

Actuators

Mechatronics applications

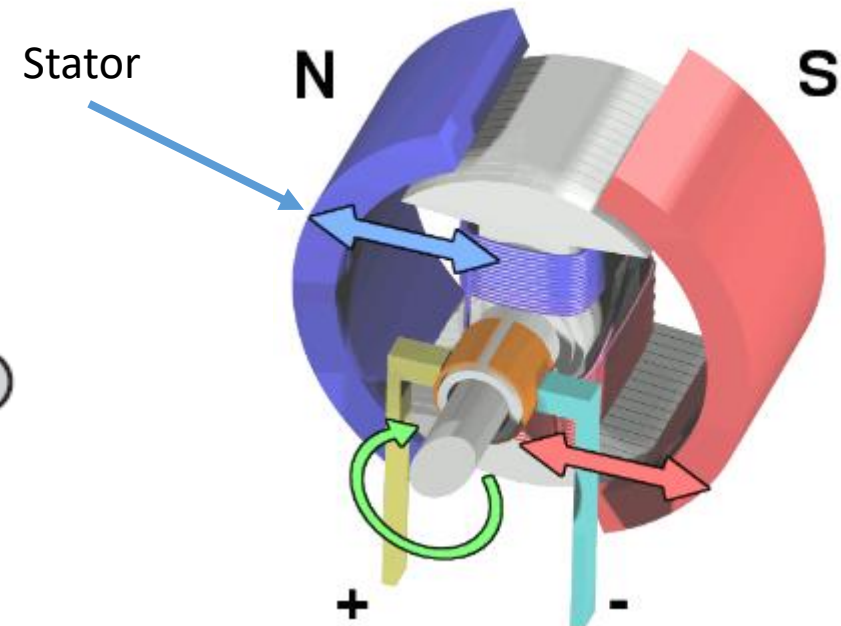
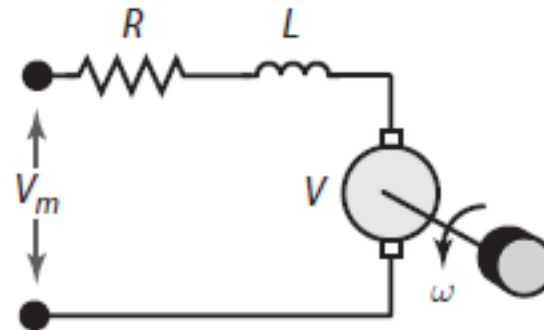
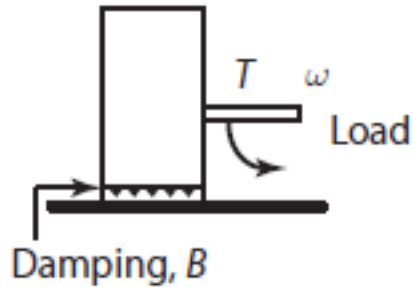
Dr. Mohammad Hayajneh

Motors

- Electric motor is used to actuate “move” something (e.g. wheels, legs, tracks, arms, fingers, sensor turrets).
- There are dozens of types of electric motors, but for robotics or mechatronics applications, the choice comes down to main three types:
 - *Continuous Direct Current (DC) motor.*
 - *Stepping motor.*
 - *Servo motor.*

DC motors

- DC motors are simplest and cheapest motors available for projects and are made of the minimum parts needed for a motor to function which are the **stator** and **rotor**.



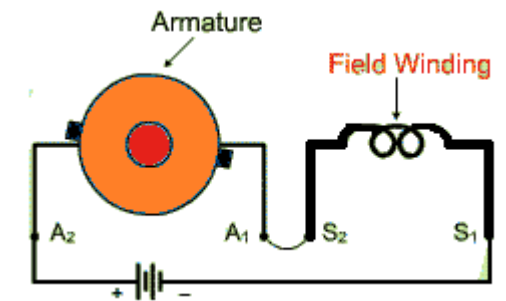
Types of DC motor

- Permanent Magnet DC motor:
 - Small size motor for small-sized applications.
 - The armature is placed inside the magnetic field of permanent magnet.
 - Applications: automobiles starter, toys, wipers, washers, hot blowers, air conditioners, computer disc drives.
- Separately excited DC motor
 - Has field coils and armature coils.
 - Separate supply is provided for excitation of both field coil and armature coil.
 - Weakening of field causes increase in speed of the motor.
 - Applications: trains and automatic traction purposes.



Types of DC motor

- DC series wound motors
 - Used as starter motor for most industrial applications dealing in heavy mechanical load like huge cranes or large metal chunks.



- Shunt wound DC motor. *Read more about this type*
- Compound DC motor. *Read more about this type*

DC Motor model

- The behavior of DC motors can be explained by two fundamental equations.

- Torque equation: $T = K_t i$
- Voltage equation: $V = K_e \dot{\theta}$

T = motor torque in N-m (newton-meters)

V = induced voltage in V (volts)

i = current in the armature circuit in A (amperes)

θ = rotational displacement of the motor shaft in rad (radians)

k_t = torque constant in Nm/A

k_e = voltage constant in V/(rad/sec)

$$V_m = R_a i + L_a \frac{di}{dt} + V$$

V_m = voltage at the armature terminal in volts (V)

R_a = armature resistance in ohms (Ω)

L_a = armature inductance in henry (H)

i = armature current in ampere (A)

- The DC motor drives a mechanical load which consists of dynamic and static components

$$T = J\ddot{\theta} + B\dot{\theta} + T_L$$

J = the moment of inertia of the rotor

B = the viscous damping coefficient

T_L represents the load on the motor

- The behavior of DC motors can be explained by two fundamental equations.
 - Torque equation: $T = K_t i$
 - Voltage equation: $V = K_e \dot{\theta}$

Relationship between the voltage applied to the motor and the rotational displacement of the motor shaft

- The total torque on the motor is given by the following relation: The shaft of the motor is connected directly to the centre of the pulley A

$$T_l - Fr = J_P \ddot{\theta} \quad \text{---- (1)}$$

- The force F is derived by the dynamic in the mass m as follow:

$$F - mg = m\ddot{y} \quad \text{----- (2)}$$

- We substitute the value of F in eq. 2, this yields

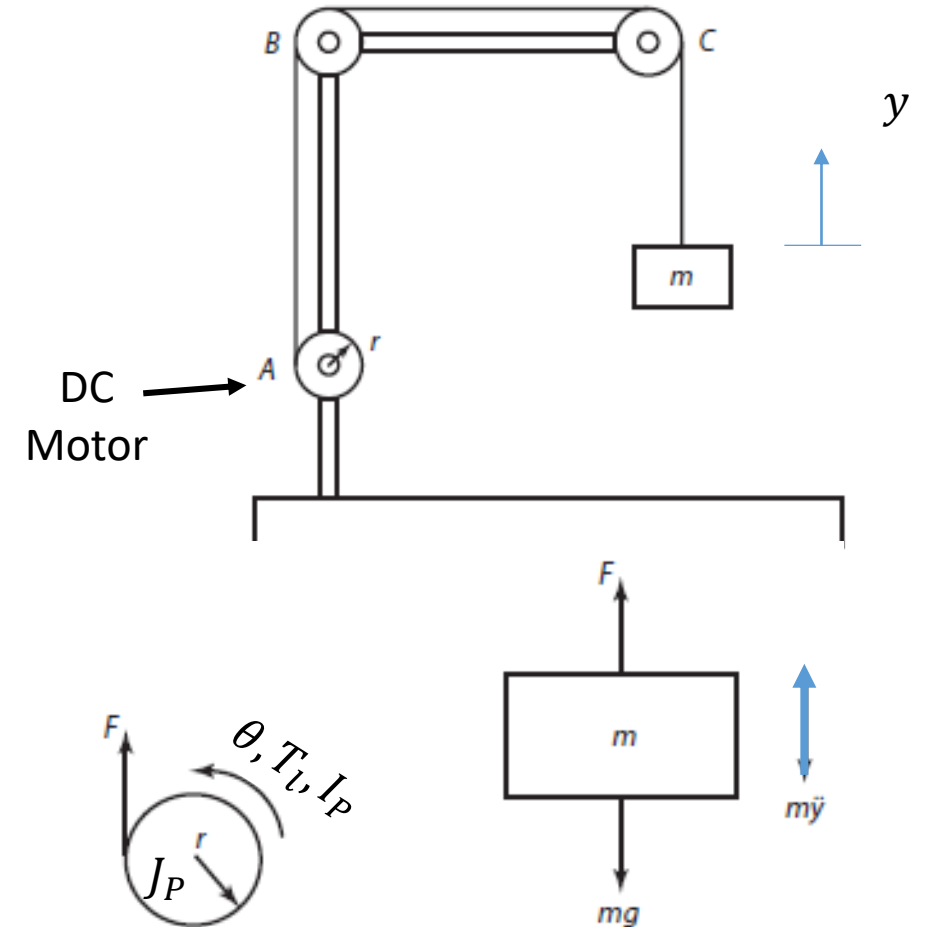
$$T_l = J_P \ddot{\theta} + mr\ddot{y} + mrg \quad \text{---- (3)}$$

- The relationship between the linear position y and the angular one θ is given by:

$$y = r\theta \Rightarrow \dot{y} = r\dot{\theta} \Rightarrow \ddot{y} = r\ddot{\theta}$$

