Portescap

WHITE PAPER

HOW TO SELECT AND ADAPT A COIL BASED ON THE REQUIRED MOTOR WORKING POINT AND THE POWER SUPPLY

The heart of an ironless DC motor is its rotor, based on a self-supporting coil.

INTRODUCTION

Regardless of its construction, a DC motor is always performing the same job - converting electrical energy (DC) into mechanical energy. The voltage and current supplied to the motor will be converted to output torque and rotational velocity of the motor shaft. However, many applications, e.g. portable medical devices like infusion pumps, are requiring not just any DC motor but a motor which does this task with the highest efficiency to achieve a long-lasting and reliable solution. This is typically where an ironless DC motor comes into play.

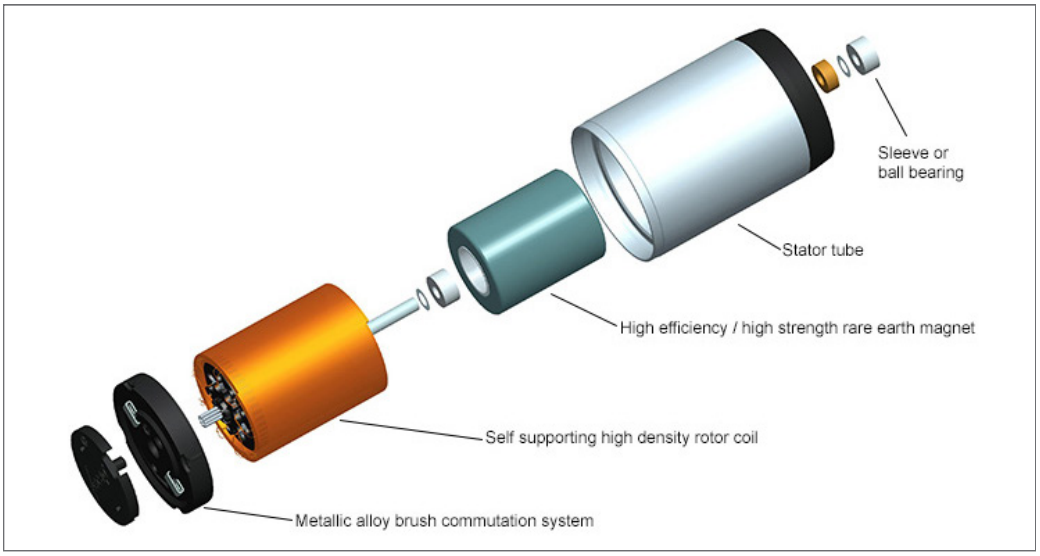
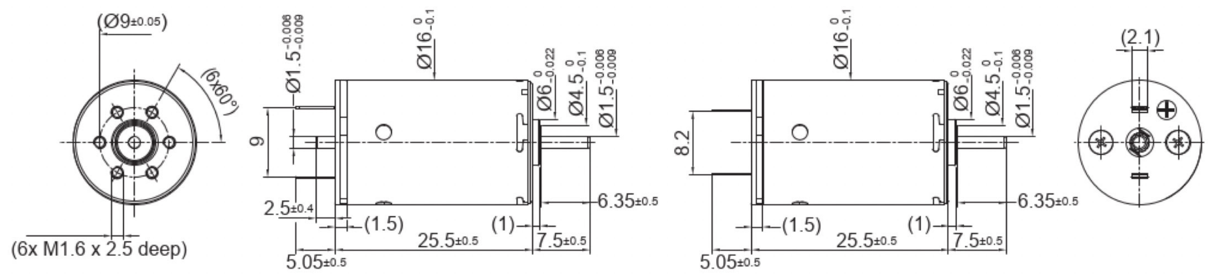


Figure 1 - Design of a Portescap Ironless DC Motor

Considering as an example that the motor is required to operate continuously at around 7000 rpms and a torque of 4 mNm, the motor needs to provide 2.9W continuous power. A Portescap 16DCT Athlonix™ ironless DC motor with precious metal commutation is a good fit in this example, as it supports a maximum continuous power of up to 4.2 W (see figure 2).

