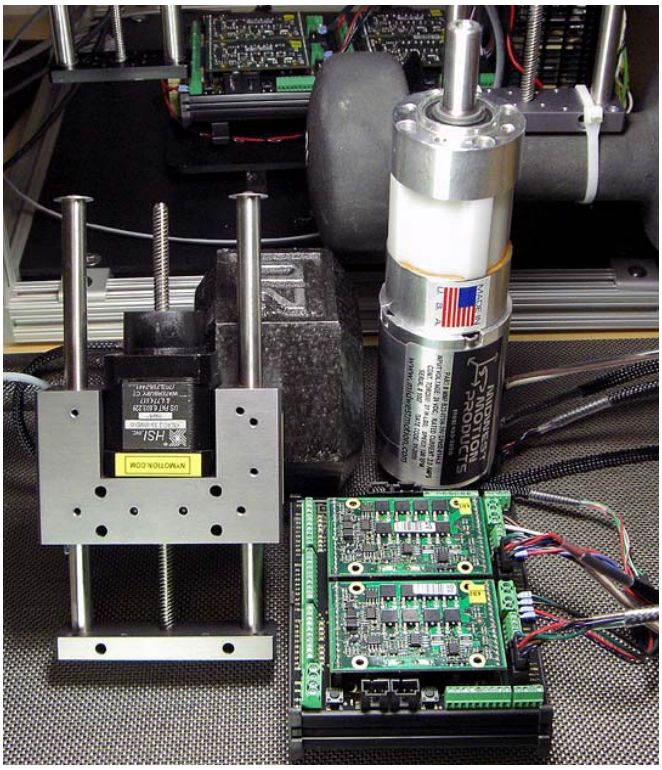
This paper provides an introduction to operating industry standard hybrid step motors and linear actuators in servo mode with NYT-AP Series Drive/Controllers.



1. Background. Driving hybrid step motors in servo mode is not a new technology. Over the years various motion suppliers have introduced and "reintroduced" the technology concentrating on rotary applications. This approach runs into fairly stiff customer resistance on a single question. Why? With the availability of reasonable, "instrument grade" brushless motors from a variety of sources, driving a hybrid stepper in servo mode has questionable value. The relative price – performance advantage of hybrid servo systems diminishes as the cost of instrument grade servo motors lowers.

   Turning to the performance side of the equation, all else being equal, servo motors are a better fit in most rotary applications. This observation is based on a single, inherent design weakness affecting hybrid servo motors: Top speed is adversely impacted by the higher pole count. Hybrid step motors have 50 poles where brushless motors generally have 4 or 8 poles.

   Restating the issue: Brushless DC and Hybrid servo motors share features, functions and benefits in servo applications with speeds up 25 ~ 30 rps. In 20 – 60 rps applications, brushless motors provide superior performance.

2. Hybrid linear actuators are a different ball game. In miniature X-Y, syringe pump, lifts, valve, leveling and a myriad of other positioning applications the mechanical simplicity and cost affectiveness of hybrid linear actuators bring high performance and exceptional endurance into a very compact package. As there are no

commercially available mechanical equivalents to "captive, non-captive and external linear" actuators in the servo motor market, the ability to drive standard HaydonKerk hybrid actuators in servo mode provides equipment designers a reasonal and cost affective means to dramatically improve system performance.

Comparisons:

	Hybrid Linear Actuator	Hybrid Servo Actuator
Drive/Controller	FS/HS & µStep Drives	NYT-AP Series Drive/Controllers
Motor	Hybrid step motor	Hybrid step motor w/ Encoder
Control Modes	Speed and Position	Speed, Position and Torque (**Note 1**)
Efficiency (Note 2)	Low	High
Vm	Reasonable to 20 rps	25 to 30 rps
Accl/Decl	Low to Medium	Medium to High
Low Speed Applications	Reasonable	Excellent
Audible Noise	High	Low
Resonance	Multiple Resonance Points	No Resonance Points
Position Maintenance (Note 2)	Once motion has stopped current is stepped down to a hold current of 25 – 50%	Once motion has stopped current is drops to a level that maintains position. 1 – 100%
Current Control	A function of run and hold current settings	A function of load demand. A servo draws what is required but no more.
Motor Temperatures	High	Low

Note 1: An example of torque mode: Move assembly A into assembly B. Ramp up and maintain a constant 15 lbs thrust into B for 90 seconds while the epoxy cures.

