THE DESIGN, MANUFACTURE AND PRELIMINARY TESTS OF A LINEAR CAR SYSTEM FOR ROBOTIC APPLICATIONS

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M.Sc. Thesis in

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ABSTRACT

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M.Sc. in Mechatronics Engineering

Supervisor: Prof. Dr. Can ÇOĞUN
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In the thesis, the design, manufacture and initial tests of the Linear Car (LC) and Linear Rail (LR) systems, which provided the movement of robots on them, were presented. The LC consists of rollers to carry the load on the plate on which the robotic system is mounted. The design and selection procedures of the components of the systems, including the finite element modeling and analysis, were mentioned. The LR's lateral and vertical run-out and deflection were introduced with no load and load conditions. The manufacturing processes, materials selections and assembly procedures were given. The initial test results revealed that the LC and LR systems could be used successfully in the movement of the robots.

Keywords: Linear car, linear rail, design, manufacture, test.

ÖZET

ROBOT UYGULAMALARI İÇİN LİNEER ARABA SİSTEMİ TASARIMI, ÜRETİMİ VE ÖN TESTLERİ

ŞENOL GÖZÜTOK, Demet
Mekatronik Mühendisliği Yüksek Lisans

Danışman: Prof. Dr. Can ÇOĞUN
Aralık 2022, 45 sayfa

Bu tezde robotların üzerinde hareket etmesini sağlayan lineer araba ve lineer ray sistemlerinin tasarım, üretim ve test süreçleri sunulmuştur
Lineer araba, robotik sisteme monte edilen plaka üzerindeki yükü taşımak için silindir parçalardan oluşmaktadır. Sonlu elemanlar modellemesi, analizi ve sistem bileşenlerinin tasarım ve seçim prosedürlerine değinilmiştir. Lineer rayın yüksüz ve yüklü olarak yanal ve dikeyde salgı ve sehim koşulları sunulmuştur. Üretim süreçleri, malzeme seçimleri ve montaj prosedürleri verilmiştir. İlk test sonuçları, lineer araba ve lineer ray sistemlerinin robotların hareketlerinde başarılı bir şekilde kullanılabileceğini göstermiştir.

Anahtar Kelimeler: Lineer araba, lineer ray, tasarım, üretim, test.

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CHAPTER I
INTRODUCTION

1.1 LINEAR CAR SYSTEM

A linear rail (LR) is a machine element that provides cushioning to ensure movement on an axis and a linear car (LC) is the machine element that makes the linear motion on the LR [1]. LR provides silent and precise operation by decreasing friction. Linear guides (LG), composed of an LC and LR, are essential to precision machining equipment, such as computer numerical control (CNC) machine tools. Motion errors of LGs directly affect the machining accuracy [2]. An LG permits linear movement with the aid of rolling elements. An LG can attain a precise linear movement by using balls or rollers between the rail and the car.

Although a servo motor, step motor or asynchronous motor is sufficient for movement in LG systems, the motion can also be provided manually. There are different sizes of LRs and LCs according to the load to be carried. According to market data, the Hiwin brand [3] is the most widely used LG type. The LGs are primarily preferred in robotic systems. According to the system's load capacity, suitable LCs, slides and rails could be selected. International companies such as Hiwin, Nadella, Ina, Rexroth and Güdel are the leading linear motion system equipment manufacturers. The Rexroth brand LCs and LRs are used mainly in the robotic system (Figure 1.1.1).

Figure 1.1.1: LG Parts [4]

Leading companies in the linear guide market have achieved high movement accuracy with the adaptation of ball sliders. Ball transition vibrations can be reduced by 1/3 compared to standard models. Product developments have been achieved with high load capacity and low friction tests [14].

The main aim of this thesis is to design, construct, test and implement an LG system. The general information about the thesis, whereas this thesis is one of its parts, is given in Table 1.1. The expected performance output from the design at the first stage is its proper functionality. Additional targets of this thesis are;

a) 1-ton load for 2 LCs opposite each other,

b) reduced cost,

c) local design and production,

d) low repair and maintenance costs,

e) long handling life,

f) high-speed motion,

g) low friction.

CHAPTER II
DESIGN PHASE

2.1 GENERAL STRUCTURE

The LC design carried out in the study is sown in Figure 2.1.1 The following data were taken into account in the design calculations.

-Material Selection

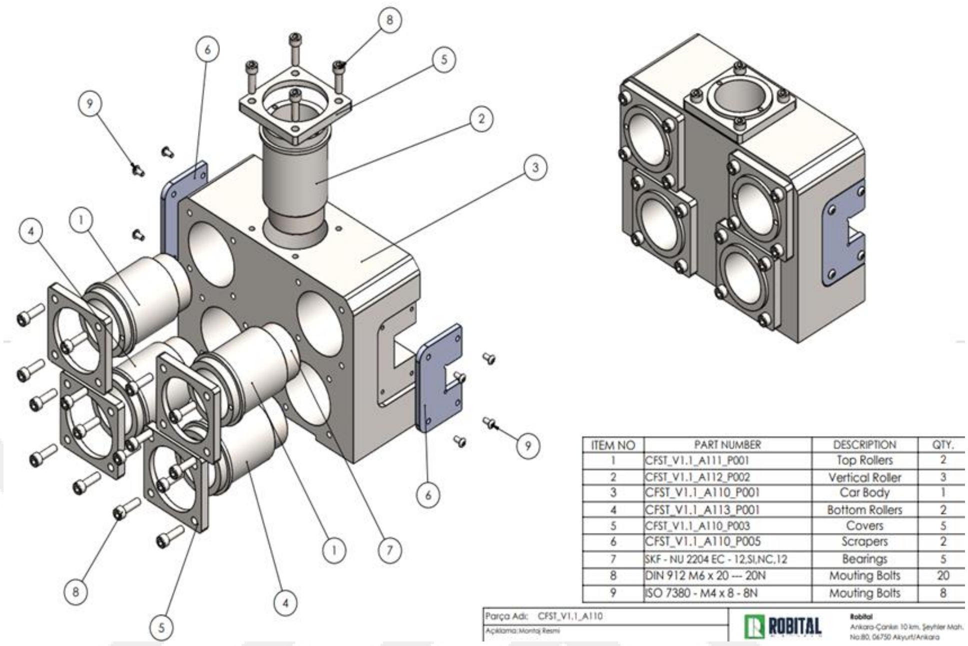
-Movement and Direction

-Links

-Sensibility

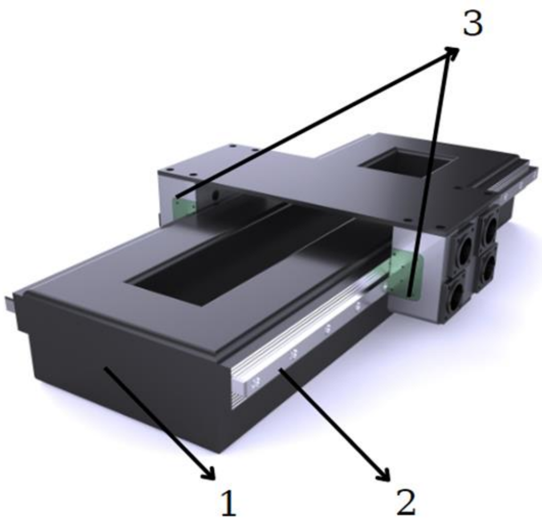
-Strengths in the whole system

The designed car is composed of the car body (3), top rollers (1), bottom rollers (4), vertical roller (2), covers (5), scrapers (6), bearings (7) and mounting bolts (8, 9). The overall system consists of 2 car bodies, ten rollers, ten covers, four scrapers, two rails and one slider (Figure 2.1). The design data is given in Appendix A. The system is expected to move linearly on a slider. It works automatically with the help of the integrated motor. The maximum load capacity is the basis of the LC system design. When the load of the robotic system is above the design load, more than one LC could be used to carry the system.



ITEM NO	PART NUMBER	DESCRIPTION	QTY.
1	CFST_V1.1_A111_P001	Top Rollers	2
2	CFST_V1.1_A112_P002	Vertical Roller	3
3	CFST_V1.1_A110_P001	Car Body	1
4	CFST_V1.1_A113_P001	Bottom Rollers	2
5	CFST_V1.1_A110_P003	Covers	5
6	CFST_V1.1_A110_P005	Scrapers	2
7	SKF - NU 2204 EC - 12,SI,NC,12	Bearings	5
8	DIN 912 M6 x 20 --- 20N	Mouting Bolts	20
9	ISO 7380 - M4 x 8 - 8N	Mouting Bolts	8

Figure 2.1.1: The Parts and Assembled LC Design



1	Slider
2	Linear Rail
3	Linear Car

Figure 2.1.2:The LC System

2.2 MATERIAL SELECTIONS

The cost, wear resistance, hardness, machinability and heat treatability characteristics were considered when selecting the materials of the LC system components. The SAE 1040 steel, which has high allowable strength values, toughness, abrasion resistance and heat treatability (hardening), was used in designing and manufacturing the prototype LC system.