Brush DC Motors **Portescap**

16DCT Athlonix™ Ø 16 mm • Precious metal commutation • 5.45 mNm



16DCT 26P2 •••• .2 16DCT 26P1 •••• .1

Dimensions in mm.

Electrical Data		Symbol	16DCT 26P1/P2 •••• .* 219P	219E	213E	211E	207P	Unit
1	Nominal Voltage	V	3	6	9	12	15	Volt
2	No-Load Speed	n_0	8081	8600	7970	7968	8599	rpm
3	No-Load Current	I_0	28.6	15.2	9.4	7.1	6.1	mA
4	Terminal Resistance	R	0.7	2.3	7.5	13.8	18.6	Ω
5	Output Power	$P_{2max.}$	4.2	4.2	4.2	4.1	4.1	W
6	Stall Torque	mNm	16.12 (2.29)	17.13 (2.43)	12.77 (1.81)	12.33 (1.75)	13.21 (1.88)	mNm (oz-in)
7	Efficiency	$h_{max.}$	85	85	83	83	83	%
8	Max Continuous Speed	$n_{e\ max.}$	10000	10000	10000	10000	10000	rpm
9	Max Continuous Torque	$M_{e\ max.}$	5.28 (0.75)	5.27 (0.75)	5.36 (0.76)	5.27 (0.75)	5.25 (0.75)	mNm (oz-in)
10	Max Continuous Current	$I_{e\ max.}$	1.53	0.81	0.51	0.38	0.32	A
11	Back-EMF Constant	k_E	0.37	0.69	1.12	1.49	1.73	mV/rpm
12	Torque Constant	k_M	3.52	6.62	10.70	14.27	16.53	mNm/A
13	Motor Regulation	R/k^2	52.47	52.55	65.35	67.66	68.15	10^3/Nms
14	Friction Torque	T_F	0.08 (0.011)	0.08 (0.011)	0.08 (0.011)	0.08 (0.011)	0.08 (0.011)	mNm (oz-in)
15	Mechanical Time Constant	τ_m	7.79	7.80	7.56	7.51	6.63	ms
16	Rotor Inertia	J	1.48	1.48	1.16	1.11	0.97	g-cm²

Figure 2 - Datasheet Extract of a Portescap 16DCT (coils above 15 V not shown)

Knowing that this motor can provide the necessary continuous power, only the motor coil remains to be selected. To choose the right motor coil the following two points are critical to understand:

- The maximum continuous torque of a DC motor is dependent on its capability to dissipate heat and therefore mainly on its dimensions. Changing the coil of a DC motor will not impact its maximum continuous torque.
- Changing the coil makes it possible to adapt the motor to the available power supply (voltage and current) to create an efficient motor solution.

In the following article we will first take a quick look at the important formulas involved in selecting a DC motor coil. Then we will look at different scenarios where various power supplies are available and show their impact on the coil selection to better understand the above-mentioned points.

THEORY REVIEW

Torque

The torque produced by a DC motor can be described with the following relationship: The output torque produced is equal to the torque constant of the motor multiplied by the current consumed.

$$T = k_M * I$$

T = Motor torque [Nm]

k_M = Torque constant [Nm/A]

I = Motor current [A]

If we further develop the torque constant to its basic dependency, we can represent the same formula as:

$$T_{Motor} = \underbrace{2 * r * l * B * N}_{k_M} * I_{Motor}$$

r = radius of the coil [m]
B = magnetic flux density [T]
l = length of the magnet [m]
N = number of turns of the motor coil [-]

Parameters $"r"$,$"l"$ and $"B"$ depend on the chosen motor and its dimensions. Therefore, to design different coils for with different torque constants the number of coil turns $"N"$ is varied.

