Estimation and Approximation of DC Motor Parameters

charles guan / 13 february 2012

Most inexpensive or surplus motors sold for a particular consumer or hobbyist market (e.g. electric vehicles and robots) have very poor documentation or non-technical datasheets. Often, critical parameters are missing that would be helpful in calculating drivetrain and actuator performance. The goal is to estimate or deduce what these parameters are, to within "ballpark" values, to aid in design.

Goals:

- Given some combination of "hobby" specifications such as No Load Speed, Voltage, Watts, Stall Current, or "Torque", approximate the DC motor torque constant Kt and the winding resistance Rm
- Distinguish between input (electrical) watts and output (mechanical) watts

DC Motor Review

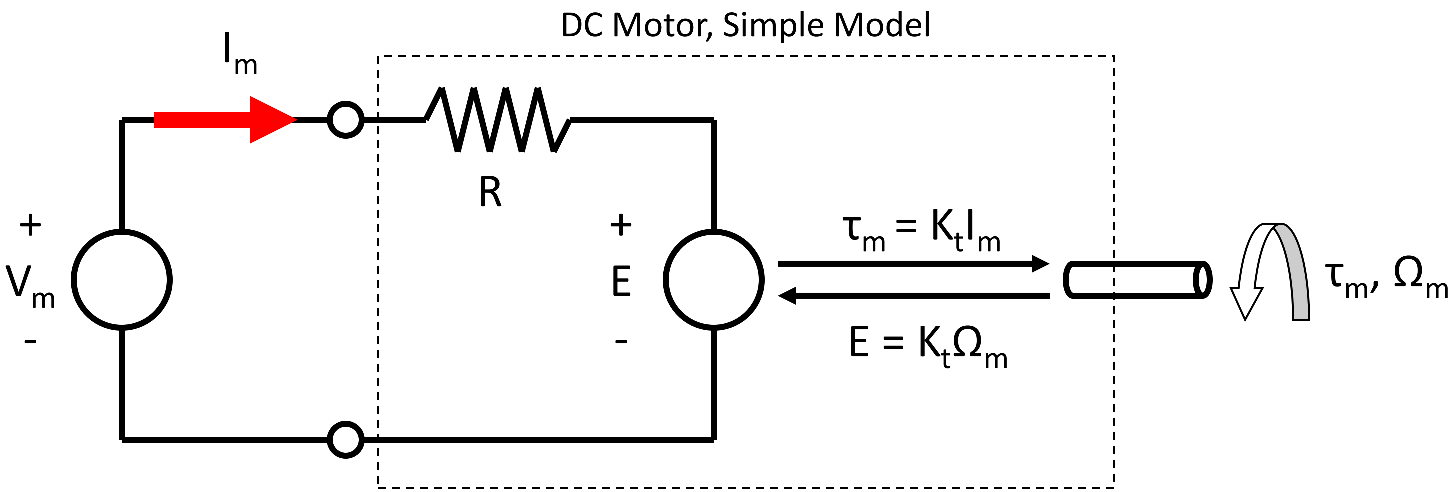

Figure by Shane Colton

E = "Back EMF"
R = "Winding Resistance"

- Knowing Kt and R completely characterizes the motor
- *E* sets the speed of the motor, not Vm
- Kt is a property of the transformative element of the motor
- R is a property of the dissipative element of the motor
- Some detail on both sides of the transformation must be known

Example: Fairly complete datasheet

24 Volt 300 Watt Motor with 11 Tooth #25 Chain Sprc

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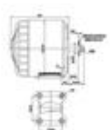

Description	Specs	Compatibility

Voltage: 24Vdc
Rated Speed: 2650-2900 Rpm
Rated Current: 16.0-16.4A
Output: 300 Watt
Sprocket: Removable Bolt Sprocket
Case Length: 4-1/8" (105 mm)
Case Diameter: 3-15/16" (100 mm)
Drive Shaft Length: 1" (25 mm)
Drive Shaft Diameter: 5/16" (8 mm)
Bolt Hole Distance (Adjacent): 4-1/8" (105 mm)
Bolt Hole Distance (Cross Bracket): 2-3/16" (56 mm)

Known:

- **"Rated"** means one operating point along the motor's T-S curve. *"At 2650 RPM, the motor draws 16.0A"*
- Output mechanical power (W)
- Input voltage Vm

Finding:

- Output power can be split into output torque and output speed: $P = \tau * \omega$
- Using rated speed 2650 RPM in SI: 277.5 rad/s
  - $300 = \tau * 277.5$
  - $\tau = 1.08N$
- **Kt can be found**:
  - Kt = 1.08N / 16.0A = **0.067 Nm/A**
- Input power P = V * I = 24V * 16.0A = 384W
- Implies Rm must dissipate 84W at 16.0A
- **From Ohm's Law, Rm** = 84W / ($16.0A^2$) = **0.328 Ω**
- This is a reasonable resistance for a motor – most motors have a Rm < 1 Ω