Note 2: Efficiency and power management. In most applications, servo drives are significantly more energy efficient than comparable constant current stepper drives. As hybrid servo motors are in fact true servo motors, drawing as much current as required to accelerate or hold a load, the designs are inherently more efficient. On the other hand, Hybrid step motors are sized and their drives are set to provide a torque (= current) with a safety margin of 1.35 X or higher.

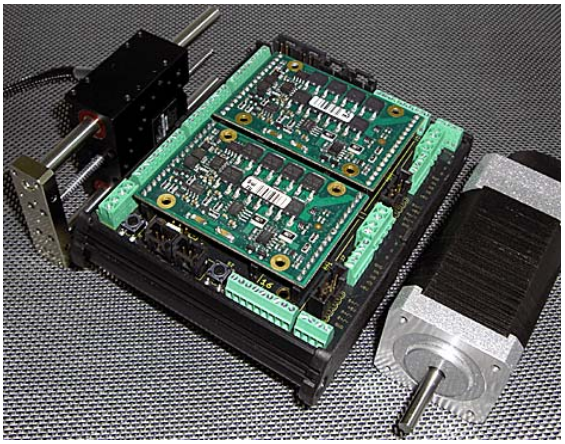
Nymotion NYT-AP Series drive/controllers provide machine designers the means to use standard HaydonKerk linear actuators in servo mode. The outcome is higher throughput, lower audible noise, lower risk (closed loop) performance with a significantly lower carbon footprint.

Caution:

NYT-AP Series Drive/Controllers provide a significant level of design and performance control. Turning up the tuning parameters, peak current and Accl/Decl rate to unrealistic levels for a lead screw positioning system will impact life. Begin with

reasonable performance improvements, cycle test then continue with incremental improvements.

Testing and determining the suitability of a rotary step motor, linear actuator and the NYT-AP Series Drive/Controller family in a specific application is a customer responsibility. To assist our customers, Nymotion LLC has an active test and evaluation program in place and in OEM applications involving customer designed or 3d party positioning slides, Nymotion provides contract design and testing services on a time and materials basis.



Life testing with the desired motion profile (Accl/Vm/Decl) and Duty Cycle is important. Some design issues are discussed below.

- On the HaydonKerk web site view the Size 11 Double Stack Force – Speed curves. On the curves, note the 30 lb "Recommended Load Limit". In servo mode, this actuator can be driven with 2 – 3 X peak currents. As a result, lifting a normally "reasonable" 10 lb load against high friction seals or fluid back pressure could subject the actuator's 4.76mm (0.188") dia screw and nut to forces exceeding 90 lbs.

- We will use the same HaydonKerk web page to illustrate another issue. HaydonKerk Force – Speed curves are generated from dead lift testing. No Accl/Decl ramps are used to generate these "worse" case curves. As HaydonKerk actuators use lead screws and the nuts in two design options (captive and non-captive) are at the core of the motor (where temperature rise is significant) the term "duty cycle" introduces another level of quality control risk that needs testing.

  Consider a well plate scanning application that executes a continuous duty, serpentine scanning of multiple well plate cells. New well plates are shuttled into position A as the X-Y scanner works on position B. In this example, the X-Y actuators (in stepper mode) have an Accl/Decl of 150 mm/s^2 . As the cell-to-cell moves on a 384 position well plate are 4.5 mm, this continuous duty cycle application is for the most part all Accl and Decl moves. The same X-Y actuators (in servo mode) can execute the same 4.5 mm moves with Accl/Decls in the 1000 - 2000 mm/s^2 range. The duty cycle remains 100% but lead screw and nut friction as well as linear bearing friction will ramp temperatures into "runaway".

