PL 3 - DC motors (brushed) - Selection

Objectives: Selection of a PM (permanent magnet) DC, brushed motors, using a step-by-step procedure.

Documents available

PL classes: 1) EN_2237_CXR_DFF.pdf 2) EN_1741_CXR_DFF.pdf

Web sites: www.faulhaber.com

www.maxonmotor.com

https://www.crouzet.com/products/dc-motors/

Selection and sizing of electric motors

The choice and specification of a certain type of electric motor, for a given application, involves several considerations to be taken into account, from the characterization of the requirements imposed by the load to be driven, the power supply and control conditions of the defined driving system and the characteristics of the motor series available. As a first approach, we will consider some general principles and a procedure for dimensioning low-power permanent magnet DC motors, based on the recommendations of manufacturers of this type of electric motor (eg Faulhaber-Micromo; Crouzet...)

A- General principles

(1) Load requirements (constant, variable, …)

(2) Restrictions on maximum temperatures of motor frame and windings

(3) Existing standard motor series

(4) Motor technical specifications:

- power, duty cycle, velocity, torque, voltage, current, …;
- rated and maximum, or minimum, values;
- sizes and weight;
- …

B- Selection and specification of PM-DC, brushed, motors

B1- General characteristics

- Available series of small motors
- High starting torque
- Torque decreases with increasing velocity (motor velocity adjusts to motor load)
- Linear relation between torque and velocity
- Linear relation between torque and current
- Motor efficiency is maximum at high velocities and low torques
- Maximum power is not at maximum efficiency
- Possibility of operation above, or below, the rated values

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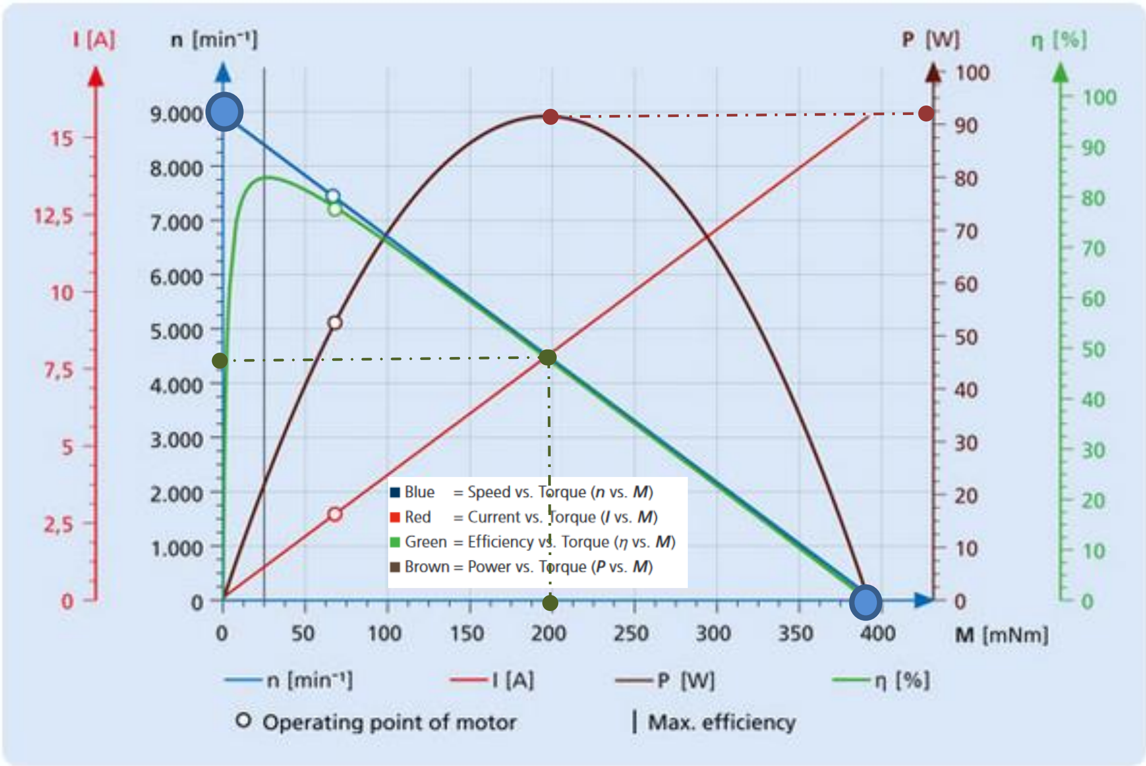
- Example of characteristic curves



