ENGINEERS APPENDIX

Portescap

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MOTION SOLUTIONS THAT MOVE LIFE FORWARD.™

Engineering Section

Examples of DC Coreless Motor calculations

This chapter aims to provide all the information necessary to select a DC Coreless Motor and to calculate the values at the desired operating point.

Example: Direct Drive without a gearhead attached to the motor.
For this application we are looking for a DC Coreless Motor for a continuous duty application. The application requirements are:

Available voltage:	10 vdc		
Available current:	1 Amp		
Motor operating point	2,000 rpm	[rpm]	desired motor speed
	6 mNm	[M]	desired output shaft torque
	30°C	[T_{amb}]	operating temperature environment
	Continuous operation		
Motor dimensions	25mm		maximum allowable length
	∅ 40mm		maximum allowable diameter

The escap DC Coreless motor 22N is the smallest motor capable of delivering a torque of 6 mNm continuously.

Lets examine the motor series 22N 28 213E.286, which has a nominal voltage of 9 vdc. The characteristics we are mostly interested in is the torque constant (k) of 12.2 mNm/A, and the terminal resistance (R) is 10.3Ω. Neglecting the no-load current (Io), for a load torque (M) of 6 mNm the motor current is:

$$I = \frac{M}{K} \qquad \text{[A] (1)}$$

$$I = \frac{6mNm}{12.2mNm/A} = 0.49\ A$$

Now we can calculate the drive voltage (U) required to run the motor at 22º C, for running a speed of 2,000 rpm with a load torque of 6 mNm:

$$U = R * I + K * \varpi \qquad \text{[Vdc] (2)}$$

$$\varpi = 2\pi * \frac{n}{60} = 2\pi * \frac{2000}{60} = 209.44\ rad/s \qquad \text{[rad/s] (3)}$$

$$U = 10.3 * 0.492 + (12.2 * 10^{-3}) * 209.44 = 7.62\ Vdc$$

We note the current of 0.492 A, is quite close to the rated continuous current of 0.62 A. We therefore need to calculate the final rotor temperature (T_r) to make sure it stays below the rated value of 100 ºC and the voltage required is within the 10 Vdc available. P_{diss} is the dissipated power, R_{Tr} is the rotor resistance at the final temperature and α is the thermal coefficient of the copper wire resistance.

$$\Delta T = T_r - T_{amb} = P_{diss} * R_{th}$$ [°C] (4)

$$P_{diss} = R_{th} * I^2$$ [W] (5)

$$R_{Tr} = R_{22} * (1 + \alpha(T_r - 22))$$ [Ω] (6)

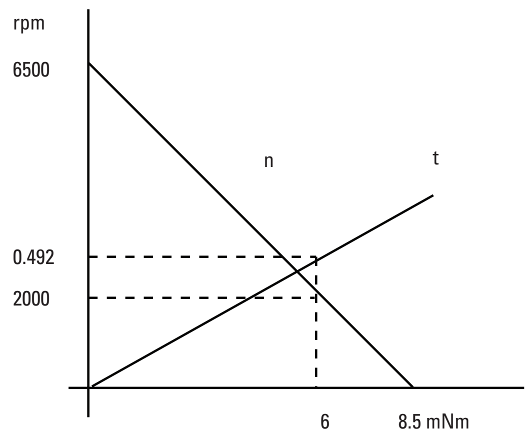
$$\alpha = 0.0039$$ [1/°C] (7)

$$R_{th} = R_{th1} + R_{th2}$$ [°C/W] (8)

The catalog values for the thermal resistance rotor-body and body-ambient are 6º C/W and 22º C/W, respectively. They are indicators for unfavorable conditions. Under <<normal>> operating conditions (mounted to a metal surface, with air circulating around it) we may take half the value for R_{th2}.

By solving equations (4) (5) and (6) we obtain the final rotor temperature T_r:

$$T_r = \frac{R_{22} * I^2 * R_{th} * (1 - 22 * \alpha) + T_a}{1 - \alpha * R_{22} * I^2 * R_{th}}$$ [°C] (9)



With current of 0.48 A the rotor reaches a temperature of:

$$T_r = 82.4°C$$

At that temperature and according to equation (6), the rotor resistance is R82.4 = 12.73Ω, and requires a drive voltage of 7.62 Vdc.

$$Power = 0.492\ A * 7.62\ Vdc = 3.75\ W$$

The motor requires an electrical power of 3.75 watts.

✓ The problem is now solved. The DC Coreless motor series 22N 28 213E.286 would be a good choice for the application. In case the application requires a particularly long motor life, use of the next larger motor (series 22V) could possibly be considered.

Engineering Section

Examples of DC Coreless Gearmotor calculation

Example: Direct Drive with a gearhead attached to the motor.

For this application we are looking for a DC Coreless Motor & Gearhead for a continuous duty application. The application requirements are:

Available voltage:	15 vdc		
Available current:	1.5 Amp		
Motor operating point	30 rpm	[rpm]	desired motor speed
	500 mNm	[M]	desired output shaft torque
	22°C	[T_{amb}]	operating temperature environment
	Continuous operation		
Motor dimensions	80mm		maximum allowable length
	∅ 25mm		maximum allowable diameter

The gearhead specification page for the R22 shows this torque can be achieved with this planetary gearhead. When choosing the reduction ratio we should keep in mind the recommended maximum input speed of the R22 gearhead should remain below 5,000 rpm in order to assure low wear and low audible noise.

$$i \le \frac{n_{\max}}{n_{ch}} \qquad \text{[-] (10)}$$

$$i \le \frac{5000\ rpm}{30\ rpm} = 166.7\ rpm$$

The catalog indicates the closest ratio to the desired one calculated above is 111:1, the efficiency for this ratio is 0.6 (or 60%). We may now calculate the motor speed (n_m) and the reflected torque (M_m) on the motor shaft.

$$M_m = \frac{M}{i * \eta} \qquad \text{[mNm] (11)}$$

$$M_m = \frac{500\ mNm}{111 * 0.6} = 7.51 * 10^{-3}\ Nm = 7.51\ mNm$$

$$n_m = n_{ch} * i = 30 * 111 = 3{,}330\ rpm \qquad \text{[rpm] (12)}$$

The motor table shows the 22V28 series motor can deliver torque of 7.5 mNm continuously. The 22V28 series motor is available as a standard combination with the planetary gearhead R22. After choosing a voltage winding we can calculate the motor current and voltage the same way as in the previous example.

