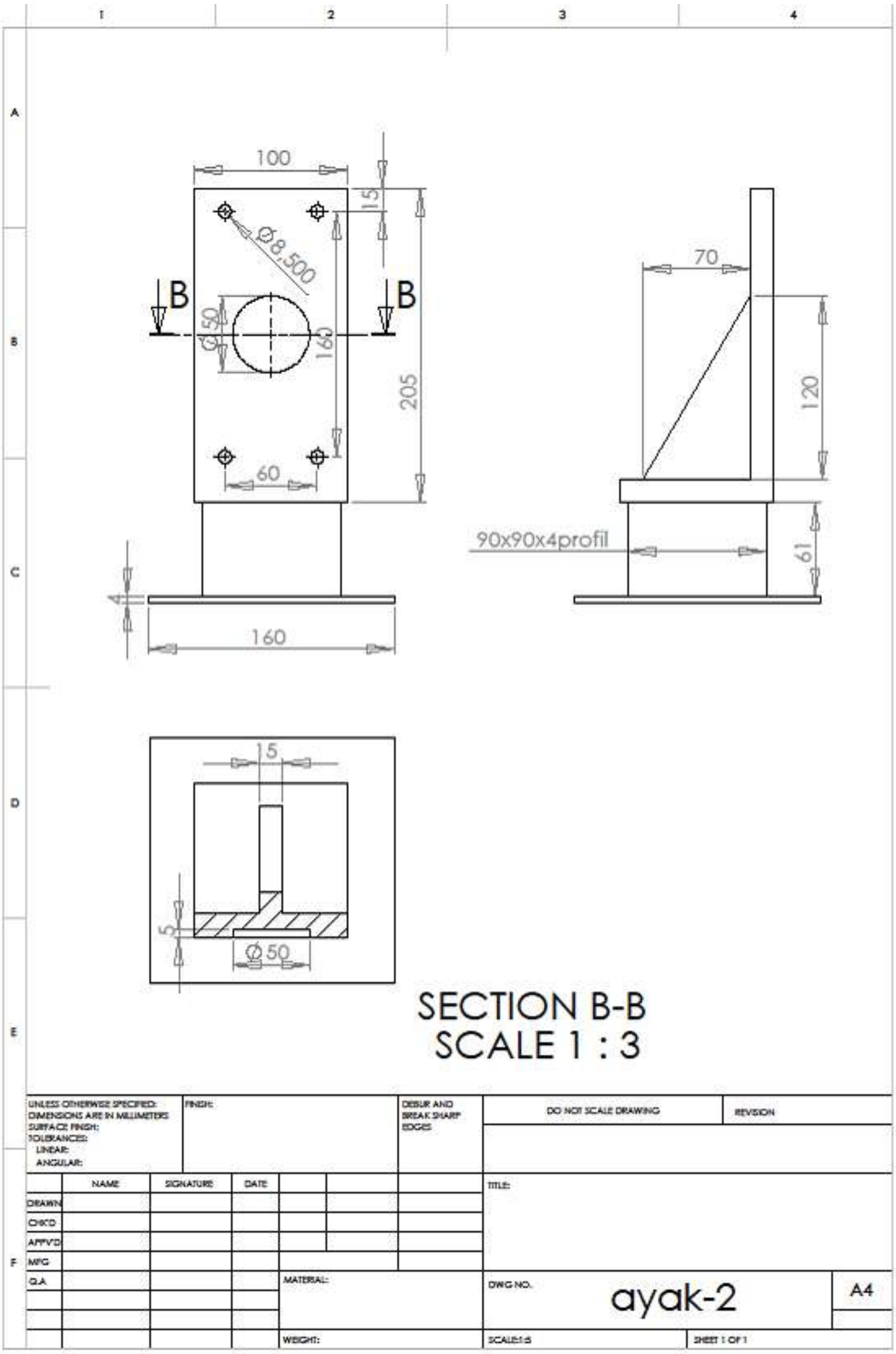
WEIGHT:
SCALE:1:20
SHEET 1 OF 1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205
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90x90x4profil
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SECTION B-B
SCALE 1 : 3
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SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
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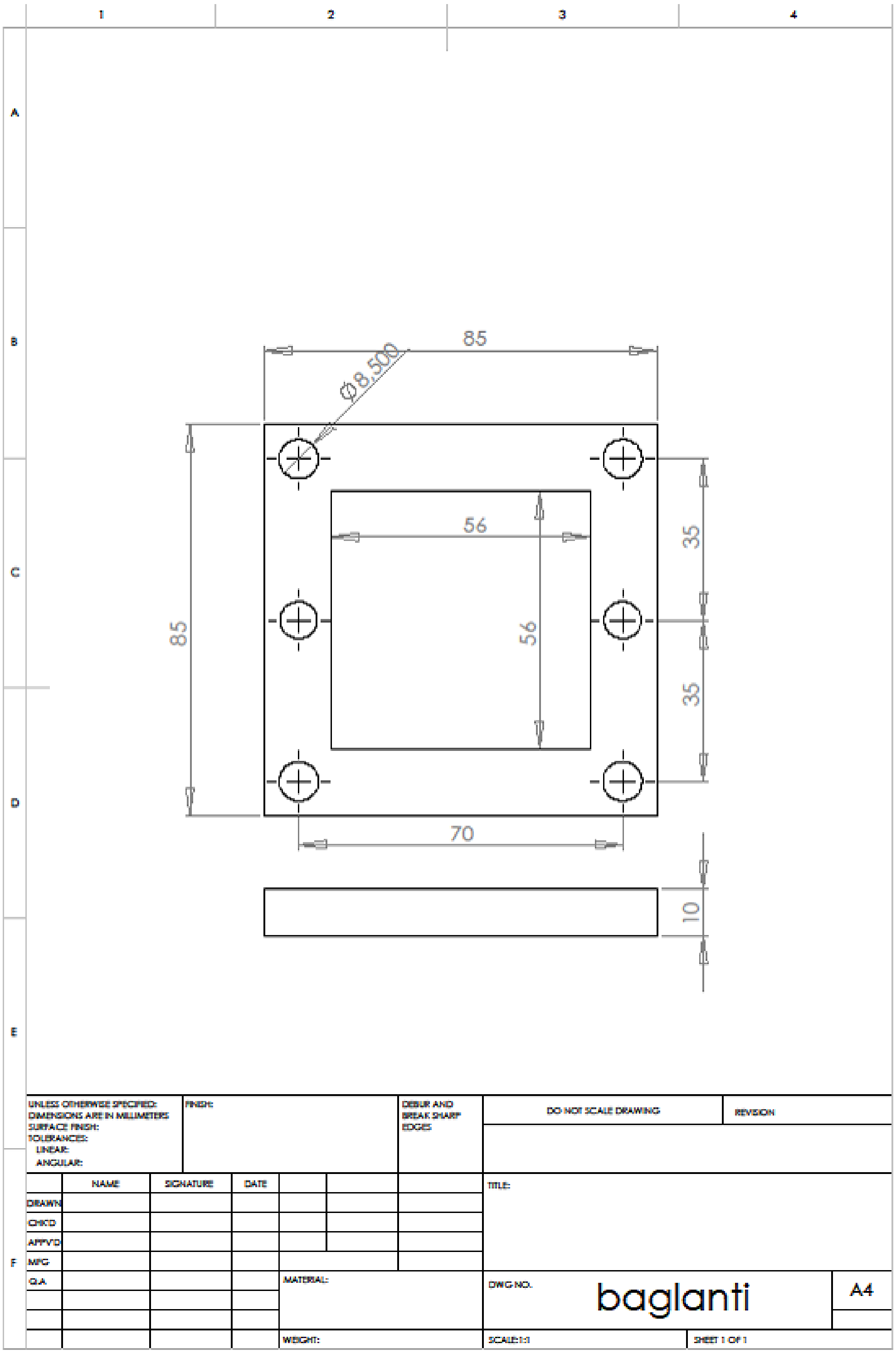
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
DWG NO.
ayak-2
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1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TOLERANCES:
LINEAR:
ANGULAR:
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BREAK SHARP
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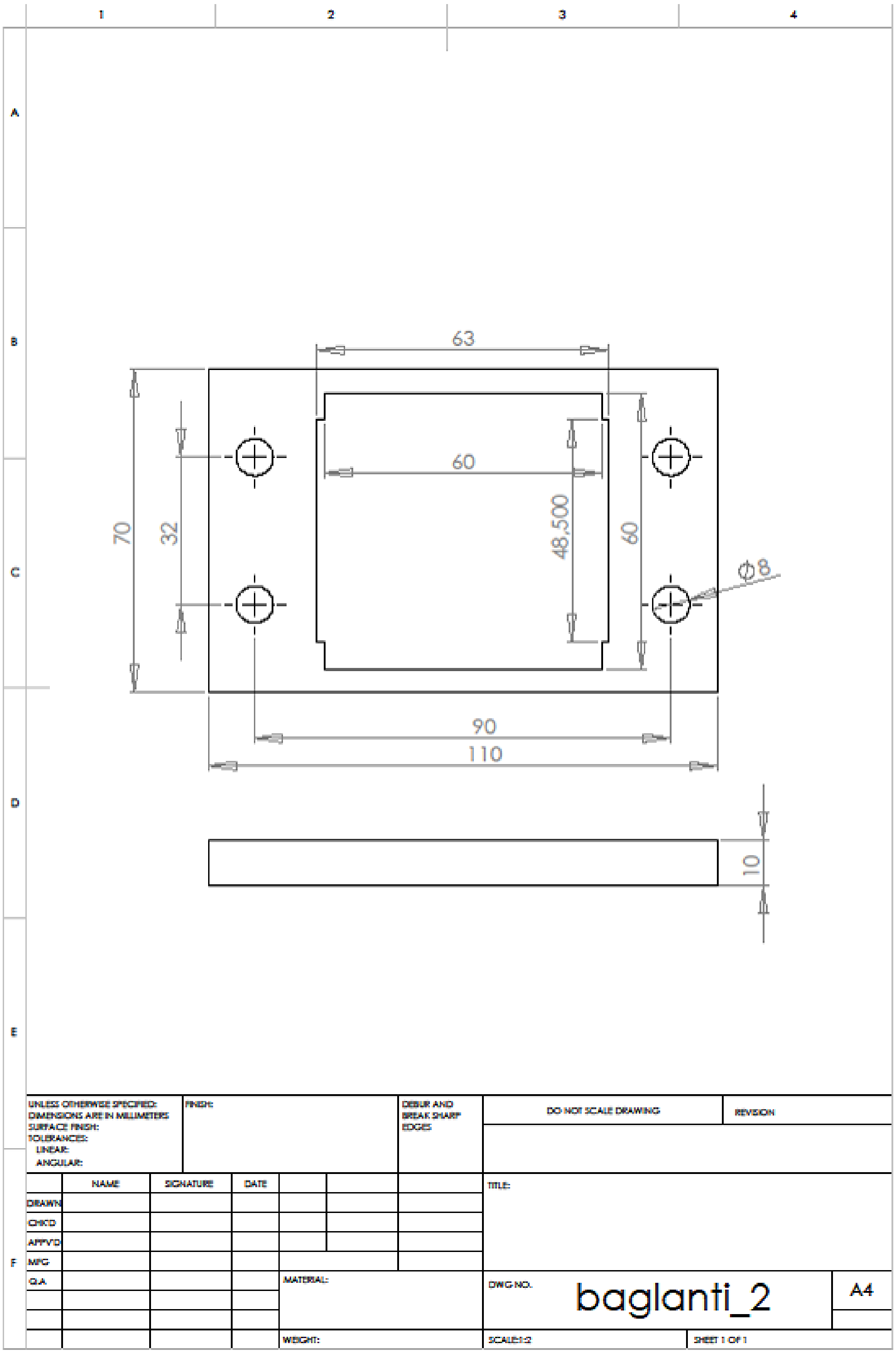
WEIGHT:
SCALE:1:1
SHEET 1 OF 1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63
60
70
32
48,500
60
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90
110
10
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
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NAME
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DATE
TITLE:
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CHK'D
APPV'D
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MATERIAL:
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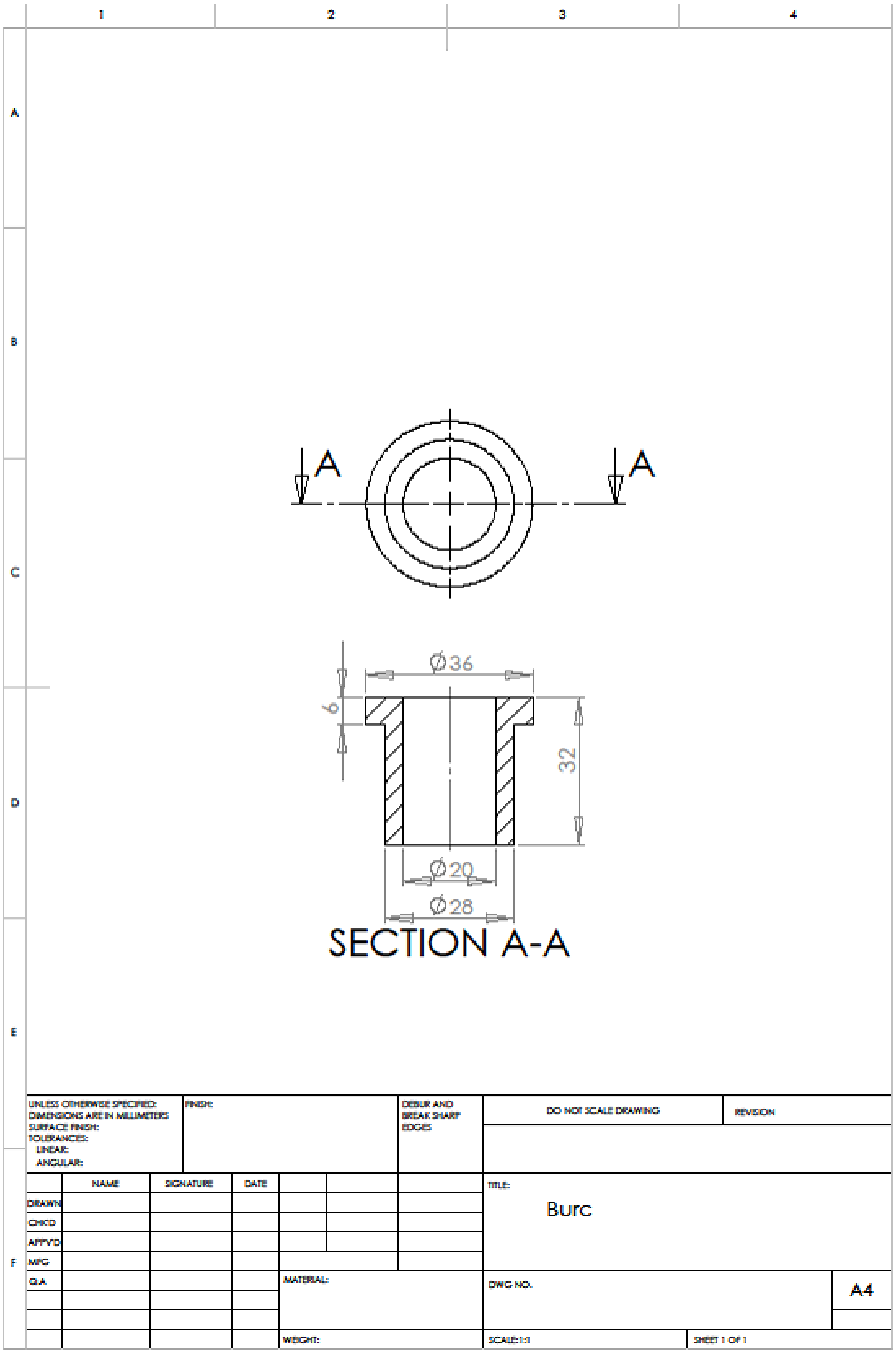
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1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6
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Ø28
SECTION A-A
UNLESS OTHERWISE SPECIFIED:
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SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
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NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
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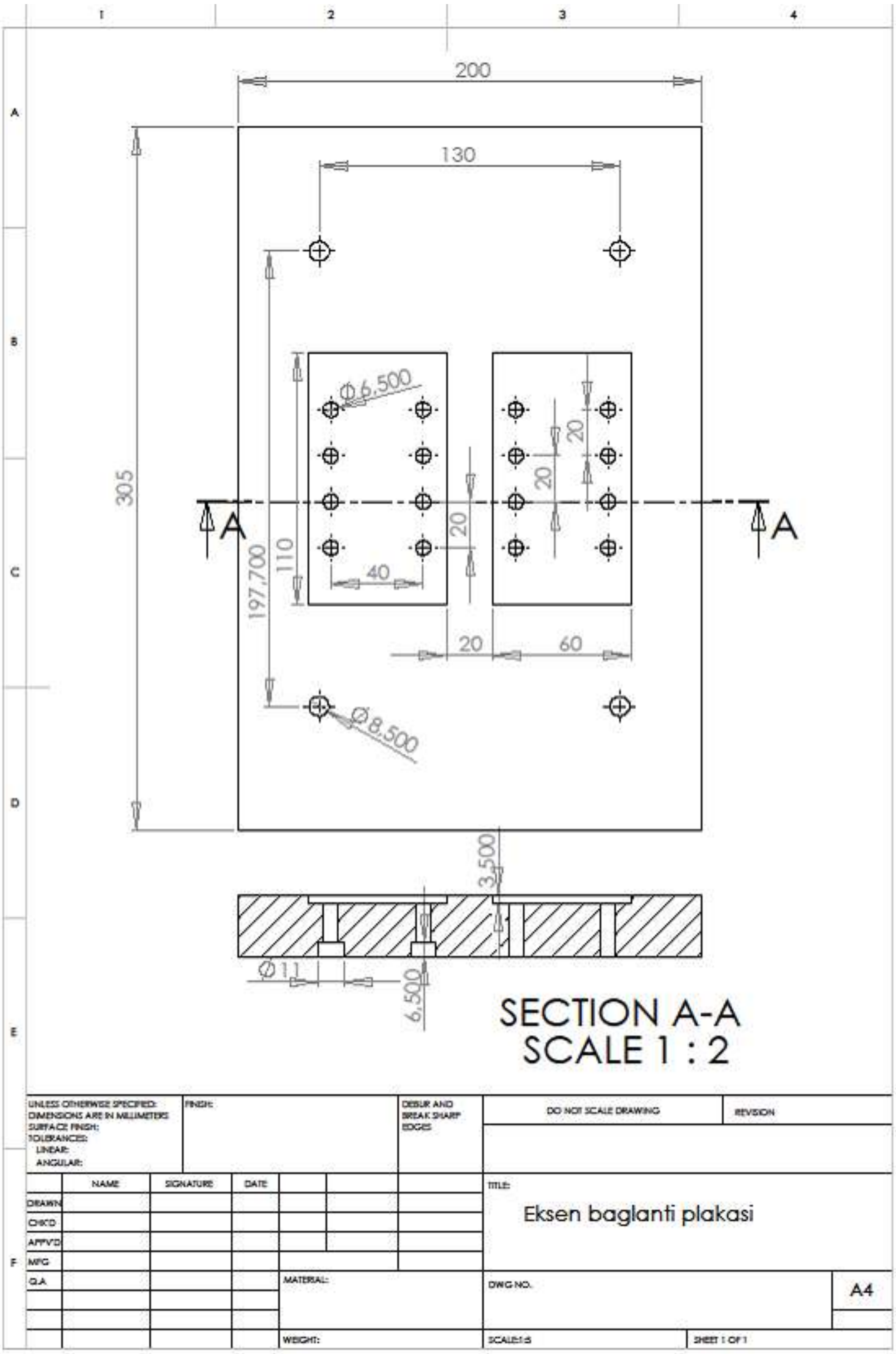
Burc
MATERIAL:
DWG NO.
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1