2.3 SELECTIONS AND LIFE EXPECTANCY OF BEARINGS

The most appropriate bearing is selected by considering the expected bearing performance and functions (such as application, number of revolutions, expected life, load (magnitude, direction and type), vibration, working temperature, assembly-disassembly conditions, the possibility of lubrication, and methods) among different bearing types [7].

The maximum LC system load was 10000 N. This value is determined by considering used robots and systems. So, the radial load on each roller (Figure 2.1.1, numbers 1 and 4) bearing was 10000/8=1250 N. The expected life of the system was 300 hours. The maximum linear speed of the table was 1 m/s, corresponding to the rollers' rotational speed of 400 rpm. The system works 8 hr/day in a vibration-free medium at a maximum of 50oC. The selected bearings for the top and bottom rollers (Figure 2.1.1) were The ORS 62204-A-2RSR ball bearing. The bearing selection calculation is given below:

This bearing selection was determined by considering flexural strength under concentrated load and dimensional property. One of the essential factors in bearing selection is bearing life. The most common way to determine bearing life is to use bearing load ratings and the required loads of the application. The standard measure is "$\mathbf{L_{10}}$" life. It is defined as the number of turns just before metal fatigue first appears in 10% of bearings in a large group of bearings of the same type. This corresponds to the "basic life value" or "fatigue life" [7].

The formulas we use for life calculations are;

L_{10}: Basic rating life [millions of revolutions] [9]

L_{10h}: Basic rating life [operating hours]

C: Dynamic load rating= 12.7 kN

P: Equivalent dynamic bearing load= 1250 N

n: Rotational speed [rpm]= 9400

p: Exponent of the life equation= 3 [10]

$$L_{10} = \left(\frac{C}{P}\right)^{p} \qquad (2.1)$$

$$L_{10} = (12.7 \div 1250)^{3} = 0.01 \qquad (2.2)$$

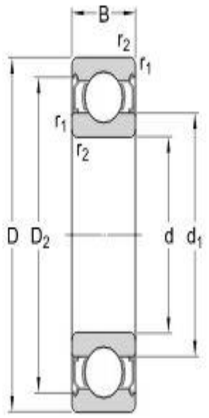
If the speed is constant;

$$L_{10h} = \frac{10^{6}}{60\,n} L_{10} \qquad (2.3)$$

$$L_{10h} = (10^{6} \div (60 \text{ x } 9400)) \text{ x } 0.01 = 1.7 \qquad (2.4)$$

Dimensions are given in Table 2.1. After the selection of bearings, outer rings, bolts and camber head bolts were determined and supplied.

Table 2.3.1: The ORS 62204-A-2RSR Ball Bearing Dimensions



d		20	mm
D		47	mm
B		14	mm
d_1	≈	28.8	mm
D_2	≈	40.59	mm
$r_{1,2}$	min.	1	mm

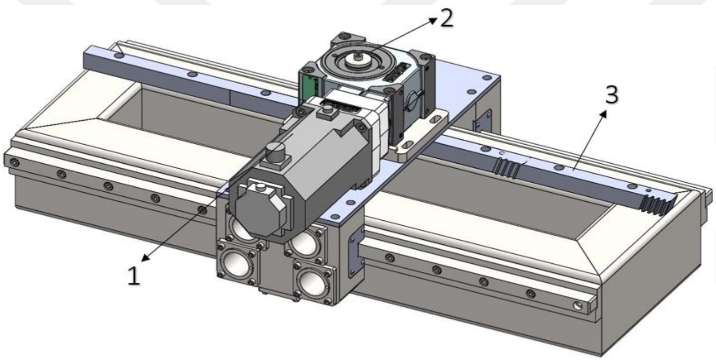
Table 2.3.2: The Life Testing Information Sent to ORS Company

Property	**Value**
Type of material	1040 steel
Total axial load	10000 N
Rotational speed	400 rpm
Working speed	1m/s
Daily working hour	8 hr
Vibration	Absent
Surface roughness	Ra 1.6 micrometer
Operation Temperature	50 ^{o}C
Environment cleaning	Less dusty (there is a scraper in the system) and oily environment.
Sound level	Lower than 85 dB.

The life test requested from the Ors company (Table 2.2) revealed that the life of the selected bearing under the selected conditions was between 400-500 hours.

2.4 MOTOR TORQUE AND SPEED CALCULATIONS

The gearbox, motor selections and calculations were made for a maximum 1 m/s LC linear speed. The gearbox and motor selections were made by examining the products of the contracted brands using specific catalog values.



1	Servo Motor
2	Gearbox
3	Pinion

Figure 2.4.1: The LG Modular System

The data, symbols, and units used in the calculations are presented in the table below.[15]

Table 2.4.1: Nomenclature Used in the Analysis of Motor Torque and Speed

Definition	Symbol
LG Mass	m (kg)
LC speed	V (m/s)
Time	t (s)
Gravity	g (m/s²)
Friction coefficient between LC and LR	μ
Pinion diameter of the gearbox (for system movement)	d
Load factor	K_A
Operation time factor	b_B
Security factor	S
Gearbox input speed	n_1 (rpm)
Gearbox efficiency	ɳ
LC acceleration	a (m/s²)
Force of LG system	F (N)
Required minimum torque value for the system	T (Nm)
Torque available of LG system	$T_{2.}$ (Nm)
Servo motor output torque	T_{motor}
Gearbox output speed	n_2 (rpm)
Gearbox ratio	i
Recommended gearbox ratio	I

The Atlanta gearbox and Fanuc servo motor products were chosen in compliance with the system's needs. The following data from the datasheets (Appendix B) were used to calculate the LC’s final velocity.

- From the Atlanta model’s catalog, a 9.25 ratio gearbox [16].
- From the Fanuc model’s catalog, a 3000 rpm gearbox [15].
- From the Atlanta model’s catalog, a 63.66 mm pinion diameter [17].

The system's gravity and friction values were considered while calculating the force. The desired values were chosen in addition to the fixed coefficient values specified in the computations above.

The system's motor and gearbox choice is heavily influenced by output torque. The ideal values were presented after the catalogs' motor and reducer value was tested. There was no limitation to the system's operation in the values that the calculations produced.

LC acceleration;

(2.1)

$$a = V \div t$$

$$a = 1 \div 1$$

$$a = 1 \text{ m/s}^2$$

Force of LG system;

(2.2)

$$F = m \times g \times \mu + m \times a$$

$$F = 1000 \text{ x } 9.81 \text{ x } 0.003 + 1000 \text{ x } 1$$

$$F = 1029.43 \text{ N}$$

Required minimum torque value for the system;

(2.3)

$$T = F \times d \div 2000$$

$$T = 1029.4 \text{ x } 63.6 \div 2000$$

$$T = 32.7 \text{ Nm}$$

Torque available of LG system;

(2.4)

$$T_2 = T_2 \div K_A \times b_B \times S$$

$$T_2 = 74 \div 1.25 \text{ x } 1.2 \text{ x } 1.3$$

$$T_2 = 37.9 \text{ Nm}$$

Servo motor output torque;

(2.5)

$$T_{motor} = T_2 \div I$$

$$T_{motor} = 37.9 \div 14.5$$

$$T_{motor} = 2.6 \text{ Nm}$$

Gearbox output speed;

(2.6)

$$n_2 = V \div d \times \pi \times 60000$$

n_2 = 1 ÷63.66 x 3.14 x 60000

n_2 = 300 rpm

Recommended gearbox ratio;

(2.7)

$$I = n_1 \div n_2$$

I = 3000 ÷300

I = 10 rpm

2.5 FINITE ELEMENT MODELLING AND ANALYSES

Finite element modeling (FEM) and analysis of stresses and deformations in the LR and LC systems (Figure 2.5.1) were performed [11]. The Ansys software package (2022 R1) was used in the FEM. In FEM, the following data was used [11]: A total of 10000 N load was applied to the red surfaces of the cars (Figure 2.5.2). SAE1040 material (Table 2.5.1) was used in the LR and LC components. Mesh settings were initially evaluated using the default value of the Ansys software package. Then, various mesh size ratios, such as to enhance the number of observations in the mesh structure analysis, various mesh size ratios, such as 2, 5, and 8 was attempted. The resolutions have been investigated at various sizes. Since the default resolution provided by the Ansys software package is ideal, this resolution is used in the analyses (Figure 2.5.3).