The motor having a load torque value (M) of 7.5 mNm is required to be driven at a speed of 3,330 rpm. The ambient temperature (T_{amb}) is 22º. The available voltage in the application is 12 vdc.

Lets examine the motor series 22V 28 213E.202, which has a nominal voltage of 12 vdc. The characteristics we are mostly interested in are the torque constant (k) of 14.9 mNm/A, and the terminal resistance is 11.9Ω. Neglecting the no-load current (Io), for a torque load of 7.51 mNm the motor current is:

$$I = \frac{M}{k} = \frac{7.51 mNm}{14.9 mNm / A} = 0.50\ A \qquad \text{[A]}$$

Now we can calculate the drive voltage required to run the motor at 22º C, for a desired speed of 3,300 rpm with a load torque of 7.5 mNm:

$$U = R * I + K * \varpi \qquad \text{[[Vdc]}$$

$$\varpi = 2\pi * \frac{n}{60} = 2\pi * \frac{3{,}330}{60} = 348.72 \qquad \text{[rad/s]}$$

$$U = 11.9 * 0.50 + (14.9 * 10^{-3}) * 348.72 = 11.15\, Vdc$$

We note the current of the motor under load is 0.50, which is quite close to the rated continuous current of 0.58 A. We therefore calculate the final rotor temperature (T_f) to make sure it stays below the rated value of 100º C and the voltage required is within the 12 Vdc available. P_{diss} is the dissipated power, R_{Tr} is the rotor resistance at the final temperature and α is the thermal coefficient of the copper wire resistance.

$$\Delta T = T_r - T_{amb} = P_{diss} * R \qquad \text{[°C]}$$

$$P_{diss} = R_{th} * I^2 \qquad \text{[W]}$$

$$R_{Tr} = R_{22} * (1 + \alpha (T_r - 22)) \qquad [\Omega]$$

$$\alpha = 0.0039 \qquad \text{[1/°C]}$$

$$R_{th} = R_{th1} + R_{th2} \qquad \text{[°C/W]}$$

The catalog values for the thermal resistance rotor-body and body-ambient are 6º C/W and 22º C/W, respectively. They are indicators for unfavorable conditions. Under <<normal>> operating conditions (mounted to a metal surface and with air circulating around it) we may take half the value for R_{th2}.
By solving equations (4), (5) and (6) we obtain the final rotor temperature T_r:

$$T_r = \frac{R_{22} * I^2 * R_{th} * (1 - 22 * \alpha) + T_a}{1 - \alpha * R_{22} * I^2 * R_{th}} = \frac{11.9 * 0.50^2 * 17 * (1 - 22 * 0.0039) + 22}{1 - 0.0039 * 11.9 * 0.50^2 * 17} = 85°$$

With a current of 0.50 A the rotor reaches a temperature of $T_r = 85°C$

At that temperature and according to equation (6), the rotor resistance is R_{85} = 14.82Ω, and we need a drive voltage of 12.60 Vdc.

$$Power = 0.50\ A * 12.60\ Vdc = 6.3\ W$$

The motor requires an electrical power of 6.3 watts.

✓ The problem is now solved. The gearmotor series 22V28 213E.202 R22 0 111 would be a good choice for the application. In case the application requires a particularly long motor life, use of the next larger motor (type 23V) could possibly also be considered.

Engineering Section

Examples of DC Motor calculation

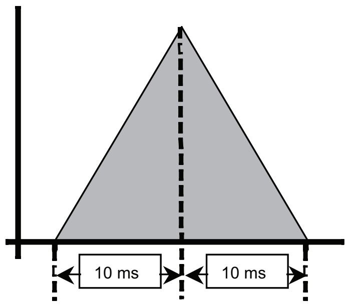
Example: Positioning with a DC Coreless Motor.

In this application we are looking for a DC Coreless Motor to move a load inertia (J_{ch}) of 40 * 10^{-7} kgm^2 to be moved by an angle of 1 rad in 20 ms

The application requirements are:

Available voltage:	48 vdc	
Available current:	4 Amp	
Motor operating point	1 rad	[radian] desired motor movement
	40*10^{-7} kgm^2	[J_{ch}] motor load inertia on the output shaft
	20 msec	[msec] desired move time
	40°C	[T_{amb}] operating temperature environment
	Intermittent operation	
Motor dimensions	68mm	maximum allowable length
	∅ 35mm	maximum allowable diameter

Friction is negligible, with this incremental application we consider a duty cycle of 100% and a triangular speed profile.



The motor must rotate 0.5 rad (θ) in 10 ms while accelerating, then another 0.5 rad in 10 ms while decelerating. First let us calculate the angular acceleration α :

$$\alpha = 2\frac{\theta}{t^2} \qquad [rad/s^2]\ (14)$$

$$\alpha = 2\frac{0.5}{0.01^2} = 10{,}000\ rad/s^2$$

The torque necessary to accelerate the load is:

$$M_{ch} = J_{ch} * \alpha \qquad [mNm]\ (15)$$

$$M_{ch} = 40 * 10^{-7} * 10{,}000 = 40\ mNm$$

If the motor inertia equaled the load inertia, torque would be twice that value. We then speak of matched inertia's where the motor does the job with the least power dissipation. If we consider that case, the motor torque becomes:

$$M_m = (J_{ch} + J_m) * \alpha \qquad [mNm]\ (16)$$

$$M_m = 2 * M_{ch} = 2 * 40\ mNm = 80\ mNm$$

According to the motor overview, the type 35NT2R 82 can deliver 90 mNm continuously. As an example, let us examine the -426P coil with a resistance (@ 22°C) of 0.85Ω and a torque constant of 25.4 mNm/A. Consider a total thermal resistance of: rotor-body 4° C/W - body-ambient 8° C/W. The rotor inertia is 71.4 * 10^{-7} kgm^2

