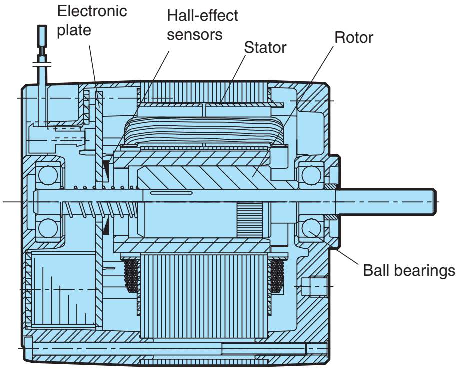
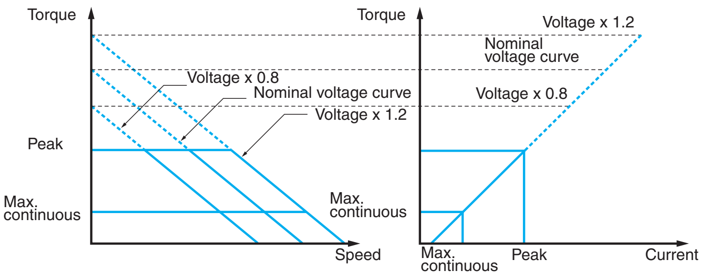
Principle

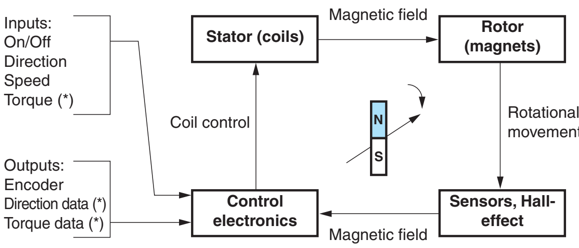
D.C. brushless motors principally comprise a wound stator and a permanent magnet rotor. They differ from D.C. brushed motors, which have stator magnets and rotor windings together with a commutator, which switches over the power supply to the coils according to the position of the rotor. Brushless motors require control electronics to carry out this switching.

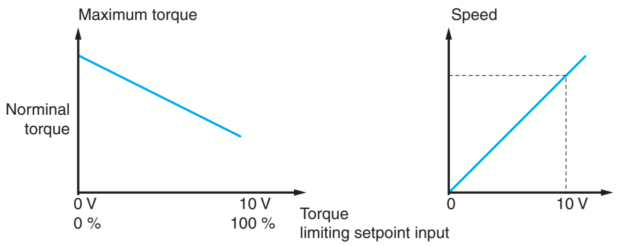


Since brushed DC and brushless DC structures are similar, the performances obtained are of the same type. Linear curves, performances varying according to the supply voltage.



By introducing an electronic circuit to support the Hall-effect sensors inside the motor (they decode the position of the rotor so that the control electronics know when to switch over the coils), additional functions (e.g. a temperature probe) or even in some cases the control electronics themselves can be added.
The motor performance is very closely linked to the control electronics (current and speed limiting, control loop settings, etc.).

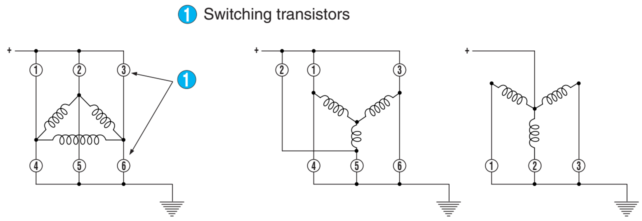




Customer requirements vary so widely in terms of functions, simplicity, connections, dimensions, price ranges, etc., that it is impossible to provide a single electronics system to meet every requirement.
That is why Crouzet offers a range of brushless motors without electronics (allowing the customer to use its own electronics system with its specific characteristics) or with internal control electronics, or with control electronics external to the motor.
The control electronics are designed and manufactured by Crouzet Automatismes too. We are therefore able to offer our customers tailored software adaptations to further improve operation in the machines or even to integrate the machine functions.