The finite element analysis revealed the following findings. The maximum deformation value of the LC was 0.04 mm (Figure 2.5.4). The regions in red (upper and lower sections of the LC body) were exposed to more deformations. The value is acceptable for the robotic operations performed on the LC system. The maximum Von-Mises stress value was 104.43 MPa between LR surfaces and bearings (Figure 2.5.5). The stresses on the LC for the static loading condition were around 100 MPa (Figure 2.5.6). The maximum equivalent stresses were observed in the regions where the bearings operate and on the surfaces where LC force is applied to the rail (Figure 2.5.6). Since the yield strength of the SAE 1040 steel (250 MPa) is much above the findings of the analysis and maximum deformation is tolerable, the design is safe.

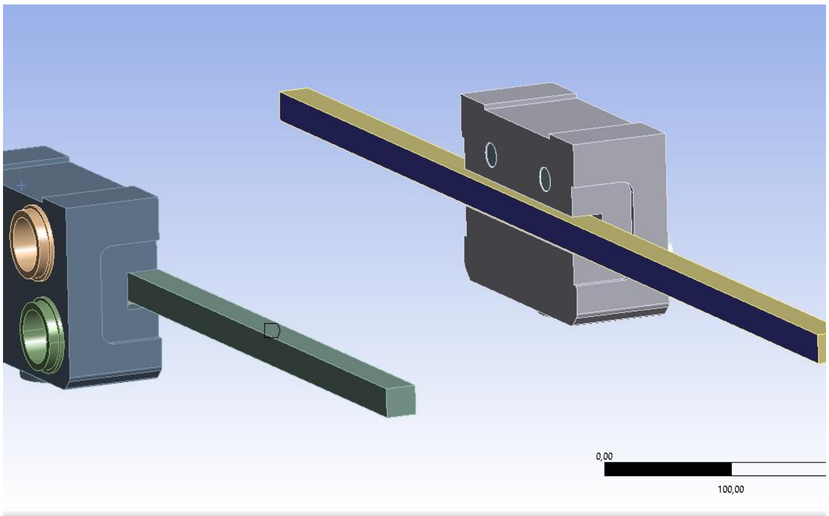


Figure 2.5.1: FEM of the LC and LR

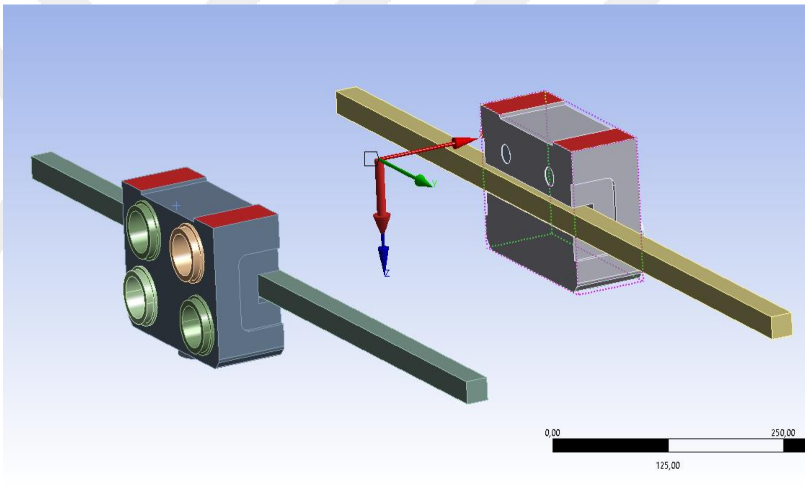


Figure 2.5.2: Axial Load Acting Surfaces on the LC and LR

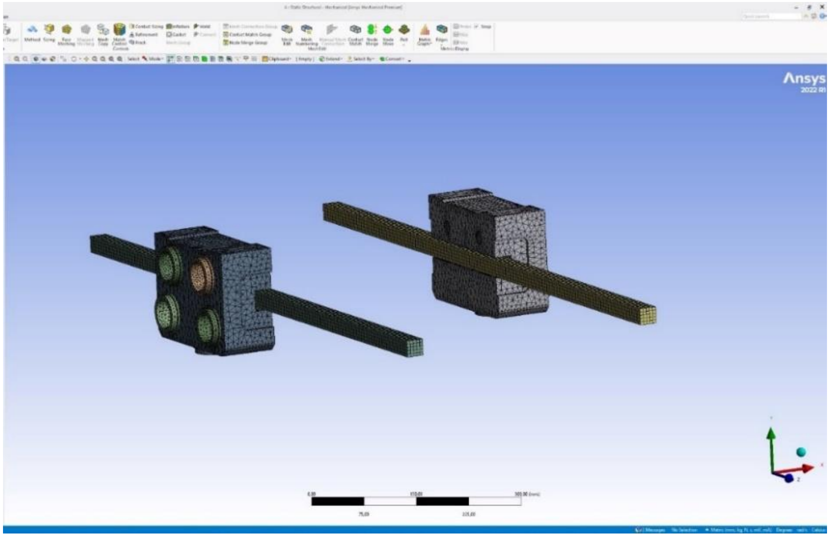
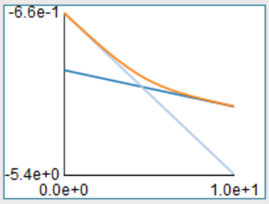
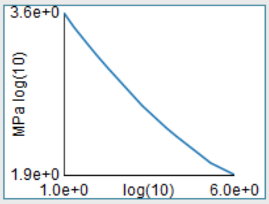


Figure 2.5.3: Meshing of the LC and LR

Table 2.5.1: SAE 1040 steel Properties Input to Ansys Software

Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	2e+05 MPa
Poisson's Ratio	0,30000
Bulk Modulus	1,6667e+05 MPa
Shear Modulus	76923 MPa
Isotropic Secant Coefficient of Thermal Expansion	1,2e-05 1/°C
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	250,00 MPa
Strain-Life Parameters	
S-N Curve	
Tensile Ultimate Strength	460,00 MPa
Tensile Yield Strength	250,00 MPa

Thermal	
Isotropic Thermal Conductivity	0,060500 W/mm·°C
Specific Heat Constant Pressure	4,34e+05 mJ/kg·°C