SPEED

The rotational speed of a DC motor can be described with the following relationship:

$$\omega = \frac{U}{k_M} - \frac{R}{k_M^2}(T_f + T_l)$$

ω = Rotational speed [rad/s]
R = Terminal resistance [Ohm]
U = Supply voltage [V]
T_f = Friction torque [Nm]
k_M = Torque constant [Nm/A]
T_l = Load torque [Nm]

When looking at a specific motor size (e.g. 16mm diameter and 25mm length), the motor regulation factor $R/k_M{}^2$ is constant across different coils. Neglecting friction, the no-load speed ω_0 of the motor is defined by the available supply voltage and the torque constant of the coil:

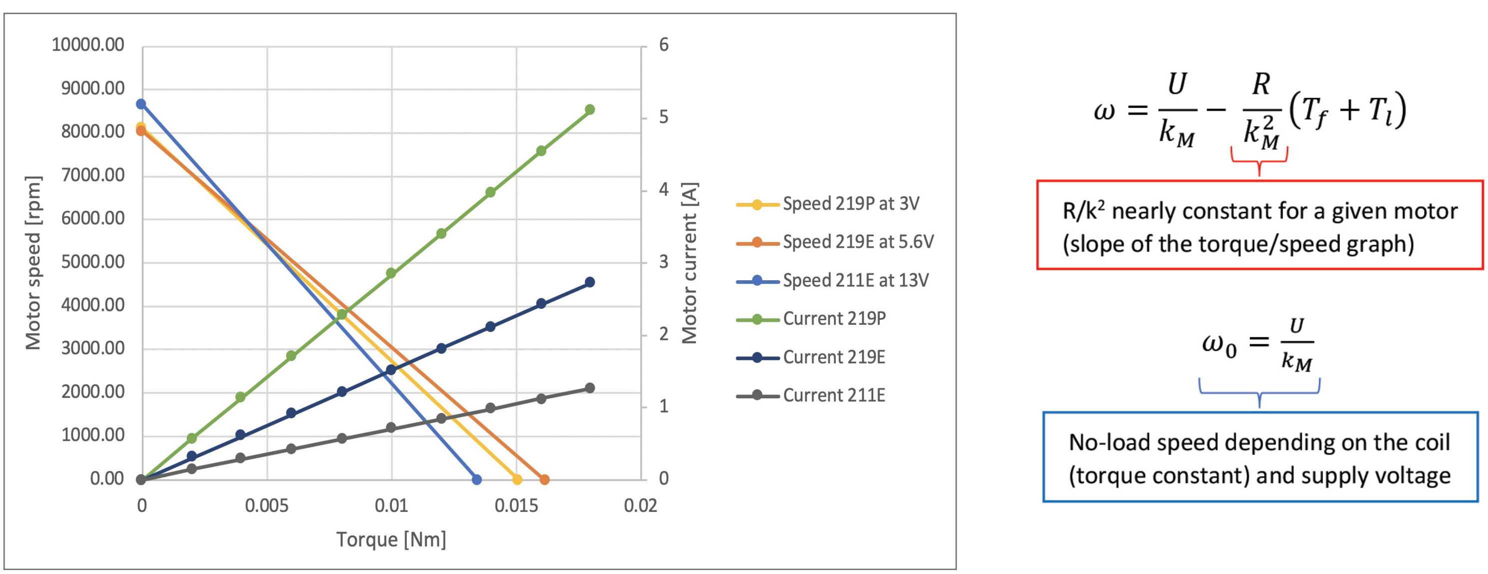


Figure 3 - Motor Speed and Current in Dependance of Torque for a 16DCT with Three Different Coils

The above example clearly shows why typically different coils for a specific motor are available to choose from: all coils shown are able to achieve the same working point, in example at 5500 rpm and a torque of 5 mNm, however with different supply voltages and different current requirements. The coil is therefore chosen to adapt the motor to the available power supply.

