

## High Speed Linear Actuators

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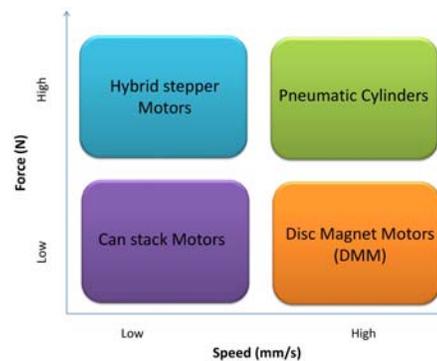
### Introduction

The first thing that comes to mind when we talk about linear actuators is a pneumatic cylinder with some control valves. They have been an indispensable part of the automation industry and still hold importance. Pneumatic cylinders are suitable for a variety of automation applications at a high speed or high loads.

Despite many advantages, pneumatics cylinders still face some fundamental problems which make engineers review alternate solutions. It is always difficult to position pneumatic actuators precisely under load due to the compressible nature of air, especially at high speed. A substantial waste of electricity due to idling of compressors, and leakages in the pipe lines keeps running costs of the system high. You always find a big maintenance manual under the hood, which speaks volumes about the high operational and maintenance costs involved in pneumatic systems.

Electric actuators, on the other hand, have many advantages over air cylinders even though the load and speed capabilities are lower. Most of these linear actuators utilize a screw and nut mechanism to convert the rotary motion into linear movement.

Depending upon the load and speed requirement of the application in conjunction with other factors, various electric motors can be chosen as a prime mover. In this article, we are looking for motors for possible high speed linear actuation. Due to its precise positioning capability, only stepper motor is examined here.



**Fig. i Four Block Matrix**

The four-block matrix in Figure i shows a broad classification of linear actuators based on load lifting capability at various speeds. A linear speed of over 500 mm/s can be considered as high speed range. Can stack motors are widely used as linear actuators in the **Low Load/Low Speed segment** with their reliability and cost effectiveness. Hybrid stepper motors are well known for their high load lifting capacity over other stepper technologies and are the best choice under **High Load/Low Speed segment**. The remaining **Low Load/High Speed segment** is the focus of our article.

### Disc Magnet Motor (DMM)

Disc Magnet Motor, often called the Turbo Disc Motor, becomes an excellent choice for high speed applications with low loads. As the name suggests, DMM uses a thin magnetic disc to generate the torque output of the motor. Due to its low rotor inertia, it provides an exceptionally high acceleration for a given torque which is suitable for most of the high-speed demands. This technology is less popular due to the lack of knowledge about the advantages it brings.



Fig ii



Fig iii

### Linear Actuators from Disc Magnet Motors

Figure ii and iii are typical examples of a linear actuator that could be designed from existing disc magnet motors. The electrical and mechanical characteristics of standard DMM motors are available at [www.portescap.com](http://www.portescap.com). The designs can either be a rotating screw as in Fig. ii or a rotating nut as in Fig. iii.

Fig. iv and Fig v show the performance of a DMM actuator for various lead screw combinations. These actuators provide a wide range of speed in the low load region between 0 to 1200 mm/second which is quite wide compared to hybrid stepper motor or can stack motor of same frame size.

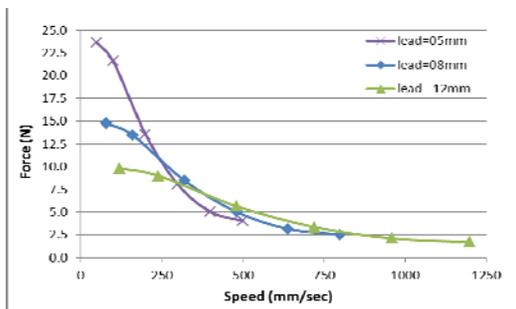


Fig. iv DMM P430; Frame size = 39X39 mm  
Full step, Bipolar voltage drive@36V

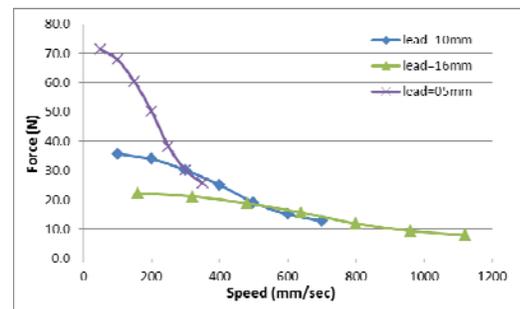


Fig.v DMM P532; Frame size=52X52 mm  
Full step, Bipolar voltage drive@2A,36V

### Typical Speed vs. Load Curve

Key parameters which determine the performance of any motor at higher speed are its **dynamic torque** capacity, **rotor inertia**, **load to motor inertia mismatch**, **iron losses** and **perfect sinusoidal shape** of output torque curve.