Let's review: Your share holders were impressed and awed by a 30 minute demo where a Size 11 actuator weight lifted 90 lbs and linear scanning matched the accl/decl profile of a brushless linear motor X-Y costing 8 times more; But an instrument life of 29 minutes wasn't exactly what they had in mind.

Design Notes and Discussion

3. Which rotary motors are suitable for hybrid servo mode? High quality, low inductance, 1.8 deg/step hybrids work well. Nymotion stocks an 8 lead (parallel hookup) Size 17 rotary motor that performs nicely. In general, lower inductance (less than 3.5 mH) motor windings perform well. Contact Nymotion engineering for additional guidance.

4. As Nymotion LLC has been a specialist in linear actuators, devices and systems since 1986, we concentrate on HaydonKerk linear actuators. Which HaydonKerk Hybrid Linear Actuators are suitable for servo mode? Size 8 – 23 frame sizes and all mechanical styles: Captive, Non-Captive and External Linear w/ bipolar wiring and encoder.

	Size 8	Size 11	Size 14	Size 17	Size 23
Voltage	2.5V	2.1V	2.33V	2.33V	3.25
1-Stack:	1.5 mH	1.5 mH	2.80 mH	1.90 mH	3.5 mH
2-Stack:		1.1 mH	1.95 mH	1.33 mH	2.3 mH
Encoder	E4-360 1440 ppr	E8P-512 2048 ppr	E5-1250 5000 ppr	E5-1250 5000 ppr	E5-1250 5000 ppr
	E8P-512 2048 ppr	E5-1250 5000 ppr			E6-2500 10000 ppr

   A. Size 34 testing. TBA.

   B. Size 8 performance with the E4-360 is acceptable but a higher line count works better. A transition plate mounted E8P performs better but there is a size mismatch.

   C. The E8P-512 works well and fits perfectly on the S11 but it lacks an index. In servo applications where there is no room for a home limit, home-on-a-hard-stop (viewing current) provides a reasonably repeatable home of +/- 30 µm.

   D. The E5-1250 and E6-2500 have the 3d channel, one-per-rev "index" that allows a home-on-a-hard-stop followed by a move to an index routine. This home technique tightens repeatability to +/- 5 µm.

   E. Conventional home limits (recommended) are repeatable to +/- 5 µm.

5. NYT-AP Series Drive/Controllers

NYT-AP Series	NYT1X-AP	NYT2X-AP	NYT3X-AP-HS
Number of Axis:	1	2	3
Control Mode:	µStep or Servo	µStep or Servo	µStep or Servo
Supply Voltage:	12 – 28Vdc	12 – 28Vdc	12 – 28Vdc
Current:	**Module Options**	**Module Options**	**Module Options**
µStep Resolution:	/256	/256	/256
Servo Resolution:	**Encoder Options**	**Encoder Options**	**Encoder Options**

Module Options	PIM2401	PIM2403
Current:	1A rms/ 3A peak	3A rms/ 6A peak
Sizing:	25 Watts @ 24Vdc	75Watts @24Vdc

Encoder Option	E4-360	E8P-512	E5-1250	E6-2500
Line Count:	360	512	1250	2500
Counts (Pulses)/Rev:	1440 ppr	2048 ppr	5000 ppr	10000 ppr
Index (1 per rev):	No	No	Yes	Yes

Resolution Notes: Given a 6.25 mm/rev (0.25 in/rev) Lead

- Open Loop Microstepping @ /16 provides 200 FS/REV * 16 MS/FS = 3200 µs/REV. Therefore: 6.35 mm/rev / 3200 µs/FS ~ 0.002mm or 2 µm / µs
- Closed Loop Servo w/ 2048 ppr: 6.35 mm/REV / 2048 ppr ~ 0.003 mm or 3 µm / encoder count
- Closed Loop Servo w/ 5000 ppr: 6.35 mm/REV / 5000 ppr ~ 0.00127 mm or 1.27 µm / encoder count
- Closed Loop Servo w/ 10000 ppr: 6.35 mm/REV / 10000 ppr ~ 0.000635 mm or 0.635 µm / encoder count