EFFICIENCY AND MECHANICAL POWER

The efficiency is defined as the mechanical power output divided by the electrical power input:

$$\eta = \frac{P_{mech}}{P_{elec}} = \frac{T * \omega}{U * I}$$

P_{mech} = Mechanical power [W] T = Motor torque [Nm] ω = Motor speed [rad/s]
P_{elec} = Electrical power [W] U = Supply voltage [V] I = Motor current [A]

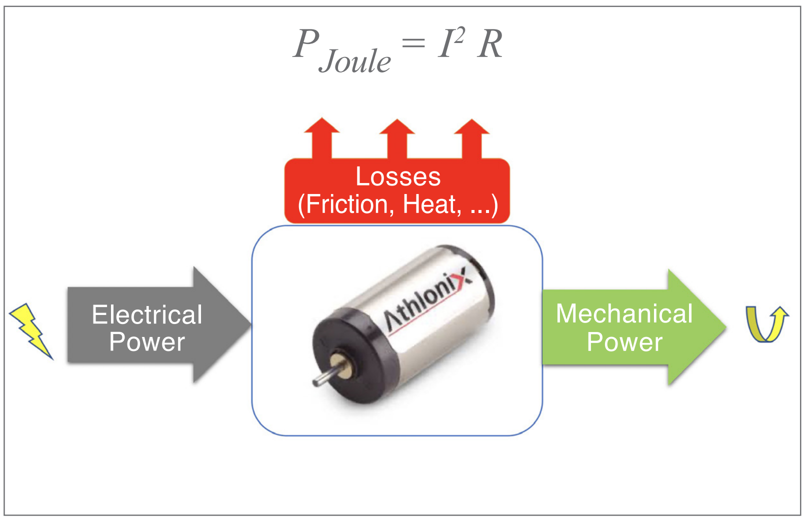


Figure 4 - When converting electrical to mechanical power with a DC motor, friction and heat will lead to losses

Portescap DC motors typically reach up to 90% efficiency thanks to their ironless design and optimized magnetic circuit. However besides friction, part of the electrical power will always be lost mainly due to heat created by the current running through the copper wire of the coil. These heat losses are called Joule losses and they are proportional to the coil resistance multiplied by the square of the current.

To achieve high efficiency, the goal must therefore be to create the maximum mechanical power at lowest possible joule losses. This is achieved by using the motor at a high speed and low torque, as it can be seen in the below graph.