Then substitute the value of \ddot{y} in eq.3 yields:

$$T_l = J_P \ddot{\theta} + mr^2 \ddot{\theta} + mrg = (J_P + mr^2) \ddot{\theta} + mrg$$



Relationship between the voltage applied to the motor and the rotational displacement of the motor shaft

- Then the desired torque from the motor is given by:

$$T_m = J\ddot{\theta} + B\dot{\theta} + T_l$$

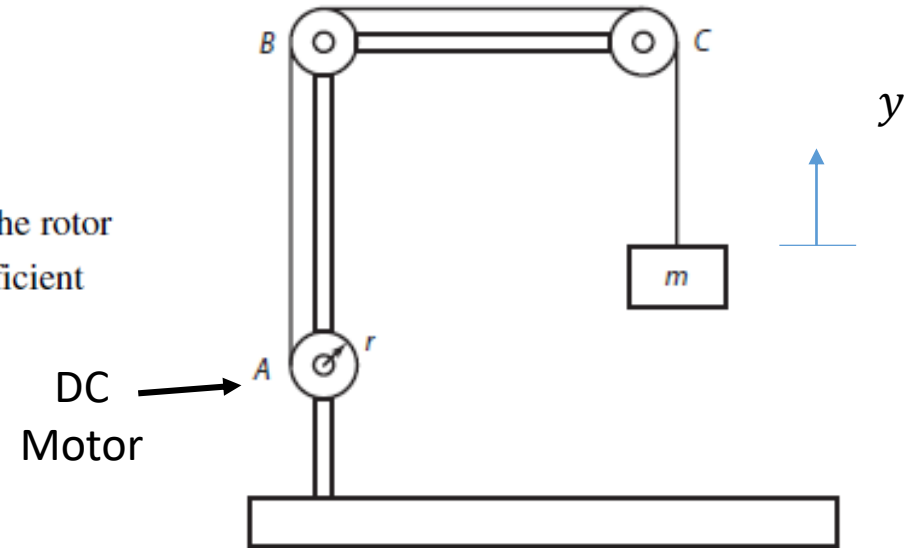
Or $T_m = (J + J_P + mr^2)\ddot{\theta} + B\dot{\theta} + mgr$

J = the moment of inertia of the rotor

B = the viscous damping coefficient

- The torque equation $T_m = K_t i$ connect between the motor torque and the current i

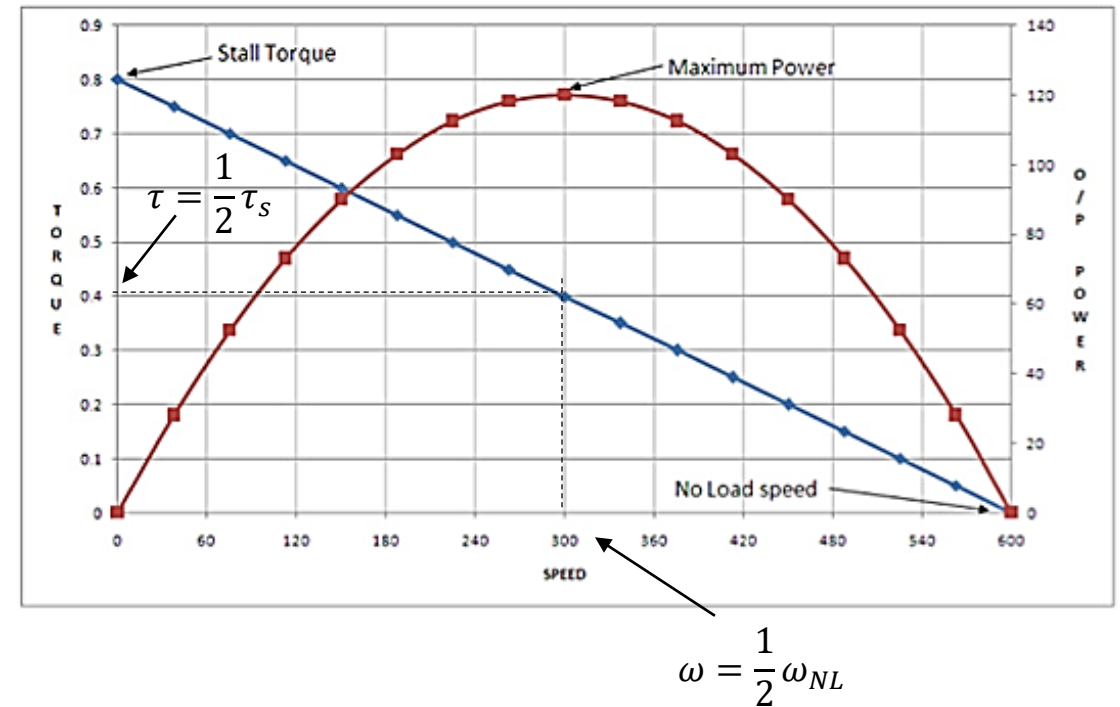
Where $V_m = R_a i + L_a \frac{di}{dt} + V$, $V = K_e \dot{\theta}$



How this system can be represented by a block diagram to define the relation between Input voltage V_m and the angular position θ ?
Try to build the Simulink model in MATLAB.

DC Motor Characteristics (PM and SE types)

- For every motor, there is a specific Torque/Speed curve and Power curve.
- For Permanent magnet and separately excited motor types, the torque speed relation is linear as shown in figure.
- Motor characteristics are frequently given as two points
 - The **stall torque**, τ_s , represents the maximum torque achieved by the motor (The shaft is not rotating anymore).
 - The **no load speed**, ω_{NL} , is the maximum output speed of the motor when no load is applied to the output shaft.
- The torque at any operation point :
 - $\tau_m = \tau_s - \frac{\omega \tau_s}{\omega_{NL}}$



Motor calculations

- For a DC motor relatively small size, the behavior of the motor can be derived from physical laws and the characteristics of the motor.
- The nominal supply voltage from the power source must be equal in magnitude to the sum of the voltage drop on the armature windings and the back EMF generated by the motor:

- $V_m = R_a i + V$

- $V = K_e \omega$

The back EMF constant of the motor

..... (1)

- The torque produced by the rotor is directly proportional to the current in armature windings:

- $\tau = K_t i$

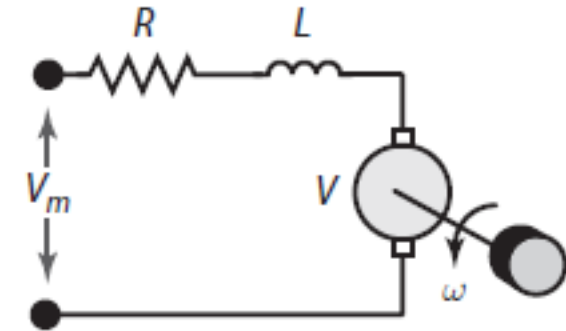
The torque constant of the motor

..... (2)

- Substitute (2) in (1) you get:

- $\tau = K_t \frac{V_m - K_e \omega}{R}$

- The torque developed at the rotor is equal to the **friction** of the motor and the torque due to the **external load**.



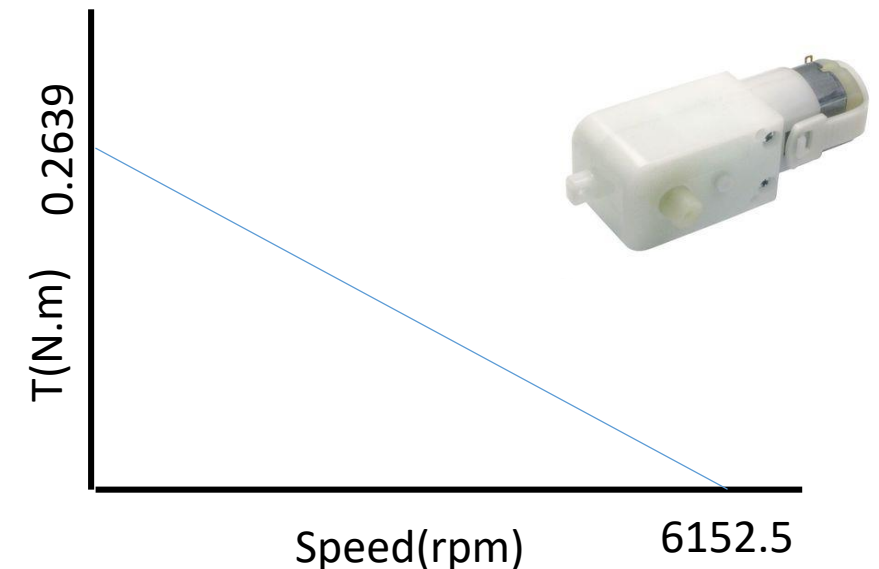
K_e and K_t are usually specified by the motor manufacturer in volts/ RPM or mV/RPM.

Reading a motor characteristics from a datasheet

- Motor GM9X34 is to be operated with **12 volts** applied to the terminals of the motor.
- The datasheet of the motor provide
 - information of no-load and peak(stall) currents
 - Torque and back EMF constants
 - Resistance and inductance values
- The no-load speed can be calculated as follow:
 - $$\omega_{NL} = \frac{V_m - R_a i_{NL}}{K_e} = \frac{12 - 0.83 \times 0.33}{0.0182} = 466.3 \frac{rad}{s} = 6152.5 \text{ rpm}$$
- Maximum torque(stall) = $K_t i_s = 0.0182 \times 14.5 = 0.2639 \text{ N.m}$
- How much the torque on the motor without load (the motor torque because of the friction)?
 - $$\tau_{NL} = K_t \frac{V_m - K_e \omega_{NL}}{R} = ? ?$$
- If the external load on the motor is 0.1 N.m, What is the motor speed?