Electric	
Isotropic Resistivity	0,00017000 ohm·mm

Magnetic	
Isotropic Relative Permeability	10000

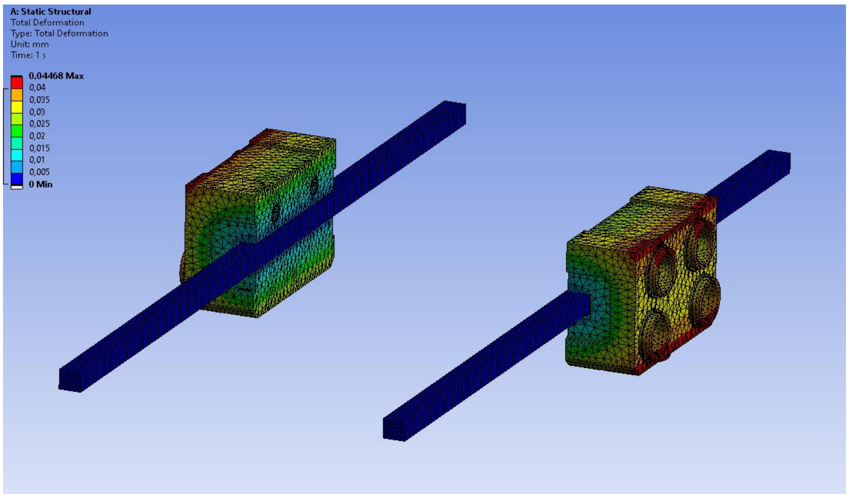


Figure 2.5.4: Deformation at Static Condition

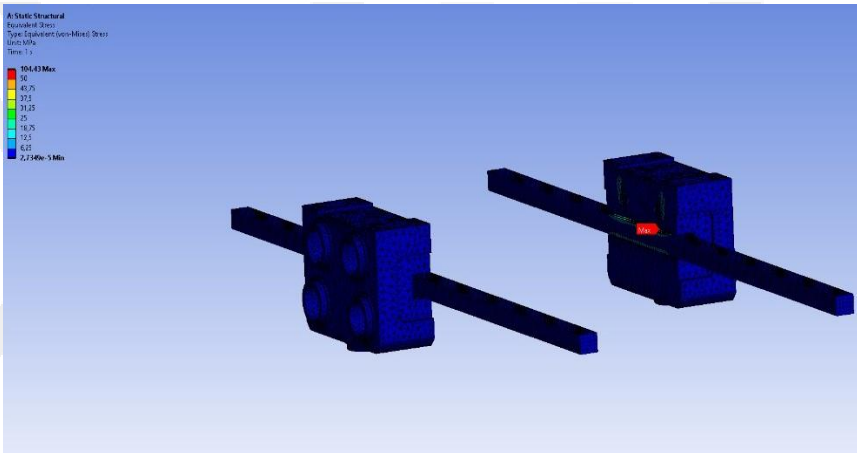


Figure 2.5.5: Von-Mises Stresses

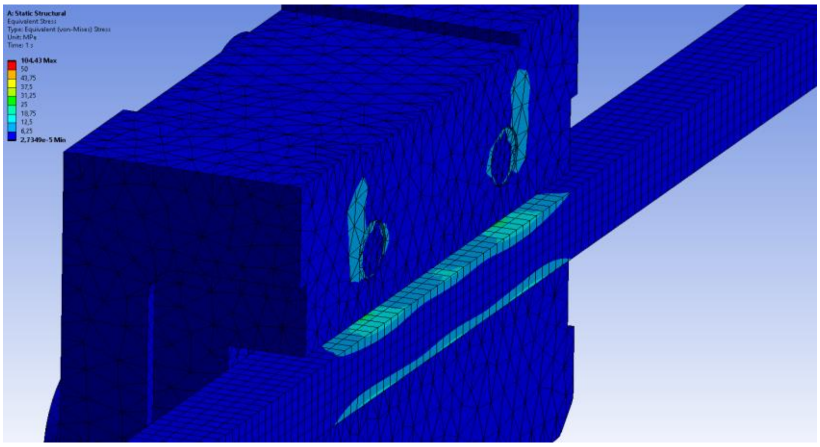


Figure 2.5.6: Stress Analysis (High Equivalent Stress Regions)

CHAPTER III
MATERIAL AND METHOD

3.1 MANUFACTURE AND ASSEMBLY OF THE LC AND LR COMPONENTS

The manufacturing methods and systems were chosen to reduce the machining cost at an acceptable dimensional accuracy and product repeatability. LG body (Figure 3.1.1) was machined with Deckel Maho DMU 60T (2021) 5-axis machine. The rough gauge of the rail was machined on the Haas VF6 40 M2001 machining center and sent to the grinding machine for finishing (Figure 3.1.2). Caps and scrapers (Figure 3.1.2) were machined in the same machining center. The rollers were machined with Topper(2008) lathe. Since 3 of the five rollers in the system are eccentric, attention has been paid to this eccentricity in processing.

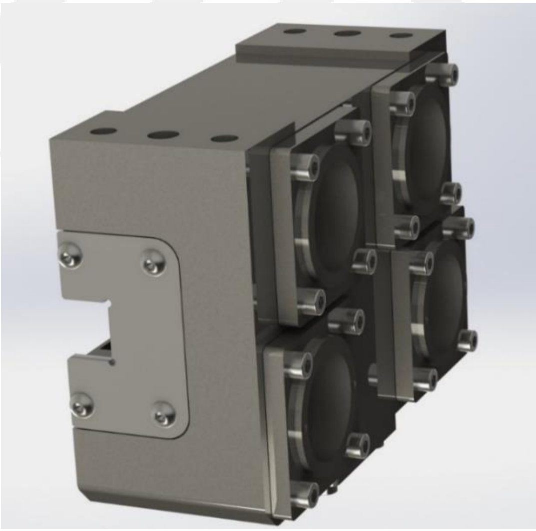


Figure 3.1.1: Linear Car

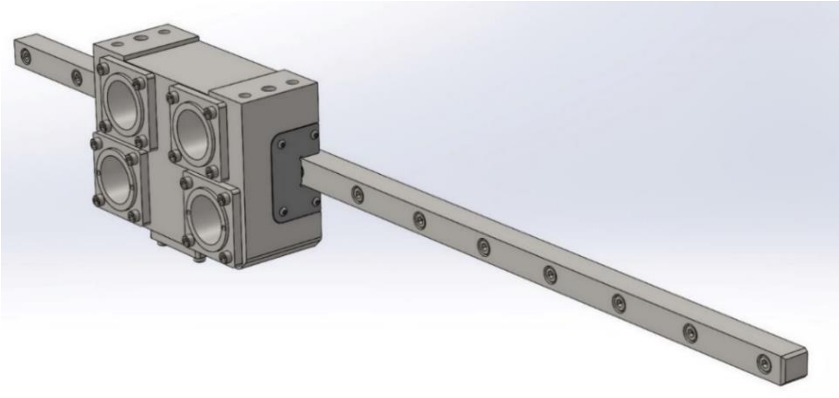


Figure 3.1.2: LC and LR

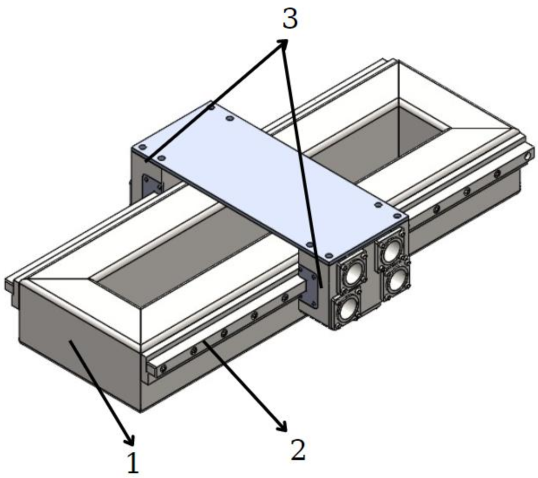
3.2 ASSEMBLY

First, the bearings were assembled into the roller sleeves (Figure 3.2.1). Afterward, the rollers with bearings were mounted to the car body (Figure 3.2.2). Finally, the body assembly was completed by attaching the cover screws (Figure 3.2.3). The system after the assembly operations is shown in Figure 3.2.4.

Figure 3.2.1: Assembly of Bearings to the Rollers

Figure 3.2.2: Assembly of Rollers with Bearings

Figure 3.2.3: Screwing Cover Screws



1	Slider
2	Linear Rail
3	Linear Car

(a)

(b)

Figure 3.2.4: LC and LR Systems After Assembly, a) Schematic View, b) Photographic Image

CHAPTER IV
PRELIMINARY FUNCTIONALITY TESTS

The tests generally used in LG systems are as follows [12][13];

- Loading Tests
- Comparator Test
- Fatigue Test
- Abrasion Test
- Corrosion test

In this thesis,we applied loading and comparator tests. Fatigue and abrasion tests continue to be looked at in the long term. A corrosion test was not required due to the application area.

4.1 LOADING TESTS (MANUEL OPERATION)

In this thesis, several loading tests were applied to understand the behavior of a system under normal operation and maximum load conditions. The most critical requirement for the system (Figure 4.2.1) is that it works under the desired load capacity. As aforementioned, the maximum load capacity has been determined as 1 ton, and each car body has a load capacity of 5000 N. Some 400 N dead weights were placed on the 8 mm thick plate, which integrates the cars. During the manual operation, no LC or LR deformation and noise problems were detected in the system up to 5000 N load. For the weights above 5000 N, deformations occurred in the plate. So, the tests were successful for 15 mm and 20 mm thick plates. For the durability and rigidity of the LG system, the 20 mm thick plate was assembled for the LC system.

4.2 LOADING TESTS (MANUEL OPERATION)

4.2.1 LR Tests With no Load

A dial gauge was used to measure the run-out (out-of-parallelism) of the LR in the lateral and vertical directions, respectively. In the LR lateral test, the dial gage was moved all along the length of the LR lateral surface using the machining head of the universal milling machine (Figure 4.2.1). The LC was stationary. The test aimed to determine the amount of run-out of the LR due to machining inaccuracies and deformation of the LR during the assembly process. The lateral LR test yielded a maximum of 0.8 mm. The same test was repeated by placing the dial gauge probe on the LC lateral surface (Figure 4.2.2). This time the LC moved through the length of the LR. The tests were done with no load condition. The test yielded a maximum of 0.05 mm deflection. The lower deflection observed when the measurement was taken from the LC lateral surface was attributed to the two rails guiding effect on the LC in the lateral direction.