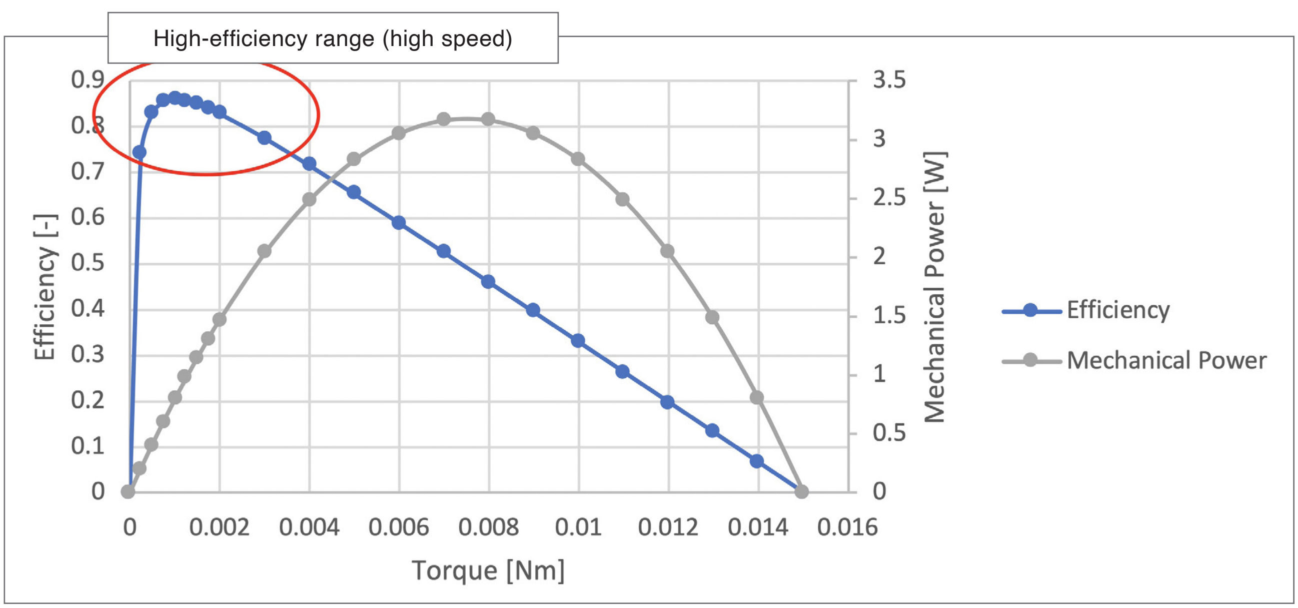


Figure 5 - Efficiency and Mechanical Power of a 16DCT 26P1 219P .1 at 3V

Even though the mechanical power of a DC motor is greatest when used at half of its stall torque, its efficiency is much higher at lower torque due to the lower motor current and therefore lower joule losses. To use the motor at the highest possible speed and therefore the highest efficiency, the motor coil is selected accordingly.

CHOOSING THE RIGHT COIL, BASED ON AVAILABLE CATALOGUE COILS

When identifying the right motor solution, customizing the coil is not always an option. Developing a new coil requires time and money being invested by both the customer and the motor manufacturer. Therefore, this first section will focus on choosing the right coil from available catalogue coils only.

Scenario 1 – Voltage Source Power Supply

Let us look at the same example as in the introduction but considering the available power supply well:

- Working Point: continuous operation around 7000 rpm at a torque of 4 mNm, equal to 2.9 W
- Chosen Motor: Portescap 16DCT Athlonix™ ironless DC, max. continuous output power = 4.2 W
- Available Power Supply: voltage source with 10.8 V fixed voltage

Coil 213E and coil 211E seem to be a reasonable choice, as they've been designed to operate at roughly 8000 rpm at 9V and 12V respectively. The motor speed and current at the working point with 10.8V supply voltage can be calculated using the formula introduced in the introduction and the coil parameters available in the datasheet:

$$\omega = \frac{U}{k_M} - \frac{R}{k_M^2}\left(T_f + T_l\right)$$

$$T = k_M * I$$

	COIL 213E	COIL 211E
Supply Voltage	10.8 V	
Load Torque	4 mNm	
Friction Torque	0.08 mNm	
Terminal Resistance	7.5 Ω	13.8 Ω
Torque Constant	10.70 mNm/A	14.27 mNm/A
Motor Speed at Load	7086 rpm	4587 rpm
Motor Current	0.38 A	0.29 A