200
130
305
197,700
110
Ø6,500
Ø8,500
20
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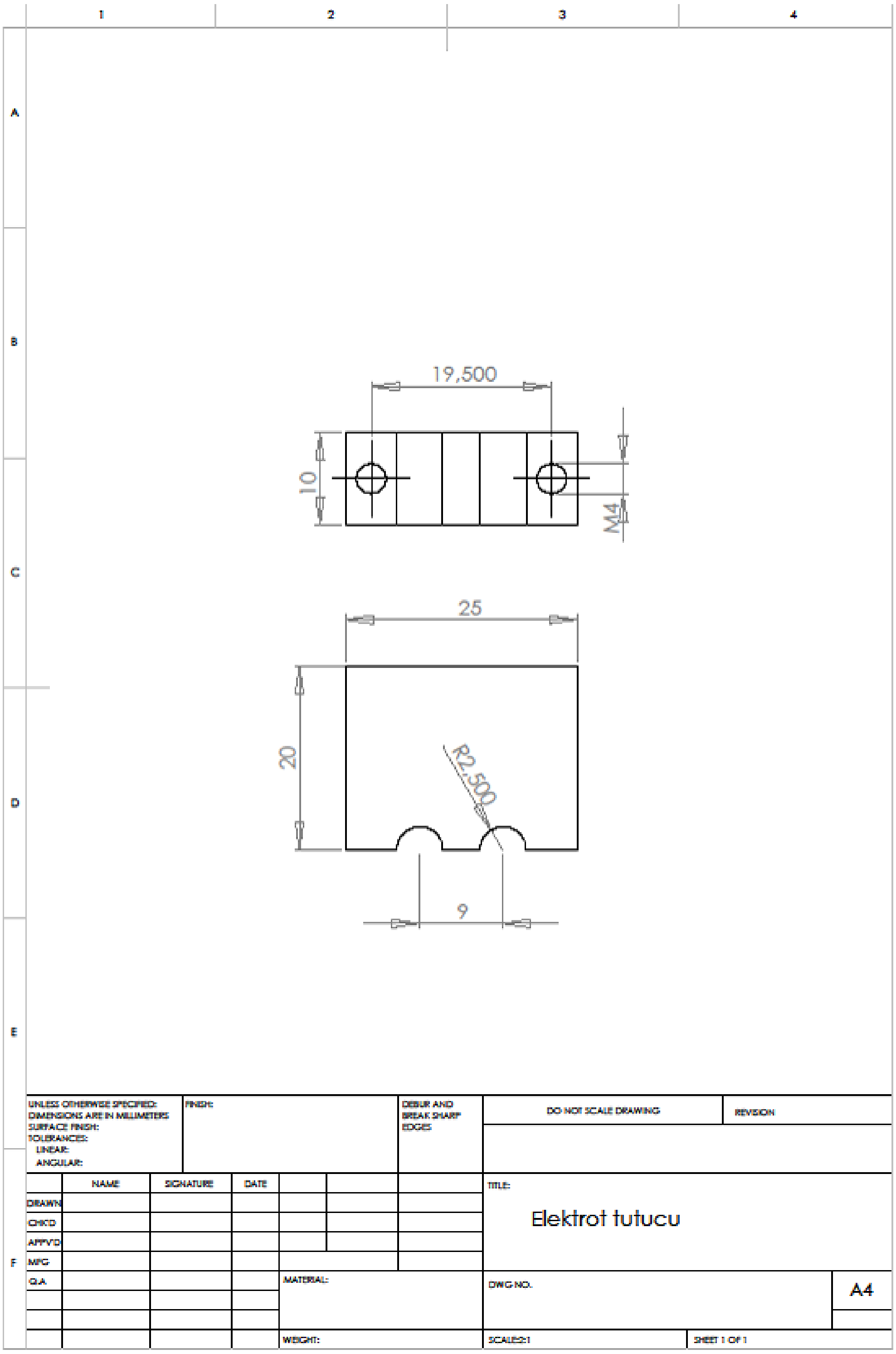
20
60
A
A
3,500
Ø11
6,500
SECTION A-A
SCALE 1 : 2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
Eksen baglanti plakasi
DWG NO.
A4
SCALE:1:5
SHEET 1 OF 1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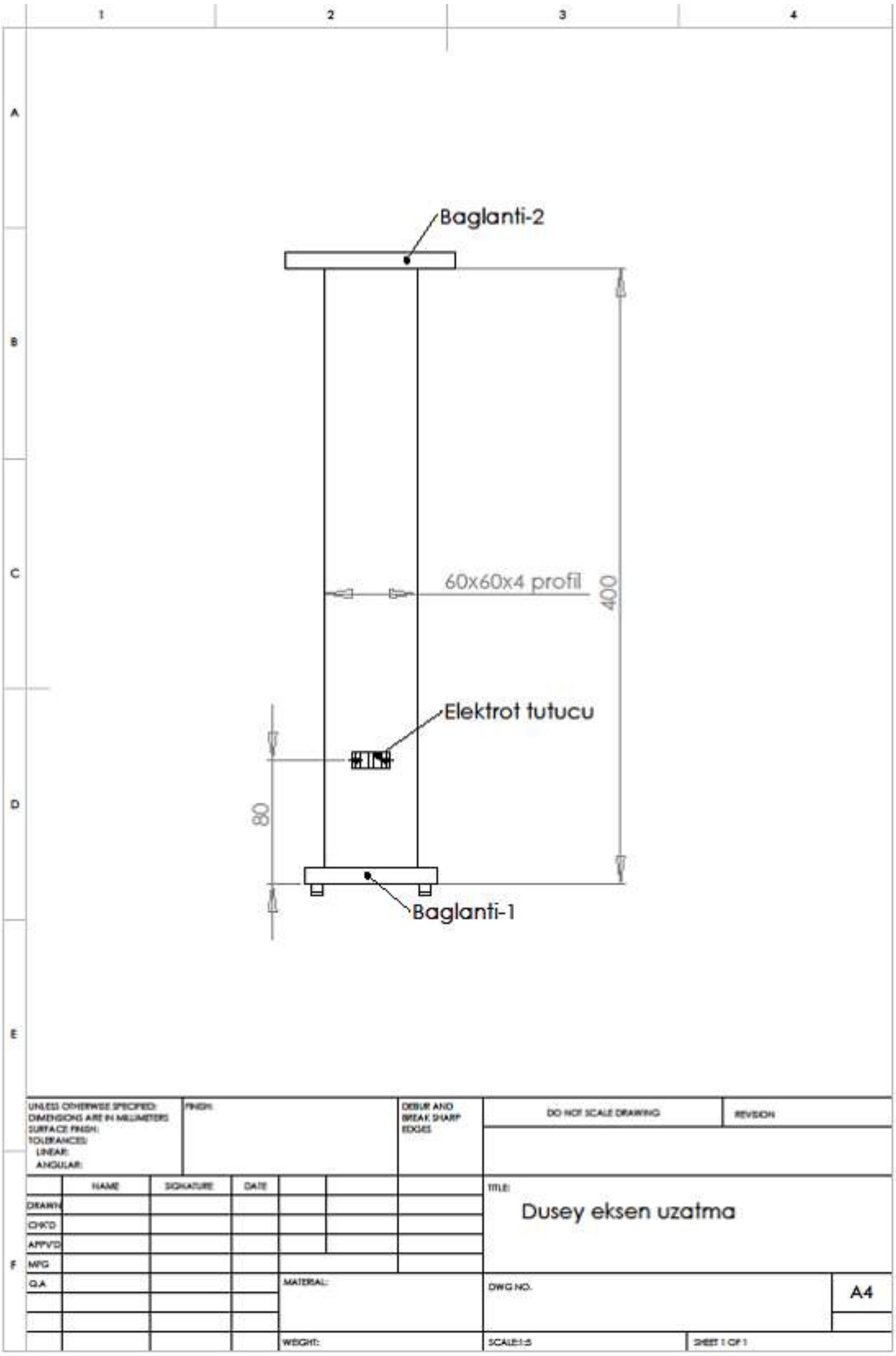
B
C
D
E
F
19,500
10
M4
25
20
R2,500
9
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND
BREAK SHARP
EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Elektrot tutucu
MATERIAL:
DWG NO.
A4
WEIGHT:
SCALE:2:1
SHEET 1 OF 1