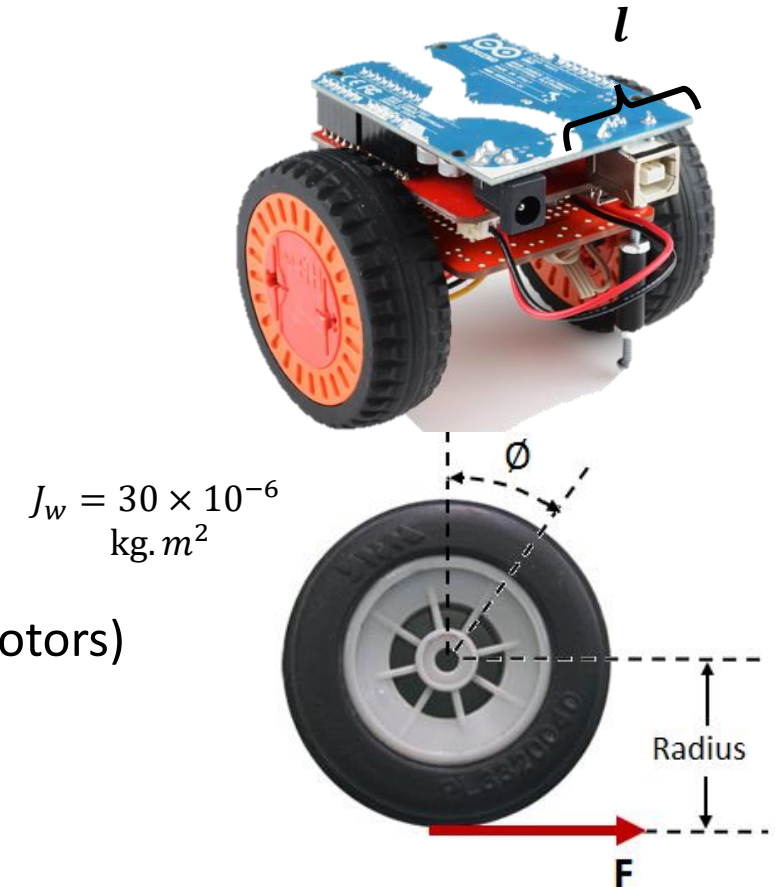
Model GM9X34 Winding Data (Other windings available)

Line No.	Parameter	Symbol	Units	
58	Reference Voltage	E	V	12.0
59	Torque Constant	K_T	oz.in/A	(18.2 X 10 ⁻³)
60	Back-EMF Constant	K_E	V/krpm (V/rad/s)	1.91 (18.2 X 10 ⁻³)
61	Resistance	R_T	Ω	0.83
62	Inductance	L	mH	0.63
63	No-Load Current	I_{NL}	A	0.33
64	Peak Current (Stall)	I_p	A	14.5



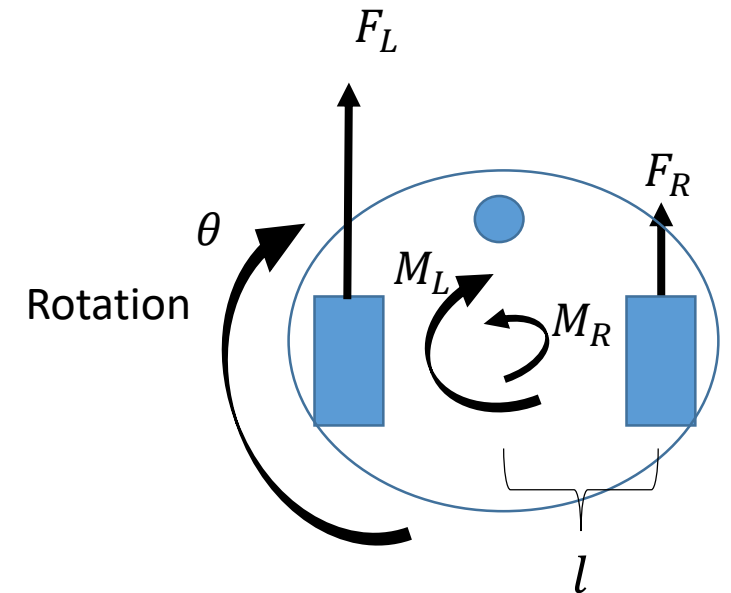
Choosing a DC Motor for a Specific Application

- **Functional Requirement:** DC Gear head motor capable of accelerating a 6Kg, two-wheel drive robot with wheel diameters of 20 cm at a rate of $1m/s^2$. Top speed required will be around 2m/s.
- **Step One:** Calculate the Required Wheel Torque and RPM
 - The required wheel RPM to maintain a speed of 2 m/s
 - $S = \varnothing r$
 - Linear speed (\dot{S}) = $\dot{\varnothing}r = \omega r \rightarrow \omega = \frac{\dot{S}}{r}$
 - Top rotational Speed required = $\frac{2}{0.1} = 20 \frac{rad}{s} = \mathbf{191rpm}$
 - Linear acceleration $\ddot{S} = \ddot{\varnothing}r \rightarrow \ddot{\varnothing} = \frac{1}{0.1} = 10 \text{ rad/s}^2$
 - $\sum F_r = Ma = 6 \times 1 = 6N$
 - Required force on each wheel $F = 6/2 = 3N$. (the vehicle has two motors)
 - Torque at each wheel $T_w = J_w \ddot{\varnothing} + F \times r$
 $= 0.00003 \times 10 + 3 \times \frac{0.2}{2} = \mathbf{0.30003 \text{ N.m}}$



Rotation and curving

- When the robot turn right or left around its center, each motor produce equal torques but opposite speeds.
- The robot make long curve path when one of the motor produce more torque than the other and both of them rotate in the same direction.
- The torque on the center of the robot because of rotation can be given by:
 - $\sum_C M = M_R + M_L = J_r \ddot{\theta}$
 - $\sum_C M = F_R l + F_L l = J_r \ddot{\theta}$
- If the maximum rotation speed of the robot is 1rad/s and could be reached in 1second. **Calculate the torque on the motor to rotate the robot around its center.**

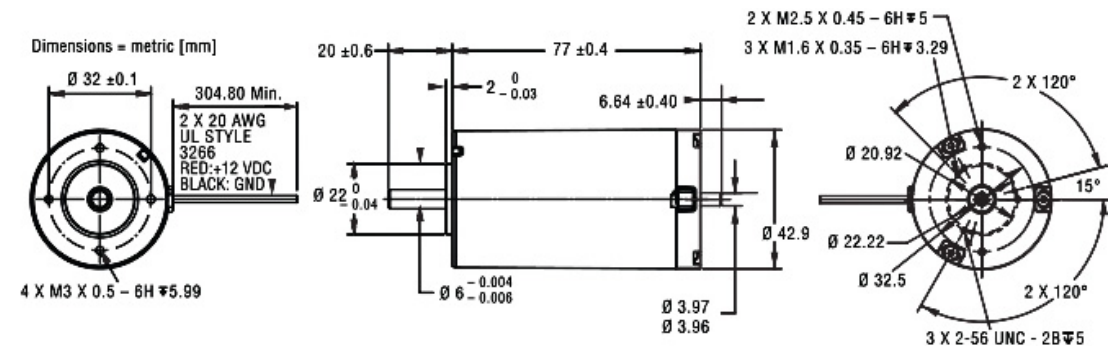


- **Step two** :Search for a motor that meet the functional requirements

- **Design Parameters:** Supplied Voltage = 12Volts, Motor size limited to an overall diameter of approximately 45mm and an overall length of not more than 100mm.

- We need a motor with a continuous rated torque output of at least 0.30003 Nm.
- Since the rpm we require is low, we can choose a motor series with less torque and use a transmission to lower the rpm while raising the torque.

- The gear ratio = $\frac{\text{Requiered torque}}{\text{Motor rated torque}} = \frac{0.3}{0.042} = 7.1$

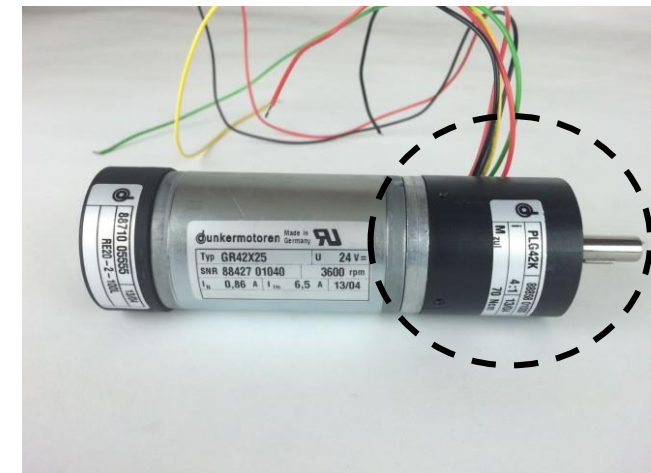


MOTOR DATA	SYMBOL	UNITS	EC044A-20D0-803
Rated Voltage	V_r	V	12
Rated Torque ¹	T_r	Nm	0.042
Speed at Rated Torque ¹	ω_r	rpm	2375
Current at Rated Torque ¹	I_r	Amps	1.9
Rated Power ¹	P_r	Watts	10.5
Peak Torque (2 sec.)	T_{pk}	Nm oz-in	0.071 10.0
Peak Current (2 sec.)	I_{pk}	Amps	3.0
No-Load Speed	ω_{nl}	rpm	4200
No-Load Current	I_{nl}	Amps	0.30

- Let's calculate the torque at the transmission output shaft of the gear box with a 8:1 gear reduction transmission.
- Output Torque (Tran. shaft) = Input Torque (Motor) x Gear Reduction x Transmission Efficiency = $0.042 \times 8 \times 0.9 = \mathbf{0.302 \text{ N.m}}$
- The output speed after the gearbox = $\frac{2375}{8} = \mathbf{297 \text{ rpm}}$ (more than what we need). What we have to do? What are your suggestions?