Note: Note how all four solid plots change as a result of increased resistance in the copper windings and weakened torque output, due to heat rise. So your results may differ slightly depending on whether your motor is cold or warm when you plot your graphs.

[https://www.faulhaber.com]

Based on this representation, of the characteristic curves, of a permanent magnet DC motor complete below the values for the following characteristics:

(1) Maximum power: ____92 ____ [W]
(2) Maximum torque: ____400______ [mNm] ____0.4____ [Nm]
(3) Maximum velocity: _____9000________ [rpm] _____942__ [rad/s]
(4) Torque at maximum power: _______200___ [mNm] ____0.2____ [Nm]
(5) Velocity at maximum power: _______4500___[rpm] ____471____ [rad/s]

<u>B2- - Some indications regarding variations in the voltage power supply</u>

- Admissible variations: [$0.5 \times V_n < V < 2 \times V_n$]

Note that if used a lower voltage, the motor will have less power. If used a higher voltage, the motor will have higher power but will heat up more (need to check for motor operating temperature and the motor may be only suitable for intermittent operation). (http://cdn.crouzet-motors.com.s3.amazonaws.com/assets/library/DC-brush-motors.pdf)

- Variations between -25% to +50%, the curves T- ω can be considered to be parallel to the T- ω curves based on rated values. The maximum output power is: $P_{max}=P_n\ (V/V_n)^2$; for example, a 20% voltage increase of V_n will give:

$$T_0\big|_{1.2V_n} = 1.2T_0\big|_{V_n}$$

$$\omega_0\big|_{1.2V_n} = 1.2\omega_0\big|_{V_n}$$

$$P_{\max}\big|_{1.2V_n} = 1.44P_{\max}\big|_{V_n}$$

- It can normally be assumed that the torque-velocity-relation does not change when the supply voltage to the motor changes.

B3- Procedure for choosing a brushed DC motor, permanent magnet, under constant load conditions

Step 1: Specifying the power required by the load (P_{load})

Step 2: Specifying the reference value for the motor power (P_{motor})
- higher than the power required by the load (ex. P_{motor} =[1.5 to 2]·P_{load})

Step 3: Selecting a motor from a motor manufacturer's catalogue
- identify the torque-velocity characteristic curves (T, ω), for the available voltage supply
- verify the velocities ratio reference value ($\omega_{load} / \omega_0 > 70\%$)

Step 4: Repeat calculations with data from the selected motor
- include the no-load torque, or current,
- verify the velocity when taken into account the total load (current or torque)

Step 5: Verify the motor heating behavior under the load conditions
- calculate the electric power loss in the armature, due to the current consumption or Joule's law ($P_{loss} = R_a I_{total}^2$)
- calculate the temperature variation associated with the motor's capability to transfer the electric power loss (P_{loss}) to the surrounding environment, using the respective armature and frame thermal resistances (R_{th1} e R_{th2})
- calculate the motor's temperature, taking into account the environment temperature
- check whether the motor can withstand the calculated temperature.

Additional verifications could be required to take into account the frequency of start/stop operations, duty cycle, size, weight, …).