From equation (1) we obtain:

$$I = \frac{M}{k} = \frac{80mNm}{25.4mNm/A} = 3.15\ A$$

From equation (9) and (4) we obtain:

$$T_r = 101.7°C \qquad\qquad R_{Tr} = 1.11\Omega$$

For the triangular profile we then calculate the peak motor speed:

$$\varpi_{\max} = \alpha * t \qquad \text{[rad/s] (17)}$$

$$\varpi_{\max} = 10{,}000 * 0.01 = 100\ rad/s$$

According to the equation (3), we obtain:

$$n_{\max} = 100\ rad/s * 9.5493 = 955\ rpm$$

We then apply equation (2)

$$U = R * I + K * \varpi = (.85 * 3.15) + ((25.4 * 10^{-3}) * 100 = 5.22\ vdc$$

This is the minimum output voltage required by a chopper driver.

✓ The problem is now solved. It is possible to reach the operating point with the DC Coreless motor series 35NT2R 82 426P.1, which could make the desired move quite easily.

Engineering Section

Examples of BLDC Motor calculation

Introduction and objective:

This chapter aims to provide all the information necessary to select a BLDC motor and to calculate the values at the desired operating point. The following examples are for motor applications running in continuous operation.

1) Example: Brushless application requirements
For this application we are looking for a BLDC motor with high speed capabilities in a continuous duty operation. The motor will be controlled by an amplifier for motor with Hall Effect sensors.

Available voltage:	30 vdc	
Available current:	3 Amps	
Motor operating point	20,000 rpm	desired motor speed
	10 mNm	motor shaft output torque
	22°C	operating temperature
	Continuous operation	
Motor physical dimensions	60mm	maximum allowable length
	∅ 25mm	maximum allowable diameter

Motor pre-selection - Using the information found on the specification page on the speed torque curve and Maximum allowable operating specifications, it is possible to select the potentially correct motor solution.

Upon looking at the speed torque charts and the maximum allowable operation specifications we find the BLDC motor series 22BHM capable of operating at the desired operating point.

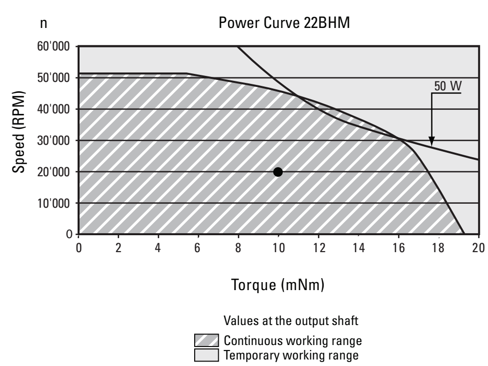


figure1

The operating point is shown in figure 1.

The motor 22BHM is available in 4 different windings. All being 24 vdc windings, the differences are the amount of torque and the speeds of the motor. Since the desired motor speed is 20,000 rpm we will investigate the
22BHM 8B H.01 motor. This motor winding having a no load speed of 28,300 rpm.

Calculating for the motor current we find:

$$I = \frac{T}{k} = \frac{10mNm}{8.3mNm/A} = 1.20\ A$$

T= mNm motor shaft output torque
k= mNm/A motor torque constant

The supply current of the system in question is 3 amps and therefore there should be no difficulties.

Calculating the voltage required to run the motor at 20,000 rpm follows the formula:

$$U = R * I + k * \varpi$$

$$\varpi = 2\pi * \frac{n}{60} = 2\pi * \frac{20{,}000}{60} = 2094.39\ rad/s$$

$$U = 0.99 * 1.20 * 8.3 * 10^{-3} * 2094.39 = 20.65\ vdc$$

✓ The problem is now solved. Since the voltage required is less than the available voltage, it is possible to reach the operating point with the BLDC slotless motor series 22BHM 8B H.01, which could do the job quite easily.

The amplifier able to accomplish this is the EBL-50-H-03, which has:

- Speed control via hall sensors
- Voltage inputs from 5.5 – 50 vdc
- Maximum continuous current 3 Amps

Mechanical power at the motor shaft:

$$P_{mech} = T * \varpi$$

T= mNm motor shaft output torque
n= rpm Motor shaft speed

$$P_{mech} = 10mNm * 2094.39 = 20.94watt$$

Motor efficiency (ignoring core losses):

$$\eta = \frac{P_{mech}}{P_{elec}} = \frac{P_{mech}}{U * I} = \frac{20.94}{20.65 * 1.2} = 84.5\%$$

U = vdc motor voltage
I = Amp Motor current

Engineering Section

Examples of BLDC Motor calculation

2) Example: Brushless motor with a Gearhead
For this application we want to drive a load at an extremely low constant speed. The customer needs a combination of a Brushless DC-Servomotor with a gearhead.

Available voltage:	20 vdc	
Available current:	2 Amps	
Gearmotor operating point	60 rpm	desired gearmotor speed
	150 mNm	gearmotor shaft output torque
	22°C	operating temperature
	Continuous operation	
Motor physical dimensions	120mm	maximum allowable length
	∅ 20mm	maximum allowable diameter

Gearhead pre-selection
Before selecting a motor we must first determine which gearhead is suitable for the application. The two important parameters for this are the specifications relating to the operating point at the shaft of the gearhead.

Once an appropriate gearhead has been determined, the working point at the motor shaft can be calculated. From here the motor type can be defined using the same procedure as in the previous example for motor only.