Gear box models

SPECIFICATION	UNITS	PLG42K 4:1	PLG42K 8:1	PLG42K 16:1
Maximum Load	Nm	0.7	0.7	1.3
	oz-in	99	99	184
Weight (Mass)	g	160	160	200
	oz	5.64	5.64	7.1
Length (L _G)	mm	48.2	48.2	60.0
	inches	1.90	1.90	2.36
Stage	–	1	1	2
Ratio	–	4 / 1	8 / 1	16 / 1
Efficiency	–	0.90	0.90	0.81



Motor datasheet



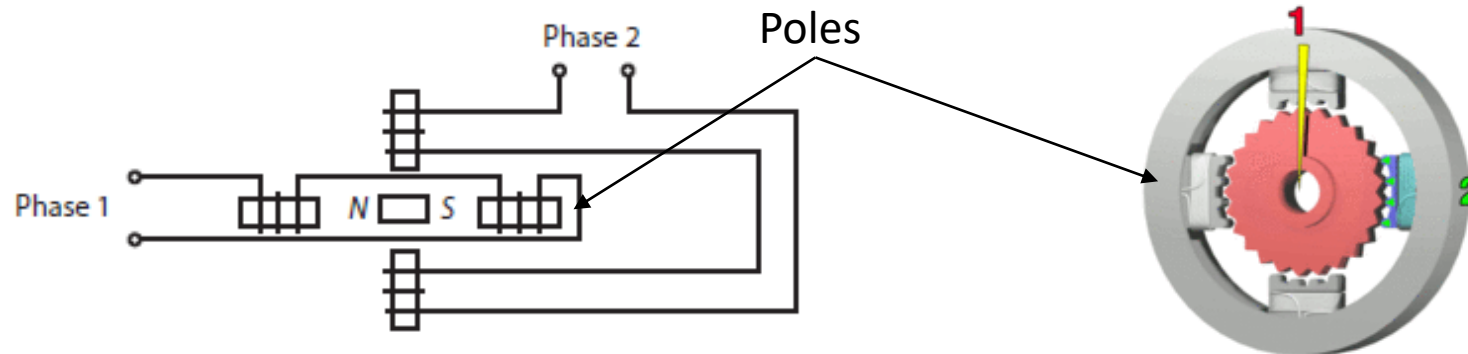
Data Group: 217
 SKU: 1112421
 Weight (Kg):
 Description: HP3SN-26135-12V
 HS Code: 8501.31.6000
 Applications: Electric tool, Vacuum cleaner, R/C car
 Document:
 PDF File: 

MFG Model	VOLTAGE		NO LOAD	
	OPERATING	NOMINAL	SPEED	CURRENT
	VDC	VDC	RPM	A
HS3SN-4070	6.0-12.0	12	11000	0.5
HS3SN-22240	12.0-24.0	12	3000	0.11
HP3SN-5048	6.0-12.0	12	16200	0.86
HP3SN-26135	12.0-24.0	24	5400	0.2

AT MAXIMUM EFFICIENCY						STALL		
SPEED	CURRENT	TORQUE		OUTPUT	EFF	CURRENT	TORQUE	
RPM	A	g-cm	mNm	W	%	A	g-cm	mNm
9300	2.87	235	23.04	22.58	65	16.46	1580	154.90
2300	0.56	162	15.88	3.84	58	2.07	695	68.14
13800	5.38	312	30.59	44.34	69	32.55	2186	214.31
4400	0.98	163	15.98	7.50	65	5.43	1081	105.98

Stepper Motors

- The stepper motor is an actuator which translates electrical pulses into precise, equally spaced, angular movements of the rotor in the form of steps.
- They are extremely well suited for use in open-loop applications due to their accuracy and noncumulative position-error characteristics.
- Compared to DC servo motors, stepper motors produce considerably less torque, lower speeds, and higher vibrations; however, for many applications, their benefits outweigh their drawbacks.



VR Stepper motor and PM stepper motor

- Two types of stepper motors are:
 - Variable reluctance (VR) stepper motors.
 - Permanent magnet (PM) stepper motors.
- In *VR motors*, the stator windings are excited in a sequence that will cause the rotor to align to a position that minimizes magnetic reluctance between the stator and rotor. In *PM motors*, the excitation pattern is provided by the permanent magnets
- The two most commonly used types of stepper motors are the permanent magnet.

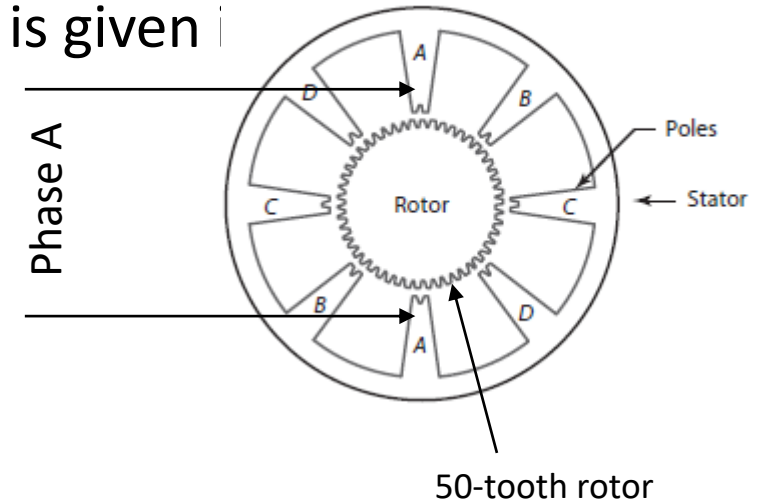
	PM stepper motor	VR stepper motor
Step size	Smaller (Typical 1.8°)	Larger (Typical 15°)
Torque	Lower (usually under 3.5 N-m)	Higher (under 14 N-m)

When to Use a Stepper Motor

- A stepper motor can be a good choice whenever controlled movement is required.
- Stepper motors have found their place in many different applications. Some of these include printers, plotters, hard disk drives, medical equipment, fax machines, CNC Machines, moving a conveyor belt, automotive and many more.

PM stepper motor modeling approach

- The dynamic performance of the stepper motor system is given by
 - Drive
 - Motor
 - Load
- Clockwise phase excitation (A, B, C, D) results in counterclockwise rotor motion and vice versa.
- All phases are identical, the electromagnetic torque produced by one phase is first modeled.
- The digital motion control of the stepper motor requires that the number and the frequency of pulses are calculated by the computer and sent to the stepper motor to produce the required motion.



A **four-phase**, 1.8° PM stepper motor has eight stator poles with two or more teeth per pole and a 50 tooth rotor.

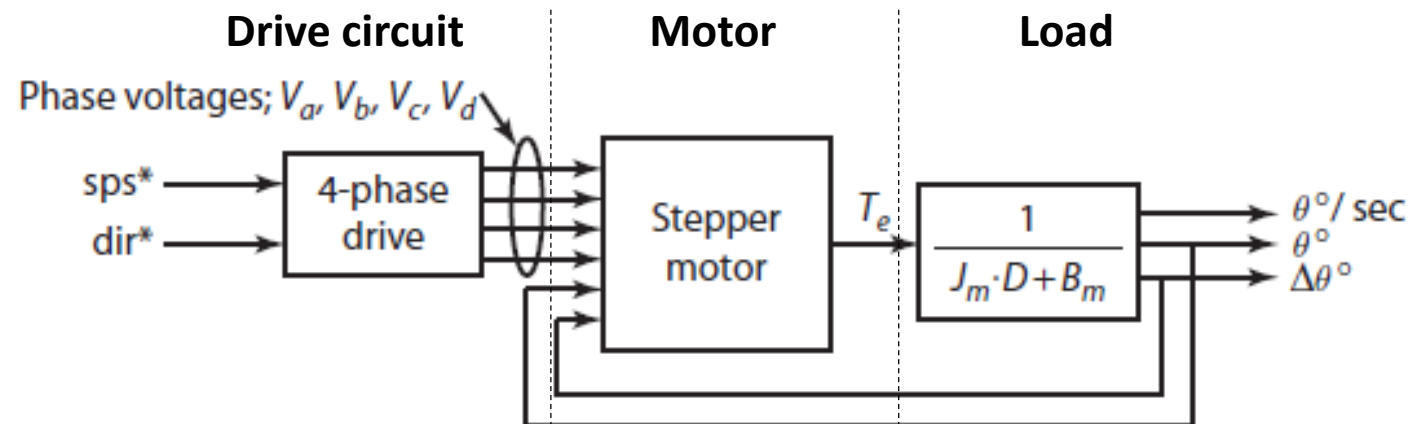
Modeling approach

1) **The load model** is forced by the difference between the applied electromagnetic torque from the motor and the reaction torque from the load.

