Linear motion using stepper-based linear actuators

Part 1: Linear Actuator styles

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Synopsis

Stepper motor linear actuators are an optimal choice when converting rotary torque to linear force.

The construction of these actuators allow for new designs that are more compact and reliable by replacing conventional system mechanicals such as rack and pinion sets, belt and pulley systems and pneumatic air cylinders with electric motor actuators.

Introduction

Linear motion systems using electric motors are all about converting rotary torque to linear force.

Converting rotary to linear motion is typically accomplished using a rotary motor and conventional mechanical components such as a rack and pinion set or a belt and pulley system.

The most efficient and economical method of converting rotary to precision linear motion is inside the motor itself. Direct-drive electric motor linear actuators can reduce the system size, cost, and complexity while increasing reliability by eliminating some of the mechanical components and hardware.

Stepper motor linear actuators

Stepper motor linear actuators develop force from rotary power by replacing the motor's shaft with a lead screw and nut. Precise positioning is possible due to the fine increments a stepper motor is capable of when driven by a high-resolution microstepping driver.

Figure 1
Stepper motor linear actuators

There are three design variations which we will look at:

1. External shaft
2. Non-captive shaft
3. Captive shaft

Each design style serves a unique purpose and has advantages and disadvantages.

External shaft

Figure 2

External shaft linear actuator with plastic nut

External shaft linear actuators replace the motor shaft with a rotating lead screw. Force is developed via a stationary nut which travels along the length of the screw.

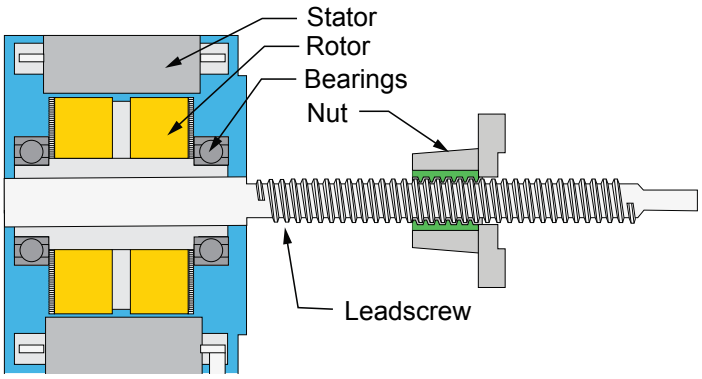

Figure 3

External shaft linear actuator construction

Advantages

- External shaft linear actuators have a flexible force profile due to the different materials which may be used to make the external nut. Brass or bronze nuts will increase the force available to the load, while plastics increase the lifespan of the device while reducing audible noise.
- A preloaded nut may also be used, at the sacrifice of force, to compensate for mechanical backlash, which is lost motion due to gaps between the nut and screw threads.

Disadvantages

- The lead screw may require lubrication, and is susceptible to wear, reducing the life and efficiency of the device.
- The length of the screw is limited, as longer screws may be susceptible to vibration issues during high-speed moves.
- The maximum available force may be lower than non-captive and captive styles, due to limitations of the nut material and design.

Application areas

Ideal applications for external shaft stepper motor linear actuators are:

- XYZ stages
- 3D printers

Non-captive shaft

Figure 4

Integrated and stand-alone non-captive shaft linear actuators

Non-captive shaft linear actuators convert torque to force via a threaded nut bound internally to the rotor, with force being transferred to a lead screw running through the motor body.

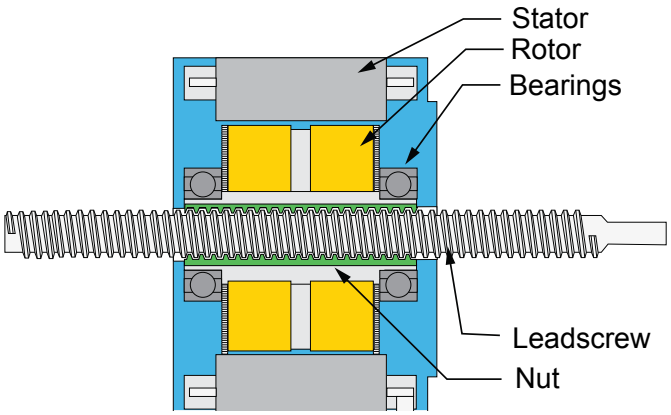

Figure 5

Non-captive shaft linear actuator construction

Non-captive shaft linear actuators are unique among stepper-based actuators in that they can be applied using one of two methods:

1. **Supported stationary lead screw:** The load is attached to the motor body. The internal nut moves the motor back and forth along the length of the lead screw. (Figure 6)

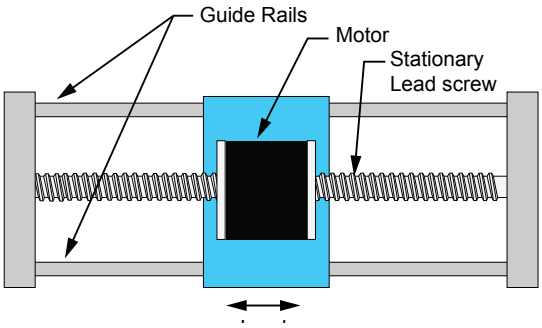

Figure 6

2. **Stationary motor:** The load is attached to the end of the lead screw. The internal nut moves the lead screw back and forth through the motor body. (Figure 7)

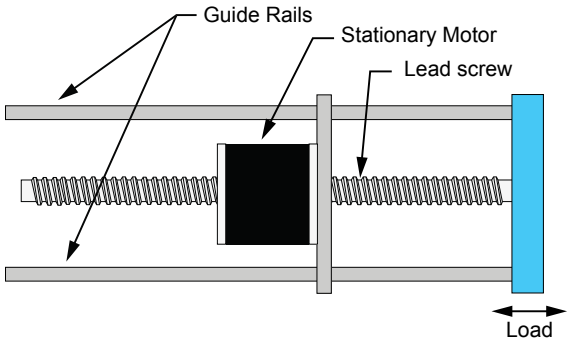

Figure 7

Advantages

The benefits of using a non-captive linear actuator style are:

- A longer lead screw may be used, allowing for a greater range of travel.
- When the load is attached to the motor, the mass of the motor will act as a damper, reducing vibration. Having a non-rotating screw may also be advantageous for safety and performance reasons.
- It is the least expensive style of stepper motor linear actuator, although only marginally less than the external shaft style actuators.

Disadvantages

- Size. The diameter of the motor is typically larger than the diameter of the nut on an external shaft actuator. Also, the size of the additional fixturing required to support both ends of the screw, as well as guides for the load, may be prohibitive.
- When the load is attached to the motor, the motor's mass may limit acceleration rates.

Application areas

Non-captive shaft linear actuators are useful in applications such as:

- XY tables
- Auto-dispensing

Captive shaft

Figure 8

Integrated captive shaft linear actuators

In captive shaft linear actuators, force is developed much like in the external shaft style, where a rotating lead screw moves a nut along the length of the screw. The main difference is that the force is transferred to a sliding cylinder, which is splined to prevent rotation. The cylinder extrudes and retracts as the nut travels along the screw.

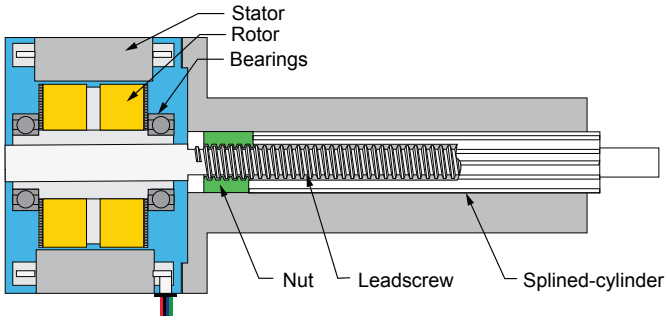

Figure 9

Captive shaft linear actuator construction

Advantages

- Small size
- The lead screw and nut are contained inside the cylinder housing. The only exposed moving part is the non-rotating cylinder.
- Greater force output than comparable external shaft model.
- An excellent replacement for small pneumatic actuators in new designs.

Disadvantages

- Length of travel is limited.
- More expensive than other linear actuator styles.

Application areas

Captive shaft linear actuators are useful in applications such as:

- Plunger
- Clamping

Conclusion

Flexible alternatives for linear motion

The three styles of stepper motor linear actuators offer system designers and integrators a great deal of flexibility in choosing the right actuator for low speed, high force applications. Compact, direct-drive linear actuators with integrated driver and controller allows them to reduce the size, component count and mechanical linkages in a system as well as replacing technologies such as air-driven cylinders.

Part 2 of this series will discuss lead screw mechanics, with focus on ACME lead screws.

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