Indirect Permanent Magnet Rotor Temperature Measurement Technique

Developed by John O'Connor, Oztek Corp.
Contact Mike Drumm – **mdrumm@eandaUSA.com**
925 685-0227

It is not an easy task to make a direct measurement of the temperature of a high-speed rotor. Infrared temperature measuring devices are not widely available and many times access to a direct line of sight to the spinning rotor is not readily available.

Fortunately, for synchronous (Permanent Magnet or PM) machines the rotor temperature can be measured indirectly through induced voltage. By carefully measuring a permanent magnet motor's Back Electromotive Force (BEMF) constant at room temperature, and again immediately after operation, rotor temperature during operation can be estimated. Note that this measurement is ratio-metric (the output voltage is directly proportional to the input), so precision is more critical than absolute accuracy. A digital oscilloscope that's able to capture waveforms and provide values of captured signal amplitude and frequency can be used to acquire this data. Alternatively, a pair of Digital Multi-Meters (DMMs) that can be triggered to make fast, simultaneous measurement of AC RMS voltage and frequency can also be used. Note that if using an oscilloscope, a high voltage differential probe, such as Rigol RP1025D, is required. There are several companies that produce this type of probe.

Test Procedure:

1. Connect the differential probe across two motor terminals (phase-to-phase).
2. Measure the stator temperature *(Tini)*. It is assumed that at rest, rotor and stator are initially at the same temperature.
3. Using a second motor or a drill, spin the motor through a coupling or belt (see comments below regarding measurement accuracy).
4. Configure the scope to display several cycles of the BEMF waveform.
5. Capture the waveform and record the BEMF voltage *(V$_{rms\_ini}$)* and the frequency (F$_{ini}$).
6. Operate the drive under conditions where the value of rotor temperature is required and allow the rotor temperature to stabilize.
7. Configure the scope to display several cycles of the BEMF waveform.
8. Disable the drive, allowing the motor speed to coast.
9. Immediately capture the waveform and record the BEMF voltage (V$_{rms\_opp}$), and the frequency (F$_{opp}$).

Analysis:

1. Calculate initial BEMF constant:

$$K_{v\_ini} = \frac{V_{rms\_ini}}{F_{ini}}$$

2. Calculate operating BEMF constant:

$$K_{V\_opp} = \frac{V_{rms\_opp}}{F_{opp}}$$

3. Rotor temperature:

$$T_R \approx T_{ini} + \frac{\left(1 - \frac{K_{V\_opp}}{K_{v\_ini}}\right)}{K_M}$$

where k_M = magnet temperature coefficient (0.0011/°K for Neodymium Iron Boron, or 0.00035/°K for Samarium Cobalt). If using as direct input into RotorTemperatureTable.xlsx below, Neodymium Iron Boron magnet temperature coefficient is 0.11%/°K, and for SmCo it is 0.035%/°K.

Notes on Maximizing Measurement Accuracy:

a. This method of estimating rotor temperature is only valid within the magnet's specified operating temperature range.

b. If practical, use the same scope or DMM settings for the initial and operating measurements. This will eliminate gain errors between different ranges. However, if initial and operating speeds are far apart, it is better to set the instrument range such that the signal is close to full scale.

c. Take several measurements for both initial and operating BEMF at slightly different speeds. Calculate K_{v_ini} for each measurement and average results for each data set to minimize sampling errors (more beneficial for scope than DMM measurement).

d. If the motor takes many seconds to coast down, capture BEMF at fixed time intervals to determine thermal time constant.

e. If calculated rotor temperature change is minimal during coast down, capture "operating" BEMF using the same settings as used initially, at approximately the same speed. Use the estimated thermal time constant to extrapolate temperature at the point in time where the drive was disabled. This allows first order cancelation of most measurement errors.

RotorTemperatureTable RA.xlsx – an Excel File is available as a way of aiding in the capture of data and calculation of the estimated Rotor Temperature as described in this paper. See www.eandaUSA.com under Support & Downloads for free access to the file. Below is a screen shot of the file contents: