Duty Cycle, Peak Current and Temperature

There has long been a "rule of thumb" in the brushless servo motor industry about what is acceptable to use as a duty cycle when operating in the "peak" or "intermittent" range. Many times you will hear reference to numbers like one second, or half a second as acceptable times to operate in the peak range, and it is believed that if you are in peak for one second, and then off for one second, you'll have an acceptable duty cycle, in this case, 50%.

That is very far from the truth. The following is true for virtually any brushless servo motor. When the motion profile of a brushless servo motor requires that it enter the peak or intermittent range during every cycle, the duty cycle is limited somewhat exponentially as the percentage peak current increases.

The graph below illustrates a brushless motor's duty cycle curve for operating in the peak or intermittent range. The current is normalized such that 100% duty cycle corresponds to "1" being the motor's maximum continuous current for a 130°C winding with a 25°C ambient and the motor attached to a 12" x 12" x 0.5" heat sink. Hence "2" on this curve corresponds to twice the continuous rated current.

In this curve you will see that if operating at 2X continuous current, the acceptable duty cycle is 4%. So, if you are at 2X continuous current for one second, you will need to be without power to the motor for 24 seconds to achieve the acceptable duty cycle of 4%. Another item to consider is that depending upon the motor's thermal time constant, powering the motor "on" with 2X current for 10 minutes and then turning it "off" for 240 minutes corresponds to 4% duty cycle; however, a 60mm or 90mm motor will overheat in less than 10 minutes with 2X rated current. Hence this curve is only a guideline and cannot be applied blindly.

When considering how long a motor can be operated in the peak range, the starting temperature must also be accounted for. The maximum allowable time "on" is going to be the time in which the motor's stator reaches 130°C. This time is obviously longer if the starting temperature is 25°C rather than 55°C. The cool-down time must then allow for cooling back to the original starting temperature.

Another critical factor to consider is that using a motor's case temperature as a gauge of allowable duty cycle is only acceptable when operating beneath the continuous rated current of the motor.

Because the thermal time constant of the wire in the motor's stator is far shorter than the thermal time constant of the motor's case, the wire in the stator will heat many times faster when subjected to currents in the "peak" or "intermittent" range, than will the motor's case.

For example, at 2X rated current, one tested motor's stator increased from 25°C to 130°C in 90 seconds. In that same 90 seconds, the motor case had increased only 10°C. Also due to the interrelationship between the components of the motor with different thermal time constants and the flow of energy in the motor, the motor's case will continue to rise in temperature when the power is removed in this example. Also, the thermal time constant of the wire in the stator is less than that of temperature sensors and switches that are integrated into the stators.

Therefore, when subjected to high peak currents, it is possible for the stator to be damaged before the thermal switch or sensor has indicated that the motor is in an overheated condition.

%Duty Cycle vs Motor's Normalized Continuous Current
(%Duty Cycle = Time "on"/(Time"on" + Time"off")
Motor Attached to 12"x12"x1/2" Aluminum Heat Sink,
Maximum Winding Temp = 130°C, Ambient = 25°C