Motors without electronics

Brushless motors are generally designed with a 3-phase configuration (3 coils, 3 output leads) because the efficiency is better, the torque less pulsed and the control more accurate.
All the brushless motors in our range are 3-phase motors.
The coils are interconnected in the motor in a delta or star configuration.



The motors can be supplied with power at any supply voltage within the limits of their isolation system (a dielectric strength of 500 V means that the motor must not be supplied with a supply voltage above 75 V DC in accordance with European regulations).

The performance of a motor is determined by the following factors:
- The capacity to deliver the highest possible torque without overheating (causing the coils to be destroyed). We refer here to torque peak and maximum continuous torque
- Within the smallest possible dimensions (motor diameter and length)
- With the lowest possible electrical power consumption. We refer here to motor constant (= torque/UI½).

This key data is not dependent on the motor winding; it is linked to the size of the motor, the magnets (shape and performance), the quality of the magnetic steel sheets, the shapes of the poles, the air gap, etc., all of which are independent of the winding.

The speed is obtained by altering the supply voltage or the winding resistance (number of turns, diameter).
Speeds and currents vary according to the windings and the supply voltages used.
The most important values are the electromotive force produced by the magnets in the coils, the resistance and the inductance of the motor, which reduce the build-up of current.

Some explanations of the data provided in the catalogue:

➜ Maximum speed

Above this speed, mechanical problems may damage the rotor (centrifugal force on the magnets). Higher speeds are available on special request (we can use our expertise to obtain speeds of up to 100,000 rpm).
A common error:
Confusing the maximum speed with the motor speed

➜ Speed of rotation

The speed of rotation of the motor depends on the supply voltage that you use and the torque that the motor has to deliver, depending on your machine. Therefore the speed has to be calculated. All Crouzet sales staff have tools for doing this. However, a good approximation can be obtained using the following equation:
Voltage = speed x EMF constant + resistance x torque / torque constant

➜ Torque peak

This is the torque that can be delivered for 10 seconds without exceeding a temperature of 125/155°C in the motor windings (starting from cold).

➜ Maximum continuous torque

Maximum torque that can safely be produced continuously. This value is measured with the motor mounted on an aluminium heatsink until the windings reach a temperature of 125/155°C.
All torque values are given at rest; the actual torque for the user varies according to the speed because the losses (bearing friction + iron losses) vary according to the speed.

➜ Motor constant

= Torque peak/(UI)½
This describes the ability of the motor to deliver a torque with very little energy (it replaces the concept of efficiency when the speed is zero).
The higher the constant, the better the motor.

➜ Electrical time constant

= L/R = time taken for the current to build up in the motor (at 63% of the value)
This value is used by electronics designers to determine how to adjust their current controller, etc.

➜ Mechanical time constant

This is the time taken by the motor to reach 63% of its stabilised speed (with the torque limited to the "torque peak").
It is an indicative value because it changes as soon as the user adds the inertia of his application.

➜ Energy losses at torque peak

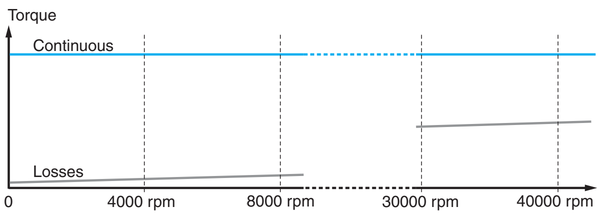
= R x Ipeak^2 = Theoretical energy losses at torque peak (cold motor)
Used to calculate the "motor constant".

➜ Torque/speed factor (at zero impedance)

This is the theoretical slope of the torque/speed curve when the inductive effect of the winding is discounted.
This slope is therefore a "true" value at very low speeds when inductance is negligible.
However, it can only be used when the motor is running at high speed. Nevertheless it does allow different motors to be compared.

➜ Friction torque

This is a "friction-equivalent torque" representing the total value of the losses to be deducted from the peak and continuous torques.
Its typical shape is as follows:



For speeds below 10000 rpm its value is low. In this case the calculations are simplified by assuming it to be constant.