Baglanti-2
60x60x4 profil
400
Elektrot tutucu
80
Baglanti-1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
Dusey eksen uzatma
DWG NO.
A4
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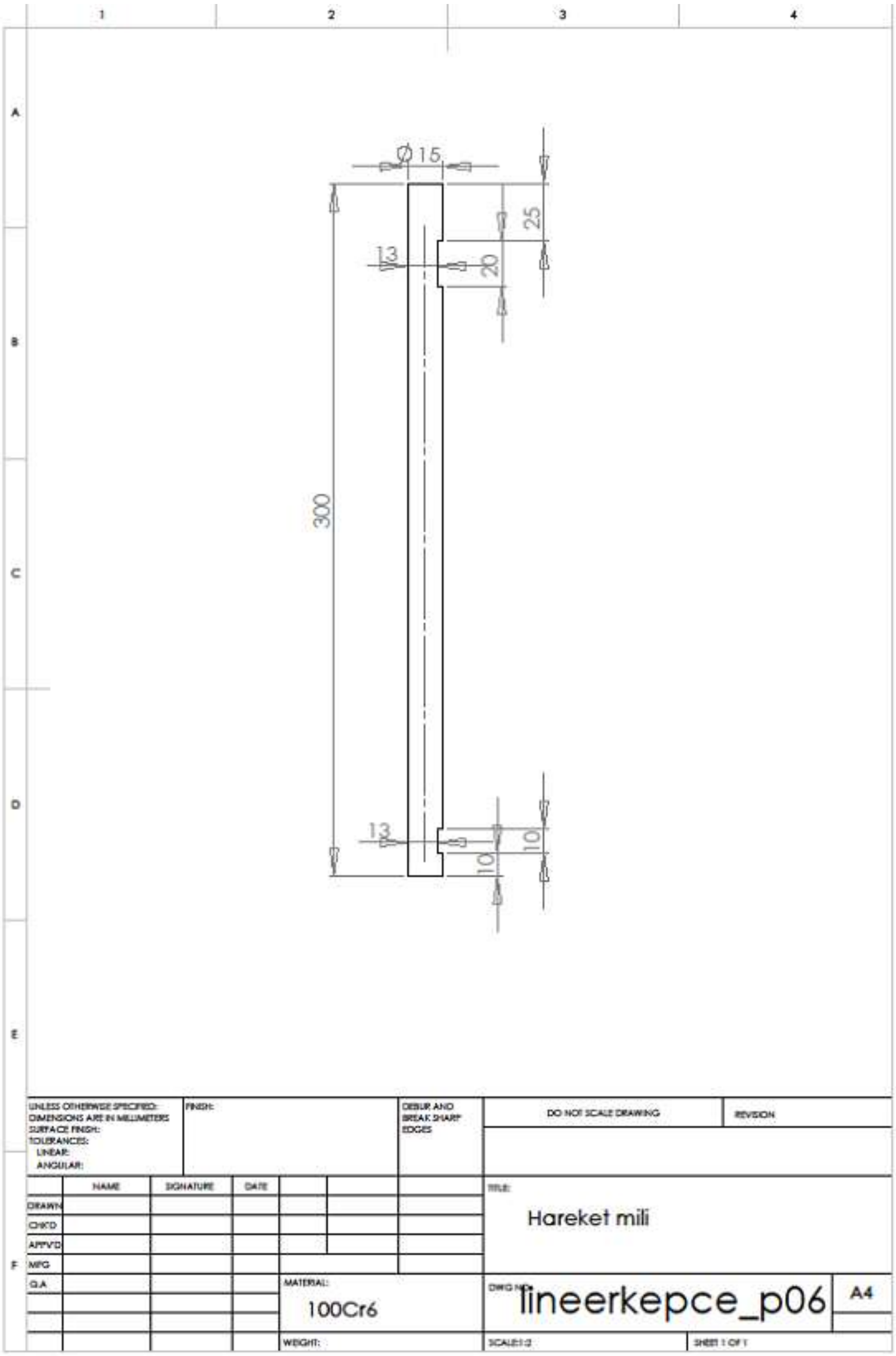
SHEET 1 OF 1


