Why We Use Stepper Motors for High-Thrust Web Guiding Actuators

Blog Post

An engineer-to-engineer look at the design choices behind our high-thrust linear actuators, including the tradeoffs we accept and the ones we don't.

The Default Assumption — and Why It Deserves Scrutiny

Ask any motion control engineer to spec a high-force, precision linear actuator for an industrial web guiding application and they will almost reflexively reach for a servo motor. The arguments seem compelling: closed-loop position control, smooth torque across the speed range, high bandwidth, clean direction reversals. Stepper motors, by contrast, carry a reputation as "open-loop" devices prone to step loss, resonance, and thermal issues — fine for light-duty positioning, unsuitable for serious industrial work.

That reputation is not unfounded. Steppers do have real limitations, and we will address them directly in this article. But after years of building and deploying high-thrust linear actuators in web guiding applications — moving heavy unwind and rewind stands on linear bearings — we have found that the specific demands of web guiding change the motor selection calculus in ways that are worth examining carefully.

This is not an argument that steppers are universally better than servos. It is an explanation of why, for this particular application profile, we chose steppers and continue to stand behind that choice.

Understanding What Web Guiding Actually Demands

Before selecting a motor technology, you need to characterize the application honestly. Web guiding is not a general-purpose positioning problem. It has a specific operating profile that shifts the engineering tradeoffs significantly:

Correction bandwidth is very low. In most web guiding applications, the web edge wanders at 0.5 to 2 Hz. This is extremely slow in motion control terms. The high-bandwidth torque loop arguments that favor servo motors — current loop rates of 1-5 kHz, rapid direction reversal response — are simply not being exercised at these correction rates. Nearly any motor technology can track a 2 Hz correction signal without issue.

A deadband is standard practice. Rather than continuously driving the error to zero, most web guiding controllers use a deadband — a tolerance window within which no correction fires. This means the motor is at rest the vast majority of the time, making discrete low-speed moves followed by a return to standstill.

Instead of continuous reversals through mid-speed ranges, you have occasional discrete moves separated by dwell periods.

The outer loop closes on the web, not the motor. The position feedback in a web guiding system comes from a Roll-2-Roll® Sensor — a fiber-optic array, camera, or ultrasonic sensor reading the actual web position. This sensor closes the loop over the entire drivetrain: motor, coupling, ballscrew or roller screw, and any mechanical compliance in the system. It corrects for everything downstream, including any positional imprecision from the motor itself.

These three characteristics — low bandwidth, deadband operation, and web-sensor outer loop — collectively transform the motor selection problem. It shifts from a high-performance tracking challenge to a reliable, consistent actuation challenge. The motor needs to be a dependable, low-hysteresis device that moves predictably when commanded. The web sensor handles the rest.

This analysis is not controversial. Any controls engineer examining the transfer function requirements would reach similar conclusions. Where things get more interesting is what happens when you follow these requirements through to the motor selection decision.

Where Servos Earn Their Premium — and Where They Don't

We want to be clear about something: servo motors are excellent. In applications with high closed-loop bandwidth requirements, continuous operation through frequent direction reversals at speed, or where the motor is the primary position feedback element, servos earn their premium many times over. We are not arguing against servos in general.

What we are arguing is that when each of those conditions is absent — as in low-bandwidth, deadband-controlled, web-sensor-corrected applications — the servo advantage narrows to the point where other factors dominate the selection.

Low bandwidth reduces the dynamic performance argument. The servo's ability to execute clean, high-speed direction reversals with minimal settling time matters less when your correction loop is running at 0.5 Hz. A conservatively tuned servo and a well-sized stepper both execute a slow correction move adequately. The servo's edge at higher speeds and bandwidths is real — it simply is not being exercised.

The deadband reduces resonance excitation. Stepper motors have a well-documented mechanical resonance, typically in the 50-200 Hz range. We address resonance mitigation in detail below because it is a legitimate concern. But the deadband operation profile helps: you are not executing continuous oscillatory motion through resonant speed bands. You are making discrete, low-speed moves separated by dwell periods. This does not eliminate the resonance concern — it reduces how often the motor operates in conditions where resonance is most problematic.

The outer loop changes the step-loss equation. The standard objection to open-loop steppers is that a lost step is invisible and creates a permanent position error. In a web-sensor-closed-loop system, the sensor detects the resulting position error and corrects it on the next cycle. Step loss becomes a recoverable event rather than a silent fault. This does not mean step loss is acceptable — it means the system can tolerate occasional step loss without catastrophic consequences, which changes the required reliability margin from "never" to "extremely rare."