- The load model produces two outputs: rotor speed and rotor angle, which are fed back and used in the motor model.

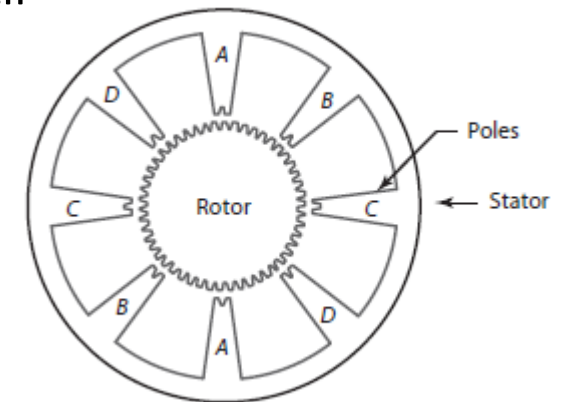
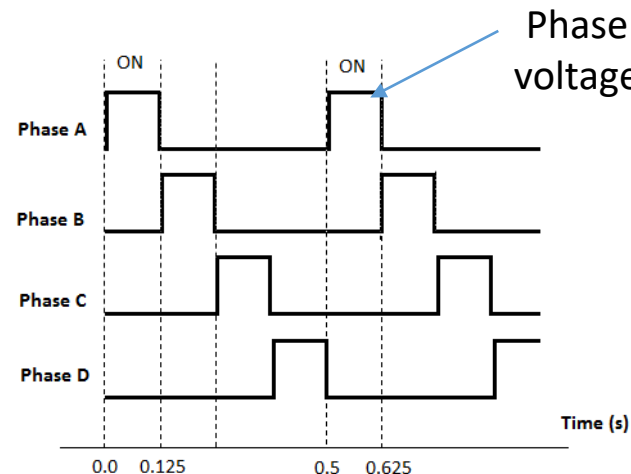
2) **The drive circuit** is modeled as a pulse generator with four sequentially triggered phases so that only one phase is ON at any given time.

- The drive circuit has two command inputs, a step per second command, sps^* , and a direction command, dir^* . It produces four voltage outputs, one for each phase of the motor.



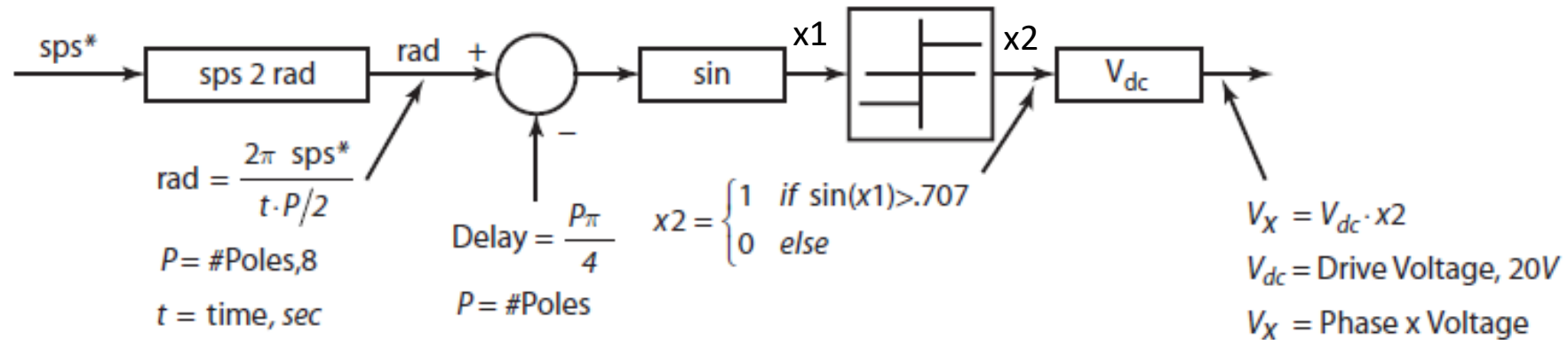
Drive Equations and Block Diagram Model

- For a specified steps per second, one phase of the four-phase drive model produces an ON-voltage pulse at a rate of $\text{sps}^*/(\text{\# of phases})$ times per second.
- The duration of time that the pulse is “ON” is $1/\text{sps}^*$ seconds.
- Ex: If $\text{sps}^* = 8$ (The rotor moves 8 steps in one seconds)
 - The phase voltage of phase A during a 1-second time is high (ON) between 0 and 0.125 seconds and between 0.5 and 0.625 seconds.
 - The phase voltages for phase B is identical in shape but is delayed by $1/\text{sps}^*$.
 - Phase C is is delayed by $2/\text{sps}^*$.
 - Phase D is is delayed by $3/\text{sps}^*$.



Drive circuit model

- The drive model produces positive, valued, and sequential pulses which will move the rotor in one direction.
- To achieve bidirectional movement, the phase voltage signal, V_x , is multiplied by the direction reference, dir^* .



Motor Equations and Block Diagram Model

- The PM motor consists of identical phases allowing the motor model to be developed based on a model of one phase which is then augmented for the remaining three phases.
- The resulting phase–current model is represented by:
- The back emf voltage, is proportional to the rotor speed and varies periodically with the rotor position according to:

$$V_X - V_{bemf} + Ri + L \frac{di}{dt} = 0$$

i = phase current, amps (A)

R = phase resistance, ohms (Ω)

L = Phase inductance, Henry (H)

V_x = supply voltage from driver, volts DC (V)

V_{bemf} = back emf voltage, volts (V)

$$V_{bemf} = -K_{bemf} \dot{\theta} \sin(r \cdot \Delta\theta)$$

V_{bemf} = back emf voltage, volts (V)

K_{bemf} = back emf constant, volts/radians (V/rad)

$\dot{\theta}$ = rotor speed, radian/second (rad/s)

r = number of rotor teeth

$\Delta\theta$ = delta rotor angle, radian, range: 0 to 1.8°

- The common inductance is neglected.
- Each phase winding produces a self inductance due to changes in the phase current and a resistance.
- The self inductance, L varies with the delta rotor position. The variation is periodic and represented by:

$$L = L_1 + L_2 \cos(r \cdot \Delta\theta)$$

L = phase self inductance, Henry (H)

L_1, L_2 = constants, Henry (H)

r = number of rotor teeth

$\Delta\theta$ = delta rotor angle, radian, range: 0 to 1.8°

- Similar to a DC motor, torque in a PM stepper motor is proportional to the phase current by a torque constant.
- The torque depend on the flux produced by the phase current, which varies periodically with the rotor position.

$$T_e = -K \cdot i \cdot \sin(r \cdot \Delta\theta)$$

T_e = electromagnetic torque, Nm

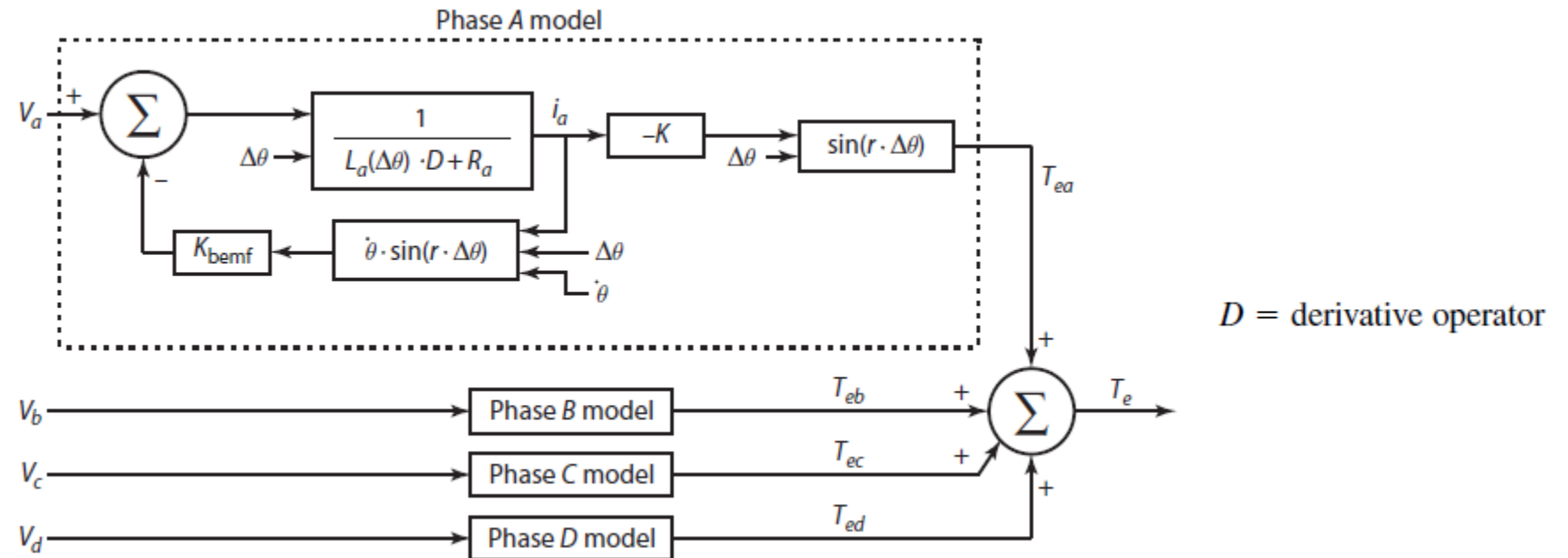
K = torque constant, Nm/A

i = phase current, amps

r = number of rotor teeth

$\Delta\theta$ = delta rotor angle, radian, range: 0 to 1.8°

- The complete block diagram model for the four-phase PM motor is presented in the figure below.
- Phase *B*, *C*, and *D* blocks are identical to that of the phase *A* model.



