Circuit Design Clinic
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Motor Parameter Measurement

by Dennis L Feucht

Q: Motor specifications often give parameters called the *voltage constant*, K_V, and *torque constant*, K_T. How do these parameters relate to a motor circuit model and how can they be measured?

A: These parameters usually appear in step-motor and other permanent-magnet synchronous (PMS) motor data. Step-motors of the industrial size (NEMA 17, 23, 34, and 42, which are the cross-sectional dimensions in deci-inches -- divide by 10 to get the inches per side of the motor) are a *hybrid* of variable-reluctance (VR) and PMS motors, but the PMS dominates and they can be applied as PMS motors.

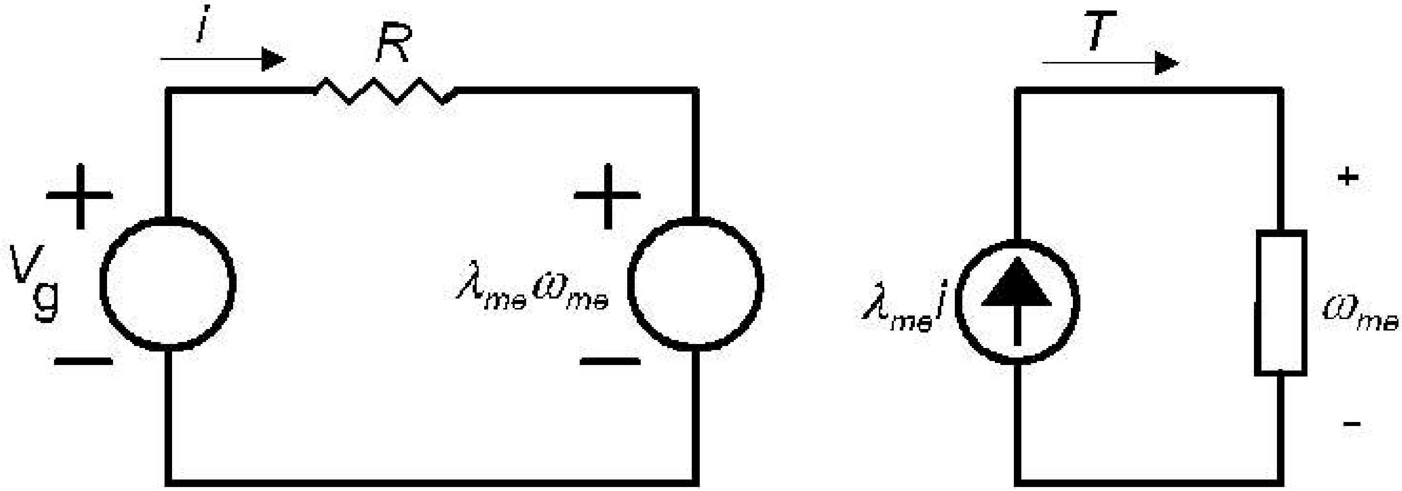
The voltage constant, K_V, is usually given in units of V/krpm and is the amplitude of the motor induced voltage, v_ω, over the motor mechanical speed, ω_{me}, or $K_V = v_\omega/\omega_{me}$. The Torque constant, $K_T = T/i_s$, where T = torque and i_s is the winding current. For multiple winding currents, this is the current vector magnitude. For 2-phase step-motors, the holding (or stall) torque is usually given with both windings driven at a specified and equal current. Then with windings separated by an electrical phase of 90°, the current vector magnitude is $\sqrt{2}\cdot i$, where i is the current of each winding.

The two parameters are equal for the minimalist, two-phase-winding model presented here. They are the same parameter, given in different units. This parameter is the circuit-referred flux (or *flux linkage*) amplitude of the motor, referred to the mechanical side of the motor, or the *electromechanical flux*. It is as important a motor parameter as β is for BJTs. I prefer to label this the *mechanically-referred flux* or *flux constant* and (after years of search for the right symbol) denote it as λ_{me}. (In the motor textbook *Electromechanical Motion Devices* by Krause and Wasynczuk, a similar but somewhat more awkward symbol is used. In more general motor theory, it is related to λ_{ds}, the stator-referred direct-axis flux, referred from the motor field to the circuit.) Then for the simple model:

$$\lambda_{me} \equiv K_T \equiv K_V = \frac{T}{i_s} = \frac{v_\omega}{\omega_{me}}$$