By comparing the desired gearhead output torque with the data of the various gearheads in continuous operation as listed in the catalog specification pages, it is possible to start the elimination process.
We find the R16 planetary gearhead (16mm diameter) capable of operating at the desired operating point

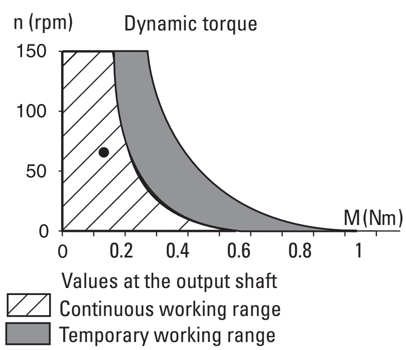


figure2

For continuous operation, one of the most important gearhead parameters to be considered is the maximum recommended input speed into the gearhead ($n_{max\ iput\text{-}gearhead}$). This specification allows us to calculate the maximum reduction ratio (i_{max}) to use for the application.

$$i_{\max} = \frac{n_{\max\ input-gearhead}}{n_{output-gearhead}} = \frac{7{,}500}{60} = 125$$

R16 ==> i_{max} = 125 ($n_{max\ input\text{-}gearhead}$ = 7,500 rpm)

The actual reduction ratio can be chosen by selecting the nearest lower value to the above results. By reviewing the catalog we choose the following gearhead and ratio.

R16 ==> i = 121

Motor speed at the shaft

$$n_{motor} = i * n_{output-gearhead} = 121 * 60 = 7{,}260\ rpm$$

Motor torque at the shaft

$$T_{motor} = \frac{T_{gearhead}}{i * \eta} = \frac{150\ mNm}{121 * .65} = 1.91\ mNm$$

η = gearhead efficiency

Since the gearhead has a diameter of 16mm we will be looking at a 16mm brushless DC motor.
On verifying above the load torque (T_{motor}) the motor will be required to turn we select the 16BHS

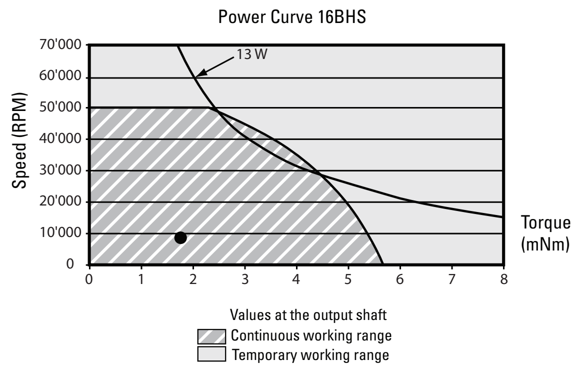


figure3

The motor 16BHS is available in 4 different windings. All being 12 vdc windings, the differences are the amount of torque and the speeds of the motor. Since the desired motor speed is 7,260 rpm we will investigate the 16BHS 8B E.01 motor. This motor winding having a no load speed of 8,150 rpm.

Calculating for the motor current we find:

$$I = \frac{T}{K} = \frac{1.91\ mNm}{13.5\ mNm / A} = 0.14\ A$$

T= 1.91 mNm motor shaft output torque
k= 13.5 mNm/A motor constant

The system is able to supply 2 Amp, therefore there are no problems with the current.
The voltage required to run the motor at 7,260 rpm follows the formula:

$$U = R * I + k * \varpi$$

$$\varpi = 2\pi * \frac{n}{60} = 2\pi * \frac{7{,}260}{60} = 760.3\ rad / s$$

$$U = 19.4 * .14 * (13.5 * 10^{-3}) * 760.3 = 11.94\ vdc$$

✓ The problem is now solved. Thanks to the BLDC slotless technology, the motor series 16BHS 8B H.01 with the planetary gearhead series R16 0 121, could do the job quite easily.

The voltage required is less than the available voltage, therefore it is possible to reach the operating point with the BLDC motor series 16BHS 8B E.01.

The amplifier able to accomplish this is the EBL-50-H-03, which has:
- Speed control via hall sensors
- Voltage inputs from 5.5 – 50 vdc
- Maximum continuous current 3 Amps

Engineering Section

Examples of BLDC (Slotted) Motor calculation

Introduction and objective:

This chapter aims to provide all the information necessary to select a BLDC motor and to calculate the values at the desired operating point. The following examples are for motor applications running in continuous operation.

1) Example: Brushless application requirements
For this application we are looking for a BLDC motor with high speed capabilities in a continuous duty operation. The motor will be controlled by an amplifier for motor with Hall Effect sensors. We will consider the same example as discussed for slotless design and select a slotted motor that meets the requirements (below).

Available voltage:	30 vdc	
Available current:	3 Amps	
Motor operating point	20,000 rpm	desired motor speed
	10 mNm	
	(1.42 oz-in)	motor shaft output torque
	22°C	operating temperature
	Continuous operation	
Motor physical dimensions	60mm (2.36′′)	maximum allowable length
	∅ 25mm (0.98′′)	maximum allowable diameter

Motor pre-selection: Since the maximum allowable diameter is 25 mm (0.98′′), we will look at motor sizes 9 and smaller that meet the operating point per their corresponding torque-speed charts.

Upon looking at the speed torque charts, we find the motor B0610-024B capable of easily meeting the desired operating point with its continuous operating torque being more than 15 mNm at 30,000 rpm. This is the smallest motor capable of meeting the above requirements. A customized motor can be made even smaller for these requirements.

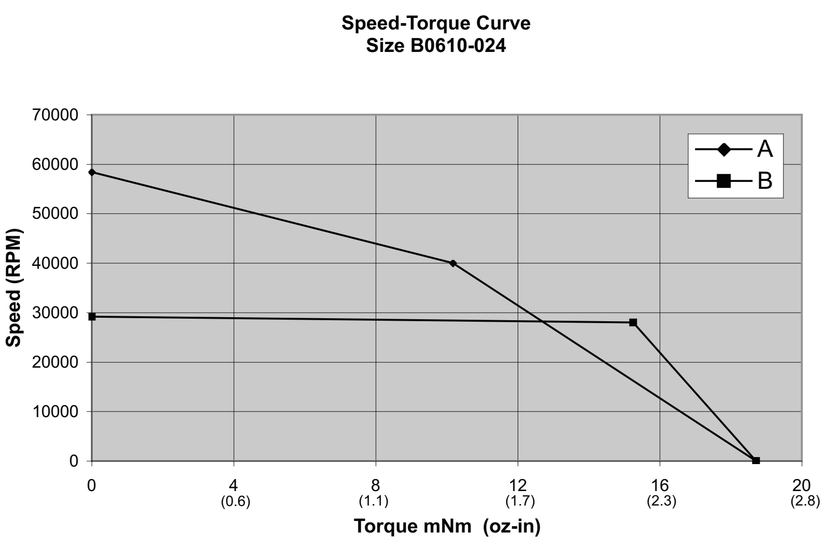


figure1

The motor B0610-024 is available in 2 different windings. Both being 24 VDC windings, the differences are the amount of torque and the speeds of the motor. Since the desired motor speed is 20,000 rpm we will investigate the B0610-024B motor having a no load speed of 29,197 rpm.

