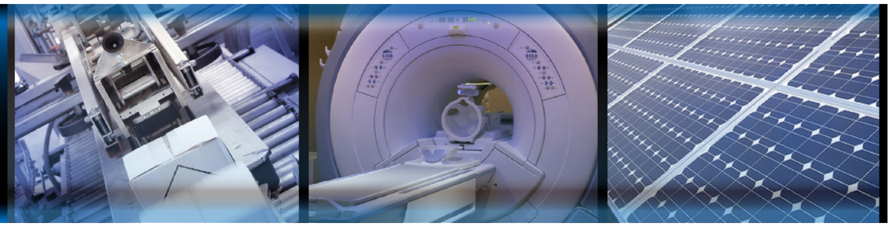
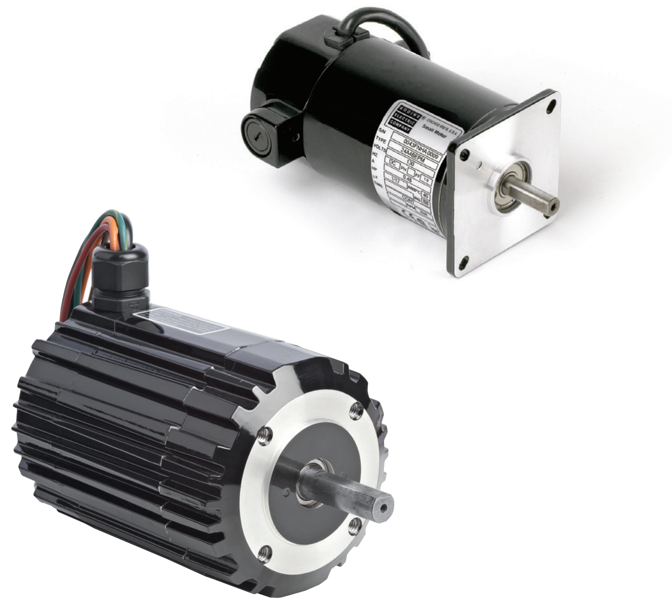
APPLICATION note — BODINE ELECTRIC COMPANY®



A TECHNICAL PAPER FROM BODINE ELECTRIC COMPANY

Introduction to Motor Constants for Fractional Horsepower Gearmotors

Motor constants are needed to calculate permanent magnet DC (PMDC) or brushless DC (BLDC) motor specifications and ratings, or to match the motor properly to an amplifier. The motor constants are required in order to predict the PMDC or BLDC motor's performance with changing variables, such as different input voltages or different loads (see Tables 1 and 2 for Bodine stock PMDC and BLDC motor constants). This application note explains what the constants are, how they are derived and how to use them.



Bodine type 24A PMDC and type 34B BLDC motors are used to power a range of Bodine gearmotors

Common Motor Constants

The most commonly used motor constants are Torque Constant (K_t), Voltage Constant (K_e), Electrical Time Constant (τ_e), Mechanical Time Constant (τ_m), and Thermal Resistance (R_{th}). Typical values for these constants are derived by using measured values of No Load Speed, No Load Current, Stall Torque, Circuit Resistance, Circuit Inductance, and Armature Inertia with the following equations:

Torque Constant (K_t) — describes the proportional relationship between torque and current. K_t is usually expressed in the units oz-in/Amp. See page 2 for additional information about torque constants.

$$K_t \text{ (oz-in./Amp)} = \frac{\text{Rated Torque (oz-in.)}}{\text{Rated Current (Amps) – No Load Current (Amps)}}$$

Voltage Constant, or Back EMF Constant (K_e) — is the Torque Constant expressed in different units, usually Volts/Krpm, in order to describe the proportional relationship between motor speed and generated output voltage when the motor is back driven as a generator in units of Volts/1000 rpm. See page 2 for additional information about voltage constants.

$$K_e \text{ (Volts/1000 rpm)} = K_t \text{ (oz-in/Amp)} \times .74$$

Electrical Time Constant (τ_e) — is the time required for a motor to reach 63.2% of its stall current after applying a test voltage with the motor shaft locked. It is usually expressed in milliseconds. Applied Voltage equals Rated Current multiplied by Circuit Resistance

$$\tau_e \text{ (msec)} = \frac{\text{Circuit Inductance (mH)}}{\text{Circuit Resistance (Ohms)}}$$

[τ_e = Time for current to reach 63% of final value]

Mechanical Time Constant (τ_m) — is the time required for an unloaded motor to reach 63.2% of its no load speed after applying its rated voltage. It is usually expressed in milliseconds.