B4- Exercise 1

Using the method described above verify if it is possible to select a motor, from the available catalogue, that is compatible with the following operating conditions:

- *Available supply voltage* $V =$ *30 Volts DC*
- *Load torque* $T =$ *10 mNm*
- *Velocity* $n =$ *6000 rpm*

- Indicate the calculations for each step and represent the characteristic curves, *(T, ω)* and *(T, I)*, of the motor.

Resolution: ex. 1

Based on the presented procedure and the attached motor data, check whether the following conditions can be met for a drive system:

Available voltage (V) = 30 Volts DC

Load torque (T) = 10 mNm

Operating speed (n) = 6000 rpm

- Present the calculations carried out in each step and the motor characteristic curves *(T,ω)* and *(T,I)*.

(1) Determination of required power (P_{load})

$$P_L = ? = T_L \times \omega_L = 10 \times 10^{-3} \times 6000 \times \frac{2\pi}{60} = 6,3\ [W]$$

(2) Chosing motor power (P_{motor})

$$P_{motor} = ? \qquad 9,5\ W \le P_{motor} \le 12,6\ W \qquad\qquad 1,5 \times P_L \le P_{motor} \le 2 \times P_L$$

(3) Selection of a motor by consulting the manufacturer's catalog

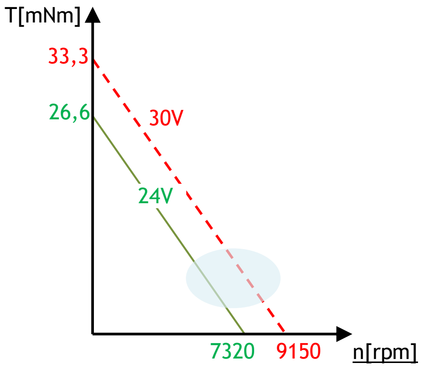
- Manufacturer: Faulhaber, (ref. EN_1741_CXR_DFF.pdf): - motor serie 1741_CXR

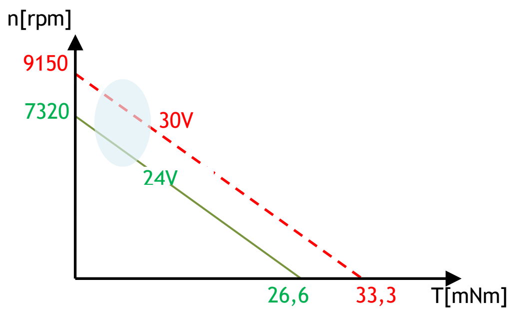
- $P_{motor} = 9\ W$; other data,

$$V_{nominal} = 24\ V \quad \leftarrow [6 - 12 - 16 - 24] ;\ n_0 = 7320\ rpm ;\ T_0 = 26,6 \times 10^{-3}\ Nm$$

$$- V_{available} = 30\ V ;\ n_0^{30V} = 7320 \times \frac{30}{24} = 9150\ rpm ;\ T_0^{30V} = 26,6 \times 10^{-3} \frac{30}{24} = 33,3 \times 10^{-3}\ Nm$$

- *curve Torque-speed (T, ω), or (ω, T), at available supply voltage (30 V)*





- *velocities ratio ($\omega_{carga} / \omega_0 > 70\%$), or recommended operating zone (higher efficiency): low torques (e.g. 10 to 30% of T_0) and high speeds (e.g. 70 to 90% of ω_0)*

$$\frac{n_L}{n_0^{30V}} = \frac{6000}{9150} = 0,66 \approx 70\%$$

(4) Calculations with selected motor

- take into account the torque, or current consumed in the motor by friction (rotation without external load) together with the torque required to activate the load in order to calculate the total torque.