Ø15
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300
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Q.A
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100Cr6
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lineerkepce_p06
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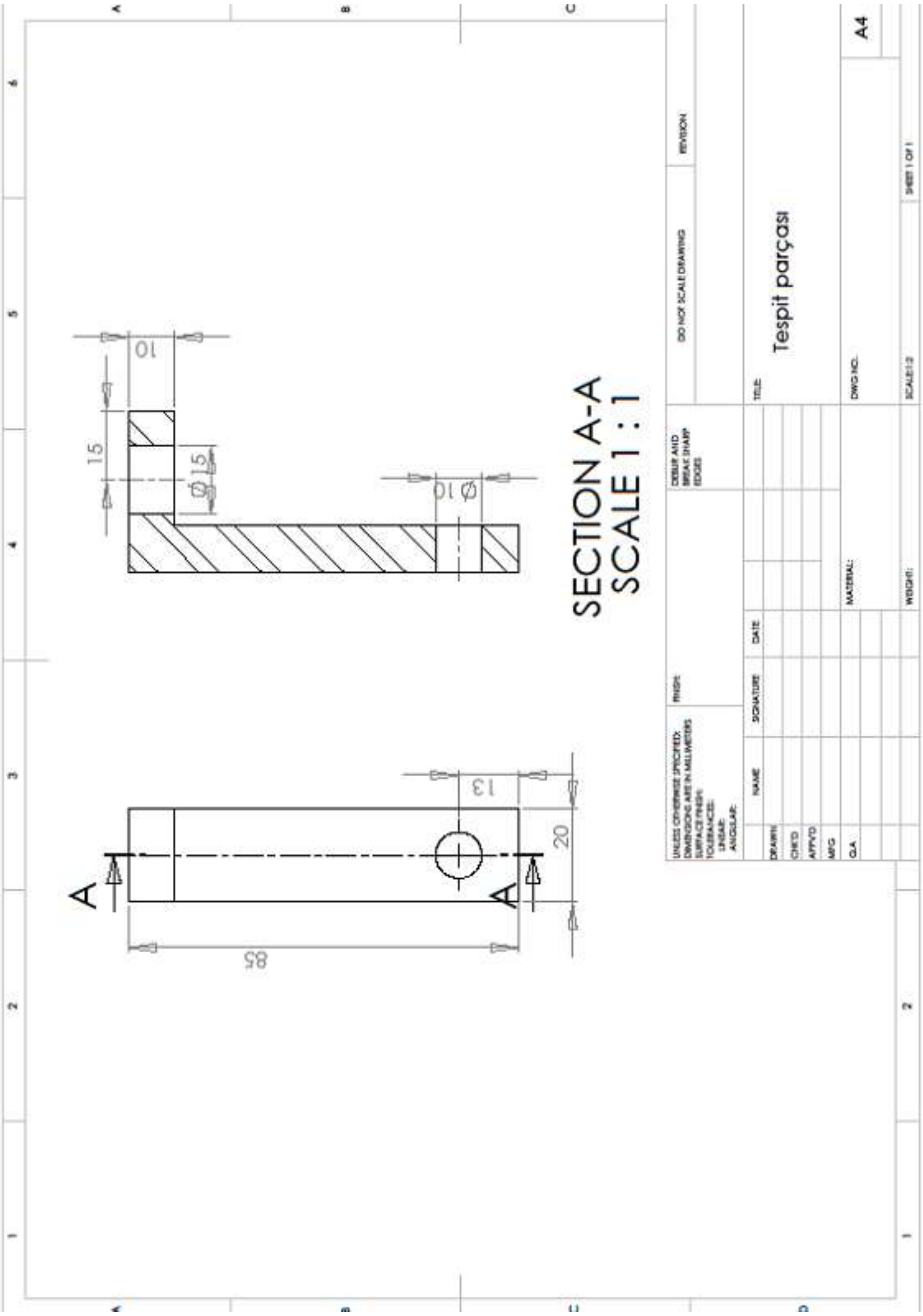
SHEET 1 OF 1