Calculating for the motor current we find:

$$I = \frac{T}{k} = \frac{10mNm}{7.84mNm/A} = 1.28\ A$$

T= mNm motor shaft output torque
k= mNm/A motor torque constant

The supply current of the system in question is 3 amps and therefore there should be no difficulties.

Calculating the voltage required to run the motor at 20,000 rpm follows the formula:

$$U = R * I + k * \varpi$$

$$\varpi = 2\pi * \frac{n}{60} = 2\pi * \frac{20{,}000}{60} = 2094.39\ rad/s$$

$$U = 1.57 * 1.28 + 7.84 * 10^{-3} * 2094.39 = 18.43\ vdc$$

✓ The problem is now solved. Since the voltage required is less than the available voltage, it is possible to reach the operating point with the BLDC slotted motor B0610-024B, which could do the job quite easily.

Mechanical power at the motor shaft:

$$P_{mech} = T * \varpi$$

T= mNm motor shaft output torque
n= rpm Motor shaft speed

$$P_{mech} = 10mNm * 2094.39 = 20.94 Watts$$

Motor efficiency (ignoring core losses):

$$\eta = \frac{P_{mech}}{P_{elec}} = \frac{P_{mech}}{U * I} = \frac{20.94}{18.43 * 1.28} = 88.8\%$$

U = vdc motor voltage
I = Amp Motor current

Engineering Section

Examples of BLDC Motor calculation

2) Example: Brushless motor with a Gearhead

For this application we want to drive a load at a low constant speed. The customer needs a combination of a Brushless DC-Servomotor with a gearhead.

Available voltage:	50 vdc	
Available current:	1 Amp	
Gearmotor operating point	2500 rpm	desired gearmotor speed
	40 mNm	gearmotor shaft output torque
	10.5 Watts	output power at the gearhead
	22°C	operating temperature
	Continuous operation	
Motor physical dimensions	70mm	maximum allowable length
	∅ 15mm	maximum allowable diameter

Gearhead pre-selection

Before selecting a motor we must first determine which gearhead is suitable for the application. The two important parameters for this are the specifications relating to the operating point at the shaft of the gearhead.

Once an appropriate gearhead has been determined, the working point at the motor shaft can be calculated. From here the motor type can be defined using the same procedure as in the previous example for motor only.

By comparing the desired gearhead output torque and envelope requirements with the data of the various gearheads in continuous operation as listed in the catalog specification pages, it is possible to start the elimination process. We find the Size 5 planetary gearhead (12.7 mm diameter) capable of operating at the desired operating point

For continuous operation, one of the most important gearhead parameters to be considered is the maximum recommended input speed into the gearhead ($n_{max\ input\text{-}gearhead}$). This specification allows us to calculate the maximum reduction ratio (i_{max}) to use for the application.

$$i_{max} = \frac{n_{\max\ input-gearhead}}{n_{output-gearhead}} = \frac{80000}{2500} = 32$$

Size 5 Gearhead ==> $i_{max} = 32$ ($n_{max\ input\text{-}gearhead} = 80{,}000$ rpm)

The actual reduction ratio can be chosen by selecting the nearest lower value to the above results. By reviewing the catalog we choose the following gearhead and ratio.

R16 ==> i = 25

Motor speed at the shaft

$$n_{motor} = i * n_{output-gearhead} = 25 * 2500 = 62{,}500\ rpm$$

Motor torque at the shaft

$$T_{motor} = \frac{T_{gearhead}}{i * \eta} = \frac{40\ mNm}{25 * .825} = 1.94\ mNm$$

Since the gearhead has a diameter of 12.7mm we will be looking at a 12.7mm or smaller BLDC motor. The motor B0508-050A from the catalog can easily run at the load torque (T_{motor}) calculated above at 62,500 rpm (per Speed-Torque chart below).

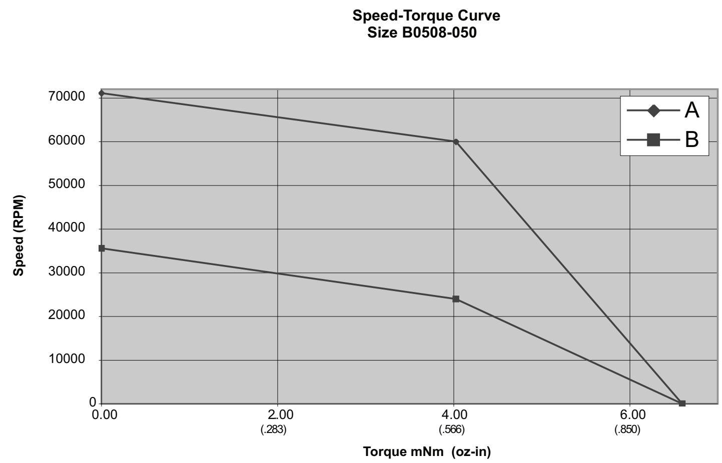


figure2

The motor B0508-050 is available in 2 different windings. Since the desired rated motor speed is 62,500 rpm we will investigate the B0508-050A motor.

Calculating for the motor current we find:

$$I = \frac{T}{K} = \frac{1.94\ mNm}{6.71\ mNm/A} = 0.29\ A$$

T= 1.94 mNm motor shaft output torque
k= 13.5 mNm/A motor constant

The system is able to supply 1 Amp, therefore there are no problems with the current. The voltage required to run the motor at 62,500 rpm follows the formula:

$$U = R * I + k * \varpi$$

$$\varpi = 2\pi * \frac{n}{60} = 2\pi * \frac{62500}{60} = 6{,}545\ rad/s$$

$$U = 7.28 * .29 + (6.71 * 10^{-3}) * 6545 = 46\ vdc$$

✓ The problem is now solved. Thanks to the BLDC technology, the motor B0508-050A with the Size 5 Planetary gearhead (25:1 Ratio), could do the job quite easily.