For PMDC Motors:

$$\tau_m \text{ (msec)} = \frac{\text{R (Ohms)} \times \text{J (oz-in-sec}^2\text{)}}{K_t \text{ (oz-in/Amps)} \times K_e \text{ (V/Krpm)}} \times 105$$

For Brushless DC Motors:

$$\tau_m \text{ (msec)} = \frac{\text{R (Ohms)} \times \text{J (oz-in-sec}^2\text{)}}{K_t \text{ (oz-in/Amps)} \times K_e \text{ (V/Krpm)}} \times 90.6$$

J = Armature/Rotor Inertia
R = Circuit Resistance

Thermal Resistance (R_{th}) — is useful for predicting the ultimate temperature rise under different loading conditions in order to determine a maximum continuous torque rating. It is usually expressed in the units °C/Watt.

$$R_{th} \text{ (°C/Watt)} = \frac{\text{Temperature Rise At Rated Load (°C)}}{\text{Power Losses At Rated Load (Dissipated Watts)}}$$

Using Performance Data to Calculate K_t and K_e

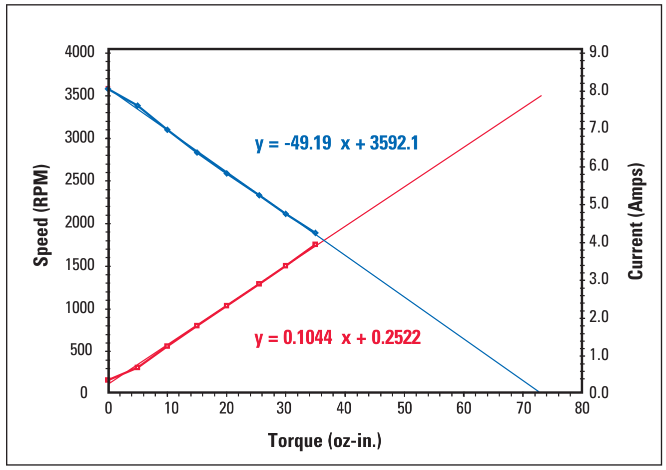
This speed/torque graph demonstrates how the linear equation of the current is used to calculate the Torque Constant (K_t) by using the slope "m." The Voltage Constant (K_e) can then be calculated.

In this example:

K_t = 1/m (one divided by the slope (m) of the linear equation for the current)

K_t = 1/0.1044 oz-in./Amps = 9.579 oz-in./Amps

$K_e = K_t$/1.3524 V/Krpm = 7.0826 V/Krpm
(or alternatively, multiply Kt by 0.74)



Performance Graph for 22B2BEBL Brushless DC Motor, Model No. 3502 (24V)

How to Calculate Torque Constant (K_t) and Voltage Constant (K_e)

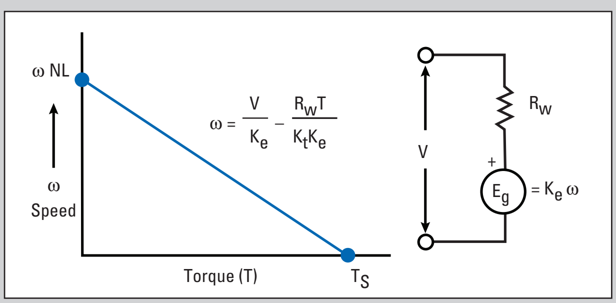
Excerpted From Section 8.2 of the Bodine Handbook, Fifth Edition

Voltage Constant (K_e)
Bodine Electric Company's Handbook shows the speed/torque curve of permanent magnet DC and brushless DC motors. Below is the equation for how to calculate the voltage constant (also known as the function of turns and magnetic flux).

$$V = R_W I + Eg$$

or $$V = R_W I + K_e \omega$$

where K_e is a function of turns and magnetic flux. K_e is called the voltage constant. It is a proportionality constant that relates the generated voltage to the shaft speed (ω).



Speed/torque curve of either a PMDC or BLDC motor

Torque Constant (K_t)
Use the graph and equations to determine the torque constant of a permanent magnet DC or brushless DC motor. The torque constant allows you to calculate exactly how much current a motor draws directly from the power supply. The output torque of the motor is directly proportional to the current going into the motor. Since the majority of Bodine products are gearmotors, the user must consider the loading of the gearbox, the duty cycle, and the gear ratio. A gearmotor might not draw nameplate rated current if lightly loaded, or if the gear ratio is very high, e.g.: above 80:1.

If the motor current (I) is constant, a proportional torque (T) is produced:

$$T = K_t I$$

where K_t is a function of turns and magnetic flux. K_t is called the torque constant and is a proportionality constant that relates current to developed torque.

Solving the torque equation for current and substituting the resulting expression for "I" in the voltage equation yields:

$$V = \frac{TR_W}{K_t} + K_e \omega$$

To learn more, please see page 8-8 in the Bodine Handbook.

R_W = Winding Resistance | I = Motor Current | Eg = Back EMF Voltage | V = Voltage applied to motor | T = Output Torque

Appendix: Typical Motor Constants for Standard Bodine Motors

Tables 1 and 2 provide all critical data for our standard permanent magnet DC and brushless DC motors and gearmotors, with both the measured motor specifications and the derived motor constants. Typical data, where applicable, corresponds to operating temperature at rated load. This data will allow you to specify a Bodine gearmotor with confidence that the product will meet your design and application performance criteria.