➜ Rotor inertia

The inertias (application + rotor) create an over-torque to be delivered by the motor when the speed value changes.
So these inertias have to be known before the overtorques can be calculated.

As a general rule, the torque peak requirement is determined by the sum of the inertias (returned to the rotor) x the maximum acceleration required.
Cpeak >= total inertia x max. acceleration

➜ Thermal resistance

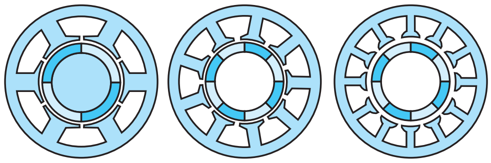
This value is used to quickly determine the temperature of the winding based on the current consumption in the steady state.
It is obtained from the following calculation:
Rth = ((hot resistance) x (I constant torque)^2)/(max. winding temp. - 25°C)

➜ Max. winding temperature

Value not to be exceeded in order to prevent damage to the components adjacent to the coils (rotor magnets or winding)

➜ Number of poles

This is the number of north and south poles of the rotor magnets. It can be 2 or 4 or 6 or 8, etc.
The higher the number, the easier it is to control the motor at low speed.
The lower the number, the less influence the inductance has at high speed.



➜ Resistance

Value measured between 2 motor leads when the motor is cold
Its value varies with the actual temperature of the windings

➜ Voltage at torque peak

Theoretical voltage to apply in order to obtain sufficient current to deliver the torque peak AT REST.
Be careful not to make this common error:
Confusing it with the supply voltage necessary to turn the motor

➜ Current at torque peak

Theoretical value of the current to deliver the torque peak.
Check that the power supply and the control electronics are compatible with the maximum current you require (at torque peak or below, depending on the application).

➜ Torque constant

= Torque/current = constant if the torque is the "magnetic motor torque"
It is therefore the torque delivered by the motor in the application + the "friction-equivalent" torque due to friction losses in the bearings and the iron losses.
NB: Torque constant (Nm) = EMF constant (rd/s)

➜ EMF

Back electromotive force
This derives directly from the rotor magnets which turn in front of the coils, thereby creating an induced voltage.
It is proportional to the speed and is alternating in the coils but only the upper part is used owing to the switching electronics.
The difference in voltage between the power supply and the back electromotive force allows a current to be generated and a motor torque to be obtained.

➜ Inductance

All windings have an inductance. The inductance has a natural tendency to oppose the rapid changes in the current passing through the windings.
The higher the speed of the motor, the faster the currents are inverted in the windings and the more the inductance limits the value of the current.

Key points when choosing a motor:

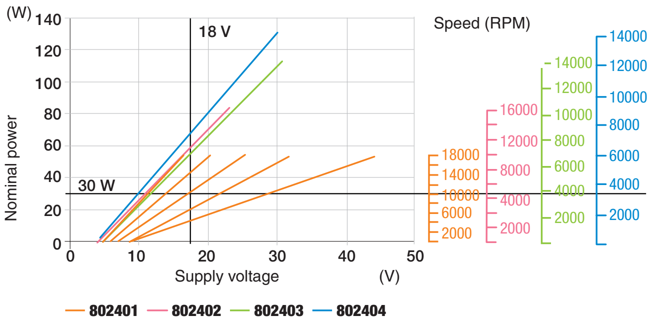
➜ For "stabilised speed" drives

The torque value to be delivered must be less than the "maximum continuous torque - friction-equivalent torque".
From the Power/Speed table choose the most appropriate winding for your application according to the supply voltage.
The lower the motor resistance, the lower the supply voltage needed to reach high speeds. This catalogue contains the low-resistance windings. The curves also show other resistance values which are available as standard. Please refer to the Crouzet Automatismes website for information about their characteristics.
The lowest resistances also work at higher voltages since the control electronics adjust the speed of rotation according to your settings.
The most suitable winding for your application will be one with a resistance slightly less than but close to your requirement. In this case the control electronics switch the lowest currents and the efficiency is improved.