Example: Horrible Surplus Website "Datasheet"

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Item# 10-2412

Our Price $2.99

6 VDC 8600 RPM JOHNSON MOTOR

349 In Stock

About Our Products

This Item is on pg. 142
of our 2011 CATALOG
Click here to view PDF page

QTY 1 Add to Cart

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Item Specs

6 VDC 8600 RPM JOHNSON MOTOR

New, JOHNSON ELECTRIC permanent magnet motor. Model 169324.

SPECIFICATIONS

- **Voltage** 6 DC
- **Amperage** 1.0 Amps (no load)
- **Speed** 8600 RPM
- **Rotation** Reversible
- **Duty** Intermittent
- **Enclosure** Open
- **Mount** 2 hole face on 25mm c/c
- **Shaft** 1/8" dia. x 3/8" long serrated
- **Size** 1-3/8" dia. x 2-1/2"
- **Shpg.** 1/2 lb.

Known:

- Input voltage Vm
- No load current
- No load RPM

There is very little that you can do in this case to fully characterize the motor. No component of *output* power is known.

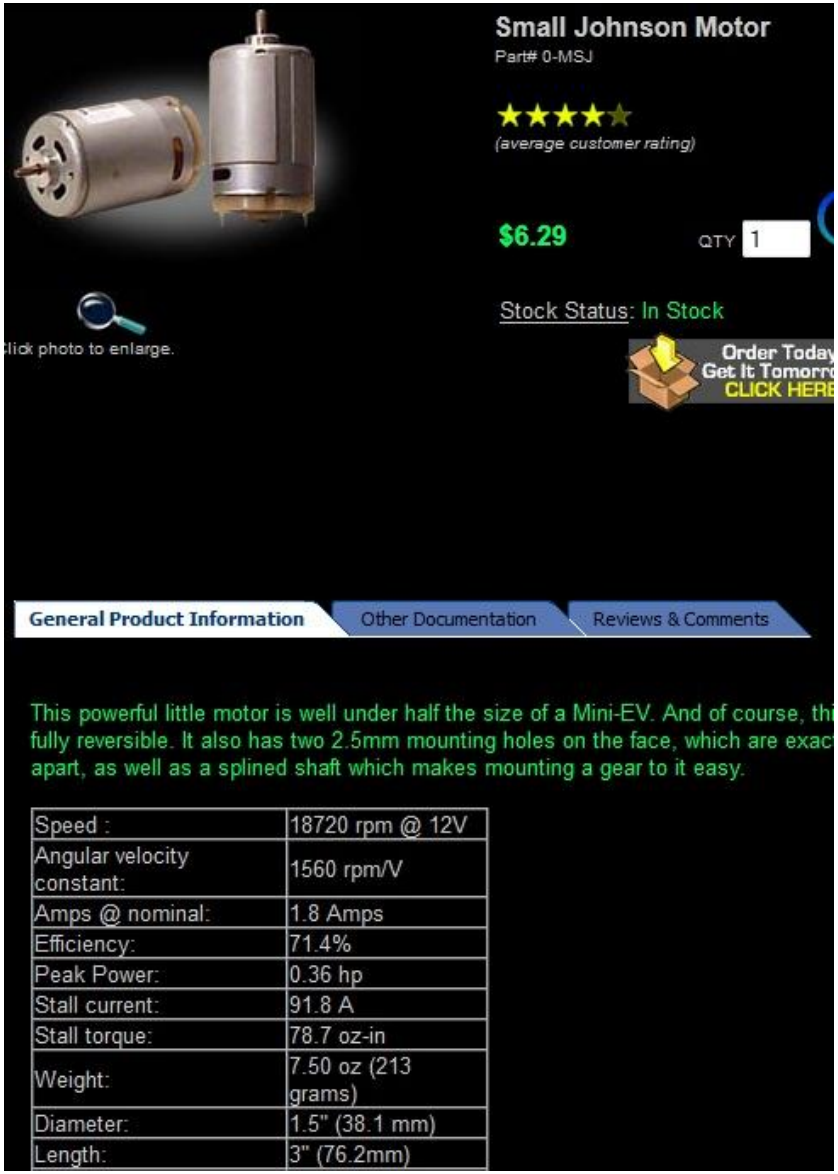
Erroneous Rm calculation (This is tempting to do!):

- Input power P = Vm * I = 6.0W
- Rm = P / I^2 = 6.0 / 1.0 = 6Ω ...
- Due to the fact that even "no load" has some torque associated with it because of friction, fluidic (air) drag in the rotor, etc.

