Faculty of Power and Aeronautical Engineering

Department of Automatic Control & Robotics

Advance mechanical design – Project

Prepared by: Abenezer Bedilu

Beidemaryam Awoke Bishaw

Natnael Aman Desalegn

Submitted to – Prof. Krzysztof Mianowski

Jan 2023

Table of Contents

List of Figure

List of Table

1. Introduction

A robot arm is a mechanical structure that uses electric motors, pneumatic, or hydraulic actuators to alter its form and reproduce movement similar to a human arm. The term DOF (degrees of freedom) is often used when designing a robot arm, and it refers to the roll, yaw, and pitch of the arm. However, due to their complex mechanisms and circuits, robot arms can be expensive. To overcome this challenge, a robotic arm can be designed with a competitive price, light weight and high power-to-weight ratio for use to move around the apartment in order to carry small objects, e.g. give an elderly and disabled person a glass of water or a plate of soup (and the like).

2. Assumptions

Table 1 Assumptions to be considered

No	Parameter	Value
1	The length of the manipulator from the axis of 1st DOF and 2nd to the center of wrist.	800mm
2	Number of degrees of freedom.	6
3	Maximum end element (gripper) speed.	0.3m/sec
4	Wrist angular velocity.	0.2rad/sec
5	Supply voltage.	12V
6	Tip position resolution.	0.01mm
7	Capacity.	10*6=60N

3. Material Selection

The selection of material for a design is based on the goals of the project, which include strength, minimum weight, and cost. Various properties of the materials, such as stiffness, yield strength, and fatigue strength, are considered and given a weight or "multiplying factor" based on their importance to the design. A decision matrix is created by considering all of these factors and is used to determine the best material for the design.

Most commonly used materials are-

- Aluminium 7075 T6
- Stainless steel 1020
- Titanium alloy
- Grey cast iron

These materials are commonly used in the construction of robot hands with 6 degrees of freedom (DOF) due to their strength, durability, and resistance to wear and tear. Aluminium 7075 T6 is a strong and lightweight material that is often used in various applications. Stainless steel 1020 is also strong and durable, and offers good resistance to corrosion. Titanium alloy is known for its high strength-to-weight ratio and excellent corrosion resistance. Grey cast iron is a relatively inexpensive material that is known for its high compressive strength and good machinability.

Table 2 Materials Property

No	Properties	Al 7075 T6	SS 1020	Titanium alloy	Grey cast iron
1	Yield strength (Mpa)	480	430	940	120
2	Elastic modulus (GPa)	70	190	110	180
3	Fatigue strength (MPa)	160	69	48	510
4	Strength to weight ratio	160	57	16	213
5	Density (kg/m^3)	2700 kg/m3	7860 kg/m3	4540 kg/m3	6640 kg/m3

Table 3 A decision matrix to select the best material

No	Properties	Weightage (w)	Al 7075 T6 Score	SS 1020 Score	Titanium alloy Score	Grey cast iron Score
1	Strength to weight ratio	3	4	1	5	1
2	Fatigue Strength	3	2	1	5	1
3	Stiffness	4	2	5	3	5
4	Availability	2	3	4	-2	3
5	Cost	2	2	3	-3	3
		Sum	42	40	32	38

In this matrix, each material is evaluated based on its elastic modulus, yield strength, fatigue strength, density, and cost. Each property is given a multiplying factor according to its importance in the design. The final score for each material is calculated by multiplying the value of each property by its corresponding multiplying factor and summing the results. The material with the highest score is considered the best choice for the design.

4. Motor Selection

Determining the load capacity and required speed of the arm, as well as the power source available. Other factors to consider include the size and weight of the arm, the environment in which it will be used, and any specific application requirements. Once these factors have been considered, the appropriate type of motor can be selected, such as:

- DC motor
- Stepper motor
- Servo motor

The motor control system, such as a controller or driver, also needs to be selected and configured to ensure proper operation of the motor.