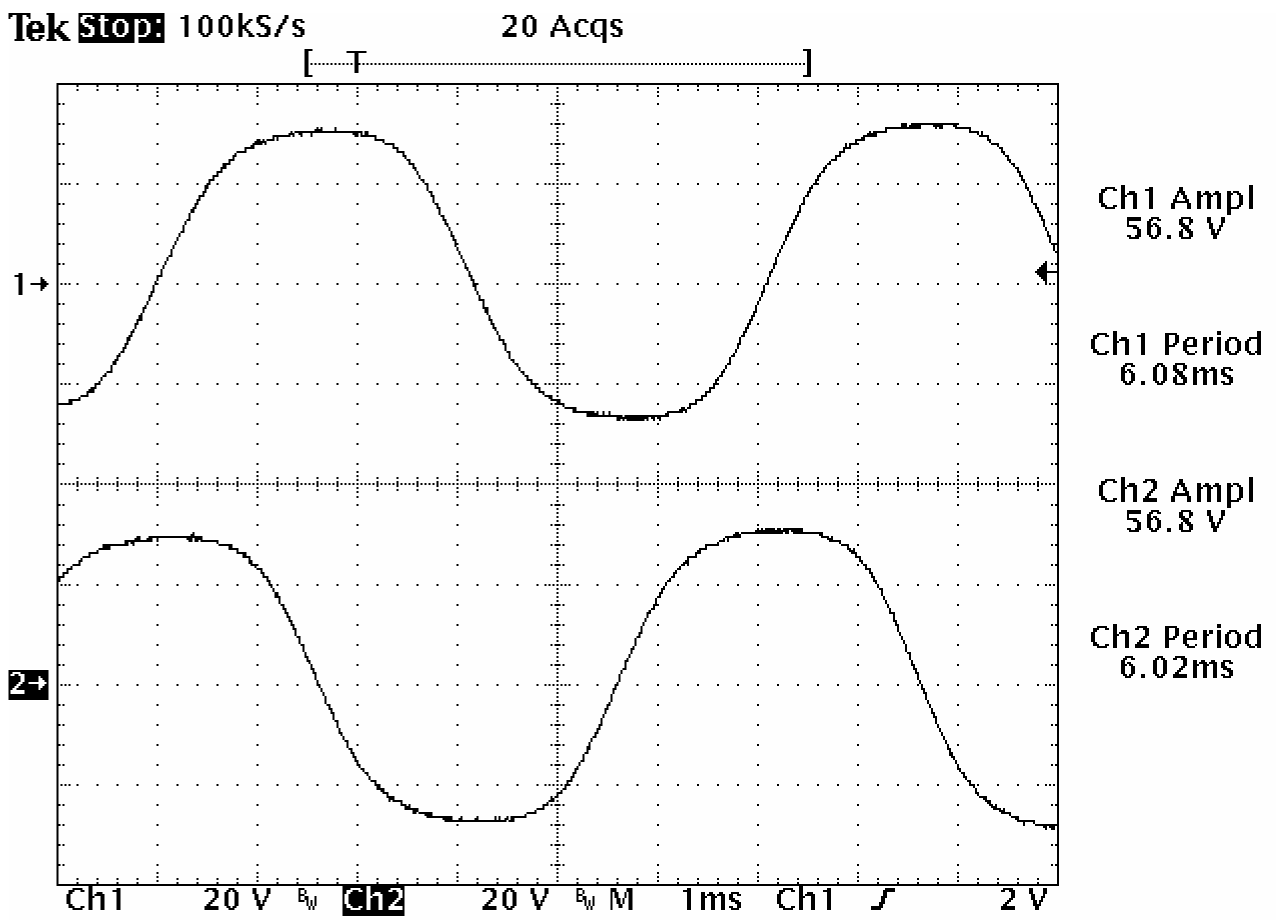
The unit of the first relationship is in N-m/A (or oz-in/A) and the second is in V/s^{-1} = V-s (or in V/krpm or V/Hz me). The V-s unit is that of magnetic flux and V-s ≡ N-m/A. For motors with other than two phase-windings, the two parameters differ by the phase-winding ratio. A three-phase motor has 3/2 the value of a two-phase motor.

The simple but useful minimalist motor model is given below that shows these relationships, using the torque-current analogy on the mechanical (right) side of the model.



It is serendipitous that only one parameter, λ_{me}, is required to relate the mechanical and electrical sides of motors.

λ_{me} can be easily measured using a DSO. Set the scope trigger mode to normal and trigger level to less than the amplitude of the induced-voltage waveform that you want to capture. Then connect windings to scope channels, set the V/div to 5 V/div and s/div to 5 ms/div, and arm the trigger. Spin the shaft of the motor with your hand. (Attach a front-panel knob to the motor shaft to make this easier.) The scope should capture a waveform that is like the one shown below.



The amplitude of the waveform is half the peak-peak value. The electrical frequency, ω, is related to the mechanical (shaft) frequency or speed by the number of pole-pairs, $P/2$, of the motor:

$$\omega = \frac{P}{2} \cdot \omega_{me}$$

1.8°/step step-motors have 100 poles or 50 pole-pairs and have an electrical frequency, as viewed on the scope, of 50 times the rotational frequency of the shaft. Therefore, to calculate λ_{me}, measure the induced-voltage frequency and divide by 50 for the mechanical frequency. Then:

$$\lambda_{me} = \frac{\hat{v}}{\omega_{me}}$$

where, $\hat{v}$ is the amplitude or peak voltage of the scope waveform. Slight variation between phase-winding measurements will occur and by taking the average of λ_{me} of the two phase-windings, a motor average value results, which can then be used and compared to the manufacturer motor data values.

For the above waveforms, taken from a 50 pole-pair step-motor (MCG IS34 027, series windings), the average of the electromechanical flux is:

$$\lambda_{me} = \frac{56.8\ \text{V}/2}{1/6.05\ \text{ms}} = 172\ \text{mV/Hz el} = 8.59\ \text{V/Hz me} = 1.37\ \text{V} \cdot \text{s} = 143\ \text{V/krpm}$$

The manufacturer's specification gives the holding (or stall or static) torque as 5.53 N-m at winding currents of 2.5 A. Then:

$$\lambda_{me} = \frac{T}{i_s} = \frac{T}{\sqrt{2} \cdot i} = \frac{5.53\ \text{N} \cdot \text{m}}{3.536\ \text{A}} = 1.56\ \text{V} \cdot \text{s}$$

This value of λ_{me} is higher than the measured value from the induced-voltage by about 12%. Expect some variation between λ_{me} values measured from induced voltage (as above) and dyno stall testing because the saturating magnetic path at full-current stall will cause the flux to be reduced somewhat. The torque-measured value should consequently be somewhat lower than the induced-voltage value. In the above case, the torque value is larger.

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