Motor selection practice session

Introduction

A servomotor is a rotational or translational electric actuator that allows precise control of kinematics (position, speed and acceleration). It is coupled to some position probe or sensor in order to obtain accurate information for position feedback. Essentially, it can be said that are close-loop motors from factory.

In this sense, servomotors result into a really attractive option for such industrial applications where the motion control is a relevant point.

It is possible to classify servomotors by three main categories or groups:

- *Positional Rotational*. This kind of servos rotate only 180 degrees. They include mechanical stop mechanisms to protect the shaft from over-rotation. Their aim is positioning.
- *Continuous Rotation*. This kind of servos does no have the limit on its operation range, as does the positional rotational group. They are mainly preferred to operate under speed inputs.
- *Linear*. Are basically one of the previous two groups but includes internally a rack and pinion mechanism. This internal rotary to linear coupling mechanism allows to understand these servomotors as translational devices.

The type of motor that is used under the "servomotor" term umbrella is not clearly defined. Servomotors are commonly sub-classified into brush or brushless servomotors

- Brushed servomotors. They are typically permanent magnet DC motors. Used for small power applications.
- Brushless servomotors. There typically two options; (i) permanent magnet AC motors (Brushless DC -BDLC- or permanent magnet synchronous machines -PMSM), (ii) induction AC motors. Induction servomotors are used for medium or high-power applications whereas BDLC or PMSM servomotors are more though on power density performance.

A servomotor is supplied by a drive that serves to apply torque/force to a mechanical axis. The drive module that pairs a servomotor is usually based on a H-bridge or three-phase inverter based on MOSFETS (*metal–oxide–semiconductor field-effect transistor*) or IGBTs (*insulated-gate bipolar transistor*) switching devices for single or three phase applications, respectively. In the particular case of induction servomotors, these drives are called in industry as variable frequency drives.

The aim of this session is to understand how an axis, composed by several mechanical elements, affects to the kinematic and dynamic specifications of the motor. Thus, this understanding can provide of a methodology to determine if a servomotor is valid or not.

Firstly, the start point is to replicate the theory class example but considering another servomotor and other inputs for the mechanical components. Secondly, a rotational to translational mechatronics applications is defined.

Both axis and motor analysis are recommended to be conducted by using excel as a calculation sheet. Other resolution options can be using Matlab/Simulink.

Exercise 1.- Rotation basic example

One of the most basic axes for an industrial application is to use a continuous rotation servomotor to follow a specific speed profile.

In this case, the axis configuration considers to include a DC brushed servomotor, a gear reducer, and a cylinder load. The profile is connected downstream the last mechanical component. The full axis can be seen in Figure 1.

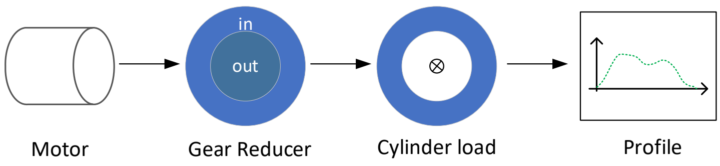

Figure 1 Axis configuration for gear reducer exercise

The following information gathers the specifications of all the participating elements, even considering the profile.

The servomotor

Use model R88M-KH1K520(F/C)-E from Omron G5 High inertia family. Figure 2 to Figure 4 show the main specification for the specific servomotor and other ones from the same family.

Assume a thermal constant of 40 s. Also consider: ke= 0.54 V·s/rad, R= 0.88 Ω and L= 9.2 mH and number of poles 10.

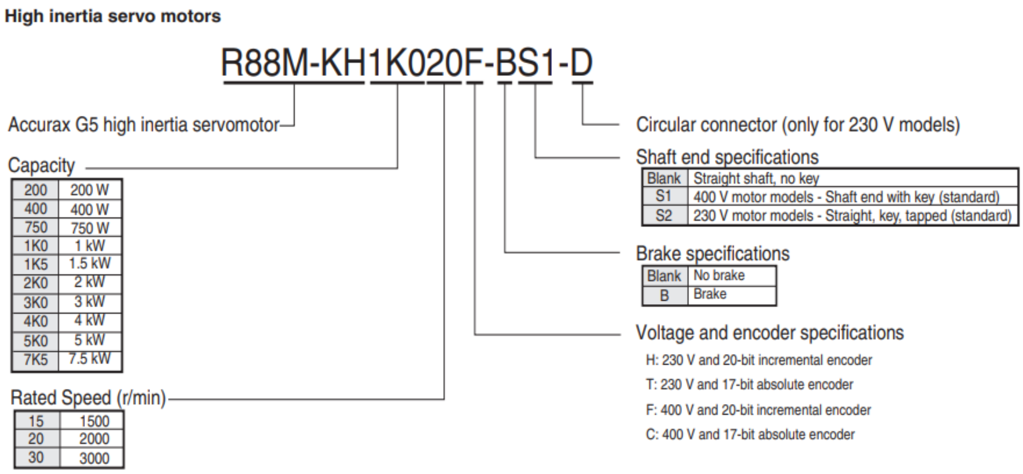

Figure 2 Servomotor designation for Omron G5 High inertia family

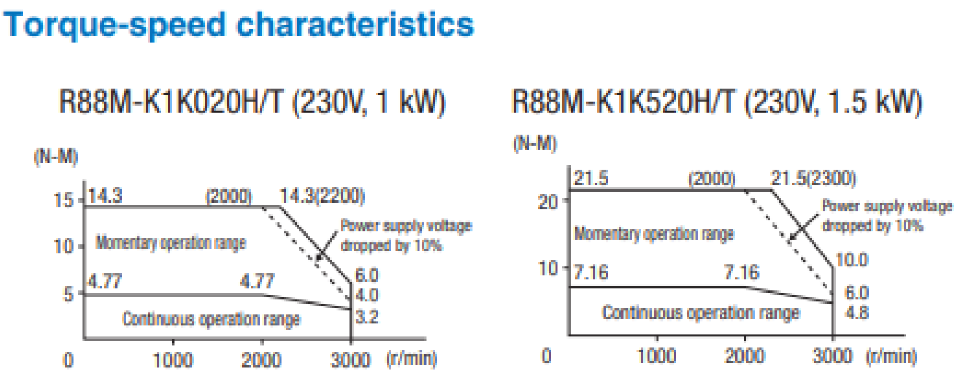

Figure 3 Servomotor torque-speed characteristics for Omron G5 High inertia family

Standard servo motors 2000 r/min, 230 V/400 V

Ratings and specifications

Voltage		230 V		400 V							
Servo motor model R88M-K□	20-bit incremental encoder	1K020H-□	1K520H-□	40020F-□	60020F-□	1K020F-□	1K520F-□	2K020F-□	3K020F-□	4K020F-□	5K020F-□
	17-bit absolute encoder	1K020T-□	1K520T-□	40020C-□	60020C-□	1K020C-□	1K520C-□	2K020C-□	3K020C-□	4K020C-□	5K020C-□
Rated output	W	1000	1500	400	600	1000	1500	2000	3000	4000	5000
Rated torque	N·m	4.77	7.16	1.91	2.86	4.77	7.16	9.55	14.3	19.1	23.9
Instantaneous peak torque	N·m	14.3	21.5	5.73	8.59	14.3	21.5	28.7	43	57.3	71.6
Rated current	A (rms)	5.7	9.4	1.2	1.5	2.8	4.7	5.9	8.7	10.6	13
Instantaneous max. current	A (rms)	24	40	4.9	6.5	12	20	25	37	45	55
Rated speed	min^{-1}	2000									
Max. speed	min^{-1}	3000									
Torque constant	N·m/A	0.63	0.58	1.27	1.38	1.27	1.16	1.27	1.18	1.40	1.46
Rotor moment of inertia (JM)	$kg \cdot m^2 \times 10^{-4}$ (without brake)	4.60	6.70	1.61	2.03	4.60	6.70	8.72	12.9	37.6	48
	$kg \cdot m^2 \times 10^{-4}$ (with brake)	5.90	7.99	1.90	2.35	5.90	7.99	10	14.2	38.6	48.8
Max. load moment of inertia (JL)	Multiple of (JM)	10 *1									
Rated power rate	kW/s (without brake)	49.5	76.5	22.7	40.3	49.5	76.5	105	159	97.1	119
	kW/s (with brake)	38.6	64.2	19.2	34.8	38.6	64.2	91.2	144	94.5	117
Allowable radial load	N	490							784		
Allowable thrust load	N	196							343		
Approx. mass	kg (without brake)	5.2	6.7	3.1	3.5	5.2	6.7	8	11	15.5	18.6
	kg (with brake)	6.7	8.2	4.1	4.5	6.7	8.2	9.5	12.6	18.7	21.8
Brake specifications: Rated voltage		24VDC ±10%									
Brake specifications: Holding brake moment inertia	(J) $kg \cdot m^2 \times 10^{-4}$	1.35								4.7	
Brake specifications: Power consumption (20°C)	W	14	19	17		14	19		22	31	
Brake specifications: Current consumption (20°C)	A	0.59±10%	0.79±10%	0.70 ±10%		0.59±10%	0.79 ±10%		0.90±10%	1.3±10%	1.3 ±-10%
Brake specifications: Static friction torque	N.m (minimum)	4.9	13.7	2.5		4.9	13.7		16.2	24.5	
Brake specifications: Rise time for holding torque	ms (max.)	80	100	50		80	100		110	80	
Brake specifications: Release time	ms (max)	70	50	15		70	50			25	
Basic specifications: Time Rating		Continuous									
Basic specifications: Insulation class		Type F									
Basic specifications: Ambient operating/ storage temperature		0 to +40°C/–20 to 65°C									
Basic specifications: Ambient operating/ storage humidity		20% to 85% (non-condensing)									
Basic specifications: Vibration class		V-15									
Basic specifications: Insulation resistance		20 MΩ min. at 500 VDC between the power terminals and FG terminal									
Basic specifications: Enclosure		Totally-enclosed, self-cooling, IP67 (excluding shaft opening)									
Basic specifications: Vibration resistance		Vibration acceleration 49 m/s²									
Basic specifications: Mounting		Flange-mounted									

*1. Applicable load inertia: The operable load inertia ratio (load inertia/rotor inertia) depends on the mechanical configuration and its rigidity. For a machine with high rigidity, operation is possible even with high load inertia. Select an appropriate motor and confirm that operation is possible.

Figure 4 Servomotor rates and specifications for Omron G5 High inertia family

The gear reducer

Use model PLF090 Series Standard & High Precision Planetary Gear Reducers from ZionKaifull Automation. In this case, choose a gear reducer that provides a reduction ratio of 3.

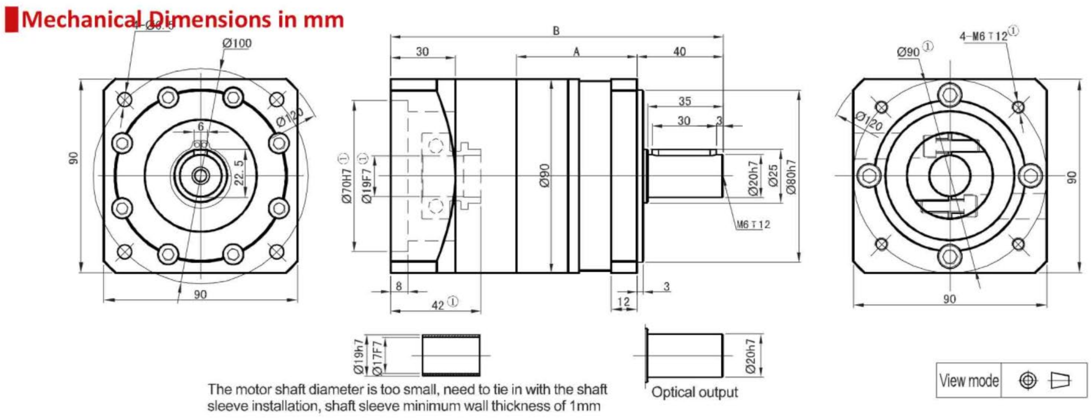

Figure 5 Gear reducer mechanical dimensions

Technical Specifications

Stage	Stage 1 (Contains the speed ratio 3 4 5 7 10)		Stage 2 (Contains the speed ratio 12 16 20 25 28 35 40 50 70 100)		Stage 3 (Contains the speed ratio 80 100 125 140 175 200 250 350 400 500 700 1000)	
	A	B	A	B	A	B
Length(mm)	56. 0	154. 5	80. 0	178. 5	104. 0	202. 5
Rated input speed(rpm)	3500		3500		3500	
Maximum input speed(rpm)	6000		6000		6000	
The maximum radial force(N)②	1020		1270		1420	
The maximum axial force(N)②	850		1100		1250	
No load torque(Nm)	About 0. 8		About 0. 4		About 0. 4	
Efficiency withfull load(%)	96		94		90	
Back lash(arcmin)	Precision: <3	Standard: <8	Precision: <5	Standard: <10	Precision: <8	Standard: <12
Noise(dB)	≤62		≤62		≤62	
Weight(Kg)	2. 8		3. 4		4. 0	
Average lifetime(h)	>20000					
Torsional rigidity(Nm/arcmin)	7. 5					
lubricant	Effective lubrication					
direction of rotation	The input and output to the same					
Protection level	IP65					
Installation	arbitrarily					