4.1. General Motor Selection

Table 4 General motor selection

Type of Motor	Advantages
DC motor	• Inexpensive and easy to control. • They can provide high torque at low speeds, but their speed and torque can vary depending on the load.
Stepper motor	• They can provide precise control of the arm's position. • They are driven by a series of electrical pulses, which cause the motor to rotate in small increments, or "steps."
Servo motor	• Rotate to a specific position, and can provide precise control of the arm's movement. • They are more expensive than DC and stepper motors but more precise and efficient.

In general DC motors are commonly used in a wide range of applications due to their simple design, high efficiency, and ability to be controlled easily. They can be found in everything from small household appliances to large industrial machines. Some of the reasons we choose a DC motor include:

- They can be easily controlled using simple control methods, such as varying the voltage or current to the motor.
- They are highly efficient, with efficiencies of up to 90% or more.
- They have a wide range of torque and speed capabilities.

- They are relatively low cost and easy to maintain.
- They are widely available and come in a variety of sizes and configurations to suit different applications.

4.2. Specific Motor Selection

Peak torque and maximum continuous torque are important factors in determining the suitable servo motors for a jointed-arm robot. The peak torque is the highest torque that a motor can produce for a short period of time, while the maximum continuous torque is the highest torque that a motor can produce for an extended period of time without overheating or causing damage. These values help to ensure that the motors chosen for the robot are capable of producing the necessary torque to move the joints and perform the desired tasks.

Table 5 Volume and mass of each part

No	Component	Volume	Mass (kg)
1	Forearm	2203174mm3= 2.20 x 10^-6 m^3	2700 kg/m3*2.20 x 10^-6 m^3 = 5.940 kg
2	Arm	1550382 mm3=1.55 x 10^-6 m^3	2700 kg/m3*1.55 x 10^-6 m^3 = 4.185 kg
3	Wrist links and gripper	240122mm3=2.40 x 10^-6 m^3	2700 kg/m3*2.4 x 10^-6 m^3 = 6.480 kg
4	shoulder	3491650mm3= 3.49x 10^-5 m^3	2700kg/m3*3.49 x 10^-5 m^3 = 9.4830 kg

$T = Fxr$

$W = mg$

$T1 = 110N * 0.8m = 88Nm$

$T2 = (6.480 \text{ kg} * 9.81)N * (0.8 - 0.046)m) = 47.93Nm$

$T3 = (4.185 \text{ kg} * 9.81)N * (0.8 - (0.046 * 2 + 0.15)m) = 22.908Nm$

$T4 = (5.940 \text{ kg} * 9.81)N * (0.8 - (0.046 * 2 + 0.15 * 2 + 0.143)m) = 14.272Nm$

$T5 = (9.483 * 9.81)N * (0.8 - (0.046 * 2 + 0.15 * 2 + 0.143 * 2)m) = 11.349Nm$

$T\_total = T1 + T2 + T3 + T4 + T5 = 48Nm + 47.93Nm + 22.908Nm + 14.272Nm + 11.349Nm = 184.449 \text{ Nm}$

$$P = T * w * \frac{1}{\eta}$$

$$P = 184.449Nm * \frac{0.3rad}{sec} * \frac{1}{0.5} = 110.6694\, Watt$$

The Maxon RE 40 Ø40 mm, Graphite Brushes, 150 Watt motor is chosen based on our power need. This motor is a high-performance brush DC motor that is well-suited for a wide range of applications. Some of the key advantages of this motor include its compact size, high power density, and high efficiency. Additionally, the use of graphite brushes allows for low wear and maintenance, and the 150 Watt power rating makes it suitable for many high-performance applications. Overall, the Maxon RE 40 motor is an excellent choice for a wide range of applications that require a high-performance, compact, and efficient brush DC motor.

