IRONLESS DC MOTOR BASICS

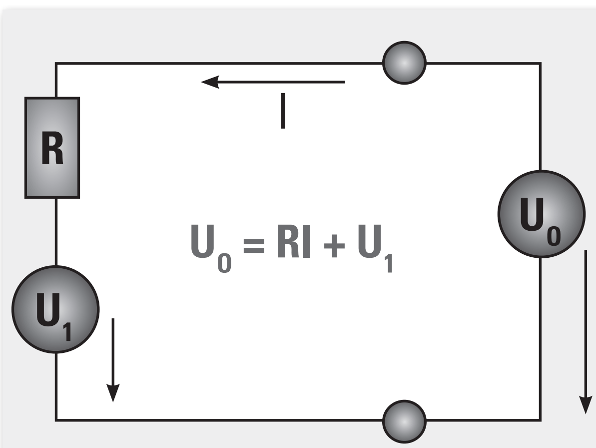
Technical Note

Brushed DC ironless motors are found in a large variety of products and applications such as medical, robotics, factory automation, security and access, civil aviation and aerospace products.

The ironless technology surpasses by far the performance of conventional ironcore brushed DC motors. The main advantages of this unique concept are: absence of iron losses, low friction and a good thermal dissipation, resulting in a very efficient motor — meaning a perfect choice for battery-operated equipment. The design of the low inertia rotor enables very high acceleration and fast reaction time. Finally the linear torque-speed characteristics make the motor very easy to drive.

This article is a brief technical introduction on ironless DC motors. It is intended to help engineers better understand the brushed DC ironless motor basics and to help them to select the best motor for their application.

1. The basic equations of the brush DC ironless motors: A motor with ironless rotor can be represented by the following simplified diagram.



U_0 = power supply voltage, V
I = current, A
V_i = voltage (EMF) inducted in the rotor, V
R = winding resistance, Ohms

The voltage induced in the rotor is proportional to the angular velocity of the rotor:

$U_i = k * \omega$

k: torque constant   ω: angular velocity

So the resulting equation is:

$U = R * I + k * \omega$
(V) (Ω) (A) (Nm/a) (rd/s)

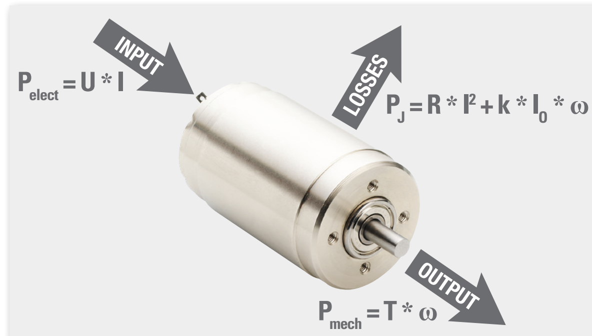
The particularity of the ironless DC motor is such that the speed and torque function are linear. The speed is proportional to the voltage and the torque is proportional to the current:

$T = k * (I - I_0)$
(Nm) (Nm/A) (A) (A)

I: armature current I_0: no load current

2. How to determine the mechanical power, the electrical power and the efficiency:

The mechanical power developed by the motor is equal to the sum electrical power given to the motor and the power dissipated (heat): $P_{elect} = P_{mech} + P_J$

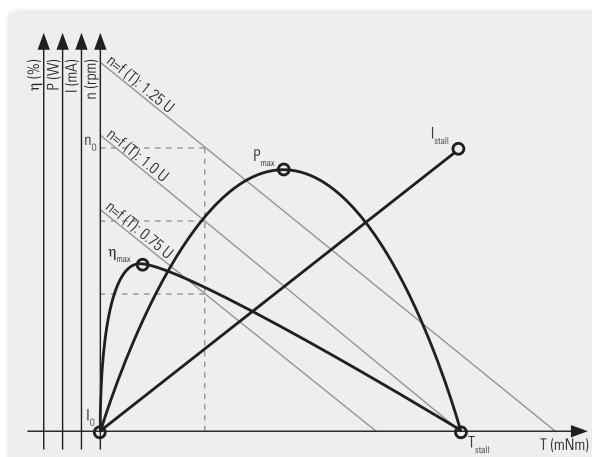


The efficiency is defined by the ratio of the mechanical power and the electrical power: $\eta = P_{mech} / P_{elect}$

The efficiency of a brushed DC coreless motor may reach up to 90%.