The Honest Tradeoffs: What We Give Up with Steppers

Before explaining why we still chose steppers, we owe you a straightforward accounting of what we gave up. Engineers trust sources that acknowledge limitations, and these are real.

Energy Efficiency

Stepper motors are less energy-efficient than servos. A servo draws current proportional to load — near-zero current at standstill under no load. A stepper draws its programmed hold current at standstill regardless of load. In continuous-duty, high-speed applications, this difference is significant.

In web guiding, it matters less than you might expect. The duty cycle is dominated by standstill dwell time within the deadband, with brief low-speed correction moves. Our intelligent microstepping drivers mitigate standstill losses through automatic hold current reduction — programmable down to 50% of run current after a configurable delay — and adaptive current control during motion that scales motor current to actual load demand. We typically see total power consumption in the range of 6.5 W to 210 W depending on actuator model. But we are not going to claim parity with servos on efficiency. Servos win this one.

Audible Noise

Steppers are louder than servos. The discrete stepping action, even with 256-microstep interpolation, produces audible noise that servo motors do not. Voltage-mode PWM — a silent operation mode designed for low-velocity, low-noise operation — significantly reduces this noise at the low speeds typical in web guiding. At walking pace and below, stepper motors driven in this mode are genuinely quiet. But at higher speeds or during acceleration, a stepper will be more audible than a comparable servo. In most web guiding installations — industrial environments with significant ambient noise — this is not a practical concern. In a quiet laboratory or cleanroom, it might be.

Speed Limitations

Stepper motor torque falls off with speed. This is fundamental to the technology — the back-EMF at high speed reduces available current, and torque drops. Our actuators are rated up to 2 in/sec (51 mm/sec), which is adequate for web guiding correction moves but would be limiting in applications requiring fast, long-

stroke repositioning. Servos maintain much flatter torque-speed curves and can deliver rated torque at significantly higher speeds.

For web guiding, the speed limitation is not constraining. Correction moves are short-stroke (typically under 0.5 in / 12 mm per correction cycle) and low-speed. But if your application requires fast homing, rapid retract, or long-stroke positioning at speed, a servo has a genuine advantage.

Thermal Dissipation at Standstill

Steppers draw current when holding position, which means they generate heat at standstill. This is the opposite of a servo, which draws near-zero current when stationary under no load. For web guiding, where the motor spends most of its time in the deadband at standstill, this seems like it should be a significant concern.

In practice, we manage this through the driver's current management features. Hold current is automatically reduced after a programmable delay following the last step — typically to 50% of run current. Adaptive current control further reduces current during low-load motion. The result is that thermal rise at standstill is modest and well within motor ratings. We have not experienced thermal failures in field installations. But the heat is there, and in a thermally constrained enclosure, it needs to be accounted for in the system thermal budget. We will not pretend otherwise.

The OEM Shipping Problem: Why We Chose Steppers Despite the Tradeoffs

With all those limitations acknowledged, here is the engineering argument that tipped our decision — and it is a practical one more than a theoretical one.

Roll-2-Roll Technologies manufactures actuators and ships them to end users for field installation. We do not commission every installation ourselves. Our customers — converters, paper mills, film extruders, battery manufacturers — install these actuators on their own equipment, often with millwrights and electricians who are skilled at mechanical and electrical installation but are not motion control engineers.

Servo motors carry a commissioning cost that rarely appears in component-level engineering comparisons: tuning.

Servo tuning is fundamentally a load-dependent process. The gain parameters that determine stability and response — the inertia ratio, friction characterization, and mechanical resonance frequencies — are all properties of the installed machine, not the actuator in isolation. A servo drive tuned on the manufacturer's bench without the actual load is tuned for the wrong system.

Modern servo drives offer auto-tuning features — Yaskawa's Sigma-7 "Tuning-less" mode, Kollmorgen's AKD2 inertia identification wizard, and others. Integrated servos like the Teknic ClearPath and Applied Motion StepSERVO have made real progress in closing the complexity gap, and we acknowledge that the servo commissioning experience is significantly better today than it was a decade ago. But auto-tuning still requires the load to be connected and the machine to execute test motions. It transfers the tuning process from the factory to the field. It simplifies it — genuinely — but it does not eliminate it.

Here is what we want to be precise about: with a stepper motor and an intelligent microstepping driver, the *motor drive* requires no field tuning. Run current, hold current, microstep resolution, and acceleration ramp are set at the factory. These parameters are not load-dependent in the sense that they need to be re-optimized per installation. Size the motor for worst-case load with adequate margin, set conservative acceleration profiles, and the drive is ready to ship.