$$T_{total} = T_L + T_{friction} = 10 + 0,4 = 10,4\ mNm$$

$$T_L = 10\ mNm$$

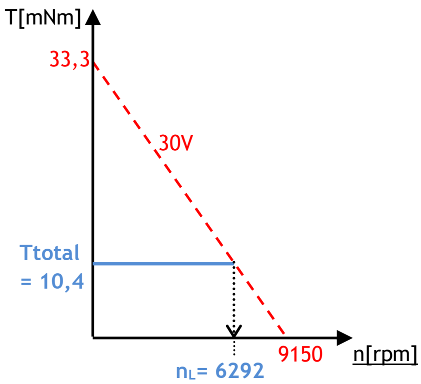
$$T_{friction}\ \therefore\ motor\ data \begin{cases} T_{friction} = T_0 \equiv M_0 = 0,4\ mNm\ ,ou \\ T_{friction} = k_T \times I_0 \equiv k_M \times I_0 = 30,4 \times 0,0132 = 0,4\ mNm \end{cases}$$

- Recheck the motor speed at full current (or full torque)

$$T = T_0 - \frac{T_0}{\omega_0}\,\omega$$

$$\omega = \omega_0 - \frac{\omega_0}{T_0}\,T$$

$$n_L = 9150 - \frac{9150}{33,3}\,10,4 = 6292\ rpm\ \ (OK!)$$



Load speed different from that specified (6000 rpm), however the difference in percentage terms (~5%) can be considered acceptable in this application.

(5) Checking thermal aspects

$$P_{thermal\ loss} = P_J = R_a \times I_{total}^2 = 26,4 \times 0,342^2 = 3,09\ W$$

$$I_{total} = I_{friction} + I_{load} = 0,0132 + 0,329\ [A];\quad \begin{cases} I_{friction} = I_0 = 0,0132\ [A] \\ I_{load} = \dfrac{T_{load}}{k_T} \equiv \dfrac{T_{load}}{k_M} = \dfrac{10}{30.4} = 0,329\ [A] \end{cases}$$

$$R_a = 26,4\ \Omega$$

$$\Delta T = P_J \times (\mathcal{R}_{TH1} + \mathcal{R}_{TH2}) = 3,09 \times (7,2 + 21) = 87,1\ ℃$$

$$T_{motor} = T_{ambiente} + \Delta T = 22\ ℃ + 87,1\ ℃ = 109,1℃$$

$$T_{máx.motor} = 100\ ℃\quad T_{motor} > T_{máx.motor}$$

$$T_{motor} > T_{máx.motor}\ \ \therefore$$

The analyzed motor cannot be used in this application, since in continuous operation it will reach a temperature higher than permitted. It is necessary to choose another motor, starting with a larger size.

(6) Students are asked to analyze other motors from the same manufacturer (or others) and repeat the procedure from step (3).

Motors serie 2237__CXR *(Ref.:EN_2237_CXR_DFF.pdf)*

Alternative 1: 2237024CXR	11,9 W, 12,4 mNm Vn = 24 V	Alternative 2: 2237036CXR	11,9W, 12,4 mNm Vn = 36 V
$V_{available}$	*30V*	$V_{available}$	*30V*
n_{load}	*7131 rpm*	n_{load}	*4469 rpm*
T_{motor}	*67,2 ºC*	T_{motor}	*66,7 ºC*

Comments:

1- ***Any of these new motors alternatives can operate continuously in ambient temperature of 22º.***
2- ***The rotation speed is significantly different from the desired speed, 19% in the case of alternative 1 and 26% in the case of alternative 2.***
3- ***The choice of a "standard" motor, from a given manufacturer, may require considering changes in some of the conditions initially imposed, for example:***
   a) ***Change the voltage to be used to power the motor, so that it is closer to the nominal voltage of the available motors;***
   b) ***Consider the use of a reducer to allow the motor to be used closer to its maximum speed, that is, in the highest efficiency zone.***
   c) ***Accept speed variations depending on the load. Alternatively consider using a speed controller.***
   d) ***It may also be justified to analyze motors from other manufacturers.***