The voltage required is less than the available voltage; therefore it is possible to reach the operating point with the BLDC motor series B0508-050.

Engineering Section

Examples of Disc Magnet Motor (DMM) calculation

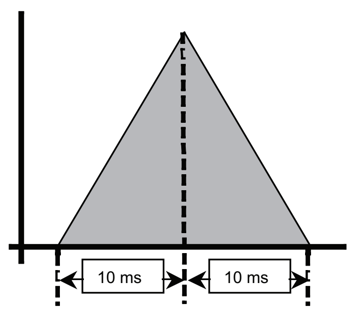
Example: Positioning with a Stepper Motor

For this application we are looking for a Stepper motor for an intermittent duty application. The application requirements are:

Available voltage:	24 vdc		
Available current:	2 Amp		
Motor operating point	0.5 rad	[radian]	desired motor position
	$20*10^{-7}$ kgm^2	[J_{ch}]	motor load inertia on the output shaft
	20 msec	[msec]	desired move time
	40°C	[T_{amb}]	operating temperature environment
	Intermittent operation		
Motor dimensions	68mm		maximum allowable length
	∅ 35mm		maximum allowable diameter

The load inertia of $20 * 10^{-7}$ kgm^2 has to be moved by an angle of 0.5 rad (θ) in 20 ms. With a triangular speed profile we find using an acceleration time of 10msec for a shaft movement of 0.25 rad, the speed required is calculated as follows:

$$\alpha = 2\frac{\theta}{t^2}$$ [rad/s2] (14)



$$\alpha = 2\frac{0.25}{0.01^2} = 5000\ rad/s^2$$

$$\varpi = (5{,}000 rad/s^2) * 0.01s = 50 rad/s$$

$$Rpm = 50\ rad/s * 9.5493 = 477.5\ rpm$$

The torque necessary to accelerate the load is:

$$M_{ch} = J_{ch} * \alpha$$ [Nm] (15)

$$M_{ch} = 20 * 10^{-7} * 5{,}000 = 10\ mNm$$

With a triangular speed profile this requires a peak speed up to 477.5 rpm, with a load torque of 10 mNm, as calculated using equations (14) and (15). At that speed, the mechanical power for the load alone is 0.5 W.

$$P = M * \omega = 10 * 10^{-3}\ Nm * 50\ rad/s = 0.5\ watts$$

Now we must evaluate the motor size necessary, and we find two possible solutions.

Direct Drive

The stepper motor P430 makes 100 steps/rev and has a holding torque of 60 mNm at nominal current. In combination with a simple L/R type driver this is quite adequate for the application, as peak speed is only 50 rad/s.

$$\frac{50\ rad/s}{2\pi} * 100\ steps/rev = 769\ steps/s$$

Let us determine if the move can be accomplished within the motor pull-in torque range. If yes, we would not need to generate ramps for acceleration and deceleration, and the controller would be substantially simplified.

In order to move the load 0.5 radians with a stepper motor that has a 3.6° / step, it will take the motor 8 steps to make this move.

$$0.5\ rad = 28.65°$$

$$\frac{28.65°}{3.6°} = 8\ steps\ of\ the\ motor$$

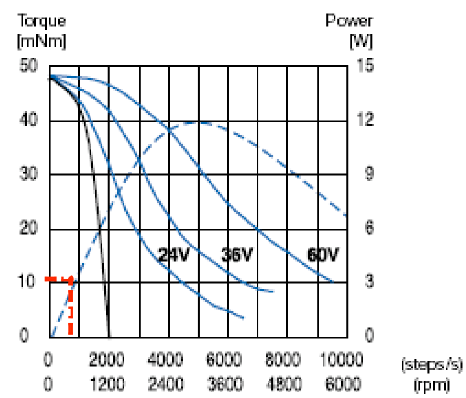
In that case we have in fact a rectangular speed profile and the move requires a constant step rate which is obtained by dividing the distance by the time:

$$\frac{0.5*100}{2\pi * 0.02} = 497.89\ steps/s$$

We must make sure the motor can start at that frequency. The curves on the motor specification page for the Disc Magnet Motor P430 shows with load inertia equal to the rotor inertia of 3 gcm^2, the motor can start at about 1700 steps/s. With load inertia of $20 * 10^{-7}$ kgm^2 this pull-in frequency becomes:

$$f1 = f0\sqrt{\frac{2J_m}{J_m + J_{ch}}} \quad \text{[Hz] (18)}$$

$$f1 = 1{,}700\sqrt{\frac{6}{23}} = 868.28\ steps/s$$



✓ The problem is now solved. Thanks to the disc magnet technology, the P430 motor can do the job quite easily, without needing a ramp, using a very simple controller and an economic driver.

Engineering Section

Examples of Disc Magnet Motor (DMM) calculation

Use of a gearhead

The stepper motor P310 makes 60 steps/rev and has a holding torque 12mNm at nominal current. This is too small for moving the load in a direct drive. However, its mechanical power is more than sufficient. A reduction gearhead can adapt the requirements of the application to the motor capabilities.