This does not mean the *system* requires no tuning. The web guiding controller itself — whether ours or a third party's — still requires configuration: PID gains, deadband width, sensor filtering, guide response aggressiveness. That tuning is application-specific and unavoidable regardless of motor technology. What the stepper eliminates is one commissioning step: the motor drive tuning that interacts with mechanical load dynamics. One fewer thing for a field technician to get wrong, one fewer support call.

That distinction matters for an OEM shipping hundreds of actuators per year. It does not make steppers universally superior. It makes them a better fit for our specific business model and deployment context.

The Load Capacity Question: Putting Real Numbers on It

One common concern about steppers in high-thrust applications is torque capacity. Servo motors offer more continuous torque at equivalent frame sizes due to better thermal characteristics. This is true, and we do not dispute it.

What we can share is our field experience: the RLA Series, using stepper motors rated at 5.5–7 A RMS, guides heavy roll stands on precision linear rail bearings without step loss. On rolling bearings at ? 0.06, the RLA-200 moves about 33,333 lb (20,000 lb at ? 0.1); see the RLA load table.

The critical nuance in any load figure: it is the total load weight resting on precision linear bearings, not the thrust force the actuator must produce. Precision linear rail bearings (recirculating ball or roller type) have a rolling friction coefficient of approximately 0.003-0.005. The actual force required to move a 30,000 lb (13,600 kg) load on these bearings is:

- Friction force: 13,600 kg x 9.81 m/s² x 0.004 = ~533 N (~120 lbf)
- Add acceleration force for a typical 50 mm/s² ramp: 13,600 kg x 0.05 m/s² = 680 N (~153 lbf)
- Total peak thrust requirement: ~1,213 N (~273 lbf) before safety factor

- With a 2x factor of safety: ~2,426 N (~546 lbf)

Our RLA models produce 500–2,000 lbf of nominal thrust (rated maximum 4,500–10,200 N), putting the motor well within its operating envelope with substantial margin. The motor is typically operating at 30-50% of its pull-out torque under these worst-case conditions. At that operating point, step loss does not occur.

The correct engineering process is sizing verification at design time — calculate worst-case static friction breakaway force (accounting for cold start, contamination, and bearing wear increasing friction coefficient over time), acceleration torque for the load inertia, and any web tension reaction forces, then size the motor so that the required torque is well below the rated pull-out torque under all conditions. We recommend a minimum factor of safety of 2.0. This is a design calculation done once, not a per-installation procedure.

Addressing Resonance Honestly

Stepper motor resonance is real and cannot be dismissed. The rotor-stator magnetic coupling creates a second-order mechanical system with natural resonance typically in the 50-200 Hz range. When a stepper is driven through these frequencies, vibration, noise, and potential step loss can occur. This is a well-documented characteristic, not an edge case.

We do not claim resonance disappears. What we can describe is how current-generation intelligent microstepping drivers provide multiple mitigation layers, and why the web guiding duty cycle reduces exposure:

Voltage-mode PWM (silent operation mode). At low velocities — which is the primary operating regime for web guiding correction moves — the driver uses a voltage-mode PWM scheme. Unlike current-chopping drivers that produce discrete current steps with sharp edges (which excite mechanical resonance), this mode produces smooth, sinusoidal current waveforms. The result is significantly reduced resonance excitation during the low-speed moves that dominate web guiding operation.

Cycle-by-cycle current control. For faster moves — during homing or long-stroke repositioning — the driver transitions to a cycle-by-cycle current regulation mode with active resonance damping. This mode measures actual motor current on each PWM cycle and adjusts to maintain the target, which damps oscillations that would otherwise build up at resonant frequencies.

256-microstep interpolation. The driver interpolates to 256 microsteps per full step, subdividing each step transition into much smaller increments. This reduces the energy impulse at each step transition, which in turn reduces the energy available to excite resonance. The motor moves more smoothly through the resonant speed band rather than being kicked through it in large discrete steps.

Configurable acceleration ramps. The driver supports S-curve and linear acceleration profiles that can be configured to minimize dwell time in resonant speed bands. By accelerating through the resonant range quickly rather than dwelling in it, resonance amplitude is limited.

Deadband operation profile. Because web guiding uses a deadband, the motor is not continuously oscillating. It makes a correction move, stops, and dwells. This intermittent operation reduces the opportunity for resonance to build to problematic amplitudes. It does not eliminate the concern during the move itself, but it limits cumulative exposure.