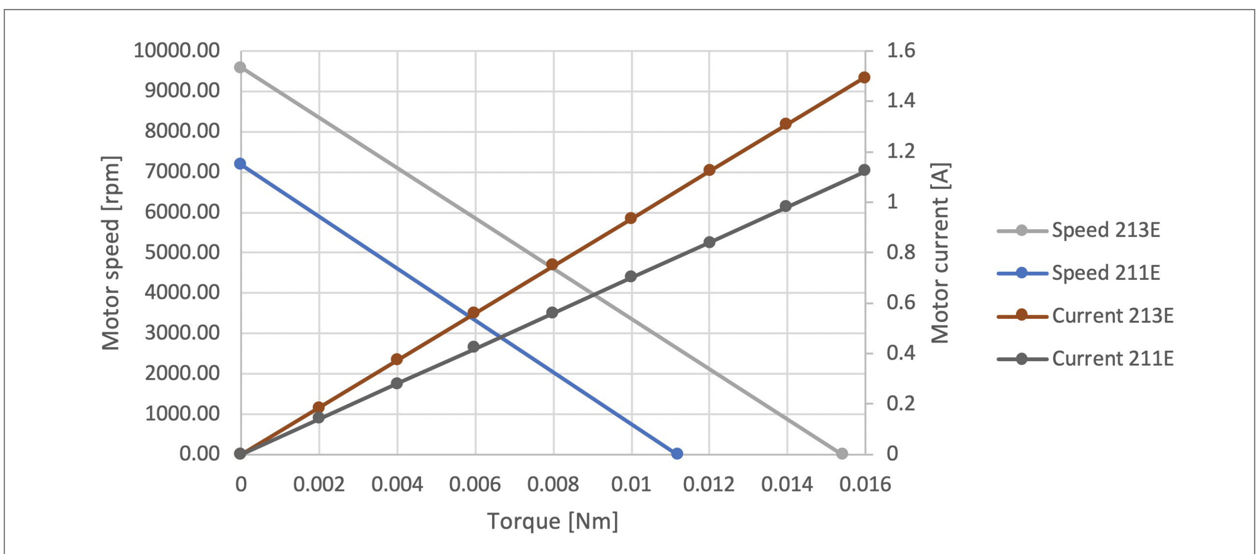


Figure 6 - Speed and Current Comparison between Coil 213E and 211E at 10.8 V

It becomes evident that only coil 213E can reach a speed above 7000 rpm with the available power supply voltage and load torque. With a voltage source, there's only one closest match for selecting a catalogue coil. To optimize the motor by choosing the best possible coil, a current source is required.

Scenario 2 – Current Source Power Supply

In this second scenario, a current source is available instead of a voltage source to achieve the same working point:

- Working Point: continuous operation above 7000 rpm at a torque of 4 mNm, equal to 2.9 W
- Suitable Motor: Portescap 16DCT Athlonix™ ironless DC, max. continuous output power = 4.2 W
- Available Power Supply: current source, max. cont. current available = 1 A, 1-15 V

The available current source can provide a continuous current of maximum 1 A, within a voltage range of 1 to 15 V. With the supply voltage being flexible, a much wider range of available catalogue coils can be considered to achieve the working point. The required voltage to reach the working point at 7000 rpm and 4 mNm can be calculated using the formula introduced in the Theory Review section of this white paper. Same as in the first scenario, the current required to reach the working point is calculated in 2 second step.

$$\omega = \frac{U}{k_M} - \frac{R}{k_M^2}(T_f + T_l)$$

Solving for U:

$$U = k_M\left(\omega + \frac{R}{k_M^2}(T_f + T_l)\right) = k_M\omega + R\left(I_0 + \frac{T_l}{k_M}\right)$$

	COIL 219P	COIL 219E	COIL 213E	COIL 211E	207P
Load Torque	4 mNm				
Friction Torque	0.08 mNm				
Terminal Resistance	0.7 Ω	2.3 Ω	7.5 Ω	13.8 Ω	18.6 Ω
Torque Constant	3.52 mNm/A	6.62 mNm/A	10.70 mNm/A	14.27 mNm/A	16.53 mNm/A
No-load Current	28.6 mA	15.2 mA	9.4 mA	7.1 mA	6.1 mA
Supply Voltage	3.4 V	6.3 V	10.7 V	14.4 V	16.7 V
Motor Current	1.16 A	0.62 A	0.38 A	0.29 A	0.25 A
Efficiency	0.75	0.76	0.72	0.71	0.71

Both coils 219P and 207P are not an option as they require a voltage respectively, a current outside the available range. Coil 219E is the most efficient one out of these three coils if the total efficiency is the criterion. However, in most cases the coil with the lowest current consumption provides the best choice. A lower current consumption will result in a longer lifetime of the commutation system and increase the number of cycles with a single battery charge for battery-powered applications.

In this scenario with a current source power supply, coil 211E draws almost half the current compared to coil 219E and therefore provides the best choice from the available catalogue coils. Compared to coil 213E selected in scenario 1 with a voltage source power supply, this allows to decrease the current consumption of the motor by almost 25% while achieving the same working point.