SECTION A-A
SCALE 1 : 1
Tespit parçası
A4
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13
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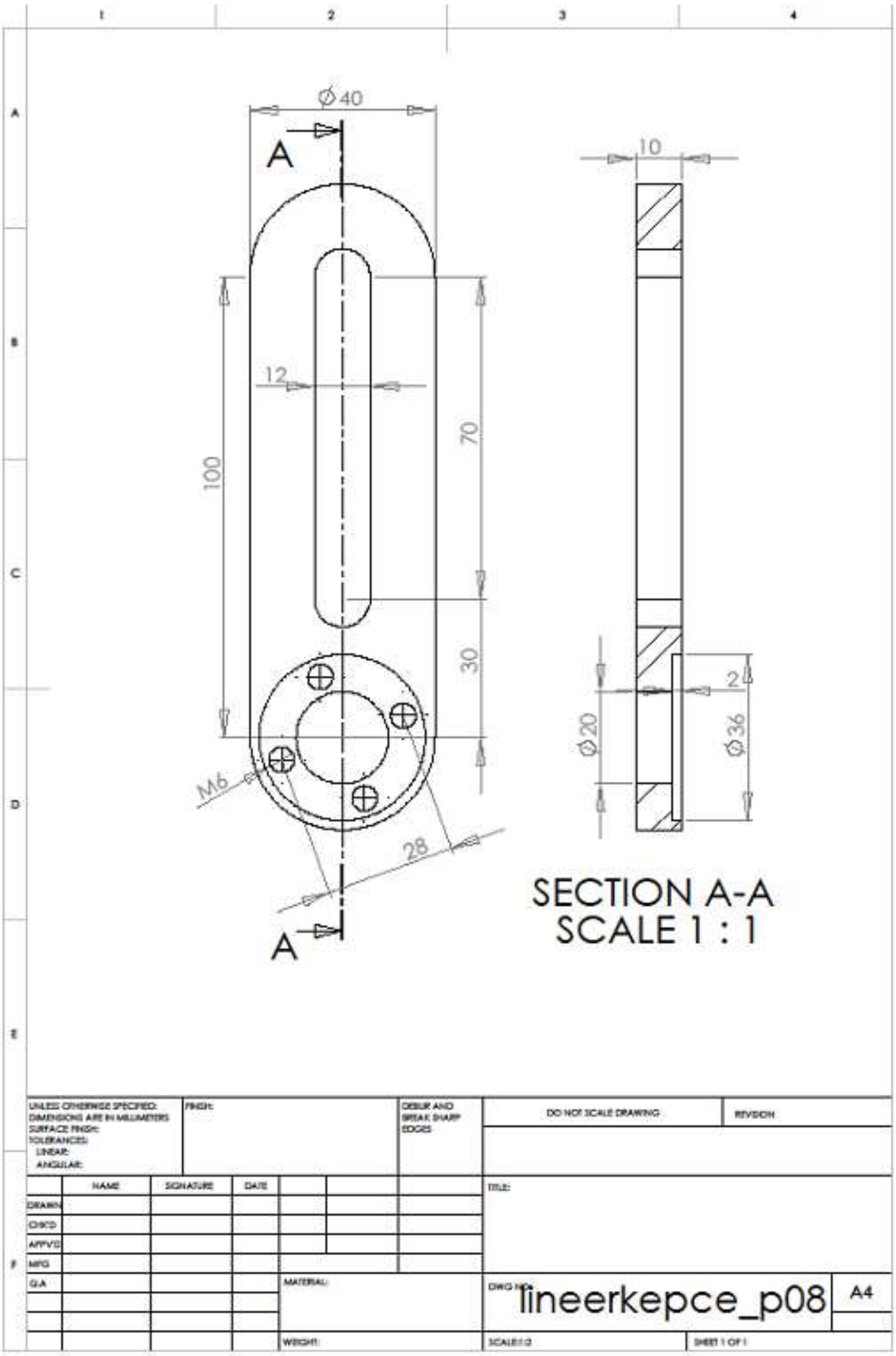
Ø15
Ø10
A
A


