Why Servo a Microstep Motor?

The servo market has made several transitions over the years. One of the more recent is a wider use of microstep capable step motors as primary movers in servo systems. This transition has been fueled by the growing availability of powerful Digital Signal Processors at affordable prices, as well as control algorithm development. These new step motor based servos include true servo motors using control algorithms which modulate motor torque to perform the requested motion, as well as pseudo servo motors which dynamically vary the step rate to prevent loss of steps.

A high quality microstep capable step motor may also be operated as a high pole count AC servo motor[i] – it just takes the right hardware and software, and a position feedback device such as an optical encoder or resolver to create a closed loop AC servo system. When operated as AC servos, these motors use servo control algorithms to produce smooth and accurate motions with rapid acceleration capability.

The “STEP” in the motor name remains only for historical reasons! The high case temperature, lost steps, and severe resonance issues associated with using these same motors in open loop step mode go away when the motor is operated as an AC servo with sinusoidal commutation. Indeed, this mode of operation enables these “step” motors to operate with less torque ripple than many brushless DC motors utilizing trapezoidal commutation!

But ***why*** change? Simply, these motors are capable of producing smooth motions with more torque and less heating at a lower cost! The high magnetic pole count in these “Step” motors, combined with fairly tight magnetic gaps, drives the high torque capability. Unlike open loop operation, closed loop servo operation of these step motors causes only the current needed to produce the motion to be applied to the windings, reducing heat generated. The well refined manufacturing process – honed by the sheer numbers of step motors produced – as well as the ability to use less costly magnets allows these motors to be produced at significantly lower costs. The reduction in winding heating may be more than 90% while producing the same torque, significantly reducing power supply size as well as system cooling requirements, and providing for higher available duty-cycle operation.

Various motor characteristics are commonly used in comparing motors, including size, rotor inertia, electrical time constant, and specifically “Figure of Merit”[ii].

The Figure of Merit, Km, (also called “Motor Constant”) describes the motor torque per square-root of power performance. Km is useful in comparing different motor types as it remains constant for different winding voltages and winding configurations, whether Y or Delta, two, three or 5 phase, 24v or 240v operation. Km is derived from the torque constant of a motor, Kt, and the winding resistance R. Kt, may be calculated by dividing the torque in Newton-meters by the current in Amps. The power dissipated in the windings as heat (I^2R) is calculated by multiplying the winding resistance by the square of the current through the winding. Km may then be calculated by dividing the torque constant by the square root of the winding resistance, or by dividing the torque by the square-root of winding power dissipation:

$$Km=Kt/sqrt(R) = Kt*I / I*sqrt(R) = T / sqrt(I^2*R) = T/sqrt(P)$$

For any given torque level, the stator winding power loss may be compared:

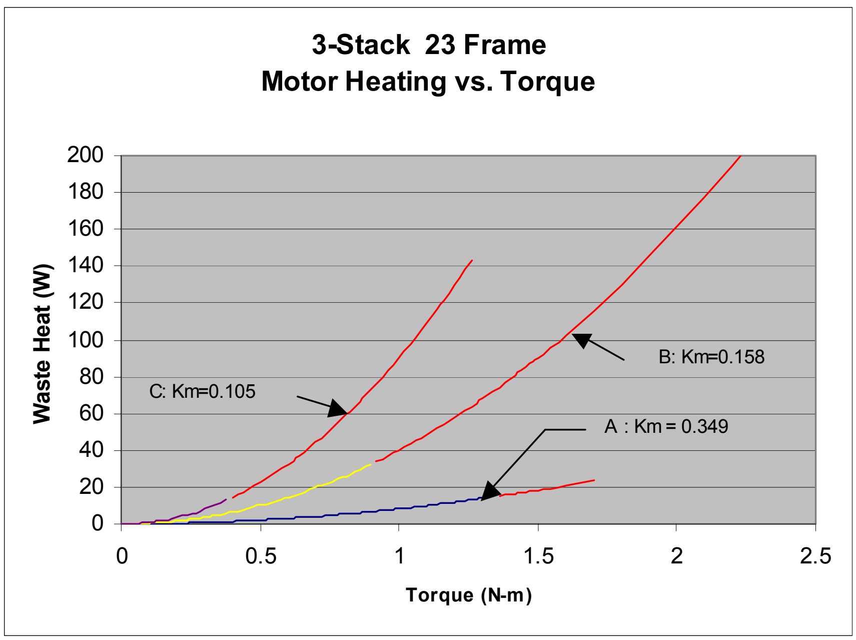
$$P_2 = P_1*(Km_1/Km_2)^2$$

As stated above, the figure-of-merit is neutral with respect to winding voltage: The torque constant of a motor may be doubled by simply using twice as many turns of wire having one half the cross sectional area. While this doubles the torque constant, this also quadruples the winding resistance, resulting in no change for the figure of merit. On the other hand, doubling the pole count of the motor, if everything else remains the same[iii], doubles the torque constant without affecting the winding resistance, and thus doubles the figure of merit of the design.

Looking at the characteristics of three typical 23 frame “3-stack” motors: A is a QuickSilver Controls A23-5, 23 Frame Step motor, while B and C are BLDC motors of similar dimensions[iv].

23 Frame Motors - "3 stack"

	Step A	BLDC B	BLDC C	Units
Tpeak	1.69	4.30	1.27	N-m
Tcont	1.34	0.90	0.38	N-m
Kt	0.33	0.31	0.1	(N-m)/A
R	0.90	3.90	0.9	Ohm
Km	0.35	0.16	0.11	(N-m)/sqrt(Ohm)



The lower curve is Step motor, A, the middle curve is BLDC motor B, and the upper curve is BLDC motor C. The red portions of each curve represent the motor as it is operated beyond continuous torque rating, but within the peak torque performance rating.

Looking at this data, it is clear that the power dissipated into the windings is parabolic. Doubling the torque for a given motor quadruples the heat. Next, one can clearly see the heat dissipated for a given torque level drops dramatically with rising motor Figure of Merit (Km). The ratio of power dissipated for the A (step) motor as compared to the C (BLDC) motor for a given torque is:

$P_A/P_C = (Km_C/Km_A)^2$ = (0.11/0.35)2 = 0.099 or roughly 10%!

Holding the same torque requires more than **TEN** times the power for BLDC Motor C than it does for the Step Motor A. Although Motor C shows a peak torque almost the same as the Step motor continuous torque, the BLDC motor C would be dissipating almost 143 watts as compared to approximately 13 watts for the stepper. This not only affects the cost of power supplies and cooling, it greatly limits the duty cycle at which the BLDC can operate while maintaining a safe and reliable temperature range. The power dissipated for BLDC motor B is between that of Step Motor A and BLDC motor C.

There are some tradeoffs in using these higher pole count motors versus the low pole count motors: the higher torque constant directly corresponds to a higher back-EMF constant. The higher the back-EMF constant, the lower the speed at which the back-EMF voltage generated reaches the supply voltage. As the motor speed approaches this limit, the available torque decreases. However, if the motor is capable of producing the needed toque at the needed speed for the given application, then cost and heat savings may be enjoyed. Many applications are speed limited by such factors as lead screw or gear-head ratings. Short indexing motions are typically limited by acceleration rather than velocity. Other systems have the application speed limited by other constraints such as milling, sawing, and glue dispensing speeds.

The low relative cost of these step motors combined with high performance available with closed loop servo operation of microstep capable “step” motors, or, more properly, high pole count permanent magnet AC synchronous motors, will continue to fuel growth in this re-awakened segment of the motion market.

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[i] See white paper “QCI-WP003 Servo Control of a Microstep Motor” at www.quicksilvercontrols.com

[ii] Proceedings 21st Annual Symposium, Incremental Motion Control Systems and Devices, “Characteristic Parameters of Permanent Magnet Motors and Their Relationship to Motor Size”, W.John Ballantyne, Leo Luk

[iii] Other parameters do, indeed, change, but the Km does significantly rise with pole count.

[iv] Values are from respective vendors data sheets, motor B is slightly longer than both A and C. The full peak torque for motor B was not shown to allow for a more easily viewable graph scale.