In the LR vertical deformation test under 4000 N load, the dial gage was moved all along the length of the LR top surface (Figure 4.2.3). Higher loads than the 4000 N were not experienced since most robotic operations exert a load lower than this value (including the weight of the robot itself). The test yielded a maximum of 0.10 mm deflection at about the mid-position of the LC on the LR (Figure 4.2.3).

The tests revealed that the lateral movement of the rail under no load (0.05 mm) and vertical movement of the LR under 4000 N load (0.10 mm) were at acceptable limits.

Figure 4.2.1: LR Lateral Run-Out Test With No Load

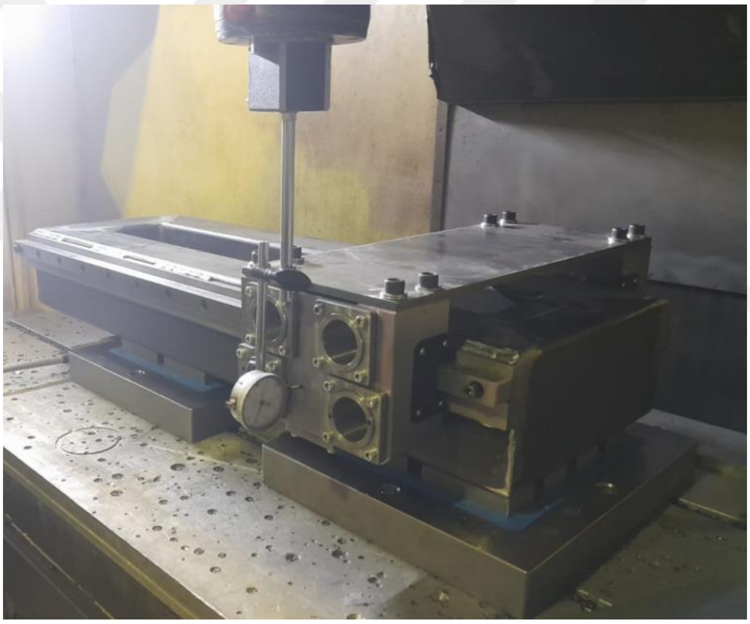


Figure 4.2.2: LR Lateral Run-Out Test With No Load (Measurement Taken From the LC Lateral Surface)

Figure 4.2.3: LR Vertical Deformation Under 4000 N Load

CHAPTER V
RESULT AND DISCUSSION

5.1 GENERAL

The SAE 1040 steel, which has high allowable strength values, toughness, abrasion resistance and heat treatability (hardening), was used in designing and manufacturing the prototype LC system.

The ORS 62204-A-2RSR ball bearing was selected to support the rollers of the LC for 10000 N maximum load on the car, 1250 N radial load on each roller, a 300 hours expected life, 1 m/s LC speed (corresponds to the rollers' 400 rpm rotational speed). The FEA revealed that the maximum deformation of the LC was 0.04 mm. This value is acceptable for the robotic operations performed on the LC system. The maximum equivalent stress on the LC for the static loading condition around 100 MPa was lower than the yield strength of the used SAE 1040 steel.

The LG body, the rough and finish machining of the LR, and the machinings of caps and scrappers were performed with CNC machine tools. The rollers were machined with a universal lathe.

During the manual operation, no LC or LR deformation and noise problems were detected in the system up to 10000 N load.

The tests revealed that the lateral movement of the rail under no load (0.05 mm) and vertical movement of the LR under 4000 N load (0.10 mm) were at acceptable limits.

5.2 FUTURE WORKS

The automatic brake system, which could be added as a design innovation, is the most critical research and development qualification issue. An automatic braking system could be equipped with acceleration and proximity sensors. The braking system performance of LC should be tested at the operating speed range.

The dimensional reductions of the LR and LC should be tried for a minimalist design. In doing so, high-strength materials like SAE 4140 and SAE 2379 could be selected.

The effect of the servo motor integrated drive system on the dynamic and deflection characteristics of the LC must be investigated. The stable operation speed range of the LC system should be determined. The braking system performance of LC should be tested at the operating speed range.

Design studies are carried out for the braking system, considering the current load and speed capacities. The primary target is to operate the system within the stipulated requirements before the braking system.

CHAPTER VI
CONCLUSION

In the thesis, the design, manufacture and initial tests of the Linear Car (LC) and Linear Rail (LR) systems, which provided the movement of robots on them, were presented. Although the typical characteristics of the LC and LR were a 300-hour expected life, 1 m/s LC speed (corresponds to the rollers' 400 rpm rotational speed), 4000 N load on the LC (500 N load on each roller), the FEA for the static loading were made for 10000 N peak load (1250 N load on each roller). The FEA revealed that the SAE 1040 steel was suitable material for manufacturing the prototype LC system since the maximum equivalent stress for the static loading condition around 100 MPa was lower than the yield strength of the material. Moreover, the FEA indicated that the maximum deformation of the LC was 0.04 mm, which is acceptable for the robotic operations performed on the LC system.

It is found that the components of the LC and LR systems should be machined with precision CNC machine tools to get better motion sensitivity, smooth operation and stable dynamic characteristics.

During the manual operation, no LC or LR deformation and noise problems were detected in the system up to 10000 N load. However, the LC and LR systems should be re-tested after being equipped with servo motors for driving and brake systems for braking. The manual tests revealed that the lateral movement of the rail under no load (0.05 mm) and vertical movement of the LR under 4000 N load (0.10 mm) were at acceptable limits.

The initial test results revealed that the LC and LR systems could be used effectively in the movement of the robots after i) integrating servo motors to drive the LC system, ii) the automatic brake system, iii) reducing the weight by using higher strength materials, and iv) determination of dynamically stable operating conditions (like speed, braking deceleration).

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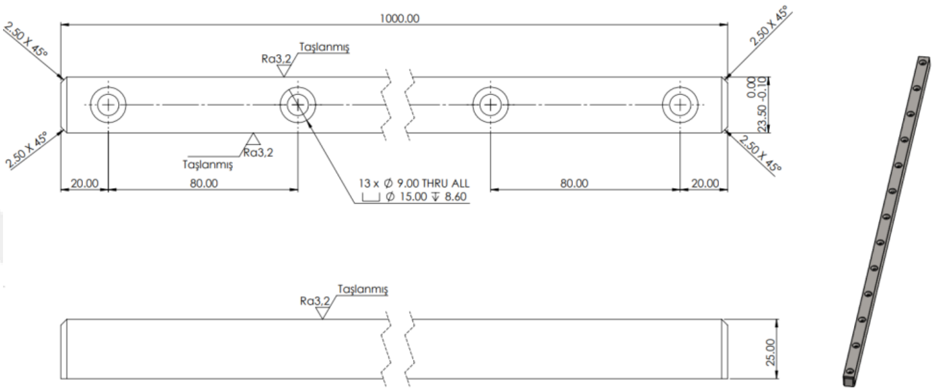
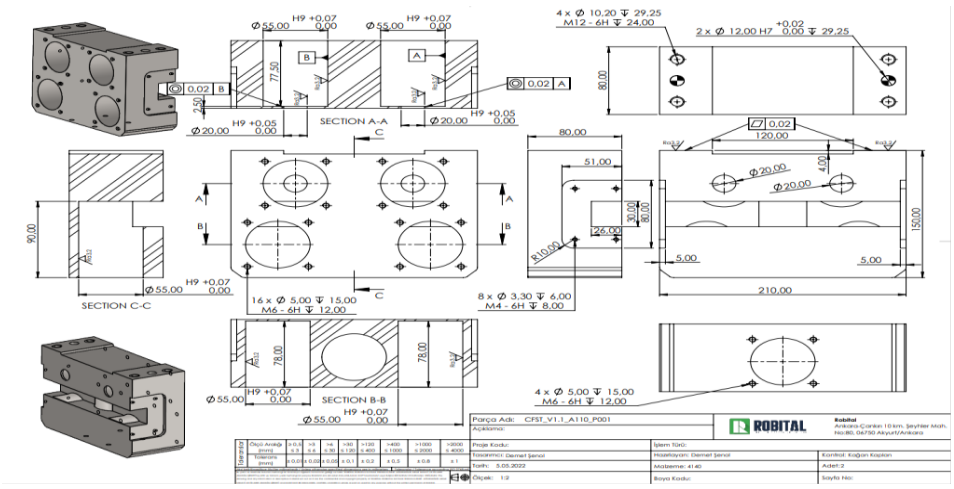
APPENDICES

APPENDIX A: THE DESİGN DATA

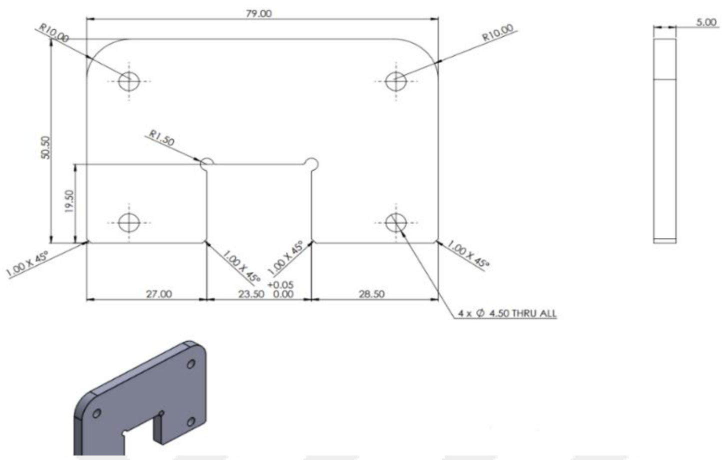
Linear Rail



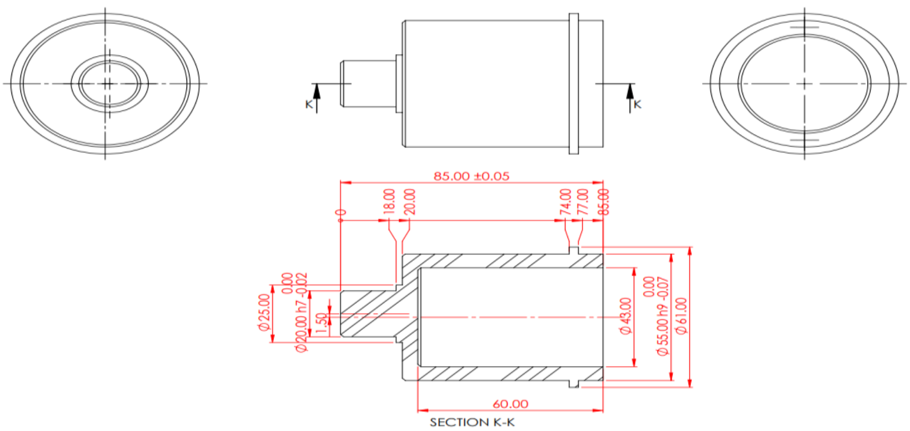
Car Body



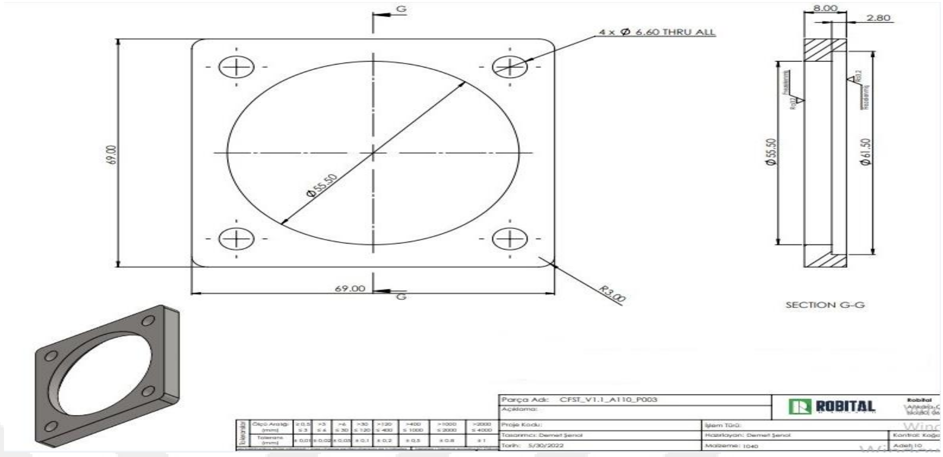
Scraper



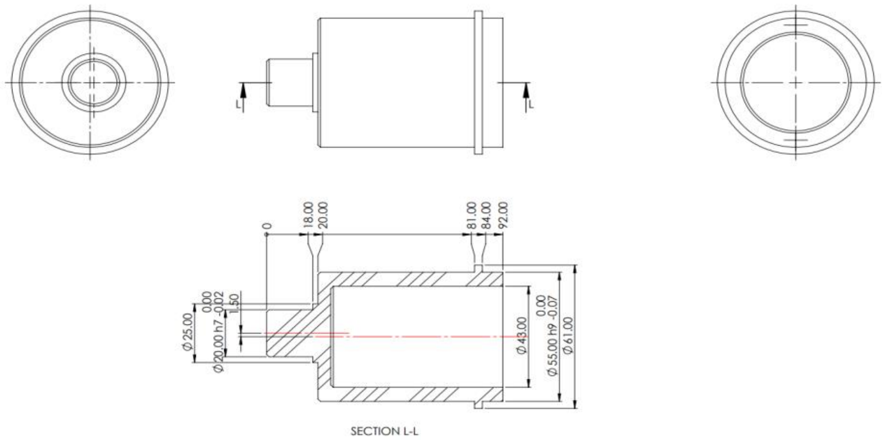
Top Roller



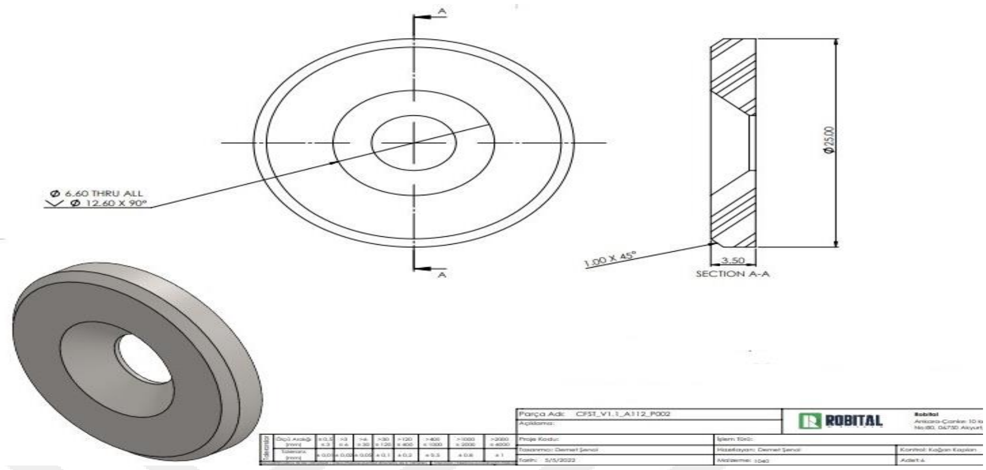
Covers



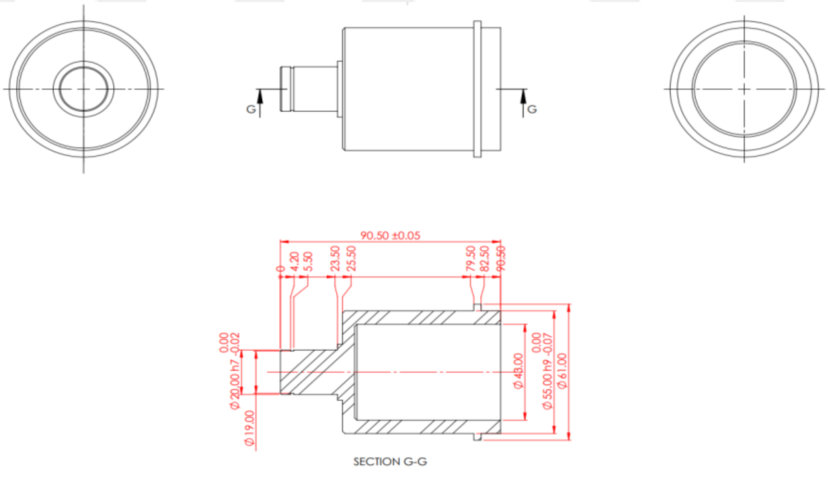
Vertical Roller



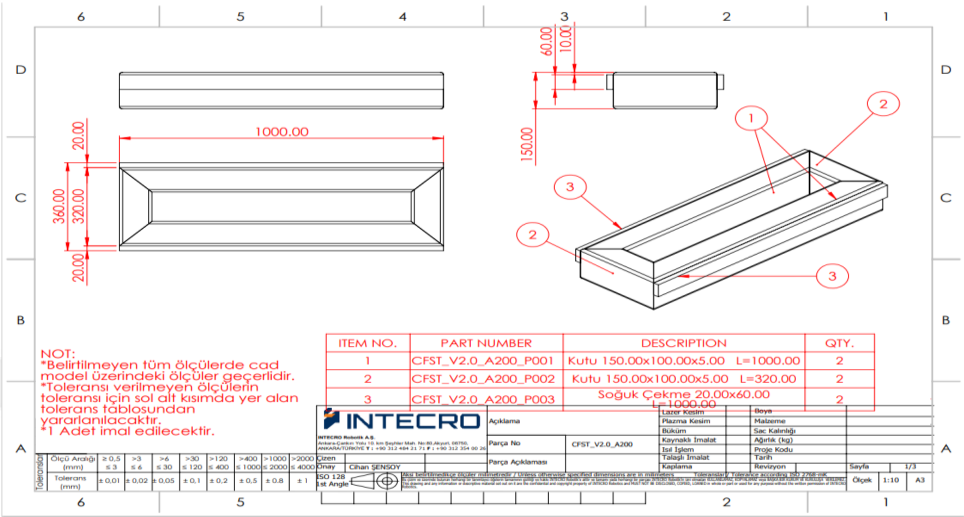
Front Bearing



Bottom Roller



Slider

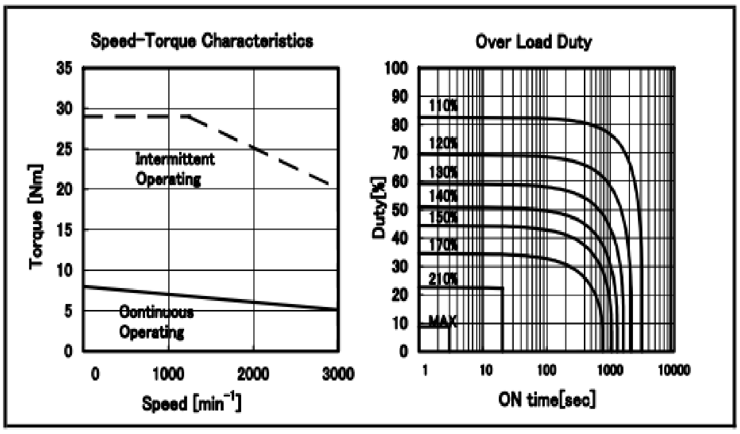

1000.00
360.00
320.00
20.00
20.00
60.00
10.00
150.00
NOT:
*Belirtilmeyen tüm ölçülerde cad model üzerindeki ölçüler geçerlidir.
*Toleransı verilmeyen ölçülerin toleransı için sol alt kısımda yer alan tolerans tablosundan yararlanılacaktır.
*1 Adet imal edilecektir.
ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
1 | CFST_V2.0_A200_P001 | Kutu 150.00x100.00x5.00 L=1000.00 | 2
2 | CFST_V2.0_A200_P002 | Kutu 150.00x100.00x5.00 L=320.00 | 2
3 | CFST_V2.0_A200_P003 | Soğuk Çekme 20.00x60.00 L=1000.00 | 2
INTECRO
CFST_V2.0_A200
Cihan ŞENSOY
1:10
A3
1/3

APPENDIX B: THE MOTOR AND GEARBOX DATA

Motor Data

B-65262EN/06 6.SPECIFICATIONS

Model αi **F 8/3000** Specification A06B-0227-B□0□



Data sheet

Parameter	Symbol	Value			Unit
Stall Torque (*)	Ts	8.0			Nm
		82			kgfcm
Stall Current (*)	Is	8.4			A (rms)
Rated Output (*)	Pr	1.6			kW
		2.1			HP
Rating Speed	Nr	3000			min^{-1}
Maximum Speed	Nmax	3000			min^{-1}
Maximum Torque (*)	Tmax	29			Nm
		296			kgfcm
Rotor Inertia	Jm	0.00257			kgm^2
		0.0262			kgfcms^2
Rotor Inertia (with Brake)	Jm	0.00264			kgm^2
		0.0269			kgfcms^2
Torque constant (*)	Kt	0.95			Nm/A (rms)
		9.7			kgfcm/A (rms)
Back EMF constant (1phase) (*)	Ke	33			V (rms)/1000 min^{-1}
	Kv	0.32			V (rms)sec/rad
Armature Resistance (1 phase) (*)	Ra	0.51			Ω
Mechanical time constant	tm	0.004			s
Thermal time constant	tt	30			min
Static friction	Tf	0.3			Nm
		3			kgfcm
Weight	w	12.3			kg
Weight (with Brake)	w	14.5			kg
Max. Current of Servo Amp.	Imax	40			A (peak)

(*) The values are the standard values at 20°C and the tolerance is ±10%.
The speed-torque characteristics very depending on the type of software, parameter setting, and input voltage of the digital servo software. (The above figures show average values.)

Gearbox Data

Bestell-Nr. / Order code		a_0 (mm)	i	$T_{2\,max}$	250 T_1 (Nm)	250 T_2 (Nm)	500 T_1 (Nm)	500 T_2 (Nm)	750 T_1 (Nm)	750 T_2 (Nm)	1000 T_1 (Nm)	1000 T_2 (Nm)	1500 T_1 (Nm)	1500 T_2 (Nm)	2000 T_1 (Nm)	2000 T_2 (Nm)
					Antriebsdrehzahl / *Driving speed* n_1 in min^{-1}											
59 01 003	59 11 003	32	3,00*													
59 01 005	59 11 005		4,75	135	3,2	12	4,2	16	4,1	16	4,4	17	3,8	17	4,3	17
59 01 007	59 11 007		6,75	100	2,0	10	2,6	14	2,8	15	2,9	16	2,8	17	3,0	17
59 01 009	59 11 009		9,25	65	1,3	9	1,8	12	1,8	13	2,0	14	1,8	15	2,1	16
59 01 015	59 11 015		14,50	85	1,0	10	1,3	14	1,4	15	1,5	16	1,4	17	1,5	17
59 01 020	59 11 020		19,50	55	0,7	9	0,9	12	0,9	12	1,0	13	0,9	14	1,1	15