Taken together, these mitigations make resonance manageable in web guiding. We have not experienced resonance-related step loss in our field installations. But we want to be clear: in applications requiring continuous high-speed oscillation through the resonant range, steppers remain problematic, and servos are the right choice. Web guiding's duty cycle avoids the worst case.

Sensorless Stall Detection: A Useful Fault Detection Layer, Not a Complete Solution

Our intelligent microstepping drivers include a sensorless stall detection feature that monitors the back-EMF signature of the motor during motion. As load increases and the rotor begins to lag the stator field, the back-EMF waveform changes in a measurable way. The driver reports a continuous load value that decreases toward zero as the motor approaches stall, and you can set a threshold for early-warning detection — before steps are actually lost.

We use this as a fault detection mechanism: identifying abnormal conditions like a jammed guide, a seized bearing, or a mechanical obstruction before they become failures. In this role, it is effective and valuable.

But sensorless stall detection has real limitations that deserve acknowledgment:

- It cannot detect partial step loss. If the motor loses a single step or a small number of steps but continues running, the detection may not flag this. It detects gross load increases approaching stall, not subtle position drift.
- It has reduced sensitivity at very low speeds. Back-EMF amplitude is proportional to speed, so at the very low speeds typical in web guiding, the signal-to-noise ratio decreases. Threshold calibration at the actual operating speed is essential, and there is a minimum speed below which the detection is not reliable.
- It is not a substitute for an encoder in applications where absolute position accuracy from the motor is required.

For web guiding, these limitations are acceptable because stall detection is not the primary feedback mechanism — the web sensor is. It serves as one layer in a multi-layer protection strategy:

1. **Torque margin** — the motor is sized with sufficient margin that step loss is extremely unlikely under normal operating conditions
2. **Web sensor outer loop** — any position error from occasional step loss is detected and corrected on the next sensor cycle
3. **Sensorless stall detection** — detects gross mechanical faults (jams, obstructions, bearing seizure) before they cause damage
4. **Limit switches** — hardware travel limits as a final safety net

No single layer is relied upon as a complete solution. The combination provides robust protection without the added cost, cabling, and potential failure mode of a motor-shaft encoder — which, in this application, would be telling you where the motor is rather than where the web is.

The Narrowing Servo Advantage — and Why It Still Matters

We would be doing you a disservice if we pretended that the servo landscape is the same as it was ten years ago. It is not.

Integrated servo motors like the Teknic ClearPath and Applied Motion StepSERVO have significantly reduced the cost and commissioning complexity that historically separated servos from steppers. These products combine motor, drive, and encoder in a single package with simplified setup workflows. The ClearPath in particular has earned a strong reputation for making servo performance accessible without deep motion control expertise.

The cost gap has narrowed. The commissioning gap has narrowed. For a new design starting from a clean sheet, the decision between a modern integrated servo and a stepper with an intelligent driver is closer than it has ever been.

We believe the stepper still holds an advantage for our specific use case — an OEM shipping actuators for field installation in web guiding systems with an outer web-sensor loop — for these reasons:

- **No field tuning of the motor drive whatsoever.** Even simplified servo auto-tuning requires load connection and test motions. Our stepper drives ship configured.
- **No encoder to fail or require alignment.** One fewer component, one fewer cable, one fewer failure mode in a dirty industrial environment.
- **Native holding torque without servo dither or power consumption.** The stepper holds position magnetically at standstill. A servo must actively servo to maintain position, even if the current is small.
- **Cost advantage at the system level.** Even as component costs converge, the elimination of encoder hardware and field commissioning time maintains a total cost of ownership advantage.

But these advantages are specific to the OEM shipping model and the web guiding application profile. If you are building a one-off machine, commissioning it yourself, and need higher speed or continuous duty — evaluate those integrated servos seriously. They are good products solving real problems.

Where the Mechanical Selection Still Matters

Choosing a stepper over a servo does not reduce the importance of mechanical design. For high-thrust web guiding with loads in the 10,000-30,000 lb range, the mechanical drivetrain is arguably more critical than the motor technology choice.

Ballscrew vs. roller screw selection. At high loads with frequent start-stop cycling, ball screws fatigue the ball track over time. Planetary roller screws distribute contact stress across many more contact lines and offer dramatically longer service life under these conditions. Our RLA series uses ball screws and roller screws depending on the load and duty cycle requirements. Vendors like Exlar (now Curtiss-Wright) and Tolomatic who design integrated roller screw actuators for servo motors are applying the right mechanical technology — the value of a properly designed screw actuator is independent of whether the motor is a servo or a stepper.