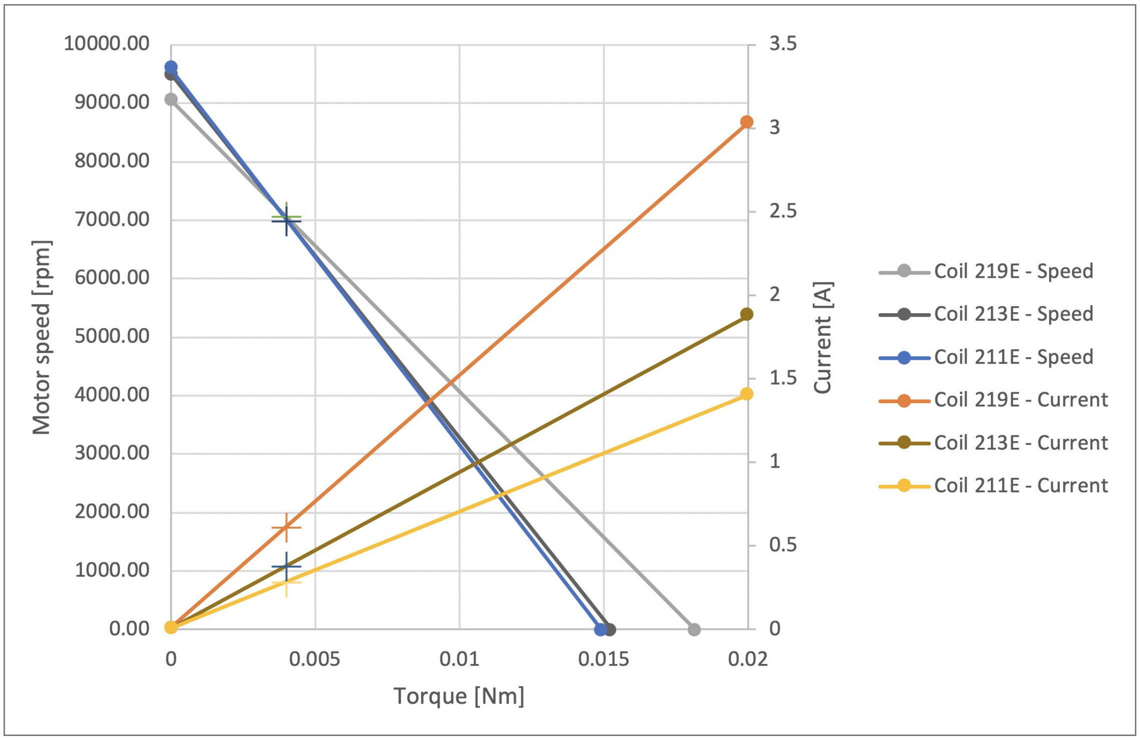


Figure 7 - Speed and Current Comparison between Coil 219E, 213E and 211E using a Current Source

ADAPT A COIL TO THE AVAILABLE POWER SUPPLY IF NOT AVAILABLE IN THE CATALOGUE

In the second scenario, it is possible to achieve the desired working point using a catalogue coil, thanks to availability of a current source power supply. However, considering coils only available in the catalogue might not always allow one to achieve the desired working point. In this case, it's best to consider a custom designed coil which is adapted to the power supply, as shown in the below example.

- Working Point: continuous operation above 6000 rpm at a torque of 4 mNm, equal to 2.5 W
- Suitable Motor: Portescap 16DCT Athlonix™ ironless DC, max. continuous output power = 4.2 W
- Available Power Supply: 7 V, current limitation = max. 0.5 A

The catalogue offers two coils which are designed for approximately 8000 rpm at no-load and 6 V resp. 9 V, however, both coils are either too slow or too fast at 7 V. Furthermore, the current consumption of coil 219E is an issue:

	Coil 219E	Coil 213E
Terminal Resistance	2.3 Ω	7.5 Ω
Torque Constant	6.62 mNm/A	10.70 mNm/A
Supply Voltage	7 V	
Load Torque	4 mNm	
Friction Torque	0.08 mNm	
Motor Speed at Load Torque	8052 rpm	3694 rpm
Motor Current	0.61 A	0.38 A

To achieve the desired working point, a coil outside the available catalogue range is required. This will be achieved by designing a special coil, which will have a number of turns in between coil 219E and 213E. A dedicated motor manufacturer is able to design and propose a new coil as described above, depending on the size of the project.