Ratio(i)	3	4	5	7	10	12	16	20	25	28	35	40	50	70
Rated output torque(Nm)	60. 0	86. 0	94. 5	64. 0	39. 5	96. 0	96. 0	96. 0	105. 5	96. 0	105. 5	96. 0	105. 5	71. 5
maximum output torque(Nm)	120. 0	172. 0	189. 0	128. 0	79. 0	192. 0	192. 0	192. 0	211. 0	192. 0	211. 0	192. 0	211. 0	143. 0
Moment of inertia(Kgcm^2)	0. 4	0. 309	0. 291	0. 285	0. 283	0. 4	0. 309	0. 291	0. 291	0. 285	0. 285	0. 283	0. 283	0. 283

Figure 6 Gear reducer technical specifications

Cylinder load

For this component is complicated to find a datasheet that describes technically it. In this case, simply assume an inertia of 0.03 [kg·m^2] and a constant torque friction of 0.25 [Nm].

The profile

A symmetrical trapezoidal profile in speed is desired. The profile is defined by

1. Increment of position: 20 [rad]
2. Time to position: 0.5 [s]
3. Dwell time: 5 [s]
4. External torque: 0 [N·m]

Results

Fill and draw according to next. All in units of the international system. In case of absence of information assume null value for that data except for efficiencies that are 100%.

1. Draw the profile kinematics.
2. Considering non-safety margin and a safety margin of 15%, fill the next table seen from the motor perspective

		Ratios [%]			
		Without safety margin		With safety margin	
		[%]	[ad]	[%]	[ad]
Motor max speed [rad/s]			--		--
Motor effective speed [rad/s]			--		--
Motor max torque [N·m]			--		--
Motor effective torque [N·m]			--		--
Motor inertia capability [ad]		--		--	

3. Draw the kinematics (position, speed and acceleration) and dynamics (torque and power) that finally requires the servomotor.
4. Draw the overload level achieved if the motion profile pattern is repeated in cycles of 600 s and then 15 mins of dwell time.
5. Assuming that the servomotor allows the possibility to brake by a short-circuit in its terminals. Draw the evolution of position and speed until the movement is totally in rest. The initial speed is the critical one, i.e., use the maximum values obtained in question 1. Do it for:
    a. No other impedance than the own motor.
    b. Assuming an extra resistance of 60 Ω per phase.
6. Provide a final judgment for the goodness of use of the servomotor proposed from results obtained in sections 1 to 5.

Exercise 2.- Pinion Rack application

In this exercise, the axis configuration looks to obtain a final sway translation movement following a trapezoidal speed profile. In this situation the axis includes a DC brushed servomotor, a gear reducer, a pinion rack and linear mass. The profile is connected downstream the last mechanical component. The full axis can be seen in Figure 7.

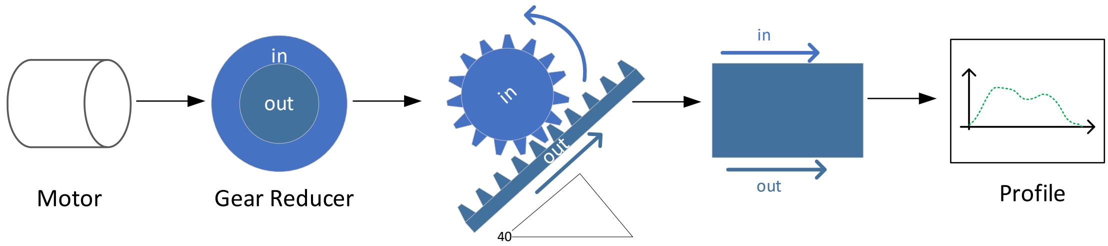

Figure 7 Axis configuration for pinion rack exercise

The servomotor

Use model R88M-K6K010C from Omron G5 family. Figure 8 to Figure 10 show the main specification for the specific servomotor and other ones from the same family.

Assume a thermal constant of 30 s.