Backlash and preload. Any mechanical backlash in the drivetrain adds dead zone to the correction response — the actuator moves but the load does not until the backlash is taken up, causing the web sensor control loop to over-command before motion begins. A properly preloaded ballscrew or roller screw, combined with appropriate coupling from motor to screw, controls this effect.

Breakaway consistency. At very high loads on linear rails, static friction at breakaway can be variable — affected by lubrication condition, temperature, contamination, and load distribution. Inconsistent breakaway means the first increment of each correction move is unpredictable, which the outer control loop must then correct. Well-maintained, properly lubricated bearing systems with consistent preload minimize this variability and are worth engineering attention regardless of motor technology.

The Complete Architecture

For a high-thrust web guiding application, the architecture we have converged on after years of field experience is:

- **Motor:** Properly sized stepper motor with at least 2x torque margin over worst-case load conditions (accounting for bearing wear, contamination, and cold start friction), driven by an intelligent microstepping driver
- **Driver configuration:** Voltage-mode PWM for low-speed correction moves (smooth, quiet, resonance-reduced), with automatic transition to cycle-by-cycle current control for faster homing/repositioning. Hold

current reduced to 50% after dwell timeout. 256-microstep interpolation enabled.

- **Fault protection:** Sensorless stall detection threshold characterized at factory operating speed and current, configured as a fault-stop condition. Supplemented by hardware limit switches and web sensor edge-loss detection.
- **Drivetrain:** Preloaded roller screw or ballscrew actuator with minimal backlash, appropriate coupling from motor to screw
- **Position feedback:** Roll-2-Roll® Sensor (fiber-optic, camera, or ultrasonic) closing the position loop at the web, not at the motor shaft
- **Control loop:** Deadband-controlled correction loop running at 0.5-2 Hz correction bandwidth, with PID gains, deadband width, and sensor filtering tuned per application

This architecture eliminates motor drive field tuning, leverages the stepper's native holding torque and mechanical simplicity, and relies on the web sensor to perform the function that a motor-shaft encoder would otherwise attempt to approximate — which is knowing where the web actually is, not where the motor thinks it is.

It does not eliminate all commissioning. The web guiding controller still needs to be configured for the specific application — gain settings, deadband, response aggressiveness. That work is inherent to web guiding regardless of actuator technology.

When Not to Use This Architecture

Engineering honesty requires identifying where our approach is not the right fit:

- **High-speed, continuous-duty applications.** If the actuator needs to move at speeds above 2 in/sec (51 mm/sec) for sustained periods, stepper torque falloff becomes limiting. Use a servo.
- **Applications without an outer position loop.** If the motor must be the primary position feedback device (no web sensor or equivalent), an encoder-based servo or closed-loop stepper is necessary. Our open-loop stepper approach depends on the web sensor closing the position loop.
- **Thermally constrained enclosures.** If the actuator is enclosed without adequate heat dissipation paths, the stepper's standstill current draw creates thermal challenges that a servo avoids.
- **Applications requiring continuous oscillatory motion.** If the actuator must oscillate continuously through a wide speed range without a deadband, stepper resonance becomes a more significant concern even with driver mitigation features.
- **Single installations where you control commissioning.** If you are building one machine, installing it yourself, and have motion control expertise available, the servo's commissioning burden is manageable and you gain efficiency, speed, and continuous-duty thermal advantages. The OEM shipping argument is strongest when multiplied across many installations.

Conclusion

The conventional preference for servo motors in high-performance positioning applications is well-founded — in general. But engineering decisions that are correct in general may not be optimal for a specific application profile.

Web guiding with a low-bandwidth outer sensor loop, a deadband, and the OEM constraint of shipping to field installations without load-specific commissioning is a specific application profile. It is one where the servo's primary advantages — high-bandwidth closed-loop response, smooth torque at all speeds, superior energy efficiency — are either not being exercised or are secondary to the practical benefits of zero motor drive tuning.

We chose stepper motors for our actuators because, in this specific application, the engineering tradeoffs favor them. We give up efficiency, speed, and some noise performance. We gain commissioning simplicity, mechanical simplicity (no encoder), native holding torque, and a total cost of ownership that holds up across hundreds of field installations.

The web sensor does the precision work. The mechanical drivetrain determines the service life. The stepper provides the force. The intelligent microstepping driver manages the stepper's known weaknesses — resonance, heat, and noise — through sophisticated silicon. Each element does what it is best suited for.

That is our engineering rationale. We have tried to present it with the tradeoffs visible, not hidden. If it helps you make a better-informed motor selection decision — whether you choose steppers or servos — then this article has served its purpose.