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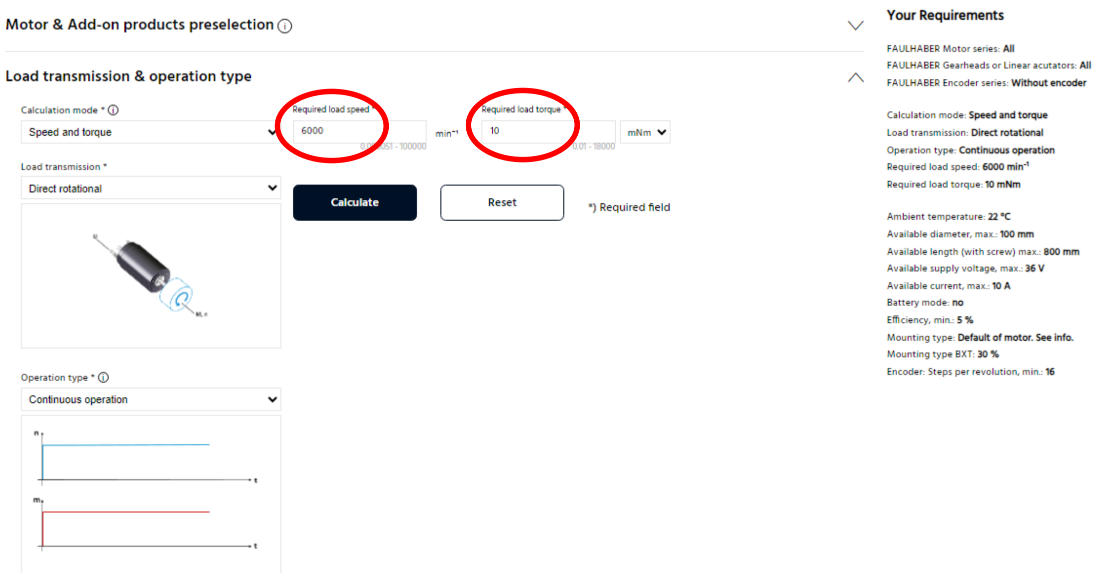
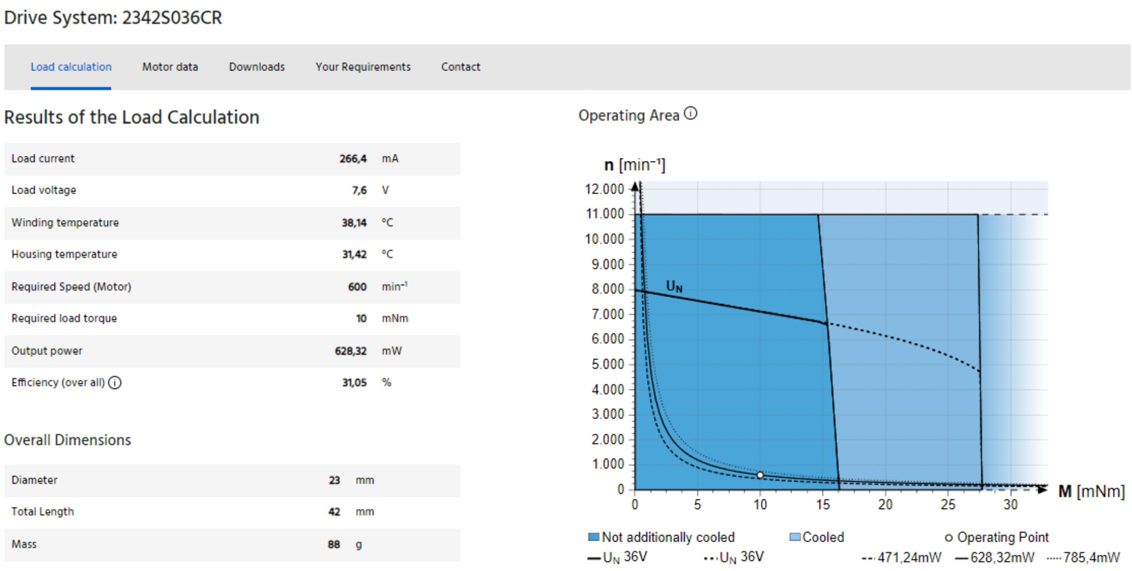
Alternative calculation using the FAULHABER Drive Calculator ([Start FAULHABER Drive Calculator])