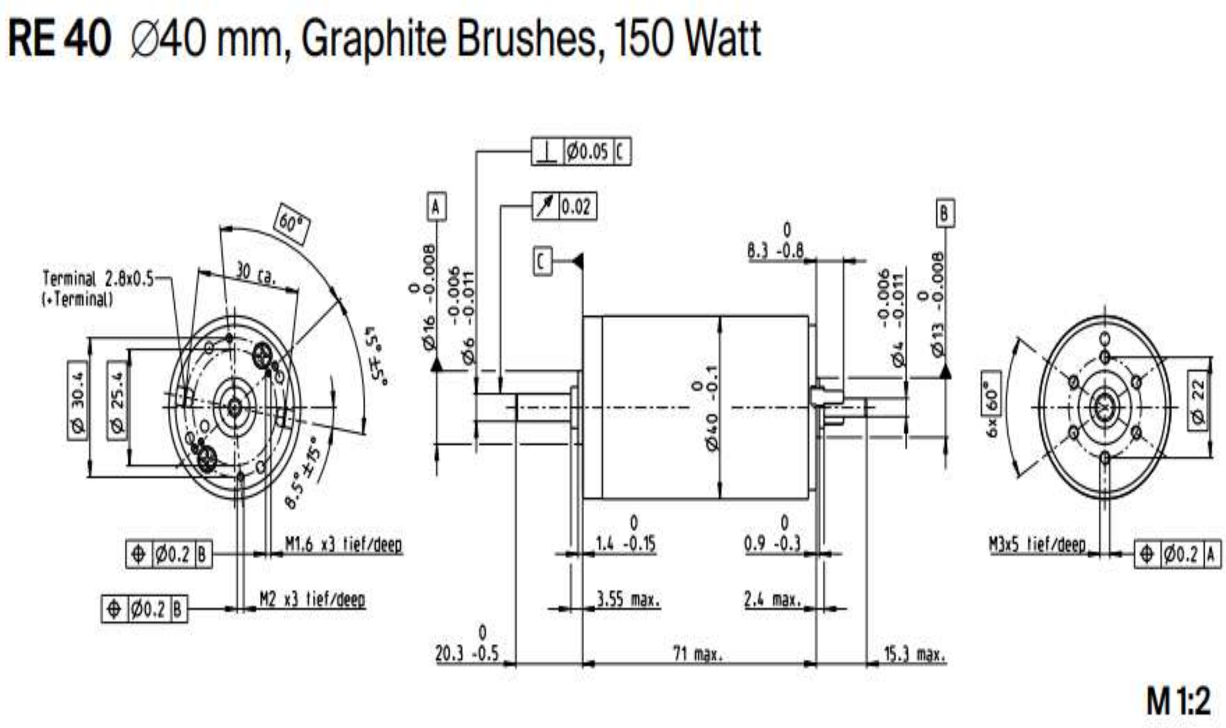


Figure 1 2 Dimensional drawing of the selected motor

Detailed information about the motor is stated in appendix 1

5. Design of Base

The design of the base of the robot described in the text appears to consist of three panels: a rotating base panel, a lower base panel, and an upper base panel. The rotating base panel is connected to a base motor and is able to rotate +/- 90 degrees from its mid position, providing a total of 180 degrees of rotation.

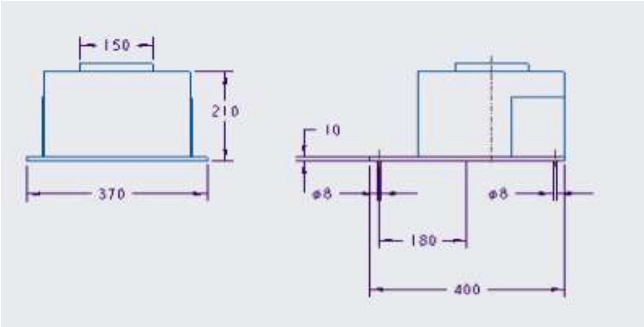


Figure 2 Base

6. Design of Arm

The design of the forearm and upper arm is focused on creating a lightweight and compact structure with a space-saving arrangement of motors. This design also has the advantage of having a low moment of inertia along the longitudinal axis of the forearm.