Remember: the highest efficiency is obtained at high speed.

3. Understand the equations - four things to remember:



η : efficiency   n: speed   P: power   I: current

#1: The current in the motor is proportional to the motor torque.
#2: The speed of the motor is proportional to supply voltage (U).
#3: The maximum efficiency is obtained at high speed.
#4: The maximum mechanical power reaches its maximum when the load torque is equal to half the stall torque.

Portescap
110 Westtown Road
West Chester, PA 19382
T: +1 610 235 5499
F: +1 610 696 4598
www.portescap.com

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4. How to determine the rotor temperature and the rotor resistance at this temperature:

(Brushed DC coreless motor maximum coil temperature is usually rated to 155° C.)

$$T_r = \frac{R_{22} * I^2 * (R_{th1} + R_{th2}) * (1\text{-}22\ \alpha) + T_a}{1 - \alpha * R_{22} * I_2 * (R_{th1} + R_{th2})}$$

$$R = R_{22} * (1 + \alpha * \Delta_{Temp})$$

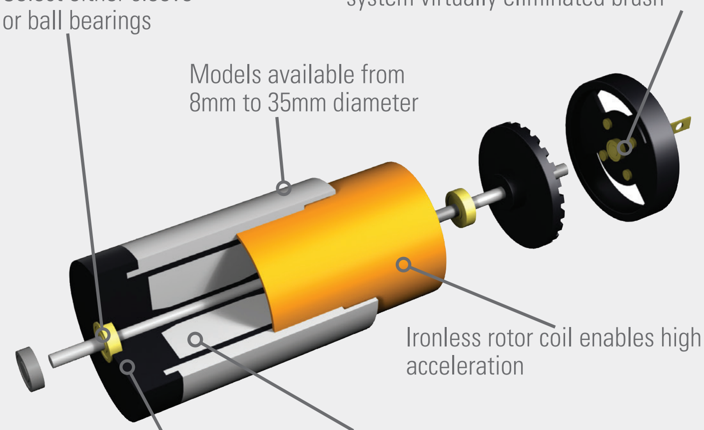
T_r: temperature of the rotor (°C)
R_{22}: motor resistance at 22° C (Ohms) - catalog value
I: current (A)
R_{th1}: thermal resistance rotor/body (°C/W) -catalog value
R_{th2}: thermal resistance body/ambient (°C/W) -catalog value
α: thermal coefficient of the resistance of copper (0.0039/°C)
T_a: ambient temperature (°C)
R: resistance (Ohms)
$\Delta_{Temp} = T_r - 22$

5. How to determine the time constant of the system and the starting time of a brushed DC ironless motor (voltage driven):

$\tau = \tau_M * (1 + J_L / J_M)$ $t = \tau * l_n (\omega_1 / (\omega^1 - \omega))$

τ: time constant of the motor + load (ms)
τ_M: time constant of the motor alone (ms) – catalog value
J_L: inertia of the load (kgm2)
J_M: inertia of the motor (kgm2) – catalog value
t: starting time (ms)
ω_1: angular velocity obtained after an infinite time (rd/s)
ω: angular velocity (rd/s) after a time = t

6. The Portescap Brushed DC Ironless technology in one glance:



CONCEPT DETAIL	MOTOR CHARACTERISTICS	ADVANTAGES FOR THE APPLICATIONS
Ironless Rotor	Low moment of inertia	High acceleration, Ideal for incremental motion Linear speed-torque function, Insensitive to shocks
	No hysteresis and eddy current losses	High efficiency, low losses from friction only Ideal for battery operation
	No magnetic saturation	High peak torques without the risk of demagnetization
Central Stator Magnet	High power per size and per weight	Ideal for portable or small equipment or requiring small dimenions
Small Sized Bearings	Low viscous damping	High peak speeds, very low speed dependent losses
	Low starting voltage	
Precious Metal Commutation System	Low friction, little electrical noise	Low losses and wear, low electromagnetic interference
Ratafente™ Series Copper-Graphic Commutation	High current densities may be commutated	High continuous and peak torques without the risk of demagnetizing the motor. Very long life. Ideal for chopper drives.
	Rated motor temperature up to 155°C	Continuous torque is exceptionally high for motor size, reducing the weight, dimensions, and the cooling system.
	Very compact commutation system	Excellent resistance to shocks and vibration
	High torque to inertia ratio	High acceleration, short mechanical time constant

7. How to select the appropriate Brush DC motor? Let's take a look, using a miniature air pump application as an example.