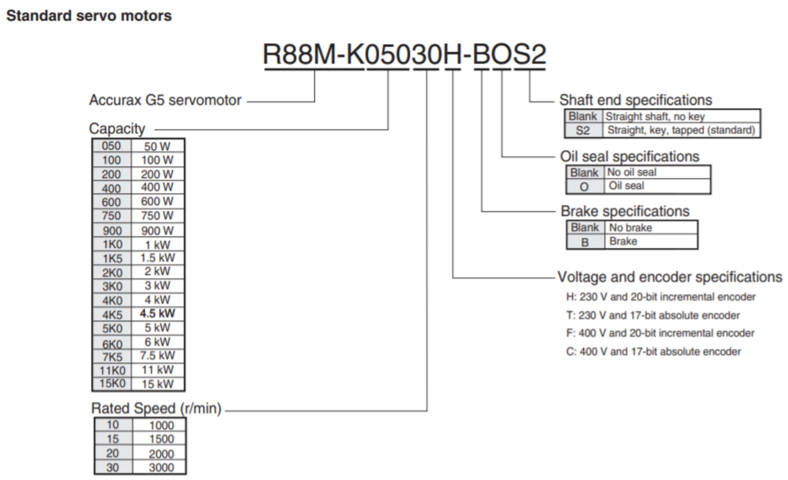

Figure 8 Servomotor designation for Omron G5 family

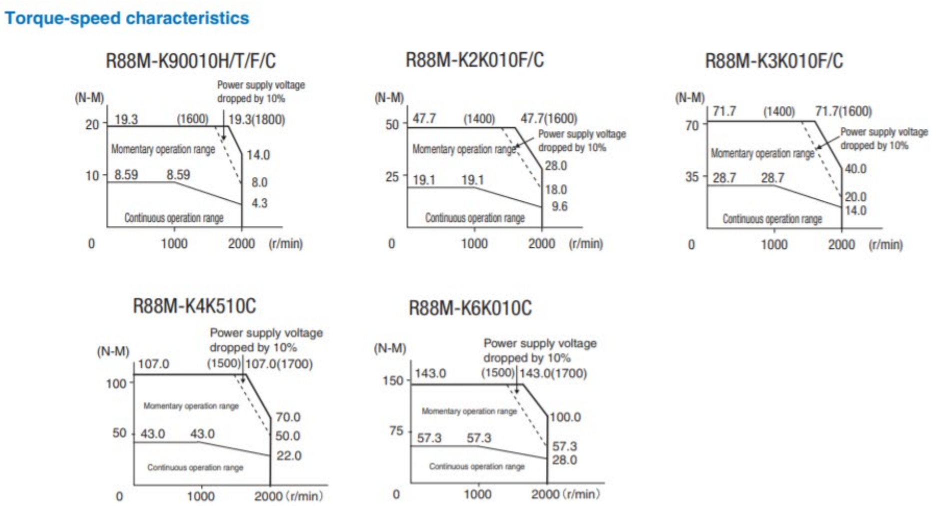

Figure 9 Servomotor torque-speed characteristics for Omron G5 family

Standard servo motors 1000 r/min, 230 V/400 V

Ratings and specifications

	Applied voltage		230 V	400 V				
	Servo motor model R88M-K□	20-bit incremental encoder	90010H-□	90010F-□	2K010F-□	3K010F-□		
		17-bit absolute encoder	90010T-□	90010C-□	2K010C-□	3K010C-□	4K510C-□	6K010C-□
	Rated output	W	900	900	2000	3000	4500	6000
	Rated torque	N·m	8.59		19.1	28.7	43.0	57.3
	Instantaneous peak torque	N·m	19.3		47.7	71.7	107.0	143.0
	Rated current	A (rms)	7.6	3.8	8.5	11.3	14.8	19.4
	Instantaneous max. current	A (rms)	24	12	30	40	55	74
	Rated speed	min^{-1}	1000					
	Max. speed	min^{-1}	2000					
	Torque constant	N·m/A	0.86	1.72	1.76	1.92	2.05	2.08
	Rotor moment of inertia (JM)	$kg\cdot m^2 \times 10^{-4}$ (without brake)	6.70		30.3	48.4	79.1	101
		$kg\cdot m^2 \times 10^{-4}$ (with brake)	7.99		31.4	49.2	84.4	107
	Allowable load moment of inertia (JL)	Multiple of (JM)	10 [*1]					
	Rated power rate	kW/s (without brake)	110		120	170	233	325
		kW/s (with brake)	92.4		116	167	219	307
	Allowable radial load	N	686		1176	1470		1764
	Allowable thrust load	N	196		490			588
	Approx. mass	kg (without brake)	6.7		14	20	29.4	36.4
		kg (with brake)	8.2		17.5	23.5	33.3	40.4
Brake specifications	Rated voltage		24VDC ±10%					
	Holding brake moment of inertia J	$kg\cdot m^2 \times 10^{-4}$	1.35		4.7			
	Power consumption (at 20°C)	W	19		31	34		
	Current consumption (at 20°C)	A	0.79±10%		1.3±10%	1.4±10%		
	Static friction torque	N·m (minimum)	13.7		24.5	58.8		
	Rise time for holding torque	ms (max.)	100		80	150		
	Release time	ms (max)	50		25	50		
Basic specifications	Time Rating		Continuous					
	Insulation class		Type F					
	Ambient operating/ storage temperature		0 to +40°C/–20 to 65°C					
	Ambient operating/ storage humidity		20% to 85% RH (non-condensing)					
	Vibration class		V-15					
	Insulation resistance		20 MΩ min. at 500 VDC between the power terminals and FG terminal					
	Enclosure		Totally-enclosed, self-cooling, IP67 (excluding shaft opening)					
	Vibration resistance		Vibration acceleration 49 m/s^2					
	Mounting		Flange-mounted					

[*1] Applicable load inertia: The operable load inertia ratio (load inertia/rotor inertia) depends on the mechanical configuration and its rigidity. For a machine with high rigidity, operation is possible even with high load inertia. Select an appropriate motor and confirm that operation is possible.