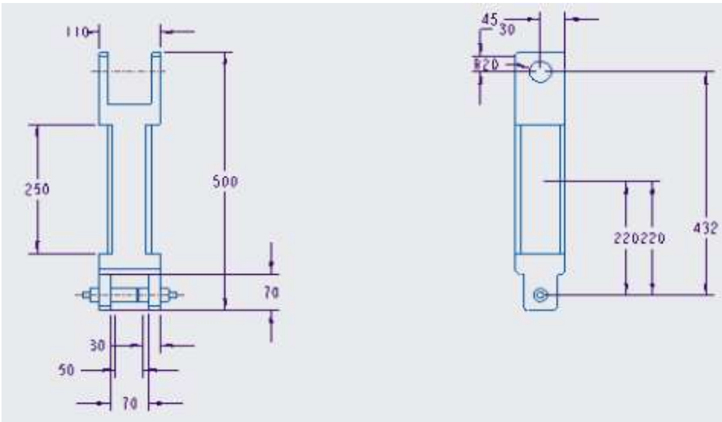


Figure 3 Lower Arm

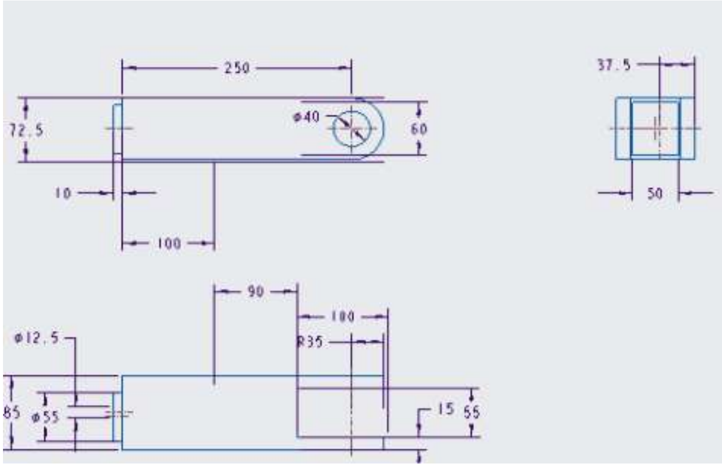


Figure 4 Upper Arm

7. Design of Gripper

The gripper consists of driven finger members. The wrist consists of 2 wrist links and a gripper motor plate. The design allows a space-saving and cheap construction.

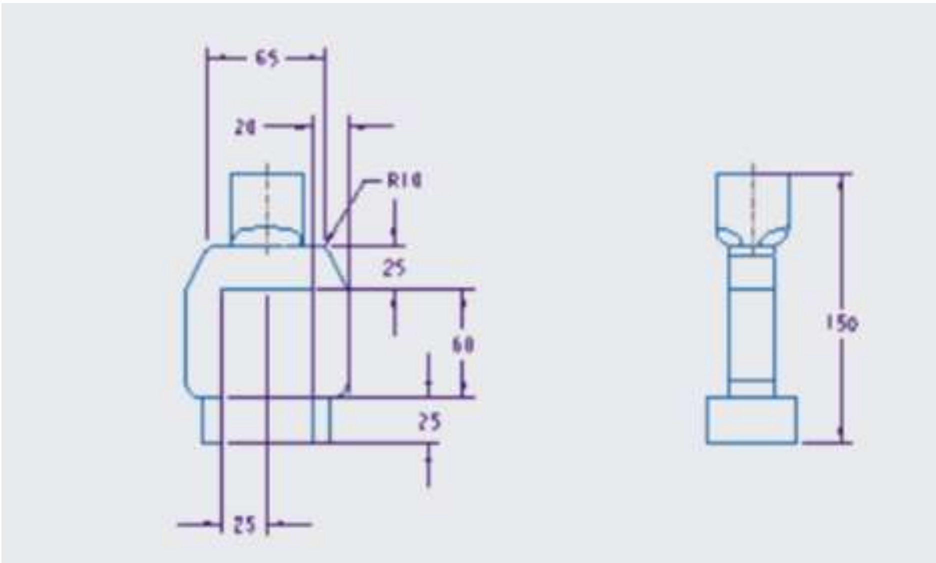


Figure 5 Gripper

8. Bearing Selection

We used a 'Design of Machine Elements by V.B Bhandari" to select the appropriate type of bearing. The maximum axial and radial forces acting on the joint should be determined using free body diagrams. From these forces, an appropriate type of bearing can be selected, in this case, deep groove ball bearings. An equivalent dynamic load can then be calculated from the axial and radial loads to help determine the appropriate size of the bearing.