Choosing a gearhead and reduction ratio

A first choice consists of matching inertias and then making sure that with the selected ratio, the motor speed remains within a reasonable range, where the necessary torque can be delivered. With incremental motion, an inertial match assures the shortest move time, with the motor providing constant torque over the speed range considered. In our example this asks for a desired ratio i_0 of:

$$i_0 = \sqrt{\frac{J_{ch}}{J_m}} \qquad [-]\ (19)$$

$$i_0 = \sqrt{\frac{20}{0.86}} = 4.82$$

From the various gearhead models available for combination with the P310 stepper motor, we select the K24. This gearhead offers the smallest ratio of 5:1. Using equations (14), (15) and (19) we find:

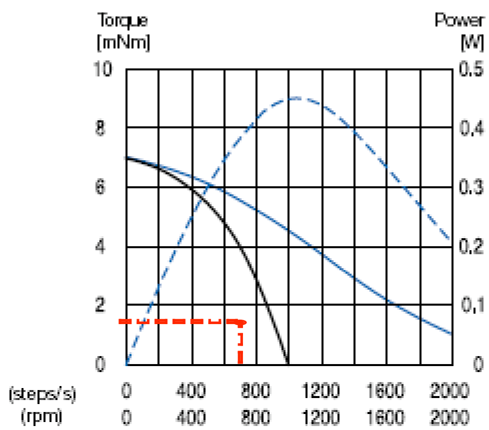
load inertia reflected to the motor shaft of $4.71*10^{-7}$ kgm^2

Motor acceleration = equation [14]

$$\alpha = 2\frac{0.5}{0.02^2} = 2500\ rad/s^2$$

$$\varpi = (2{,}500 rad/s^2) * 0.02 s = 50 rad/s$$

$$\frac{50\ rad/s}{2\pi} * 100\ steps/rev = 769\ steps/s$$



Motor peak speed of 50 rad/s = 477 rpm = 769 steps/s

Necessary motor torque = equation [15]

$$4.71*10^{-7} * 2{,}500 rad/s = 1.2\ mNm$$

✓ The problem is now solved. With the drive circuit at 24V the Disc Magnet gearmotor series P310-158-170 + K24 0 5 with coils in parallel can perform with adequate safety margin. At low step rates the available torque is substantially above the 1.2 mNm required for the triangular speed profile. By adapting this profile to the motor capabilities, the move time can be further reduced.

The smaller P110 motor with the gearhead R16 could also make the move, but would require a driver of very high performance and would be less cost effective for the application.

Examples of Canstack Stepper motor calculation

Note: Use the PULL IN curves if the control circuit provides no acceleration and the load is frictional only.

Example: Drive with a Canstack stepper motor with a frictional torque load
For this application we are looking for a Stepper motor for an intermittent duty application. The application requirements are:

Available voltage:	24 vdc	
Available current:	2 Amp	
Motor operating point	67.5°	[degree] - desired motor position
	15 mNm	[M] - desired motor torque
	< 0.06	[second] - desired move time
	Intermittent operation	

Using a Torque wrench, a frictional load is measured to be 15 mNm. The move profile desired is 67.5° in 0.06 sec. or less.

If a 7.5°/step motor is used, then the motor would have to take nine steps to move 67.5°.

$$\frac{67.5°}{7.5°} = 9steps \qquad v = \frac{9steps}{0.06\sec} = 150steps/\sec$$

In figure 1 below the maximum PULL IN error rate with a torque of 15 mNm is 275 steps/s (it is assumed that no acceleration control is provided).

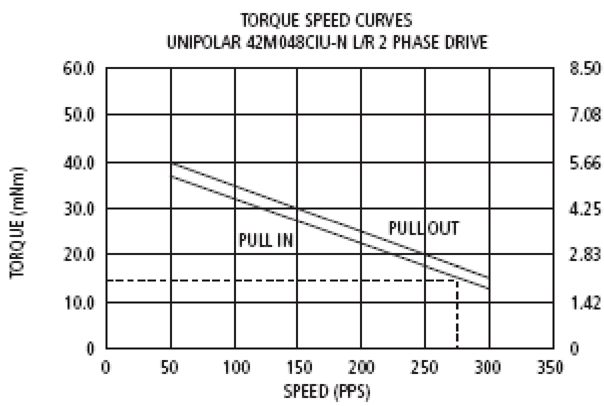


figure1

✓ The problem is now solved. The Canstack motor series 42M048C1U motor could be used at 150 steps/sec – allowing for a safety factor.

Use the PULL OUT curve, in conjunction with a Torque = Inertia x Acceleration (T=Jπ), when the load is inertial and/or acceleration control is provided.

In this equation acceleration or ramping is in rad/s² $\qquad \alpha = \frac{\Delta v}{\Delta t} = rad/s^2$

Engineering Section

Ramping
Acceleration control or ramping is normally accomplished by gating on a voltage controlled oscillator (VCO) and the associated charging capacitor. Varying the RC time constant will give different ramping times. A typical VCO acceleration control frequency plot for an incremental movement with equal acceleration and deceleration time would be as shown below.

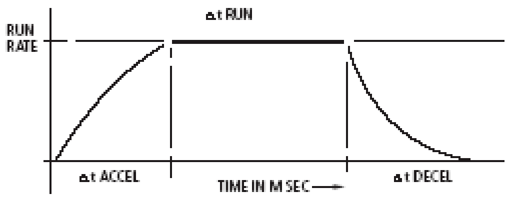


figure2

Acceleration also may be accomplished by changing the timing of the input pulses (frequency).
For example, the frequency could start at a ¼ rate; go to ½ rate, ¾ rate and finally the running rate.

Applications where: Ramping acceleration or deceleration control time is allowed.

$$T_J\,(mNm) = J_T * \frac{\Delta v}{\Delta t} * K$$

Where JT = Rotor inertia (gm²) plus load inertia (gm²)
Δv = Step rate change
Δt = Time allowed for acceleration in seconds

$$K = \frac{2\alpha}{steps/rev}$$

K= .13 for 7.5° - 48 steps/rev.
K= .26 for 15° - 24 steps/rev.
K= .314 for 18° - 20 steps/rev.

In order to solve an application problem using acceleration ramping, it is usually necessary to make several estimates avoiding a procedure similar to the one used to solve the following example:

Example: Frictional torque plus inertial load with acceleration control

For this application we are looking for Stepper motor for an intermittent duty application. The application requirements are:

Available voltage:	24 vdc	
Available current:	3 Amp	
Motor operating point	67.5°	[degree] - desired motor position
	15 mNm (T_f)	[M] – frictional load
	< 0.5	[second] - desired move time
	Intermittent operation	
Motor dimensions	60mm	maximum allowable length
	∅ 60mm	maximum allowable diameter

An assembly device must move 4 mm in less than 0.5 seconds; the motor will drive a leadscrew through a gear reduction. The leadscrew and gear ratio were selected so that 100 steps of a 7.5°/step motor = 4mm.