Positioning System Using Stepper Motor



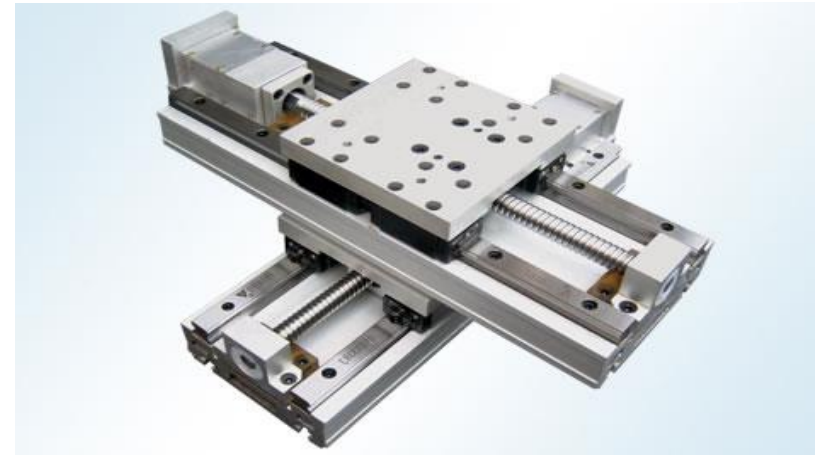
Rack and pinion



One axis CNC machine (one Stepper)



Lead screw



two-axis CNC machine (two Steppers)

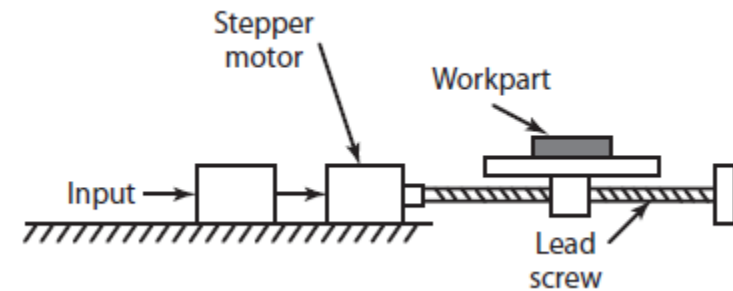
Positioning System Using Stepper Motor

- A positioning system normally uses a stepping motor and a lead screw arrangement.
- In a computer numerically controlled (CNC) machine tool, the stepping motor is driven by a series of electrical pulse signals that are transmitted from the input module.
- Each pulse causes the motor to rotate a fraction of one revolution, called the **step angle**

$$\theta = 360/n_s$$

θ = step angle, degrees

n_s = the number of step angles for the motor



- **Angle of Rotation** If the motor is directly connected to the screw without a gear box, the angle of rotation of the leadscrew is given by

$$A = n_p \theta$$

A = angle of leadscrew rotation, degrees

n_p = number of pulses received by the motor

- **Distance Moved** The movement of the table in response to the rotation of the lead screw is calculated from

$$S = pA/360$$

S = position relative to the starting position, mm

p = pitch of the lead screw, mm/rev

$A/360$ = the number of revolutions (and partial revolutions)

- **Number of Pulses** From the above equations, the number of pulses required to move a predetermined position can be found by

$$n_p = 360 S / p \theta$$

- **Rotational Speed** The pulses are transmitted at a certain frequency, which drives the worktable at a specific velocity. The speed of the leadscrew depends on the frequency of the pulses

$$N = 60 f_p / n_s$$

N = rotational speed, rev/min

f_p = pulse frequency (pulses/sec)

- The table travel speed in the direction of lead-screw axis is determined by the rotational speed as

$$v_t = N \cdot p$$

$$f_r = N \cdot p$$

v_t is the table travel speed in mm/min

p is the pitch of the leadscrew (mm/rev).

- The table travel speed can be considered as feed rate f_r .

Example

- A machine table driven by closed-loop positioning system consists of a stepper motor, lead screw, and an optical encoder. The lead screw has a pitch of 0.500 cm and is coupled to the motor shaft with a gear ratio of 4:1 (four-turns of motor for one turn of lead screw). The optical encoder generates 150 pulses/rev of the lead screw. The table has been programmed to move a distance of 7.5 cm at a feed rate of 40 cm/min. Determine the following.
- • How many pulses are received by the control system to verify that the table has moved exactly 7.5 cm?
- • Pulse rate. (Note that pitch is the axial distance traveled for one revolution of the screw.)

Solution

Lead-screw pitch = 0.5 cm/rev.

Motor rpm = 4 * lead screw rpm

Lead screw generates 150 pulses/rev

Distance to be moved, $S = 7.5$ cm

Feed rate = 40 cm/min.

Time required to travel 7.5 cm (t) = 0.188 min

If the lead-screw pitch is 0.5 cm and the distance traveled is 7.5 cm, it will cause 15 revolutions of the screw. Each revolution of the screw generates 150 pulses. Thus,

$$7.5 \text{ cm} / 0.5 = (15 \text{ rev}) * (150 \text{ pulses/rev}) = 2250 \text{ pulses}$$

$$\text{Pulse rate} = 2250 \text{ pulses} / 0.188 \text{ min} = 12000 \text{ pulses/min or } 200 \text{ pulses/sec}$$

- **Example**

A worktable of positioning system is driven by a lead screw whose pitch =6 mm. The leadscrew is connected to output shaft of a stepper motor through a gearbox whose ratio is 5:1 (five turns of the motor to one turn of the leadscrew). The stepper motor has 48 step angles. The table must move a distance of 250 mm from its present position at linear velocity =500mm/min. Determine

- a) How many pulses are required to move the table the specified distance.
- b) The required motor speed and pulse rate to achieve the desired table velocity.

Solution:

Number of step angles = 48, the step angle $\theta = \frac{360}{48} = 7.5^\circ$.

- a) Number of revolutions to move the table 250 mm is:

$$\frac{250}{6} \text{ revs in lead screw} \rightarrow \frac{250}{6} \times 5 = 208.33 \text{ revs in motor}$$

Number of pulses = $208.33 \times 48 = 10000$ pulses

- b) The total time needed to move the plate 250 mm at velocity 500 mm/min is given by

$$t = \frac{250}{500} = 0.5 \text{ min} = 30 \text{ sec}$$

$$\text{Pulse rete} = \frac{10000}{30} = 333.33 \text{ pulses /sec (Hz)}$$

Two-axis positioning system

- Two stepping motors (shown in figure below) are used in open loop system to drive the leadscrews for x-y positioning machine. The range of each axis is 250 mm. The shaft of motors are connected directly to the lead screws. The pitch of each lead screw is 3mm, and the number of step angles on the stepping motor is 125. A metallic piece is fixed on the table for a machining process.

a) How many pulses are required of each stepping motor to move the table a distance of 100mm in x direction?

b) What are the required pulse rate and corresponding rotational speeds of each stepping motor in order to drive the table at 275mm/min in a straight line from point (x=100, y=0) to point (x=130mm, y=220mm)?

Solution:

a) No motion in y direction, so number of pulses for MotorB =0.

The table is moving 100 mm in x direction. The motor requires 125 pulses for each revolution. One revolution makes 3mm translational motion.

Number of pulses of MotorA = $(100/3) \times 125 = 4167 \text{ pulses}$

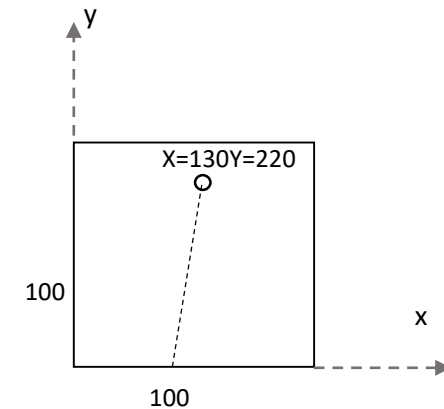
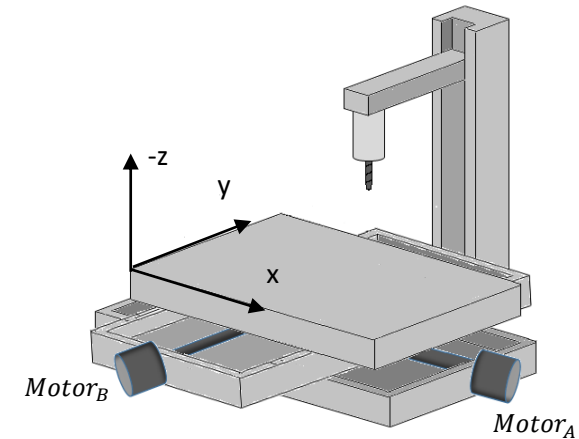
b) The operation time = $222/275 = 0.807 \text{ min}$

- The linear speed in y direction is $220/0.807 = 272.6 \text{ mm/min}$

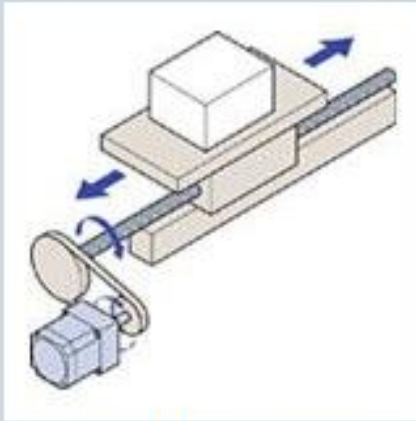
The rotational speed of MotorB = $(272.6 \text{ mm/min}) / (3 \text{ mm/rev}) = 90.87 \text{ rev/min} \rightarrow \text{Pulse rate for MotorB} = (90.87 \text{ rev/min}) \times (125 \text{ pulse/rev}) = 11359 \text{ pulse/min}$.