Potential tactics:

- Approximate Kt = Vm / ω
  - Kt = 6V / 900.6 rad/s = 0.006 Nm/A
- Must compare with other similar motors to find an approx. stall current and Rm

Example: Horrible Surplus Website "Datasheet"



Speed :	18720 rpm @ 12V
Angular velocity constant:	1560 rpm/V
Amps @ nominal:	1.8 Amps
Efficiency:	71.4%
Peak Power:	0.36 hp
Stall current:	91.8 A
Stall torque:	78.7 oz-in
Weight:	7.50 oz (213 grams)
Diameter:	1.5" (38.1 mm)
Length:	3" (76.2mm)

This is a motor which superficially looks similar, has the same dimensions, and has a similar no-load speed and no-load current. You can use the specifications listed as a guideline for your unknown motor.

- $R_m \approx 12V / 92A = 0.130\ \Omega$

Therefore for the original motor, you can approximately say

- $K_t \approx (12V - 1.8A * 0.13\ \Omega) / 1801.2$ rad/s $= 0.006$ Nm/A

Why 1801.2 rad/s? To make the approximation useful, the motors should be well-matched in specification. Observe that the "6v 8600RPM" motor will spin at 17200RPM at 12v, which is close to 18720. Using the 6v motor's no-load current will result in slightly more error, but this is negligible for approximation as long as the no-load current is a small fraction of the stall current

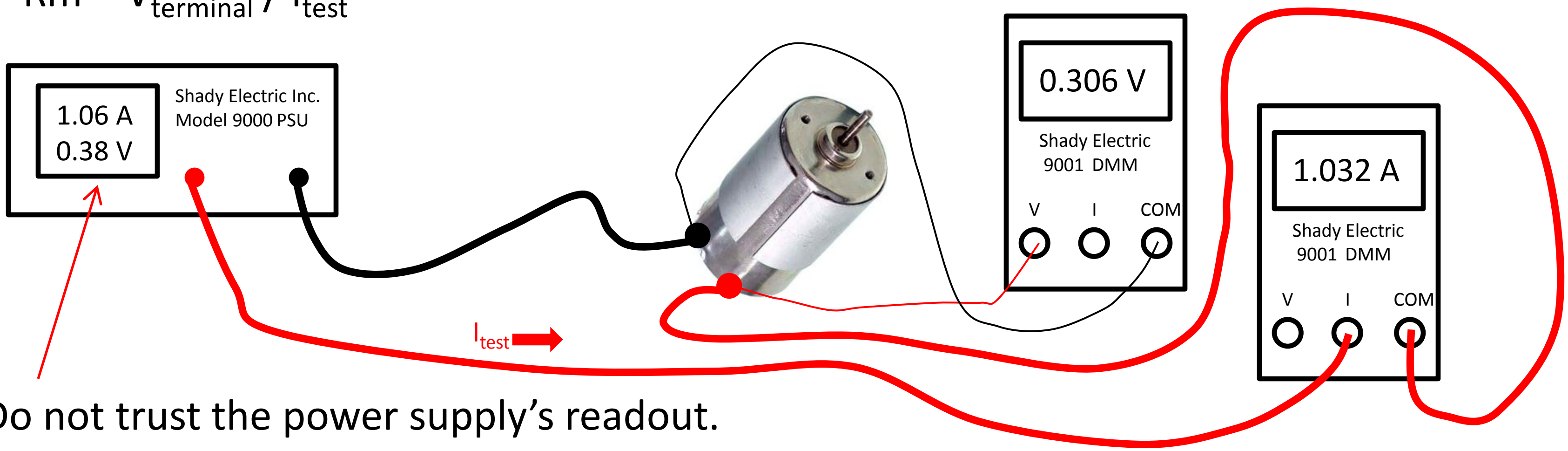
Testing to Find Motor Parameters

General procedure for finding Rm:

- Lock the shaft to eliminate Kt as a source of error due to motor movement
- Flow a known amount of current I_{test} through the motor terminals
- Measure independently the voltage at the terminals and the current flowing

The measurement should be made using “4 wire” or Kelvin methods to prevent the resistance of the test leads from being included accidentally.

- $Rm = V_{terminal} / I_{test}$



Do not trust the power supply’s readout. Especially not Voltage – it will include the resistance of the leads.
Current can be used directly if the power supply is known to be calibrated. If the power source is totally unknown, such as a bank of D-cell alkaline batteries in parallel, both quantities must be measured.

Brushless motor? Pick two leads. Leave the third unconnected. You may elect to try all three combinations and find an average Rm.