The total inertial load (rotor + gear + screw) = 25 * 10^4 gm^2.
The frictional load = 15 mNm

(1) Select a stepper motor PULL OUT curve which allows a torque in excess of 15 mNm at a step rate greater than

$$v = \frac{100 steps}{0.5 \sec} = 200 steps / \sec$$

Referring to the figure below, determine the maximum possible friction load only.

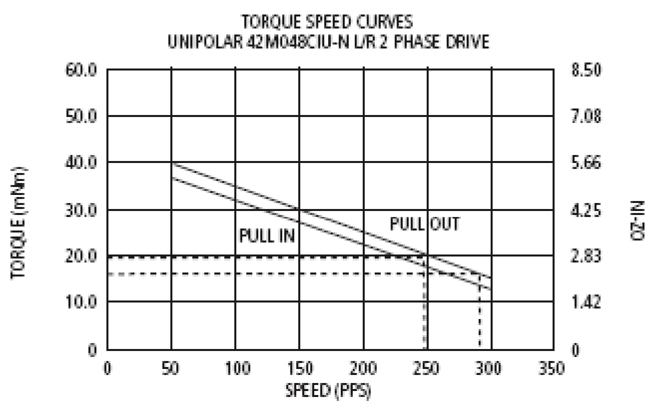


figure3

(2) Make a first estimate of a working rate (a running rate less than the maximum) and determine the torque available to accelerate the inertia (excess over T_F) T_A = Torque available

$$T_A - T_F = 20\ mNm - 15\ mNm = 5\ mNm$$

(3) Using a 60% safety margin
5 mNm * 0.6 = 3 mNm
Calculate Δt to accelerate. (refer to figure 2)

From the equation:

$$T_J\,(mNm) = J_T * \frac{\Delta v}{\Delta t} * K$$

$$\Delta t = \frac{J_T * \Delta v * K}{T_j} = 0.027$$

$$T_J = \frac{25 * 10^4 * 250 * 0.13}{0.027} = 3\ mNm$$

To accelerate Δt = 0.027 sec (note: the same amount of time is allowed to decelerate the load)

(4) The number of steps used to accelerate and decelerate

$$N_A + N_D = \frac{v}{2} * \Delta t * 2$$

< OR >

$$N_A + N_D = v * \Delta t \qquad = 250 * 0.027 = 7 steps$$

(5) The time to move at the run rate
N_T = Total steps/revolution – Step to make the desired move.

$$N_T = 100 - 7 = 93$$

$$\Delta t_{run} = \frac{N_T}{N_A + N_D} = \frac{93}{125 + 125} 0.37\sec$$

(6) The total time to move is as follows:

$$\Delta t_{run} + \Delta t_{accel} + \Delta t_{decel} = t_{total}$$

$$0.37 + 0.027 + 0.027 = 0.42\sec$$

✓ The problem is now solved. The Canstack stepper motor series 42M048C1U is the first estimate. This motor can be moved slower if more of a safety factor is desired.

Example: No ramping acceleration or deceleration control is allowed.

Even though no acceleration time is provided, the stepper can lag a maximum of two steps or 180° electrical degrees. If the motor goes from zero steps/sec to v steps/sec the lag time Δt would be

$$\Delta t = \frac{2}{v} = \sec$$

The torque equation for no acceleration or deceleration is:

$$T_J\,(torque \quad mNm) = J_T * \frac{v^2}{2} * K$$

Where : J_T = Rotor inertia (gm^2) + load inertia (gm^2) = $25*10^4$ gm^2

$$v = steps/\sec\ rate = 250$$

$$K = \frac{2\pi}{step/rev} = \frac{2\pi}{48} = 0.13$$

Example: Friction plus Inertia – No acceleration ramping.

For this application we are looking for Stepper motor for a continuous duty application. The application requirements are: A tape capstan is to be driven by a stepper motor.

Motor operating point	15.3 mNm (T_f)	[M] – frictional load
	$10*10^4$ (J_L)	[gm^2] – load inertia
	continuous operation	

The capstan must rotate in 7.5° increments at a rate of 200 steps/sec.

Since a torque greater than 15.3 mNm at 200 steps/sec is required, consider the CanStack stepper motor series 42M048C1U. (refer to figure 4)

The total inertia= motor rotor inertia + load inertia

$$J_T = J_R + J_L$$

$$= (12.5*10^4 + 10*10^4)\,gm^2$$

$$= 13.5*10^4\,gm^2$$

Engineering Section

(1) Since non acceleration ramping will be utilized, use the following equation:

$$T_J = J_T * \frac{v^2}{2} * K \quad (K = 0.13)$$

$$T_J = 13.5 * 10^4 * \frac{200^2}{2} * 0.13$$

$$T_J = 3.5\ mNm$$

(2) Total torque

$$T_T = T_F + T_J$$

$$T_T = 15.3\ mNm + 3.5\ mNm = 18.8\ mNm$$

(3) Refer to the PULL OUT curve figure (4) at a speed of 200 steps/s, where the available torque is 26 mNm.

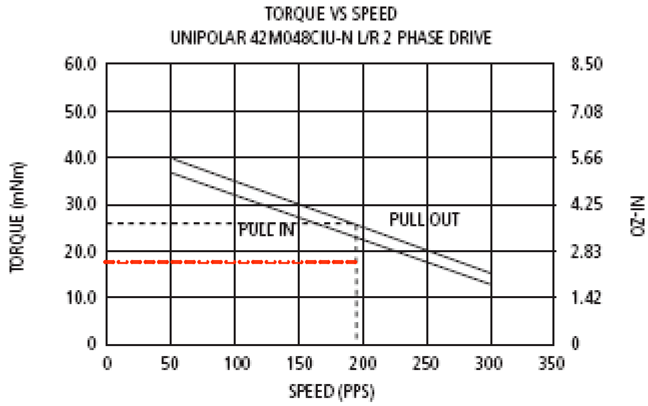


figure4

✓ The problem is now solved. The Canstack stepper motor series 42M048C1U can perform in this application adequately, with a safety margin factor.