When we select bearing we used the following Procedures:

1. We calculate the maximum radial and axial forces acting on the bearing and determine the diameter of the shaft where the bearing is to be fitted. The amount of axial force on each joint is zero. The total amount of radial force can be calculated by taking the sum of all loads which are acting in the vertical direction.

$$F_r = 60N + (6.480 \text{ kg} * 9.81)N + (4.185 \text{ kg} * 9.81)N + (5.940 \text{ kg} * 9.81)N + (9.483 * 9.81)N$$

$$F_r = 365.92328N$$

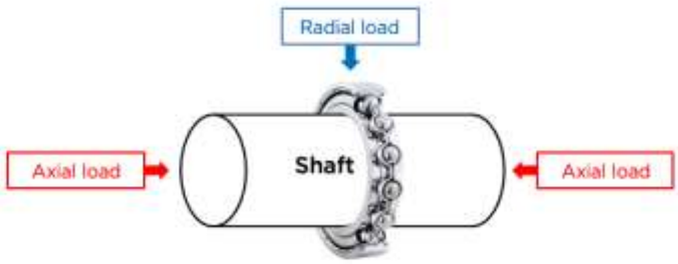


Figure 6 Forces acted on bearings

2. Determine the values of X and Y, the radial and thrust factors, from the catalogue. The values of X and Y factors for single-row deep groove ball bearings are given in Appendix 2.

$$P_e = S[XVF_r + YF_a]$$

$where \quad S = \text{Service factor/shock factor};$

$V = \text{Race rotation factor};$

$X = \text{Radial load factor};$

$Y = \text{Axial load factor};$

$\text{Fr} = \text{Radial load};$

$\text{Fa} = \text{Axial load}$

Since $F_a = 0, P_e = F_r = 315.92328N$

3. We made a decision about the expected bearing life and express the life L_{10} in million revolutions.

The information regarding the life expectancy is generally vague and values based on past experience are used. For all kinds of vehicles, the speed of rotation is not constant and the desired life is expressed in terms of millions of revolutions. The recommended bearing life for some of the applications is given in Table below.

Table 6 Recommended bearing life for some of the applications

Application	Bearing Life
(i) Machines used intermittently such as lifting tackle, hand tools and household appliances	4000–8000 h
(ii) Machines used for eight hours of service per day, such as electric motors and gear drives	12 000–20 000 h
(iii) Machines used for continuous operation (24 h per day) such as pumps, compressors and conveyors	40 000–60 000 h

Based on our application we chose a 20000h of bearing life.

The relationship between life in revolution and life in hour are related by:-

$$L_{10} = \frac{60nL_{10h}}{10^6}$$

Where n = speed of rotation in rpm

$L_{10h} =$ rated bearing life (hours)

From our motor selection n=12000 rpm

$$L_{10} = \frac{60 * 12000rpm * \quad 20000\text{h}}{10^6} = 14400 \ \ million\,rev$$

$$C = P(L_{10})^{\frac{1}{3}}$$

Where $C\ is\ loading\ factor$

$$C = 315.92328N * (14400)^{\frac{1}{3}} = 7686.036N$$

Bearing for Motors

Based on the above loading factor C and diameter of motor we chose single-row deep groove ball bearings No. 6300 from appendix 2.

- No. 601800 (C = 1480)
- No. 6000 (C = 4620N)
- No. 6200 (C = 5070N)
- No. 6300 (C = 8060N)

Bearing Between Link 1 and Link 2

Based on the above loading factor C and diameter of shaft between first link and second link we chose single-row deep groove ball bearings No. 6005 from appendix 2.