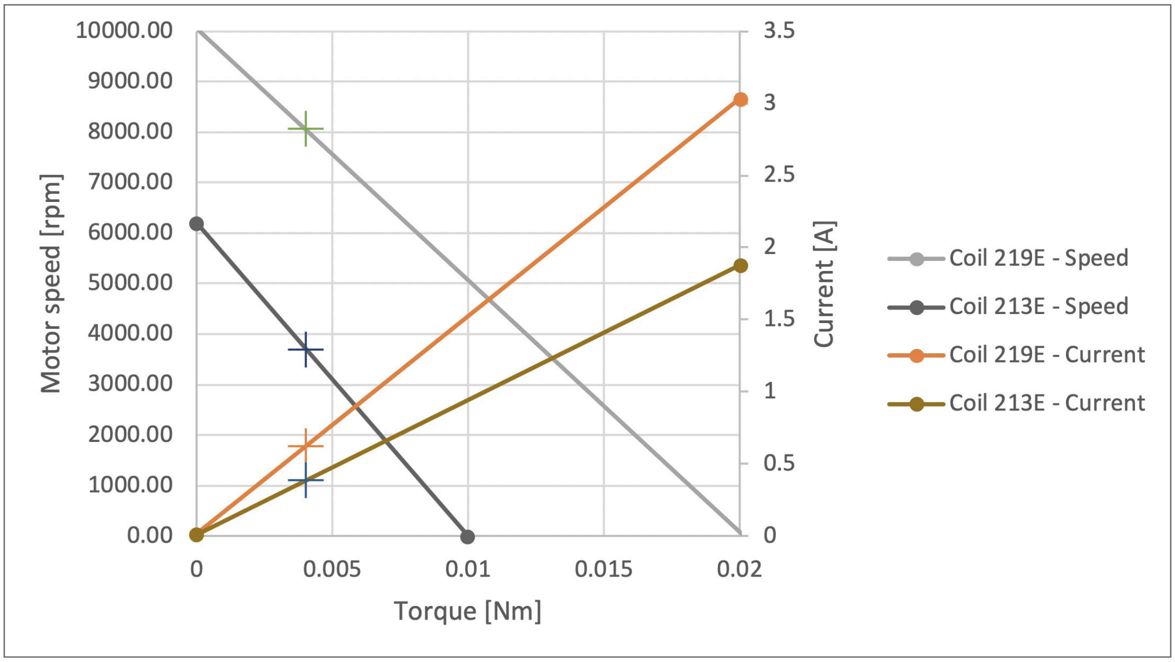


Figure 8 - Speed and current comparison between coil 219E and 213E at 7V

KEY TAKE-AWAYS

The following points are crucial to consider when selecting a DC motor for an application requiring high efficiency:

- The motor size is chosen depending on the required mechanical power. Only a motor large enough is able to develop the necessary torque, as well as dissipate the heat generated through losses in the motor.
- While choosing the motor coil the available power supply must be respected. A motor supplier will typically offer a set of coils which can achieve the same working point with different voltage and current requirements.
- For a motor solution with high efficiency, the required mechanical power must be created with high speed and low torque. This can be achieved by selecting a coil which takes the most advantage of the available power supply.

A dedicated motion solution provider can support customers in identifying the right motion solution for an application, taking the above considerations in account. **P**

Valentin Raschke
Application Engineer
Valentin.Raschke@portescap.com
Portescap

FOR MORE INFORMATION:

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:
www.portescap.com/en/contact-portescap