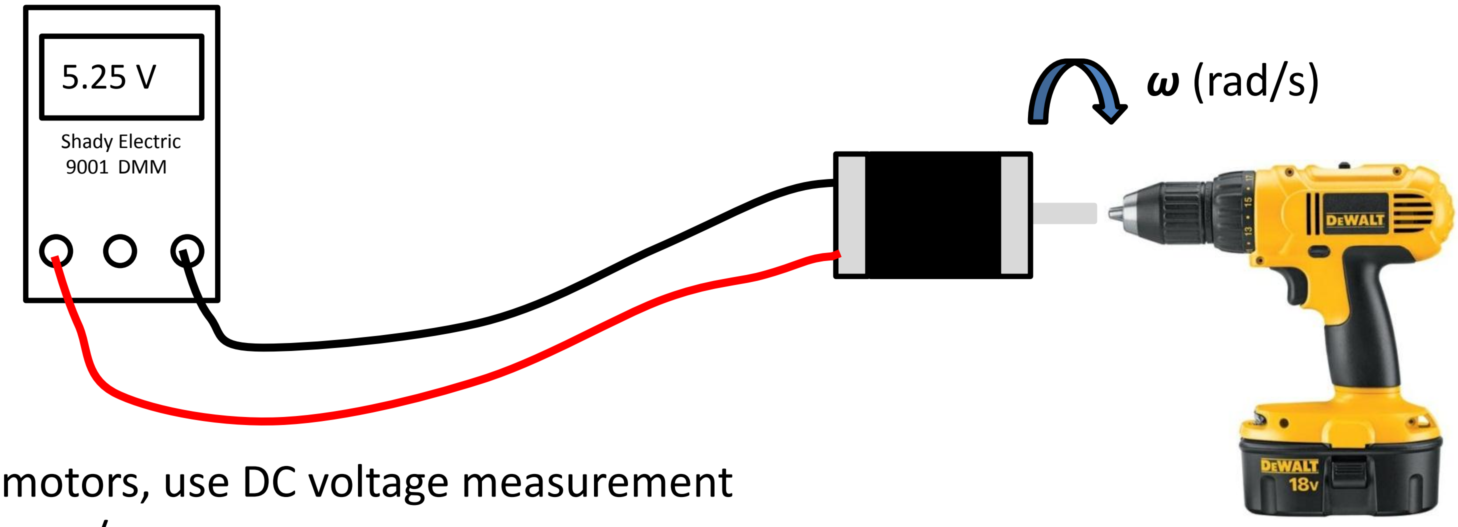
Testing to Find Motor Parameters

General procedure for finding Kt:

- Spin the motor with a known speed source, such as a power drill. The leads should be completely disconnected (no current flowing) to obviate error from Rm.
- Measure the terminal voltage (of a DC motor) or phase-to-phase voltage (of a permanent magnet AC / brushless-DC motor)
- For BLDC / PMAC motors, the result must be corrected due to the AC waveform.

For best accuracy, a tachometer should be used to verify the speed source. For approximation, the nominal speed (e.g. full trigger using a drill) can be assumed to be true.

This is one of several methods, but it is the one which yields the most intrinsic Kt; one that is not affected by how the controller switches the motor.

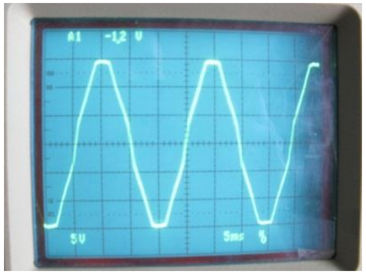


For DC brush motors, use DC voltage measurement

- $Kt = V_{dc\text{-}measured} / \omega$

Testing to Find Motor Parameters

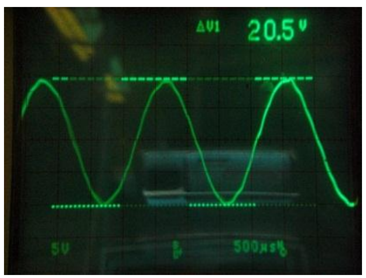
Because brushless and other AC motors output an AC waveform, many simple multimeters will wrongly report an average voltage (the “root mean square”) assuming the waveform is sinusoidal. This is usually not representative of the BEMF waveform of the motor



A trapezoidal BEMF

An oscilloscope must be used to find the shape of the BEMF for best accuracy. If an oscilloscope is available, then peak-to-peak voltage can be combined with a frequency measurement to find the Kt of the motor:

- $Kt = V_{pp} / \omega$



A sinusoidal BEMF

For measurement without an oscilloscope, refer to these empirical methods: http://www.bavaria-direct.co.za/models/motor_info.htm These will yield various estimates using a standard digital multimeter and should be used cautiously.