➜ Example of how to choose a winding

- "Stabilised speed" operation: Required speed: 4000 rpm under 18 volts at 0.071 Nm. This equates to a nominal power requirement of 4000 x 0.071 x 2Pi/60 = 30 W

If we take the curves for a motor which delivers slightly less than 0.071 Nm in continuous operation, we can read directly from the curves.

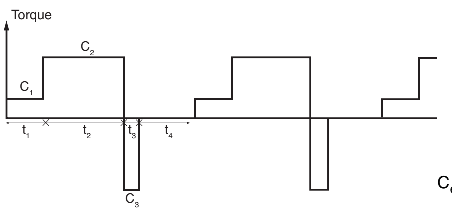


From reading the curves we see that motors 802401 and 802402 need to run at speeds above 4000 rpm in order to reach 30 W (9000 and 5000 rpm). They are not suitable.
By contrast, motors 802403 and 802404 reach 30 W at speeds above 3500 and 3000 rpm respectively. These two motors are able to deliver the necessary power. 4000 rpm is "above" the 30 W line.
Now we need to check whether there is a winding that will allow operation with electronics operating at 18 volts. The answer is yes, the two motors need a voltage greater than or equal to 11 and 13 volts to run at 4000 rpm. Their curves are to the left of the 18 V line at 4000 rpm.
Now in order to allow for production tolerances and temperature-related changes in characteristics, we take a safety margin of 20% on the value of the torque (and therefore of the power). We therefore require a power of 36 W (30 x 1.2).
On that basis only motor 802404 is suitable.
The curves included in this catalogue take account of the inductive effect of the motor on high-speed performance and can therefore be used directly.

➜ "Accelerating/decelerating" operation

- Determining the torque peak requirement:
This depends on the inertias to be driven and the accelerations required in the application. The torque peak of the motor has to be greater than or equal to the total inertia to be driven (application + motor) x acceleration.
Cpeak (Nm) >= Inertia (kgm^2) x acceleration (rad/s^2).

- Determining the continuous torque requirement:
This involves determining what will cause the motor to "heat up". We therefore simply calculate the RMS torque to be delivered.



$$C_{eff} = \sqrt{\frac{C_1^2\, t_1 + C_2^2\, t_2 + C_3^2\, t_3}{t_1 + t_2 + t_3 + t_4}}$$

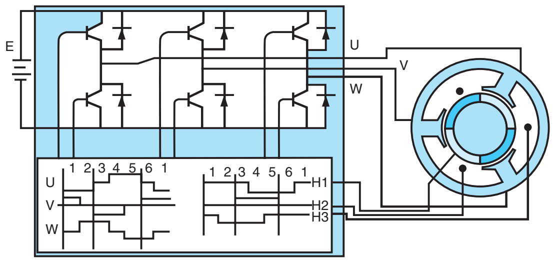
- Determining the motor winding
Once a motor has been chosen on the basis of its torque capacities, the required winding must be determined. This depends of course on the supply voltage to be used. The higher the voltage or the lower the resistance of the winding, the higher the maximum possible speed and the higher the current in the motor. At the same time, the higher the current, the more expensive the control circuit (transistors and EMC). It is therefore important to choose the right winding.
"Accelerating/decelerating" operations generally take place at relatively low speed where the inductive effect of the motors is virtually non-existent. It is therefore sufficient for the chosen winding to satisfy the following equation: U-EMF > R x current.
In other words:
Voltage - (EMF constant x speed) > resistance x torque/(torque constant)
This applies to each (torque and max. speed at this torque) in the application.
To avoid having to test every winding, they can be preselected by only choosing those for which: EMF constant < voltage/max. speed

Motors with control electronics

There are many different brushless motor commands. They can be very simple or very complex.
The Crouzet control electronics included in this catalogue are designed to build many useful functions into the applications while remaining easy to use.

➜ Power section and switching logic

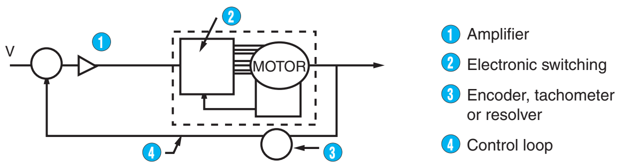
All the control electronics include this section. Without them the motor cannot operate. They are both necessary and sufficient to run the motor.