- The linear speed in x direction is $30/0.807 = 37.2 \text{ mm/min}$

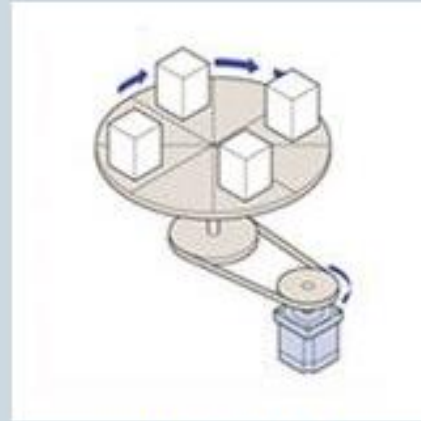
The rotational speed of MotorB = $(37.2 \text{ mm/min}) / (3 \text{ mm/rev}) = 12.4 \text{ rev/min} \rightarrow \text{Pulse rate for MotorA} = (12.4 \text{ rev/min}) \times (125 \text{ pulse/rev}) = 1550 \text{ pulse/min}$



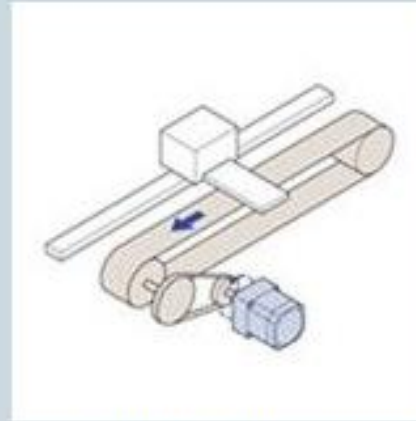
Applications



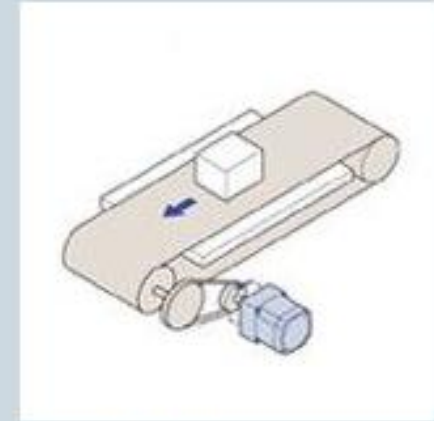
Ball/ Lead screw



Index table



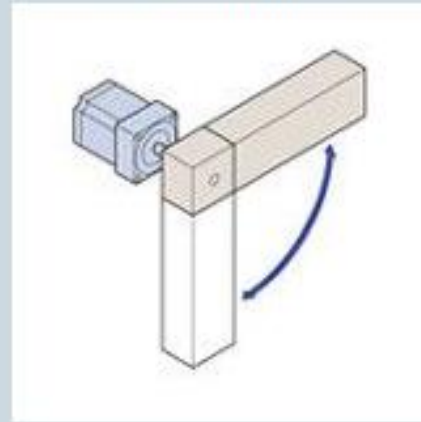
Belt actuator



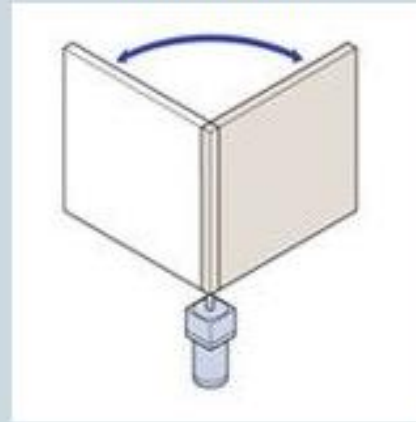
Belt Conveyor



Rotary device



Arm



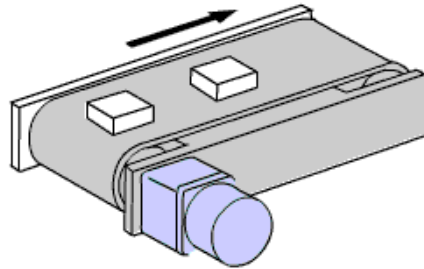
Door/ Gate

Conveyors

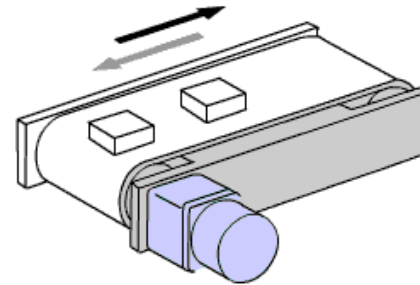
Common motor requirements for conveyors include:

- Low Vibration.
- Stopping Precision.
- Ability to withstand harsh environments.
- Acceleration, deceleration capability
- Position retention.

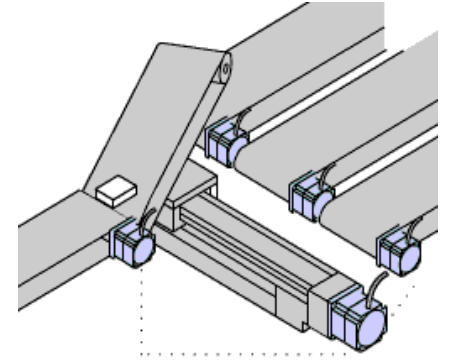
Uni-Directional Conveyor



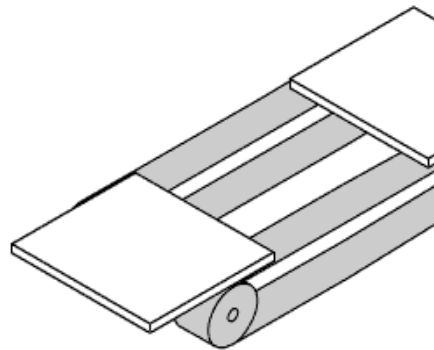
Reversible Conveyor



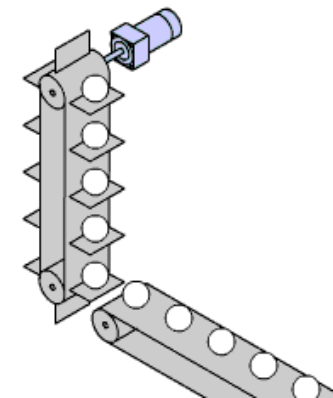
Conveyor System



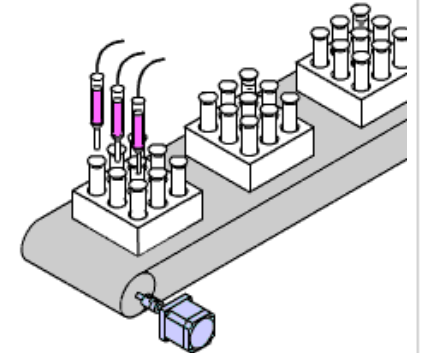
Conveyor Belt



Vertical Conveyor

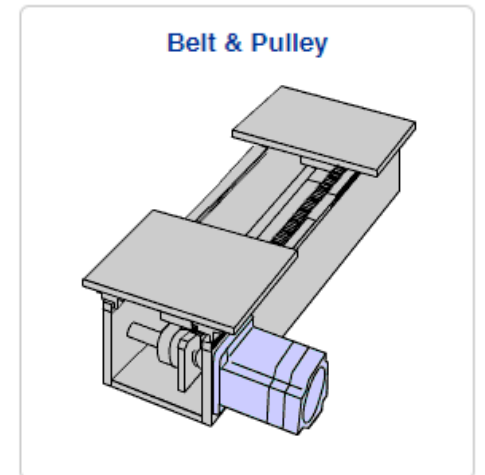
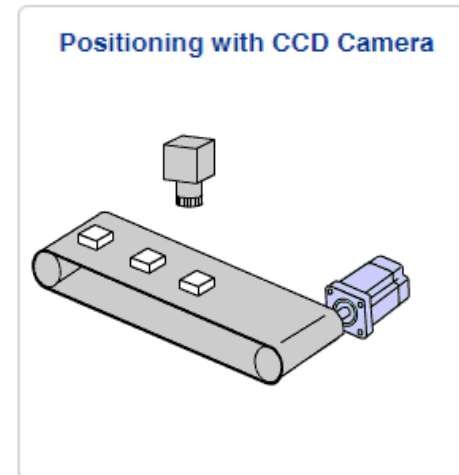
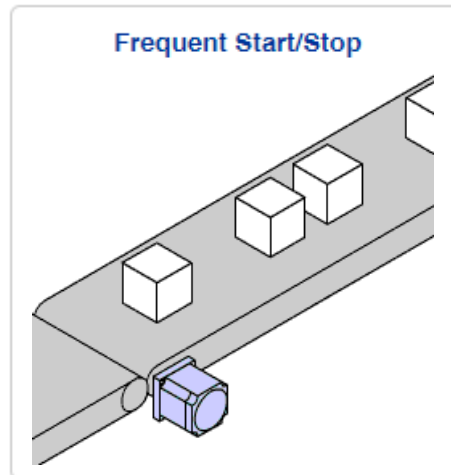
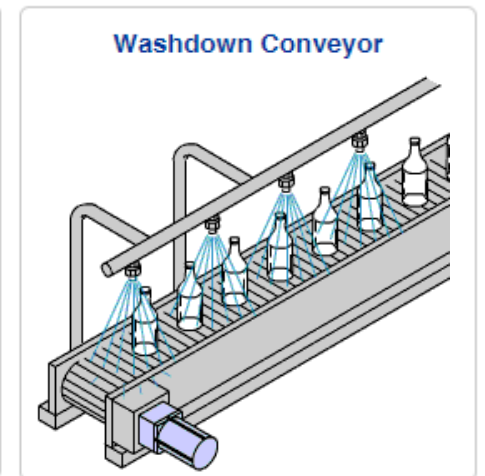