At 6 volts, 0.6 A battery-operated miniature air pump needs to have a flow range of 850 - 2500 cc/min which is equivalent to:

T = 3mNm of torque at 9'000 rpm (ω = 942.5 rd/s).

The requested mechanical power is:

$P_{mech} = T * \omega = 0.003 * 942.5 = 2.82$ W

Portescap 16G brushed DC motor series is rated for 5W maximum output power.

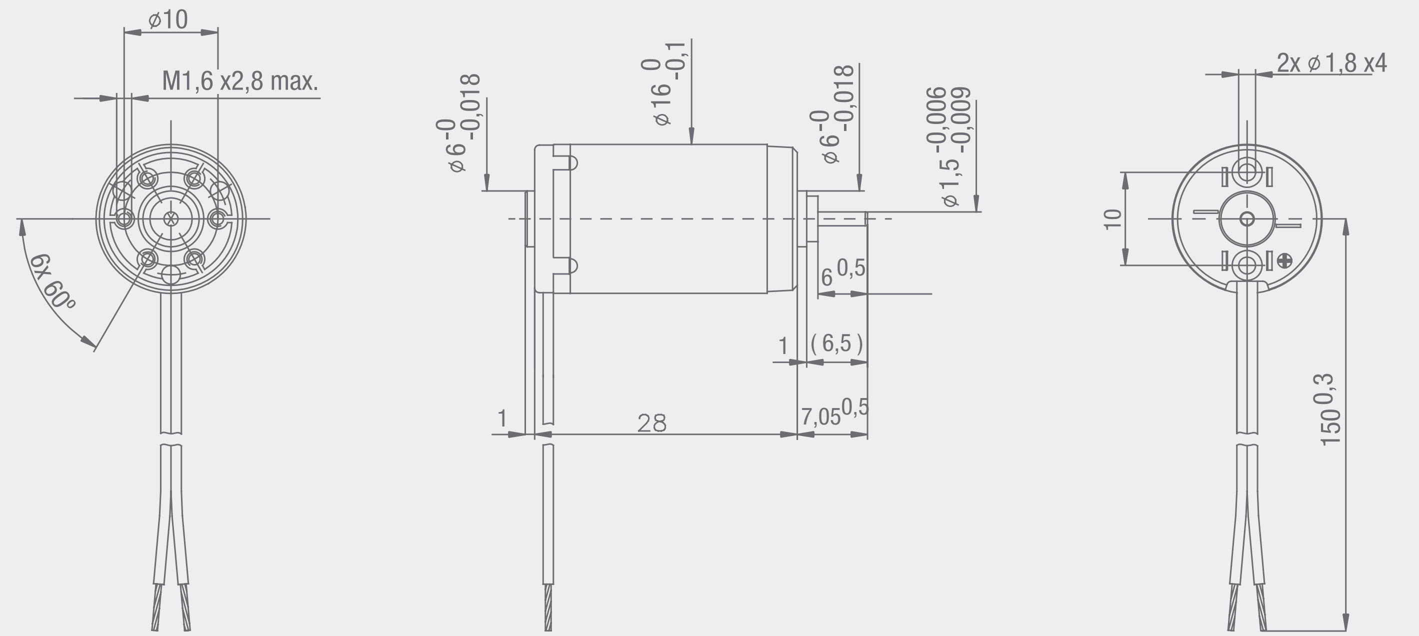
Let us consider the 16G88 -220E 1 (6v rated winding):

(See illustration and chart on Page 3.)