Ø40
A
10
12
70
100
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2
Ø20
Ø36
M6
28
A
SECTION A-A
SCALE 1 : 1
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FINISH:
DEBUR AND BREAK SHARP EDGES
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CHK'D
APPV'D
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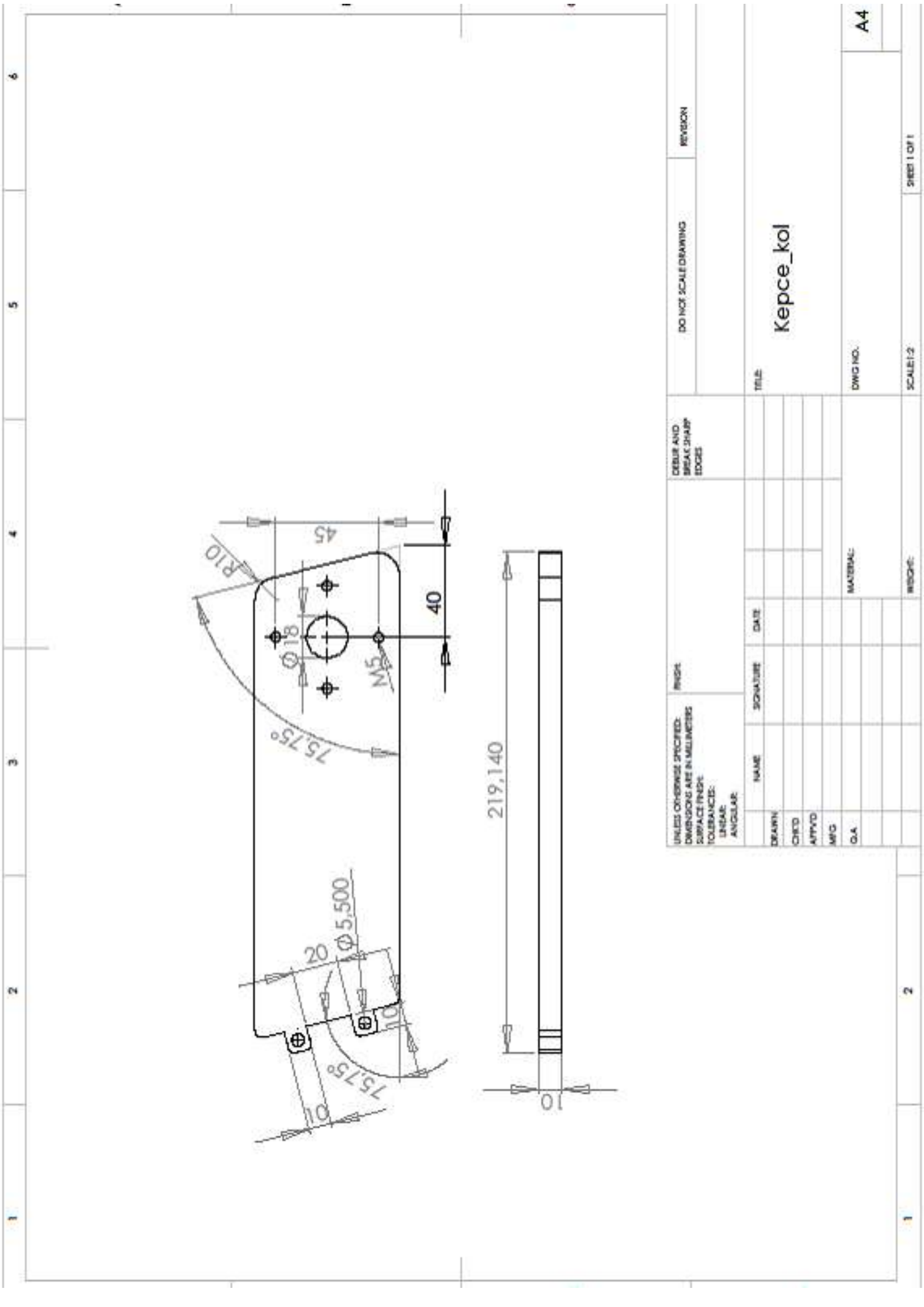