Figure vi shows the dynamic performance of hybrid motor drops drastically with the speed whereas the DMM maintains its output consistently at higher speed. The perfect sinusoidal waveform of the output torque gives maximum amplitude for the torque ripple to improve the dynamic performance. Iron losses are the function of input frequency which means the losses would be higher at higher speed. But due to the shorter magnetic circuit and proper flux path, DMM shows less iron losses and

hysteresis loss as compared to hybrid motors. These low losses and lower electrical time constant help the DMM operate at higher speeds.

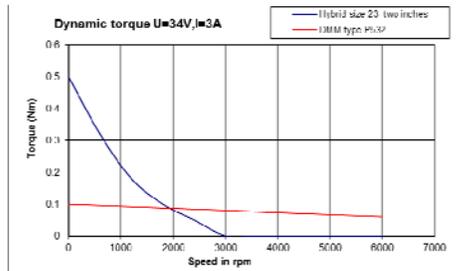


Fig. vi

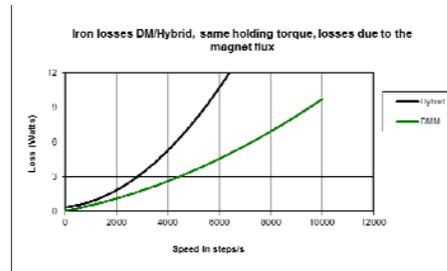


Fig. vii

### Dynamic Performance of Hybrid vs. Disc Magnet Motor

As mentioned earlier, the unique rotor design of the DMM keeps the inertia exceptionally low compared to a hybrid stepper. For a given frame size, 40 X 40 mm, the rotor inertia of DMM is as low as 3 gram-cm<sup>2</sup> which is 15 times lower than a similar sized hybrid motors. This translates to the acceleration being 15 times higher for a given torque output. The rotor inertia mismatch is also an important selection criteria for high speed actuation. Below is an illustrated example that shows how suitable a DMM motor can be in case of load inertia mismatch challenges.

The following example illustrates how suitable a DMM motor can be in case of load inertia mismatch challenges. A load of 250 g is to be moved to a distance using a lead screw of  $\varnothing 6 \times 80$  mm long with a pitch of 10 mm. How do we calculate load inertia reflected on to the motor? Efficiency can be considered roughly as 40 percent and the material for lead screw is stainless steel. The total inertia reflected to the motor ( $J_{total}$ ) = load inertia ( $J_l$ ) + lead screw inertia ( $J_{ls}$ ).

$J_l$  and  $J_{ls}$  can be calculated as follows:

$$J_l = \frac{m}{\eta} \times \left[ \frac{1}{2 \times \pi \times P} \right]^2$$

$$J_{ls} = \frac{\pi \times L \times \rho \times r^4}{2} = 1584.75 \text{ g-mm}^2$$

Now

$$J_l = \frac{250}{0.4} \times \left[ \frac{1}{2 \times \pi \times 0.1} \right]^2$$

And

$$J_{ls} = \frac{\pi \times 80 \times 7480 \times 10^{-6} \times 3^4}{2}$$

m= Mass in Grams

L=length of lead screw

r= Radius of lead screw

P= Pitch in mm/revolution

$\mu$ = Efficiency

$\rho$ = Density in kg/m<sup>3</sup>

$$\text{Total inertia reflected to the motor, } J_{total} = 1660.8 \text{ g-mm}^2$$

$$= 1.66 \times 10^{-6} \text{ kg-m}^2$$

In order to have a smooth power transmission from the motor to the output load, it is important to match the rotor inertia to the reflected load inertia, especially for high speed actuation.

Now, when you look at the standard rotor inertia of DMM motor, the P532 motor comes closer to this value i.e.,  $1.2 \times 10^{-6} \text{ kg-m}^2$ .

## **Conclusion**

A number of applications in the industrial segment need high speed actuation in the lower load band. Presently, pneumatic actuators or electric solenoids do this job without the capability of precise positioning. Though the expensive technology such as Servo pneumatic positioning systems are available, accurate positioning at high speeds is still difficult with pneumatic systems. High speed linear actuators utilizing disc magnet technology provide excellent linear speed for low load applications such as sensor movement, positioning a laser beam, pick and place of electronic components, thin solar cells for solar panel assembly, thin plates of electrodes for battery assembly, rejection mechanisms in high speed conveyors, movement of XY tables, and 3D printers. By combining the lower operating and maintenance cost together with quiet operation, electric DMM linear actuators are great choice for high speed and low load applications.