Brushless motors with "2-wire" control electronics integrated into the motor are of this type.
The characteristics of the motor are similar to those of a D.C. motor. On start-up the motor builds up speed and tries to reach its no-load speed (the speed at which the EMF is virtually equal to the supply voltage), but the torque to be delivered to run the application limits it to a lower speed. When the machine torque varies, the motor speed varies correspondingly.

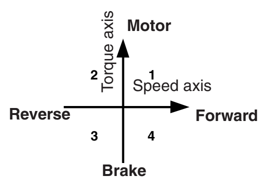
➜ Speed control

In order to have different speeds of rotation it is useful to have a speed control system which takes account of a setpoint fixed by the user.
A logic block is added to the control electronics to break up the supply voltage in the motor, thereby lowering the average voltage sent to the motor. This results in a drop in the "torque/speed" curve proportional to this setpoint. This type of control is called "open-loop control".
If the actual speed of the motor is also taken into account and compared with the setpoint, the control block automatically adapts the average voltage to maintain a constant speed, regardless of fluctuations in the torque being supplied to the machine. This type of control is called "closed-loop control".
Depending on the accuracy of the information about the "actual speed" of the motor, the motor speed control will be more or less accurate. Depending on the control parameters and the inertias to be driven, the control dynamics will be faster or slower.
The most cost-effective closed-loop speed controls use position information provided by the 3 Hall-effect sensors. More sophisticated speed controls require an encoder or tachometer outside the motor.



All the Crouzet control electronics included in this catalogue have a closed-loop speed control block which uses information from the Hall-effect sensors. There is therefore no need for an external encoder. Open-loop controls can be made to order.
The setpoints are either voltages (voltage supplied by a potentiometer) or PWM (fixed frequency with a variable cyclical ratio supplied by a PLC), sometimes both.

As well as influencing the average voltage sent to the motor, speed controls can also take into account the option of braking or not braking the motor when its speed is above the setpoint.
This is known as 2-quadrant control (without braking) or 4-quadrant control (with braking).



➜ Torque limiting/control

Since the torque is linked directly to the current passing through the motor coils, limiting the current directly limits the value of the torque that can be delivered by the motor. This function is used to deliberately check the motor at certain moments in the operation of a system:

- If there is a risk of encountering an end stop or jamming, to prevent damage to the system:
- To generate an acceleration ramp
- To maintain a force (holding in position or pressed against an end stop)
- To control the tension of a tape, a display or a conveyor belt in the case of a drive between two motors

When the torque limiting function triggers a **"torque limit reached" information output**, it is easy to create automation systems which self teach the position of the operating limit stops when the machine starts up.

➜ Current drawn

The currents drawn by the control electronics depend on the motors being driven and the torques to be delivered of course, but also on the speed control. When the electronics are not limiting the motor speed, the current absorbed is more or less equal to the current passing through the motor. When the control system reduces the motor speed (without changing the torque to be delivered), the current drawn by the electronics also falls.
Therefore the current drawn by the speed control electronics is no longer representative of the torque delivered by the motor. Only the currents sent to the windings are representative.

➜ Emergency stop by short-circuit

In order to stop the brushless motor as quickly as possible, the control electronics disconnect the motor from the power supply and short-circuit all the windings.
The EMF generated in the windings self-locks the motor very quickly by creating currents which are no longer limited by the control electronics. These currents trigger very high braking torques (NB: risk of weakening or mechanical damage to the machine). The kinetic energy is then dissipated as joule effect in the motor.
Since the braking torque decreases with the speed of rotation of the motor, depending on the application it may be useful to ensure a clean stop by means of a "position-holding torque" triggered at very low speed.