Figure 10 Servomotor rates and specifications for Omron G5 family

Gear Reducer

The gear reducer mechanism inputs are summarised in Table 1.

Input item set-up	
Load revolution [ad]	10
Motor revolutions [ad]	30
Efficiency [%]	95
Friction Torque [N·m]	0
Inertia [kg·m^2]	0.012

Table 1 Gear reducer inputs

Pinion Rack

The pinion rack mechanism inputs are summarised in Table 2.

Input item set-up	
Pinion diameter [mm]	150
Pinion length [mm]	10
Inclination [deg]	+40
Rack mass [kg]	7,5
Efficiency [%]	90
Inertia [kg·m^2]	0.075
Material	Steel

Table 2 Pinion rack inputs

Mass

The mass to move is 100 kg.

The profile

The speed profile is constituted by two segments. Initial speed is null.

Segment 1: A symmetrical trapezoidal profile in speed as follows:

1. Increment of position: 50 [mm]
2. Time to position: 0.1 [s]
3. Dwell time: 0.2 [s]
4. External torque: 0 [N·m]

Segment 2: A symmetrical trapezoidal profile in speed as follows:

1. Increment of position: -200 [mm]
2. Time to position: 0.25 [s]
3. Dwell time: 0.1 [s]
4. External torque: 0 [N·m]

Results

Fill and draw according to next. All in units of the international system. In case of absence of information assume null value for that data except for efficiencies that are 100%.

1. Draw the profile kinematics.
2. Considering non-safety margin and a safety margin of 20%, fill the next table seen from the motor perspective

	Without safety margin		**With safety margin**	
	Without motor	**With motor**	**Without motor**	**With motor**
Max Speed [rad/s]				
Effective Speed [rad/s]				
Max Torque [N·m]				
Effective Torque [N·m]				
Inertia [kg·m^2]				

		Ratios [%]			
		Without safety margin		**With safety margin**	
		[%]	[ad]	[%]	[ad]
Motor max speed [rad/s]			--		--
Motor effective speed [rad/s]			--		--
Motor max torque [N·m]			--		--
Motor effective torque [N·m]			--		--
Motor inertia capability [ad]		--		--	

3. Draw the kinematics (position, speed and acceleration) and dynamics (torque and power) that finally requires the servomotor.
4. Provide a final judgment for the goodness of use of the servomotor proposed from results obtained in sections 1 to 5.
5. Compute the braking time and braking distance and draw how the position evolves. Consider:

a. The motor is braked by an external relay that allows to short-circuit the motor.
b. The maximum speed achieved during the proposed profile.
c. Motor parameters: $k_e = 0.9854$ V·s/rad, $R = 0.16$ Ω and $L = 3.2$ mH and number of pairs of poles 5.