Kepce_kol
A4
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R10
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M5
75,75°
219,140
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Ø5,500
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DO NOT SCALE DRAWING
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DWG NO.
SCALE:1:2
SHEET 1 OF 1
MATERIAL:
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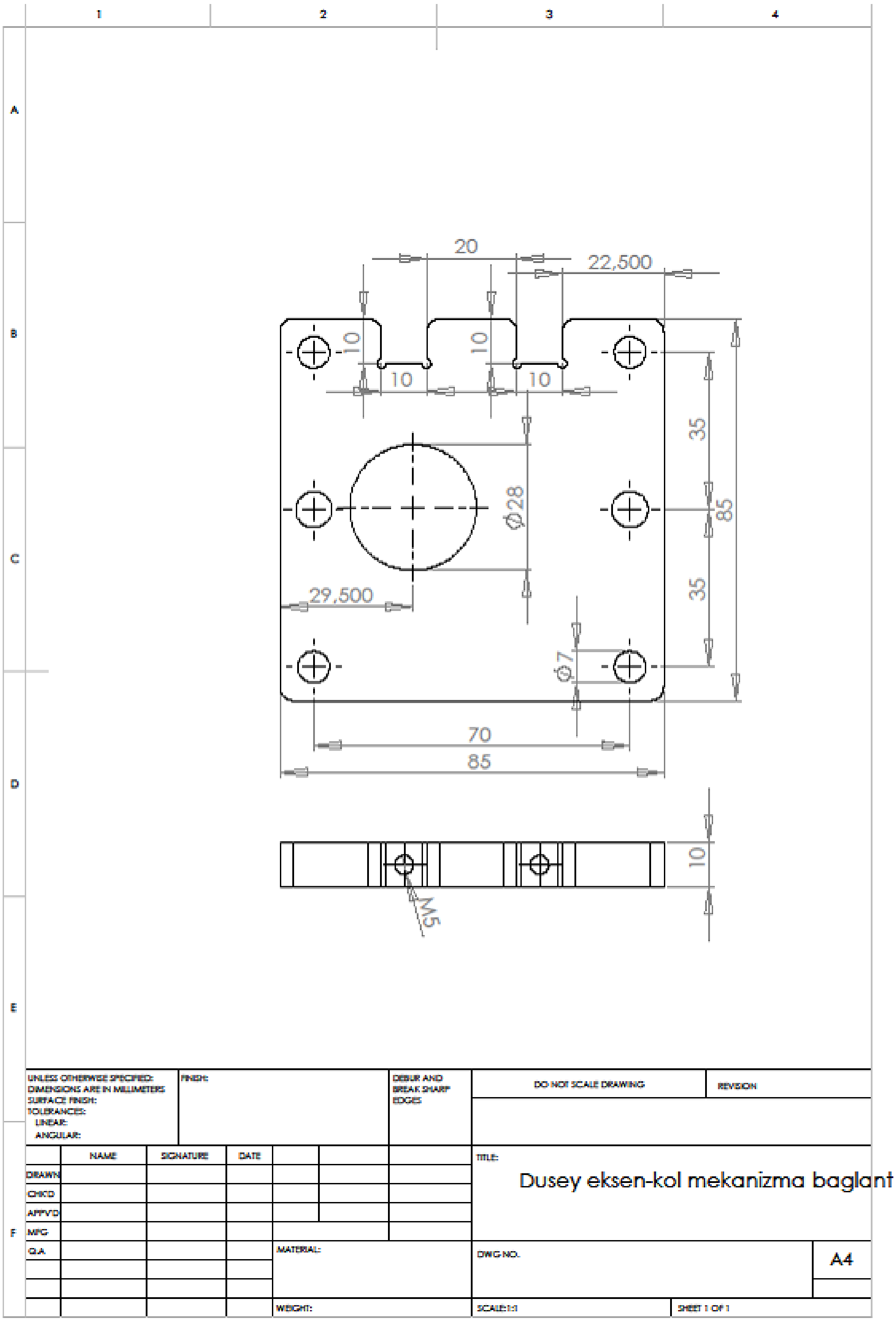
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Ø28
29,500
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85
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M5
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LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
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NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
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Dusey eksen-kol mekanizma baglant
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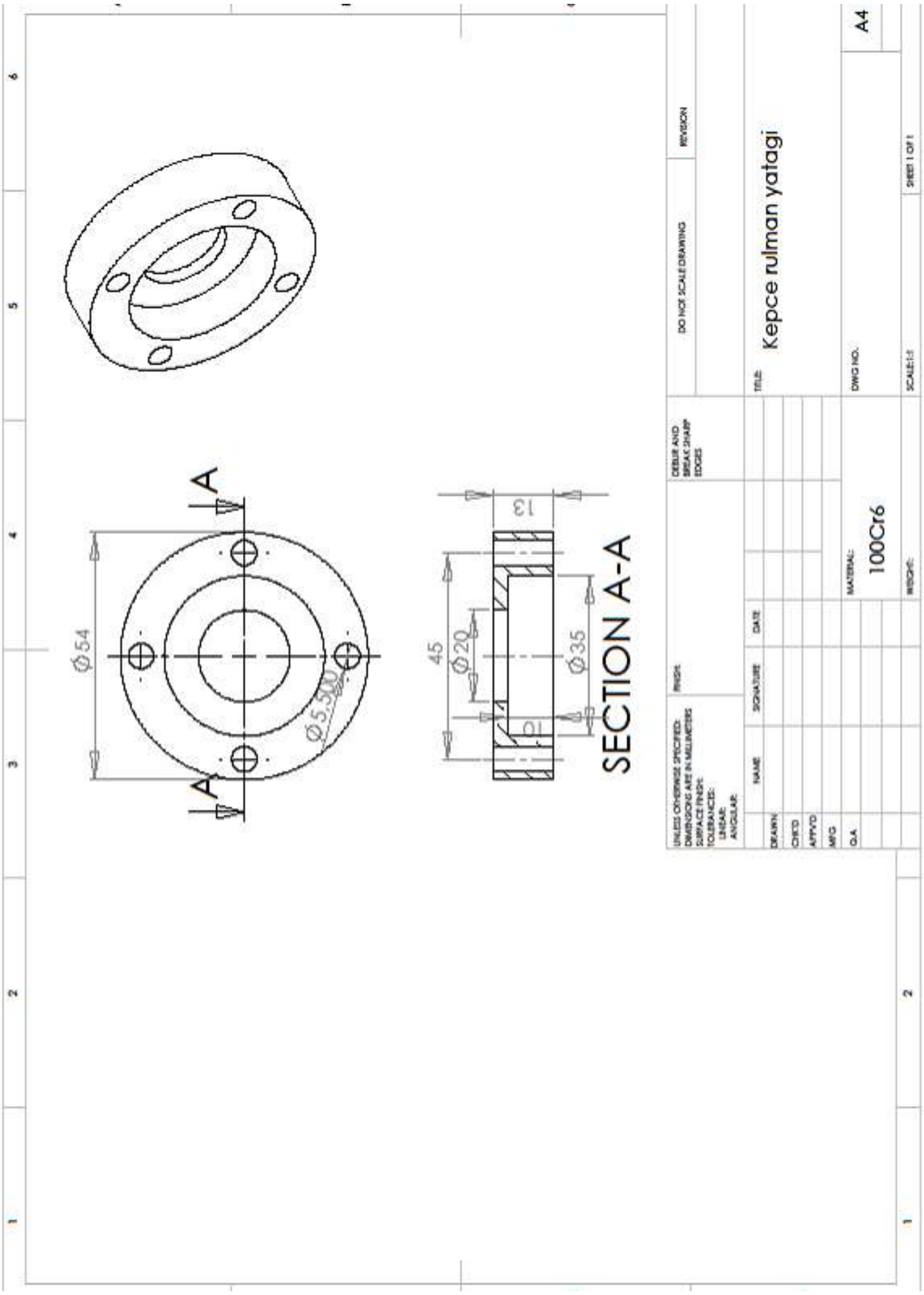
SHEET 1 OF 1



Kepce rulman yatagi
100Cr6
SECTION A-A
A4
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Ø35
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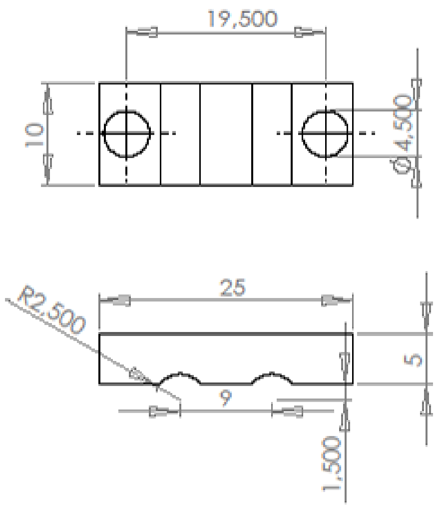
SCALE:1:1
SHEET 1 OF 1



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FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:
Elektrot tutucu kapak

MATERIAL:

