



## Calculating Winding Temperature

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In the course of applying rotary motors in applications, it sometimes becomes desirable to figure out the actual winding temperature given certain data. Read on for the method an engineer can use to calculate the actual winding temperature of Parker’s PM servo motors.

First off, we will define some terms:

Term	Definition	Units	Value (BE232D)
$R_{th\ w-c}$	Thermal resistance from winding to case	$^{\circ}C/w$	.56 (Parker Supplied)
$R_{th\ c-a}$	Thermal resistance from case to ambient	$^{\circ}C/w$	1.02 (Parker Supplied)
$R_{25C}$	Winding resistance at 25 $^{\circ}C$	Ohm	7.72 (Parker Supplied)
$w$	Shaft speed	Rad/s	Assumed or measured
$F_T$	Total friction from all sources	Nm	.0141 (Parker Supplied)
$B$	Total damping from all sources	Nm/rad/s	3.227E-5 (Parker Supplied)
$W_c$	Case losses (speed related losses)	Watts	Calculated
$W_r$	Resistive losses (power-related losses)	Watts	Calculated
$R_{hot}$	Winding Resistance at Winding Temp	Ohms	Calculated
$T_w$	Temperature of the winding	$^{\circ}C$	Calculated
$T_c$	Temperature of the case	$^{\circ}C$	Calculated or measured
$I_{rms}$	RMS current output from drive to motor	$A_{rms}$	Assumed or measured

What we do first is to calculate the resistance of the winding at the measured or assumed RMS current from the drive to the motor. The equation for this is:

$$R_{hot} = R_{25C} * (0.90175 + 0.00393T_w) \quad \text{Equation 1}$$

This will give the value for  $R_{hot}$  in terms of the unknown value,  $T_w$  – our desired term.

Next, the losses due to shaft rotation must be calculated. These losses are the case losses,  $W_c$ , and are due to the motor friction and motor damping. Failsafe brake and gearbox losses can also add to the case losses – but will be omitted from this example.

$$W_c = (F_T * w) + (B * w^2) \quad \text{Equation 2}$$

The friction and damping values are supplied by Parker. Contact Applications Engineering for these values from the motor you might have.

Once the case losses are calculated, the resistive losses should be calculated. This equation is:

$$W_r = 1.5(I_{rms})^2 * R_{hot} \quad \text{Equation 3}$$

$W_r$  will be given in terms of  $T_w$  once we plug in the equation for  $R_{hot}$ .

$$W_r = 1.5(I_{rms})^2 * (R_{25C} * (0.90175 + 0.00393T_w)) \quad \text{Equation 4}$$

Insert all known values and simplify. Equation 4 will be reduced to a simple form with  $T_w$  still as an unknown.

The final equation for the winding temperature is as follows:

$$T_w = [(R_{th\ c-a}) * (W_c + W_r) + (R_{th\ w-c}) * W_r] + 25 \quad \text{Equation 5}$$

Plug in the simplified Equation 4 for  $W_r$  and the thermal resistance values supplied by Parker. Simplify. Now you can easily solve for the winding temperature,  $T_w$ .

If you prefer, you can put everything in terms of  $T_w$  and plug in the values at the end to solve, but the equation gets long and complicated.

Also, if you are able to reliably measure the case temperature, you can increase the accuracy of the winding temperature calculation and simplify Equation 5 to the following:

$$T_w = T_c + (R_{th\ c-a}) * (W_r) + 25 \quad \text{Equation 6}$$

At that point, the case temperature would include all losses and cooling due to convection and conduction.

These equations and processes hold true for motors from other manufacturers. Parker Hannifin offers a free sizing and selection tool that automatically takes care of these type of calculations for the BE, SM and MPP motors. In some cases, doing the hand calculations is also valuable.

#### EXAMPLE:

Find the winding temperature ( $T_w$ ) for the BE232D rotating at 5000RPM with RMS current of  $1.8A_{rms}$

Plugging in the 7.72 for  $R_{25C}$  and simplifying, Equation 1 becomes:

$$R_{hot} = R_{25C} * (0.90175 + 0.00393T_w)$$

$$R_{hot} = 6.962 + 0.03034T_w$$

Converting 5000 rpm to radians/second gives us 523.6rad/s. Plugging this and the friction and damping values into Equation 2 yields:

$$W_c = (F_T * w) + (B * w^2)$$

$$W_c = (.014123 * 523.6) + (.00003278 * 523.6^2)$$

$$W_c = 16.377 \text{ W}$$

Find the resistive losses for the RMS current of 1.8A from Equation 3 and 4:

$$W_r = 1.5(I_{rms})^2 * R_{hot}$$

$$W_r = 4.86 * (6.962 + 0.03034T_w)$$

$$W_r = 33.84 + 0.147T_x$$

Finally, use Equation 5 to put it all together and solve for  $T_w$ :

$$T_w = [(R_{th\ c-a}) * (W_c + W_r) + (R_{th\ w-c}) * W_r] + 25$$

$$T_w = [(1.02 * (16.377 + 33.84 + .147T_w)) + (.56 * (33.84 + .147T_w))] + 25$$

This simplifies to:

$$T_w = 95.17 + .2323T_w$$

$$T_w = 124^\circ\text{C}$$

The speed and the current I chose happen to be the rated speed and current for the BE232D motor.

*For more information on Parker's complete line of servo and stepper motors, please visit [www.parkermotion.com](http://www.parkermotion.com).*