59 01 029	59 11 029		29,00	70	0,5	9	0,7	12	0,7	13	0,8	14	0,7	15	0,8	16
59 01 039	59 11 039		39,00	50	0,5	10	0,6	13	0,7	14	0,7	15	0,6	16	0,7	17
59 01 050	59 11 050		50,00	35	0,4	8	0,5	11	0,5	11	0,6	12	0,4	13	0,6	14
59 03 003	59 13 003	50	3,00*													
59 03 005	59 13 005		4,75	550	11,6	48	15,1	65	15,1	65	16,3	70	16,4	70	16,5	70
59 03 007	59 13 007		6,75	400	7,2	42	9,4	56	9,9	59	10,5	63	11,4	69	11,4	69
59 03 009	59 13 009		9,25	275	4,6	35	6,1	46	6,5	51	6,9	54	7,4	58	7,9	62
59 03 015	59 13 015		14,50	350	3,7	42	4,8	57	5,0	60	5,3	65	5,8	70	5,9	72
59 03 020	59 13 020		19,50	250	2,4	33	3,1	45	3,3	48	3,4	50	3,7	55	3,9	58
59 03 029	59 13 029		29,00	300	1,9	36	2,4	48	2,6	52	2,7	55	2,9	60	3,1	63
59 03 039	59 13 039		39,00	200	1,8	39	2,3	52	2,4	56	2,5	60	2,7	65	2,8	68
59 03 050	59 13 050		50,00	150	1,5	31	1,9	42	1,9	44	2,0	47	2,1	50	2,2	53
59 04 003	59 14 003	63	3,00*													
59 04 005	59 14 005		4,75	1000	37,6	163	38,9	170	41,2	180	41,3	180	39,2	170	37,4	162
59 04 007	59 14 007		6,75	750	21,5	129	27,9	170	29,4	180	29,4	180	27,9	170	26,6	162
59 04 009	59 14 009		9,25	500	10,8	85	14,2	115	15,3	125	15,9	130	16,4	135	16,4	135
59 04 015	59 14 015		14,50	600	11,1	132	13,6	165	14,7	180	14,7	180	14,7	180	14,5	177
59 04 020	59 14 020		19,50	500	5,6	87	7,2	115	7,7	125	8,0	130	8,3	135	9,0	145
59 04 029	59 14 029		29,00	650	6,9	137	8,4	175	9,1	190	9,7	205	10,5	220	10,1	212
59 04 039	59 14 039		39,00	450	4,2	106	5,2	140	5,5	150	5,8	160	6,4	175	6,6	180
59 04 052	59 14 052		52,00	300	2,4	71	3,0	95	3,3	105	3,5	115	3,8	125	4,0	133
59 05 003	59 15 003	80	3,00*													
59 05 005	59 15 005		4,75	2000	102,9	453	94,9	420	85,9	380	81,5	360	75,0	330	71,5	313
59 05 007	59 15 007		6,75	1400	65,2	402	67,6	420	61,1	380	57,8	360	53,2	330	50,7	313
59 05 009	59 15 009		9,25	1100	37,5	310	44,2	370	44,1	370	42,9	360	39,3	330	37,5	313
59 05 015	59 15 015		14,50	1300	34,9	431	35,9	450	35,8	450	33,4	420	29,4	370	27,5	345
59 05 020	59 15 020		19,50	1000	21,9	353	22,5	370	24,2	400	24,1	400	21,7	360	20,9	347
59 05 029	59 15 029		29,00	1200	22,9	498	23,3	520	24,5	550	23,6	530	21,8	490	20,8	467
59 05 039	59 15 039		39,00	850	15,0	412	15,1	430	16,0	460	17,0	490	16,7	480	15,9	457
59 05 052	59 15 052		52,00	600	6,3	216	6,6	240	7,1	260	7,5	275	8,2	300	8,5	310
59 06 005	59 16 005	100	4,75	3300	234,2	1043	197,3	880	179,6	800	169,1	750	154,3	685	147,1	650
59 06 007	59 16 007		6,75	2300	127,2	797	131,8	830	119,1	750	114,8	720	105,3	660	101,3	633
59 06 009	59 16 009		9,25	1900	94,3	794	97,6	830	88,1	750	84,8	720	77,7	660	74,8	633
59 06 015	59 16 015		14,50	2050	70,0	892	72,2	930	68,2	880	62,9	810	55,9	720	53,5	687
59 06 020	59 16 020		19,50	1800	51,8	861	53,3	900	51,3	870	47,8	810	42,5	720	40,6	687
59 06 029	59 16 029		29,00	2300	48,7	1103	49,9	1150	46,1	1070	43,7	1010	36,8	850	36,2	833
59 06 039	59 16 039		39,00	1650	35,2	1034	35,8	1080	34,0	1030	33,0	1000	29,7	900	28,5	860
59 06 052	59 16 052		52,00	1100	20,7	759	20,0	760	21,5	820	22,3	850	20,6	785	19,7	750