➜ Braking

Braking means absorbing the energy of the mechanical system. There are several different types of braking, depending on the use made of this absorbed energy:
Regenerative braking converts the energy of the system into electrical current, which will be directed to the motor power supply.
Apart from batteries, most commercially available power supplies do not accept this type of current feedback (they are known as non-reversible). It is therefore necessary to ensure that the directed current can be consumed by another device, without which the power supply may be damaged or may trip its protection systems.
This type of braking is offered as standard in Crouzet external control circuits. The BDE40 electronics include a system for absorbing this directed energy using an external braking resistor.
By contrast, control circuits built into the motor have 'non-regenerative' braking as standard. This means that on braking the kinetic energy of the system is converted into heat inside the motor itself, with no feedback to the power supply. This is the most suitable type of braking for most applications.
However, if there is prolonged braking, the heat that is generated may trip the thermal protection of the motor. For high inertia applications, or operation as a generator:
PLEASE CONSULT CROUZET. Depending on the circumstances, our specialists will advise you to select either 2-quadrant control or regenerative braking.

➜ Position holding

In applications requiring the position of a machine to be held when the motor is stopped (load lifting, barrier, turnstile), the "position holding" function is useful. In this function the motor is powered with a speed setpoint equal to zero. Torque limiting is therefore in operation, preventing the motor from running.
This function is also useful in cases where the motor is to be stopped completely after a deceleration. With speed control from an encoder generating a few pulses per revolution, it is difficult to determine the actual speed of the motor when it is close to zero. In order to stop at a fixed position, starting "position holding" when the speed drops below 100 rpm and the target position has been reached simplifies the settings.

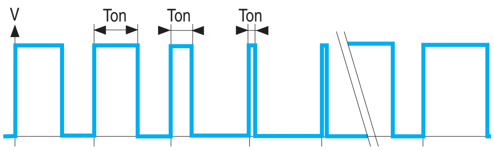
➜ 0-10 V or PWM controls

If you want to control the motor from a potentiometer, it is advisable to choose a voltage control (0-10 V for example). For controls from a PLC, on the other hand, it is more customary (and less expensive) to use PWM control. For that reason we also offer electronics that are compatible with PWM controls.

➜ PWM control

PWM (Pulse Width Modulation) control is a method of indicating the speed setpoint to the motor. **A PWM control motor should be chosen in the following cases:**

- Control by CROUZET Millenium logic controllers (see MOTOMATE information)
- Control by PLC with PWM outputs
- Control by digital control system



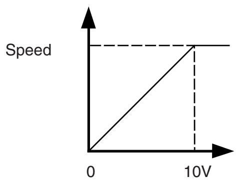
PWM control consists of pulse trains of fixed frequency (period "T") but variable width ("Ton" period of the pulse). The speed setpoint depends on the Ton/T ratio. However, it is independent of the voltage or frequency of the pulses, within the limits of the stated specifications.

Ton/T = 0%	Speed setpoint = 0
Ton/T = 100%	Speed setpoint = No-load speed of the motor
Ton/T = 50%	Speed setpoint = No-load speed of the motor/2

➜ 0-10 V control

0-10 V voltage control is the other method of indicating the speed setpoint to the motor. **A 0-10 V input motor should be chosen in the following cases:**

- Control by potentiometer
- Control by PLC with analogue converter outputs
- Control by analogue control system



In this type of control, the speed setpoint depends on the voltage U at the speed setpoint input:

U = 0	Speed setpoint = 0
U ≥ 10 V	Speed setpoint = No-load speed of the motor
U = 5 V	Speed setpoint = No-load speed of the motor/2

➜ Creating automation systems

With a motor and control electronics which can be used to control speed, forces and the direction of movement, to accelerate and decelerate and count up and down the distance covered, it is easy to create automation systems from a PLC. Examples include the position control of a 1/4 turn or multiturn valve, creating a door opening/closing system, controlling and actuating a scrolling advertising banner, etc...
For simple applications Crouzet Automatismes can simplify your applications still further by integrating the functions of your application into the control electronics of the brushless motor. The BDE 40 electronic card, for example, has an oversize memory so that it can accommodate all your requirements. The control card inputs and outputs are then revised and modified to make your machine even more simple.