With this specification, the app returns multiple possible solutions, with motors having diameters ranging from 16 up to 44 mm, being powered from distinct voltages. Note that to achieve the required operating conditions, a driver is required to adjust the voltage supplied to the motor

Selecting one of the possible solutions (Drive System: 2342S036CR) , the following data can be obtained:



Results of the Load Calculation

Load current	266,4	mA
Load voltage	7,6	V
Winding temperature	38,14	°C
Housing temperature	31,42	°C
Required Speed (Motor)	600	min⁻¹
Required load torque	10	mNm
Output power	628,32	mW
Efficiency (over all)	31,05	%

Overall Dimensions

Diameter	23	mm
Total Length	42	mm
Mass	88	g

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Drive Electronics

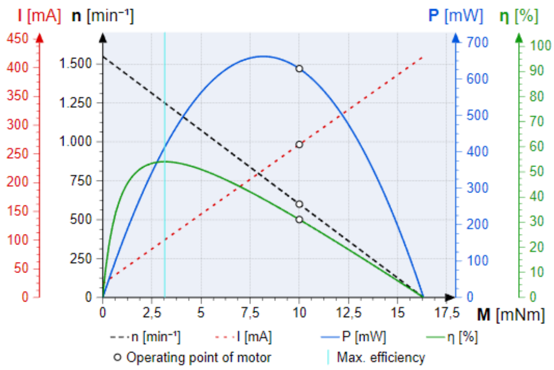
Motion Controllers

Series MC 3001 B
CiA402 servo drive, 4-Quadrant PWM, with RS232, CANopen or EtherCAT interface
Product details >
Data sheet (PDF)

Series MC 3001 P
CiA402 servo drive, 4-Quadrant PWM, with RS232 or CANopen interface
Product details >
Data sheet (PDF)

Series MC 3602 B
CiA402 servo drive, 4-Quadrant PWM, with RS232, CANopen or EtherCAT interface
Product details >
Data sheet (PDF)

Characteristic curves of motor



Series MC 3603 S
CiA402 servo drive, 4-Quadrant PWM, with RS232, CANopen or EtherCAT interface
Product details >
Data sheet (PDF)

Series MC 3606 B
CiA402 servo drive, 4-Quadrant PWM, with RS232, CANopen or EtherCAT interface
Product details >
Data sheet (PDF)

Series MC 5004 P
CiA402 servo drive, 4-Quadrant PWM, with RS232, CANopen or EtherCAT interface
Product details >
Data sheet (PDF)

Series MC 5005 S
CiA402 servo drive, 4-Quadrant PWM, with RS232, CANopen or EtherCAT interface
Product details >
Data sheet (PDF)

Speed Controllers

Series SC 2402 P
2-Quadrant PWM configurable via PC
Product details >
Data sheet (PDF)

Series SC 2804 S
2-Quadrant PWM configurable via PC
Product details >
Data sheet (PDF)

Series SC 5004 P
4-Quadrant PWM configurable via PC
Product details >
Data sheet (PDF)

Drive System: 2342S036CR

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Motor Characteristic Data

(2342S036CR)

Nominal voltage	36	V
Terminal resistance	15,9	Ω
Torque constant	42	mNm/A
No load speed	8.110	min⁻¹
Stall torque	92,9	mNm
Speed constant	228	min⁻¹/V
Rotor inductance	0,57	mH
Slope of n-M curve	86,1	min⁻¹/mNm
Rotor inertia	6,5	gcm²
Mechanical time constant	6	ms
Mounting type	55	%
Efficiency max. ⓘ	79	%