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Linear actuator drive selection – a precise balancing act

No 'one size fits all' for linear motion system drive train designs

Olaf Zeiss, Product Manager, Linear Actuators
Parker Hannifin Motion Systems Group

Designing an automated system requiring any type of linear motion is no easy task. Selecting the correct technology behind the actuator really depends upon what the designer wants to accomplish with it. Like much in engineering, making the right selection is less about focusing on a single characteristic than finding a good balance of performance from a number of different factors. Costly mistakes can be avoided by weighing up the available options analytically while designing efficient and economical motion control systems.

The majority of electromechanical linear actuators are comprised of five common types of drive trains: ball screws, lead screws, timing belts, rack-and-pinion tracks and linear motors. Understanding the strengths and limitations of each type and weighing them against the design requirements is the most logical approach. After all, linear actuators can be used in a breathtakingly wide variety of applications, from automated packaging lines and pick-and-place operations to complex machines such as 3D printers, which require precision positioning accuracy.

The most common drive train types
In linear motion, drive trains offer a dual function. They are primarily used for repetitive positioning and therefore need to provide acceptable accuracy and repeatability (the ability to back to the same commanded position repeatedly) according to the purpose for which they are required. At the same time, they apply force over distance, which requires them to possess sufficient tensile strength.

Ball screws, the popular and widely used drive trains consist of a threaded rod and matched ball nut with recirculating ball bearings between the nut and screw surfaces. Ball screws are an ideal solution for high duty cycle applications as well as applications requiring high force density, precision and repeatability. The rolling ball bearings reduce friction and provide high mechanical efficiency, even when in constant use. Ball screw can achieve moderate speed.

Lead screws consists of a threaded rod and matching threaded nut sliding interface surfaces. They are suitable for low duty cycle applications, or applications requiring small adjustments. Lead screws are typically only about half as efficient as ball screws, so they require double the torque to achieve the same thrust output of the screw. However, they offer cost efficient and compact solutions for high force applications. Moreover, they are resistant to back driving, removing the need of using a brake to hold the payload under a power loss.

The timing belt, the most simple and common drive train for linear motion systems, consists of two cogged pulleys; usually one driven and one idler, connected to a timing belt with an attached carrier. Timing belts are a robust mechanism for high-speed applications requiring long life and minimal maintenance where precision greater than 100 microns is sufficient. Timing belts are efficient and easy to operate. They can be operated at 100 percent duty cycle and are available in longer lengths than screw drives, making them ideal for long stroke applications requiring high dynamics. Due to the elasticity of the belt we need a reliable tensioning system which is limiting the accuracy.

Rack and pinion systems consist of a machined linear gear and a round mating toothed gear. Typically, the round gear is mobile and the rack is stationary. This type of drive train is useful for very long travels requiring high speed, but is not known for its precision. They offer high force density but they require maintenance to maintain the lubrication of the system. In addition, removing system backlash from this type of drive train is not always possible, and they can also often be quite noisy in operation.

Linear motors are made up of a row of magnets – simply put, a 'flattened' rotary motor – which interface with an electromagnetic carriage to move the payload in a linear direction. They offer high speed, acceleration and precision. The main drawback is the cost of implementing this technology due to the cost of the magnets and linear feedback devices required. Force density is also lower than for the other drive system. The lack of a mechanical connection between moving and static parts of a linear motor makes the use of it difficult in vertical applications.

The PETS principle
The list of potential performance characteristics that a designer might be interested in is long, so to focus the selection process more precisely, the options can be classified into the following categories: Precision, Expected life, Throughput and Special considerations (PETS).

When weighing the options with a focus on precision, always start with an understanding of your needs relative to resolution. The other considerations are repeatability, followed by accuracy and finally velocity control. Linear motors and precision ball screws are typically the most superior for precision characteristics. (The majority of motion applications do not require these high levels of precision, which is why the timing belt remains the most commonly applied technology).

Upon examining the expected lifespans of all the options, mechanical efficiency will be the number one consideration, unless the requirement is for a dirty or otherwise harsh operating environment. High efficiency of the drive train is synonymous with long life and lower energy consumption. Issues such as wear resistance, dirt resistance and maintenance requirements are also important factors to be considered in this category. Because of their high efficiency and limited maintenance needs, timing belts are the go-to drive train of choice in this category.

The category of throughput can be considered by first examining the speed and acceleration or deceleration characteristics of each technology – depending on the length of linear travel required. If you have a longer travel where more of the cycle time is spent at the top velocity, speed is the most important. If the application requires shorter moves, acceleration and deceleration characteristics will take precedence. Depending on the application also other criteria, for example frequency response, duty cycle must be taken into account. Linear motors are unparalleled from a throughput perspective, due to their ability to achieve high speeds and accelerations, and given that they have no mechanical compliance, they have a high-frequency response.

Some special considerations to take into account when looking at each technology include material costs and implementation costs to ensure that the right combination of functionality is achieved at the minimum cost. Force density is also an increasingly important factor to bear in mind as machine designs continue to miniaturise, particularly when specifying end effectors or tooling mounted to an axis.

A precise balancing act
Some applications make the choice of a linear drive train relatively simple. For example, it's clear to see from the above that timing belt drives are an ideal choice for long-travel applications requiring high linear velocity and acceleration. If the application travel length and required speed are moderate, but the acceleration should be high, or if a high positional accuracy is required, then a linear motor based drive would most likely be a better fit.

When the choice isn't as obvious, all the available application parameters should be weighed carefully to make the best possible selection. If one key performance characteristic is optimised, it is likely that another performance indicator may be sacrificed. Analyse the requirements against the abilities of each technology using the PETS principle from the beginning, or contact the specialists at Parker Hannifin for specialist advice on modular linear drive solutions.

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