Fluid Injection



Motors in Conveyors

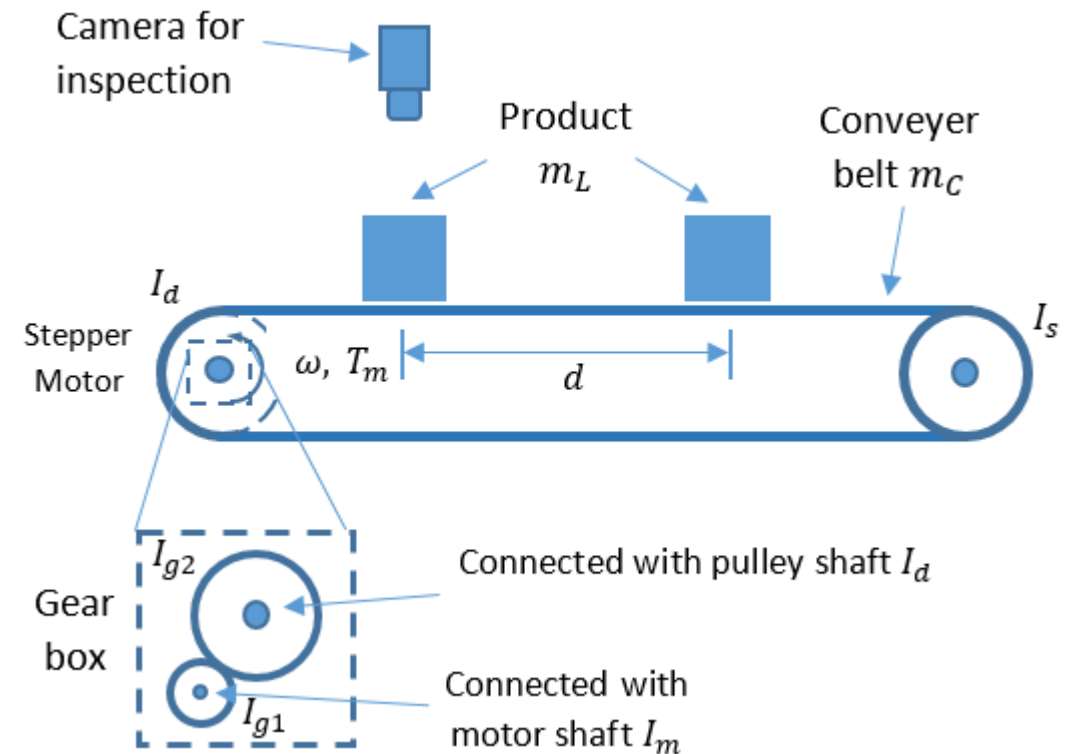
- For fixed or constant speed applications, AC motors & gear motors are well suited.
- For applications where speed control, higher speeds or maximum torque in a small area may be needed, the AC & brushless DC motor speed control systems can be used.
- For precise positioning Oriental Motor's stepper or servo motor packages are ideal.
- For vertical applications where stopping and holding loads is required, motors equipped with electromagnetic brake for stopping and holding the load.



Stepper motor for a conveyor belt

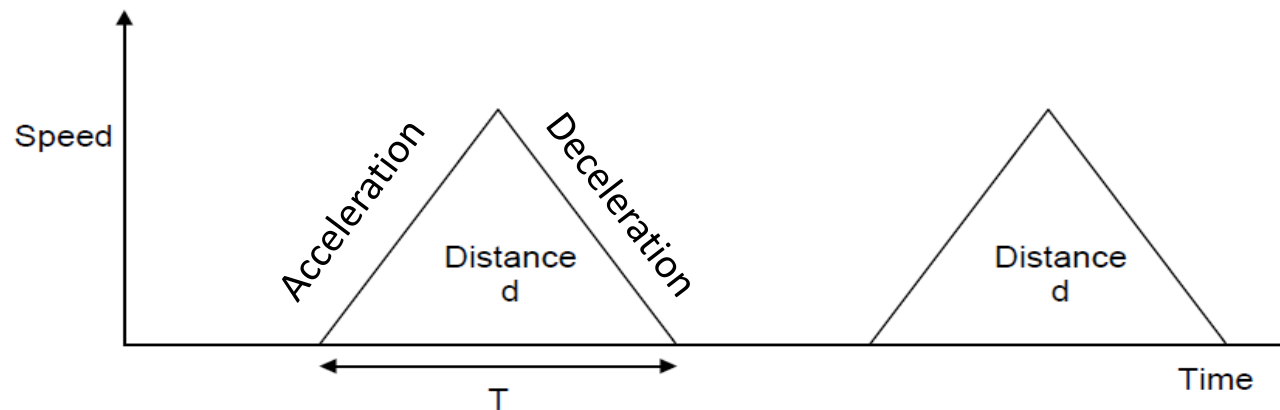
- A conveyor belt that moves objects is to be powered using a stepper motor. It has a gearing ratio of r_g and a diameter of the driving pulley of d_s . The stepper motor has an inertia I_m , the gearbox has a high speed shaft inertia of I_{g1} and a low speed shaft inertia I_{g2} . The conveyor belt pulleys have inertias of I_d and I_s . The conveyor belt has a mass of m_C and the objects on it have a total mass of m_L .

Parameter	Value	Unit	Description
I_m	see table below	$\text{kg}\cdot\text{m}^2$	Inertia of the rotor of the stepper motor
I_{g1}	50	$\mu\text{kg}\cdot\text{m}^2$	Inertia of the high speed shaft of the gearbox
I_{g2}	200	$\mu\text{kg}\cdot\text{m}^2$	Inertia of the low speed shaft of the gearbox
I_d	2.0	$\text{mkg}\cdot\text{m}^2$	Inertia of the driving pulley of the conveyor
I_s	2.0	$\text{mkg}\cdot\text{m}^2$	Inertia of the idler pulley of the conveyor
m_C	5.0	kg	Mass of the conveyor belt
m_L	5.0	kg	Mass of the objects on the conveyor
d_s	0.2	m	Diameter of the driving pulley of the conveyor
d	0.1	m	Distance to be advanced
r_g	1:2	-	Gear reduction ratio
T	0.2	s	Time during which to advance
η	80%	-	Overall system efficiency



Stepper motor for a conveyor belt

- The products on the conveyor have to stop a while under the camera for inspection separated by a fixed distance d regularly in a specified period of time T .
- In order to achieve this in the specified time, the conveyor has to be accelerated and decelerated to reset at a constant rate until it covers the distance d .
- The values of acceleration and deceleration are equal.



Stepper motor selection for conveyor

- The table below shows four motor models with each motor's available torque (holding torque) and its motor inertia. We need to select a motor suitable to drive the conveyor in

Motor Model	Available Torque (N·m) at ω_{max}	Motor rotor inertia (kg·m ²)
50 SM	0.25	11.8×10^{-6}
101 SM	0.58	35.0×10^{-6}
310 SM	2.63	187.0×10^{-6}
1010 SM	7.41	805.0×10^{-6}

- We need first to calculate the required acceleration.
- The maximum speed based on the operation is given by $\frac{v_{max}-0}{2} = \frac{\text{distance } (d) / 2}{\text{time } (T) / 2} = \frac{0.1/2}{0.2/2} \rightarrow v_{max} = 1m/s$
- The acceleration is $a = v_{max} / (\frac{T}{2}) = 1/0.1 = 10m/s^2$
- The stepper motor will be selected to overcome the accelerating conveyor with its load.
- The required value of angular acceleration at the motor shaft is $\alpha = r_g \times \frac{a}{\frac{d_s}{2}} = 2 \times \frac{10}{0.1} = 200 \text{ rad/s}^2$

Torque and Inertia calculations

- $\sum T = I_{all} \cdot \alpha \rightarrow T_m = I_{all} \cdot \alpha$
- We next need to calculate the equivalent inertia of the whole system at the high speed shaft (motor shaft).
- $I_{all} = I_m + I_{g1} + \frac{I_{g2} + I_d + I_s}{r_g^2} + \left(\frac{\frac{d_s}{2}}{r_g} \right)^2 (m_C + m_L) = ??$
- Which motor (from the table) will be fit for this system ?