- No. 6005 (C = 11200N)
- No. 6205 (C = 14000N)
- No. 6305 (C = 22500N)
- No. 6405 (C = 35800N)

Bearing Between Link 2 and Link 3

Based on the above loading factor C and diameter of shaft between second link and third link we chose single-row deep groove ball bearings No. 6005 from appendix 2.

- No. 6005 (C = 11200N)
- No. 6205 (C = 14000N)
- No. 6305 (C = 22500N)
- No. 6405 (C = 35800N)

Bearing Between Link 4 and Link 5

Based on the above loading factor C and diameter of shaft between fourth link and fifth link we chose single-row deep groove ball bearings No. 6300 from appendix 2.

- No. 6005 (C = 11200N)
- No. 6205 (C = 14000N)
- No. 6305 (C = 22500N)
- No. 6405 (C = 35800N)

Bearing between Bases

Based on the above loading factor C and inner diameter of base between we chose single-row deep groove ball bearings No. 61815 from appendix 2.

- No. 61815 (C = 12500 N)
- No. 10615 (C = 28600 N)
- No. 6015 (C = 39700N)
- No. 6215 (C = 66300N)

9. Design of Pulleys

We will use aluminum pulleys because they are lightweight, durable, and have low friction. Additionally, they have a high strength-to-weight ratio, which makes them well-suited for use in our applications where weight is a critical factor, such as in robots that need to move quickly or are required to be portable. They also have good thermal conductivity and can be easily machined to precise dimensions, which makes them ideal for use in precision mechanisms.

Let’s assume our belt is operate at 1m/sec approximately.

Let’s determine the diameters of pulley.

Diameter of smaller pulley

$$d = \frac{60*1000*V}{\pi*n}$$

$$d = \frac{60*1000*1m/sec}{\pi*1200rpm} = 15mm$$

Diameter of bigger pulley

$$D = 2*d = 30mm$$

10. Selection of Belt

We select the Dunlop Rubber as a belt because these belts are known for their durability, strength, and resistance to wear and tear, which makes them well-suited for use in demanding environments. Additionally, Dunlop Rubber's belts are designed to be resistant to heat, oil, and chemicals, which makes them ideal for use in a variety of industrial settings. They also come in different sizes, teeth and materials that can fit different application. Furthermore, Dunlop Rubber offers a wide range of custom-made belts to meet specific customer requirements.

Conclusion

In conclusion, the robot hand project aimed to provide a solution for elderly individuals living in apartments to easily retrieve items without the need for them to physically move. Through the use of advanced robotics technology, the robot hand is able to navigate the apartment and retrieve requested items for the individual. This project has the potential to greatly improve the quality of life for elderly individuals and reduce the need for assistance from family or caregivers. Future work includes testing and refining the technology for optimal performance and usability.

Appendix 1

Stock program
Standard program
Special program (on request)

Part Numbers

Motor Data		148866	148867	148877	218008	218009	218010	218011	218012	218013	218014
Values at nominal voltage											
1 Nominal voltage	V	12	24	48	48	48	48	48	48	48	48
2 No load speed	rpm	6920	7580	7590	6420	5560	3330	2690	2130	1720	1420
3 No load current	mA	241	137	68.6	53.7	43.7	21.9	16.6	12.5	9.66	7.76
4 Nominal speed	rpm	6380	6940	7000	5810	4930	2710	2060	1510	1080	781
5 Nominal torque (max. continuous torque)	mNm	94.9	177	187	186	180	189	190	192	192	190
6 Nominal current (max. continuous current)	A	6	6	3.17	2.66	2.23	1.4	1.13	0.909	0.73	0.6
7 Stall torque	mNm	1720	2420	2560	2040	1620	1020	814	655	523	424
8 Stall current	A	105	80.2	42.4	28.6	19.7	7.43	4.79	3.06	1.97	1.32
9 Max. efficiency	%	88	91	92	91	91	89	89	88	86	85
Characteristics											
10 Terminal resistance	Ω	0.115	0.299	1.13	1.68	2.44	6.46	10	15.7	24.4	36.3
11 Terminal inductance	mH	0.024	0.082	0.33	0.46	0.613	1.7	2.62	4.14	6.41	9.32
12 Torque constant	mNm/A	16.4	30.2	60.3	71.3	82.2	137	170	214	266	321
13 Speed constant	rpm/V	581	317	158	134	116	69.7	56.2	44.7	35.9	29.8
14 Speed / torque gradient	rpm/mNm	4.05	3.14	2.97	3.16	3.45	3.29	3.31	3.27	3.29	3.37
15 Mechanical time constant	ms	5.89	4.67	4.28	4.2	4.19	4.16	4.15	4.15	4.15	4.16
16 Rotor inertia	gcm^2	139	142	137	127	116	121	120	121	120	118