Bestell-Nr. / Order code		2500 T_1 (Nm)	2500 T_2 (Nm)	3000 T_1 (Nm)	3000 T_2 (Nm)	3500 T_1 (Nm)	3500 T_2 (Nm)	4000 T_1 (Nm)	4000 T_2 (Nm)	4500 T_1 (Nm)	4500 T_2 (Nm)	5000 T_1 (Nm)	5000 T_2 (Nm)	5500 T_1 (Nm)	5500 T_2 (Nm)	6000 T_1 (Nm)	6000 T_2 (Nm)
		Antriebsdrehzahl / *Driving speed* n_1 in min^{-1}															
59 01 003	59 11 003																
59 01 005	59 11 005	4,3	17	4,3	17	4,4	18	4,5	18	4,5	18	4,5	18	4,3	17	4,1	16
59 01 007	59 11 007	3,0	17	3,0	17	3,1	18	3,1	18	3,1	18	3,1	18	3,3	19	3,4	19
59 01 009	59 11 009	2,2	16	2,3	17	2,3	18	2,4	18	2,3	18	2,4	18	2,5	19	2,6	19
59 01 015	59 11 015	1,6	18	1,6	18	1,6	18	1,6	18	1,5	18	1,6	18	1,6	19	1,7	19
59 01 020	59 11 020	1,1	15	1,1	16	1,1	16	1,1	16	1,1	16	1,1	16	1,1	17	1,2	17
59 01 029	59 11 029	0,9	16	0,9	17	0,9	17	0,9	17	0,9	17	0,9	17	0,9	18	1,0	18
59 01 039	59 11 039	0,8	17	0,8	18	0,8	18	0,8	18	0,8	18	0,8	18	0,8	19	0,8	19
59 01 050	59 11 050	0,6	14	0,6	15	0,6	16	0,7	16	0,7	17	0,7	18	0,8	19	0,8	19
59 03 003	59 13 003																
59 03 005	59 13 005	25,0	70	16,8	70	16,3	67	15,8	65	15,5	63	15,1	61	14,3	57	13,6	53
59 03 007	59 13 007	17,2	69	11,6	69	11,3	67	11,0	65	10,7	63	10,5	61	9,9	57	9,4	54
59 03 009	59 13 009	12,6	66	8,1	70	8,9	70	8,5	70	8,7	67	8,4	65	8,0	61	7,6	58
59 03 015	59 13 015	9,1	73	6,2	75	6,2	75	6,3	75	6,3	75	6,4	75	6,1	70	5,8	67
59 03 020	59 13 020	6,1	61	4,3	65	4,3	65	4,3	65	4,3	65	4,4	65	4,2	61	4,0	58
59 03 029	59 13 029	4,9	67	3,0	70	3,5	70	3,5	70	3,4	67	3,3	65	3,2	61	3,0	57
59 03 039	59 13 039	4,4	71	3,1	75	3,1	75	3,1	75	3,1	75	3,1	75	3,0	70	2,9	66
59 03 050	59 13 050	3,4	57	2,4	60	2,4	60	2,4	60	2,4	60	2,4	60	2,5	62	2,5	64
59 04 003	59 14 003																
59 04 005	59 14 005	53,4	153	34,0	145	32,9	140	31,9	135	29,6	124	27,5	115				
59 04 007	59 14 007	38,1	153	24,1	145	23,4	140	22,7	135	21,1	125	19,8	116	18,6	109		
59 04 009	59 14 009	24,6	135	16,5	135	16,0	130	15,6	126	14,6	117	13,8	110	13,0	104	12,4	98
59 04 015	59 14 015	21,4	173	14,1	170	13,7	165	13,4	160	12,5	148	11,7	138	11,1	130		
59 04 020	59 14 020	14,4	155	10,3	165	9,9	160	9,7	155	9,1	144	8,6	136	8,2	128	7,8	121
59 04 029	59 14 029	14,6	203	9,4	195	9,3	190	9,1	185	8,5	171	8,0	159	7,6	149		
59 04 039	59 14 039	10,2	185	7,0	190	7,0	190	7,1	190	6,7	177	6,3	166	6,0	156	5,7	148
59 04 052	59 14 052	6,5	142	4,6	150	4,8	155	5,0	160	4,8	155	4,6	145	4,4	137	4,2	129
59 05 003	59 15 003																
59 05 005	59 15 005	102,2	297	64,6	260	58,9	254	53,2	228								
59 05 007	59 15 007	72,4	297	45,7	260	42,0	256	38,2	232	35,3	213	32,9	198				
59 05 009	59 15 009	53,5	297	33,3	260	31,2	257	28,5	234	26,6	217	24,8	202	23,3	189		
59 05 015	59 15 015	38,5	320	23,6	295	21,9	270	20,0	245	18,5	226	17,3	210				
59 05 020	59 15 020	30,3	333	19,5	320	18,0	295	16,6	269	15,4	250	14,5	233	13,6	218		
59 05 029	59 15 029	29,9	443	19,0	420	17,5	384	16,0	348	14,9	322						
59 05 039	59 15 039	22,8	433	14,8	410	13,4	377	12,4	345	11,5	319	10,8	297	10,2	278		
59 05 052	59 15 052	13,2	320	9,1	330	9,1	330	9,2	330	8,6	308	8,2	288	7,8	271		
59 06 005	59 16 005	209,5	615	132,3	580												
59 06 007	59 16 007	146,1	607	93,5	580	84,3	521	69,2	426								
59 06 009	59 16 009	107,9	607	69,0	580	62,9	526	52,2	436	53,2	442	49,6	410				
59 06 015	59 16 015	76,6	653	48,6	620	44,0	559	40,2	509								
59 06 020	59 16 020	58,2	653	37,0	620	33,7	564	31,1	516	28,8	477	26,8	442				
59 06 029	59 16 029	53,6	817	35,2	800	31,9	721										
59 06 039	59 16 039	41,0	820	26,1	780	23,9	708	19,9	587	20,4	597						
59 06 052	59 16 052	28,2	715	18,0	680	16,5	621	15,3	570	14,3	528	12,6	461				

Gearbox Efficiency Chart