Table 1: Typical Motor Constants for Standard Bodine Permanent Magnet DC Motors[2]

Model Number Product Type/Item Description	0040 24AO	0041 24A2	0043 24A4	0044 24A4	6016 33A3	6020 33A5	6021 33A5	6037 33A7	4021 42A5	4022 42A7	4035 42A5	4037 42A7
Rated Voltage (VDC)	24	130	130	24	130	130	24	130	24	24	130	130
Rated Torque (oz-in.)	8	14	24	22	34	50	95	134	101	135	101	135
Torque Constant (oz-in/Amp)	8.7	52	53	9.2	54	57	11	53.2	13	12	60	59
Voltage Constant (V/Krpm)	6.4	39	39	6.8	40	42	8.2	38.9	9.4	8.9	44	43
Thermal Resistance (°C/Watts)	4.3	4.0	3.4	3.6	2.0	1.8	1.5	1.6	1.3	1.6	1.5	1.2
No Load Speed (rpm)	3340	3150	3130	3150	3050	2860	3030	3050	2560	2650	2930	2850
No Load Current (Amps)	0.24	0.05	0.04	0.24	0.08	0.12	0.50	0.68	0.70	0.90	0.15	0.18
Stall Torque (oz-in.)[1]	36	68	140	140	240	580	550	360	1170	1250	1200	1480
Circuit Resistance (Ohms)	5.7	84	50	1.7	32	17	0.46	8.8	0.27	0.23	6.4	5.1
Circuit Inductance (mH)	6.7	130	84	2.3	67	41	0.98	20	0.64	0.45	20	17
Armature Inertia (oz-in-sec^2)	0.003	0.005	0.007	0.007	0.031	0.043	0.043	0.075	0.082	0.12	0.082	0.12
Electrical Time Constant (msec)	1.18	1.55	1.68	1.35	2.09	2.41	2.13	2.27	2.37	1.96	3.13	3.33
Mechanical Time Constant (msec)	32.3	22.0	17.6	19.9	48.1	32.0	22.8	33.4	19.4	26.8	20.6	25.1

Table 2: Typical Motor Constants for Standard Bodine Brushless DC Products[2]

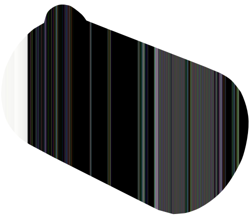
Model Number Product Type/Item Description	3302 22B2	3502 22B2	3304 22B4	3314 22B4	3306 34B3	3500 34B3	n3507 34B4	3307 34B4	n3509 34B6	3309 34B6	3317 34B4	— 48B8
Rated Voltage (VDC)	130	24	130	130	130	24	24	130	24	130	130	260
Rated Torque (oz-in.)	25	25	50	20	81	81	101	101	151	151	33	550
Torque Constant (oz-in/Amp)	56	9.8	61	16	62	9.4	9.6	56	8.6	63	18	124
Voltage Constant (V/Krpm)	35	6.7	40	8.9	42	6.9	6.9	38	6.4	43	10	77
Thermal Resistance (°C/Watts)	3.8	3.7	2.3	2.1	1.9	1.6	1.4	1.6	1.3	1.4	1.5	0.70
No Load Speed (rpm)	3620	3555	3240	14,600	3130	3460	3460	3465	3770	3040	12,700	3365
No Load Current (Amps)	0.028	0.17	0.039	0.14	0.072	0.56	0.97	0.096	0.70	0.099	0.20	0.18
Stall Torque (oz-in.)[1]	82	74	206	64	350	243	342	460	512	840	200	3168
Circuit Resistance @ 23°C (Ohms)	45	1.4	17	5.4	9.2	0.31	0.18	5.8	0.10	3.3	1.7	2.1
Circuit Resistance (Ohms)	56	1.8	20	7.6	12	0.41	0.23	7.7	0.13	4.1	2.1	3.0
Circuit Inductance (mH)	72	2.3	45	13	24	0.60	0.43	15	0.25	13	6.9	12
Rotor Inertia (oz-in-sec^2)	0.0019	0.0019	0.0038	0.0038	0.0131	0.0131	0.0179	0.0179	0.0253	0.0253	0.0145	0.199
Electrical Time Constant (msec)	1.3	1.3	2.2	1.6	2.0	1.5	1.9	2.0	2.0	3.1	3.3	4.1
Mechanical Time Constant (msec)	4.9	4.6	2.9	19.0	5.4	7.4	5.6	5.9	5.2	3.5	14.8	5.5

1. Torque Data is a theoretical value–may exceed demagnetization current.
2. Please contact our support team at info@bodine-electric.com if you need to verify the motor contstant for a specific model or winding.

Permanent Magnet DC Motors

Type 24A

Type 33A



Type 42A

Brushless DC Motors

Type 22B

Type 34B

Type 48B