Specifications

Thermal data

17 Thermal resistance housing-ambient	4.7 K/W
18 Thermal resistance winding-housing	1.9 K/W
19 Thermal time constant winding	41.5 s
20 Thermal time constant motor	809 s
21 Ambient temperature	-30...+100°C
22 Max. winding temperature	+155°C

Mechanical data (ball bearings)

23 Max. speed	12000 rpm
24 Axial play	0.05 - 0.15 mm
25 Radial play	0.025 mm
26 Max. axial load (dynamic)	5.6 N
27 Max. force for press fits (static)	110 N
(static, shaft supported)	1200 N
28 Max. radial load, 5 mm from flange	28 N

Other specifications

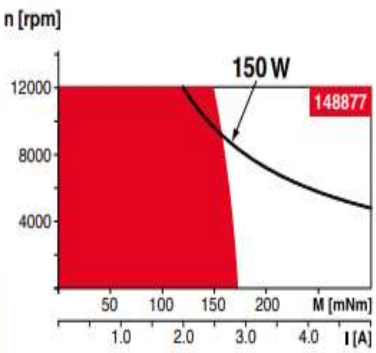
29 Number of pole pairs	1
30 Number of commutator segments	13
31 Weight of motor	480 g

Values listed in the table are nominal.
Explanation of the figures on page 72.

Option
Preloaded ball bearings

* Industrial version with radial shaft seal ring (resulting in increased no load current). IP54 protection only if mounted on brush side, in compliance with maxon modular system.

Operating Range



Comments

Continuous operation
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

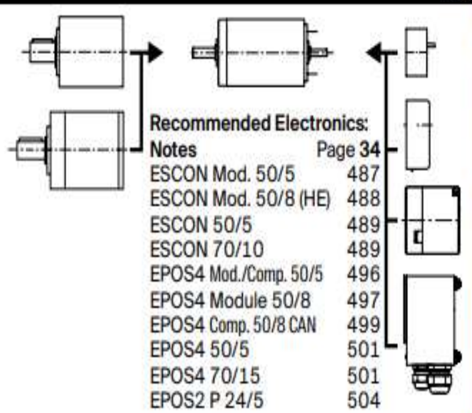
Short term operation
The motor may be briefly overloaded (recurring).

Assigned power rating

maxon Modular System Details on catalog page 34

Planetary Gearhead
Ø42 mm
3 - 15 Nm
Page 396

Planetary Gearhead
Ø52 mm
4 - 30 Nm
Page 401



Recommended Electronics:

Notes	Page 34
ESCON Mod. 50/5	487
ESCON Mod. 50/8 (HE)	488
ESCON 50/5	489
ESCON 70/10	489
EPOS4 Mod./Comp. 50/5	496
EPOS4 Module 50/8	497
EPOS4 Comp. 50/8 CAN	499
EPOS4 50/5	501
EPOS4 70/15	501
EPOS2 P 24/5	504