5 WATT

16G88 - PRECIOUS METAL COMMUTATION SYSTEM - 9 SEGMENTS

Max screw torque: 40 mNm
Max traction: 230 N



dimensions in mm
mass: 24g

16G88 ⊙ ⊙ • 1

WINDING TYPE	⊙⊙	-220P	-220E	-213E	-211E	-210E	-208E
Measured Values							
Measuring Voltage	V	3	6	8	12	15	24
No-load Speed	rpm	10600	10900	8000	8700	9000	10400
Stall Torque	mNm (oz-in)	16 (2.3)	19.9 (2.8)	12.7 (1.80)	12.1 (1.71)	12.2 (1.73)	14.3 (2.0)
Avg. No-load Current	mA	45	17	8	6.5	5.5	3.5
Typical Starting Voltage	V	0.02	0.05	0.12	0.18	0.20	0.30
Max. Recommended Values							
Max. Continuous Current	A	2.0	1.21	0.55	0.42	0.35	0.25
Max. Continuous Torque	mNm (oz-in)	5.2 (0.74)	6.3 (0.89)	5.8 (0.82)	5.4 (0.76)	5.4 (0.76)	5.4 (0.76)
Max. Angular Acceleration	10^3 rad/s^2	282	277	292	273	291	272
Intrinsic Parameters							
Back-EMF Constant	V/1000 rpm	0.28	0.55	1.12	1.37	1.65	2.3
Torque Constant	mNm/A (oz-in/A)	2.67 (0.38)	5.3 (0.74)	10.7 (1.51)	13.1 (1.85)	15.8 (2.23)	22 (3.11)
Terminal Resistance	ohm	0.5	1.6	7.6	13	19.5	37
Motor Regulation R/k^2	10^3/Nms	70	58	66	76	79	77
Rotor Inductance	mH	0.01	0.045	0.15	0.26	0.40	0.72
Rotor Inertia	kgm^2 10^{-7}	0.08	0.91	0.8	0.8	0.74	0.08
Mechanical Time Constant	ms	5.6	5.3	5.6	6.1	5.8	6.7

The first step is to calculate the current which is supplied to the motor under the conditions described on the previous page.

$T = k * (I - I_0) \longrightarrow I = T / k + I_0 = 0.003 / 0.0053 + 0.017 = 0.583$ A

The second step is to determine the supply voltage to get the requested speed.

9’000 rpm (942.5 rd/s)

$U = R * I + k * \omega = 1.6 * 0.583 + 0.0053 * 942.5 = 5.93$ V < 6 V

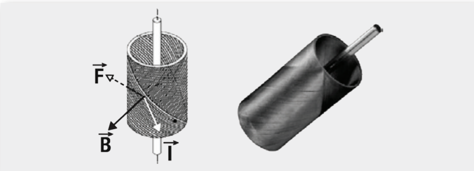
Thus the motor will reach the desired speed under the specified torque within the limitations of the battery.

Now we can determine the motor efficiency.

$P_{elect} = U \times I = 5.93 * 0.583 = 3.45$ W

Efficiency* $= P_{mech} / P_{elect} = 2.82 / 3.45 = 81\%$

Let's assume this pump needs to reach at least 5000rpm in less than 15ms:



Load inertia: 1 x 10-7 kg.m2

Rotor inertia: 0.91 x 10-7 kg.m2

$\tau = \tau_M * (1 + J_L / J_M)$ $t = \tau * I_n (\omega_1 / (\omega^1 - \omega))$

$\tau = 5.3 * (1+1/0.91) = 11.12$ms

$t = 11.12 * I_n (9000 / (9000-5000)) = 9$ms < 15ms

The speed of the pumps will be 5000rpm after 9ms.

This excellent dynamic characteristic is due to the ironless rotor concept. The low moment of inertia of the rotor enables very high acceleration.

*The motor efficiency is above 80% which will contribute to very **long battery life**. Achieving such **efficiency** is only possible thanks to the **Portescap state-of-the-art** brushed DC ironless motor technology. **P**

FOR MORE INFORMATION:

Portescap
110 Westtown Road
West Chester, PA 19382
T: +1 610 235 5499
F: +1 610 696 4598
sales.america@portescap.com
www.portescap.com

CONTACT AN ENGINEER:
http://www.portescap.com/contact-portescap