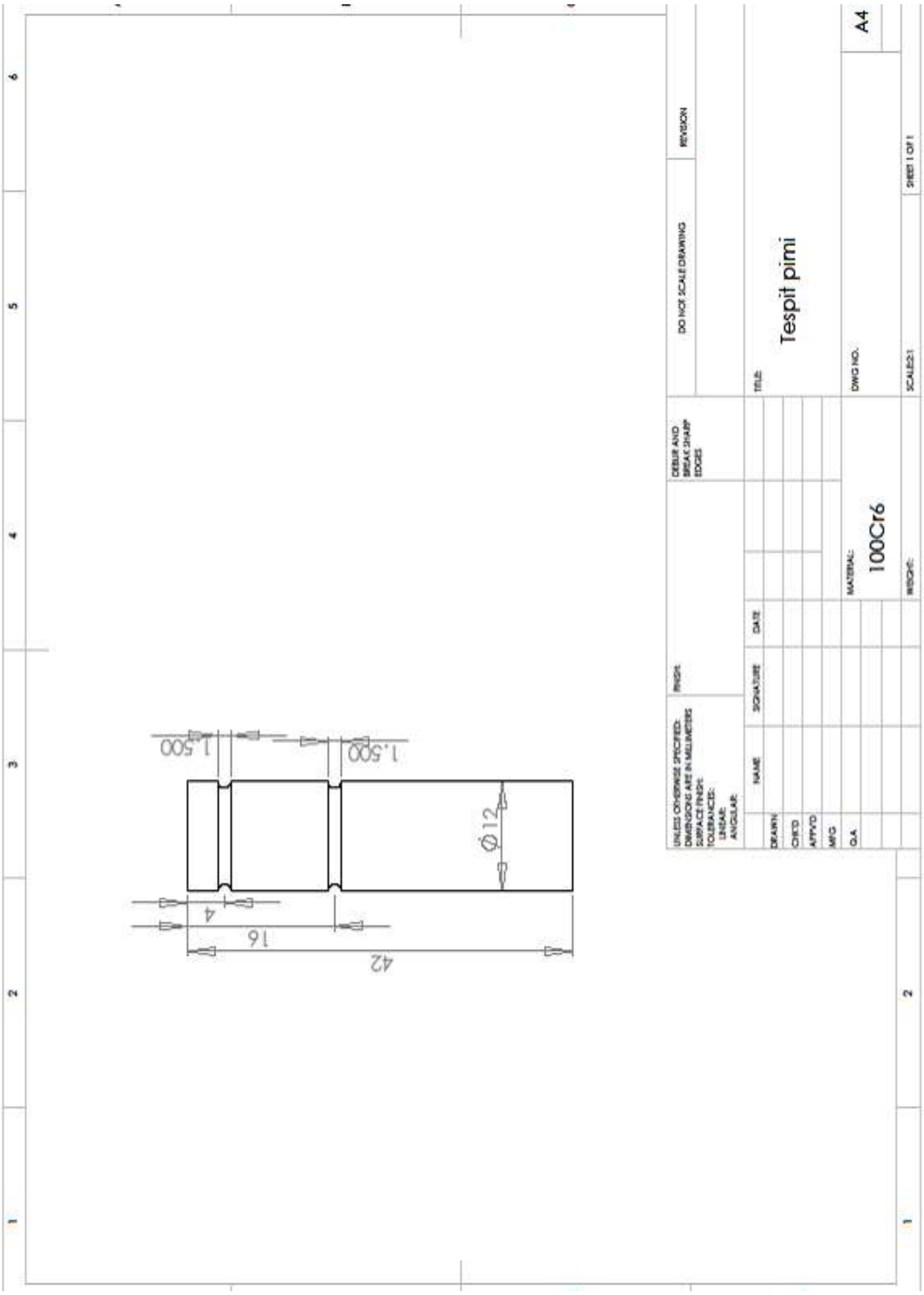
DWG NO.

A4

WEIGHT:

SCALE:2:1

SHEET 1 OF 1



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4
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42
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ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
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Tespit pimi
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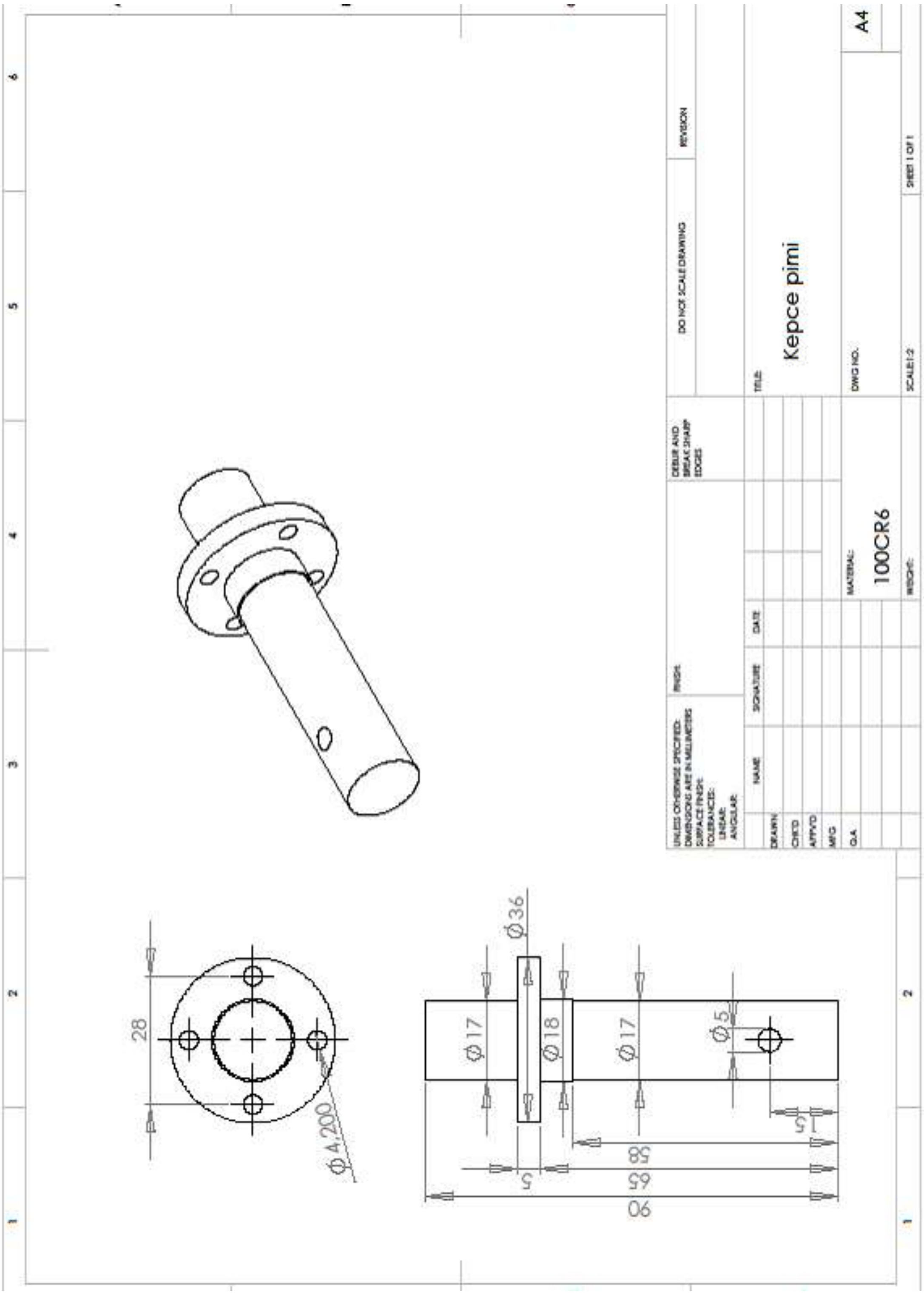
SHEET 1 OF 1


Kepce pimi
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A4
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FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
WEIGHT:
SCALE:1:2
SHEET 1 OF 1
Ø36
Ø17
Ø18
Ø17
Ø5
28
Ø4,200
15
58
5
65
90