Encoder MR
256 - 1024 CPT,
3 channels
Page 464

Encoder HED_5540
500 CPT,
3 channels
Page 471/474

Brake AB 28
24 VDC
0.4 Nm
Page 519

Industrial Version IP54*
Encoder HEDL 9140
Page 478

Brake AB 28
Page 520

End cap
Page 525

Appendix 2

Principal dimensions (mm)			*Basic load ratings (N)*		*Designation*
d	*D*	*B*	*C*	C_0	
10	19	5	1480	630	61800
	26	8	4620	1960	6000
	30	9	5070	2240	6200
	35	11	8060	3750	6300

(*Contd*)

Table 15.5 (*Contd*)

Principal dimensions (mm)			*Basic load ratings (N)*		*Designation*
d	*D*	*B*	*C*	C_0	
12	21	5	1430	695	61801
	28	8	5070	2240	6001
	32	10	6890	3100	6201
	37	12	9750	4650	6301
15	24	5	1560	815	61802
	32	9	5590	2500	6002
	35	11	7800	3550	6202
	42	13	11400	5400	6302
17	26	5	1680	930	61803
	35	10	6050	2800	6003
	40	12	9560	4500	6202
	47	14	13500	6550	6303
	62	17	22900	11800	6403
20	32	7	2700	1500	61804
	42	8	7020	3400	16404
	42	12	9360	4500	6004
	47	14	12700	6200	6204
	52	15	15900	7800	6304
	72	19	30700	16600	6404
25	37	7	3120	1960	61805
	47	8	7610	4000	16005
	47	12	11200	5600	6005
	52	15	14000	6950	6205
	62	17	22500	11400	6305
	80	21	35800	19600	6405
30	42	7	3120	2080	61806
	55	9	11200	5850	16006
	55	13	13300	6800	6006
	62	16	19500	10000	6206
	72	19	28100	14600	6306
	90	23	43600	24000	6406
35	47	7	4030	3000	61807
	62	9	12400	6950	16007
	62	14	15900	8500	6007
	72	17	25500	13700	6207
	80	21	33200	18000	6307
	100	25	55300	31000	6407

(*Contd*)

Table 15.5 (*Contd*)

Principal dimensions (mm)			*Basic load ratings (N)*		*Designation*
d	*D*	*B*	*C*	C_0	
40	52	7	4160	3350	61808
	68	9	13300	7800	16008
	68	15	16800	9300	6008
	80	18	30700	16600	6208
	90	23	41000	22400	6308
	110	27	63700	36500	6408
45	58	7	6050	3800	61809
	75	10	15600	9300	16009
	75	16	21200	12200	6009
	85	19	33200	18600	6209
	100	25	52700	30000	6309
	120	29	76100	45500	6409
50	65	7	6240	4250	61810
	80	10	16300	10000	16010
	80	16	21600	13200	6010
	90	20	35100	19600	6210
	110	27	61800	36000	6310
	130	31	87100	52000	6410
55	72	9	8320	5600	61811
	90	11	19500	12200	16011
	90	18	28100	17000	6011
	100	21	43600	25000	6211
	120	29	71500	41500	6311
	140	33	99500	63000	6411
60	78	10	8710	6100	61812
	95	11	19900	13200	16012
	95	18	29600	18300	6012
	110	22	47500	28000	6212
	130	31	81900	48000	6312
	150	35	108000	69500	6412
65	85	10	11700	8300	61813
	100	11	21200	14600	16013
	100	18	30700	19600	6013
	120	23	55900	34000	6213
	140	33	92300	56000	6313
	160	37	119000	78000	6413

(*Contd*)

Table 15.5 (*Contd*)

Principal dimensions (mm)			Basic load ratings (N)		Designation
d	*D*	*B*	*C*	C_0	
70	90	10	12100	9150	61814
	110	13	28100	19000	16014
	110	20	37700	24500	6014
	125	24	61800	37500	6214
	150	35	104000	63000	6314
	180	42	143000	104000	6414
75	95	10	12500	9800	61815
	115	13	28600	20000	10615
	115	20	39700	26000	6015
	130	25	66300	40500	6215
	160	37	112000	72000	6315
	190	45	153000	114000	6415