How to get a linear motion from a stepper motor?

Introduction

Stepper motors are designed to provide a precise angular position with an angular accuracy of approximately 3% of full step angle at its best. When a precise linear positioning is required, the solution is then to use a stepper motor with a lead screw.
FAULHABER has developed a technique to assemble a lead screw on a stepper motor in order to provide the maximum of flexibility to its customers. The idea is to press fit a lead screw on the shaft of the motor and use a nut to transform rotational motion into linear motion.
The purpose of this note is to give an overview of the lead screw options and provide some technical information to the customer.

Figure 1 : FAULHBAER stepper motor with M1.6 lead screw

Lead screws

Table 1 presents the different standard lead screw possibilities offered by FAULHABER:

Table 1 : Lead screws proposed by FAULHABER.

Lead screw (metric diameter x pitch, in [mm])	Length [mm]	Compatible motors	Material
M1.2x0.25	7.5, 15 or custom	DM0620, AM0820, AM1020	Stainless steel
M1.6x0.35	7.5, 15, (25) or custom	DM0620, AM0820, AM1020	Stainless steel
M2x0.2	7.5, 15, 25 or custom	AM0820, AM1020, DM1220, AM1524	Stainless steel
M2.5x0.25	7.5, 15, 25 or custom	AM0820, AM1020, DM1220, AM1524	Stainless steel
M3x0.5	15, 25 or custom	AM0820, AM1020, DM1220, AM1524, AM2224, AM2224R3	Stainless steel

Custom length

FAULHABER gives the possibility to the customer to design its own screw length. However, the screw must not reach unreasonable length and the maximum length ever fabricated until now is 200mm. The customer must also be aware that the longer the screw the higher the risk of misalignment and run out.

Optional ball bearing, tip and nut

It is also possible for the customer to order a lead screw with a tip at one of its end so that a ball bearing can be mounted on it. For smaller lead screw (M1.6), this option is mandatory for length exceeding 15mm. As a consequence, the denomination of the article has a T at its end. For example, if one wants a lead screw M1.6x0.35 of length 15mm with a tip, designation will be M1.6x0.35x15**T**. See Table 2 for a complete overview of the options.

Table 2 : Availability of tip, nut and ball bearing options.

Lead screw (metric diameter x pitch, in [mm])	Tip available	Nut	Ball bearing
M1.2x0.25	No	6502.00366 (mat. PEEK)	-
M1.6x0.35	Yes	6502.00370 (mat: PEEK)	6502.00102
M2x0.2	Yes	6502.00337 (mat: PEEK)	6502.00097
M2.5x0.25	Yes	6502.00336 (mat: PEEK)	6502.00097
M3x0.5	Yes	6502.00323 (mat: PEEK)	6502.00103

Figure 2 and Figure 3 show the nut and ball bearing options and the dimensions of the lead screw assembled on a stepper motor respectively. From figure Figure 3, it is important to note that the space between the lead screw and the front plate of the motor is kept constant (2.3mm for all motors except AM2224 + M3 where it is 3mm).

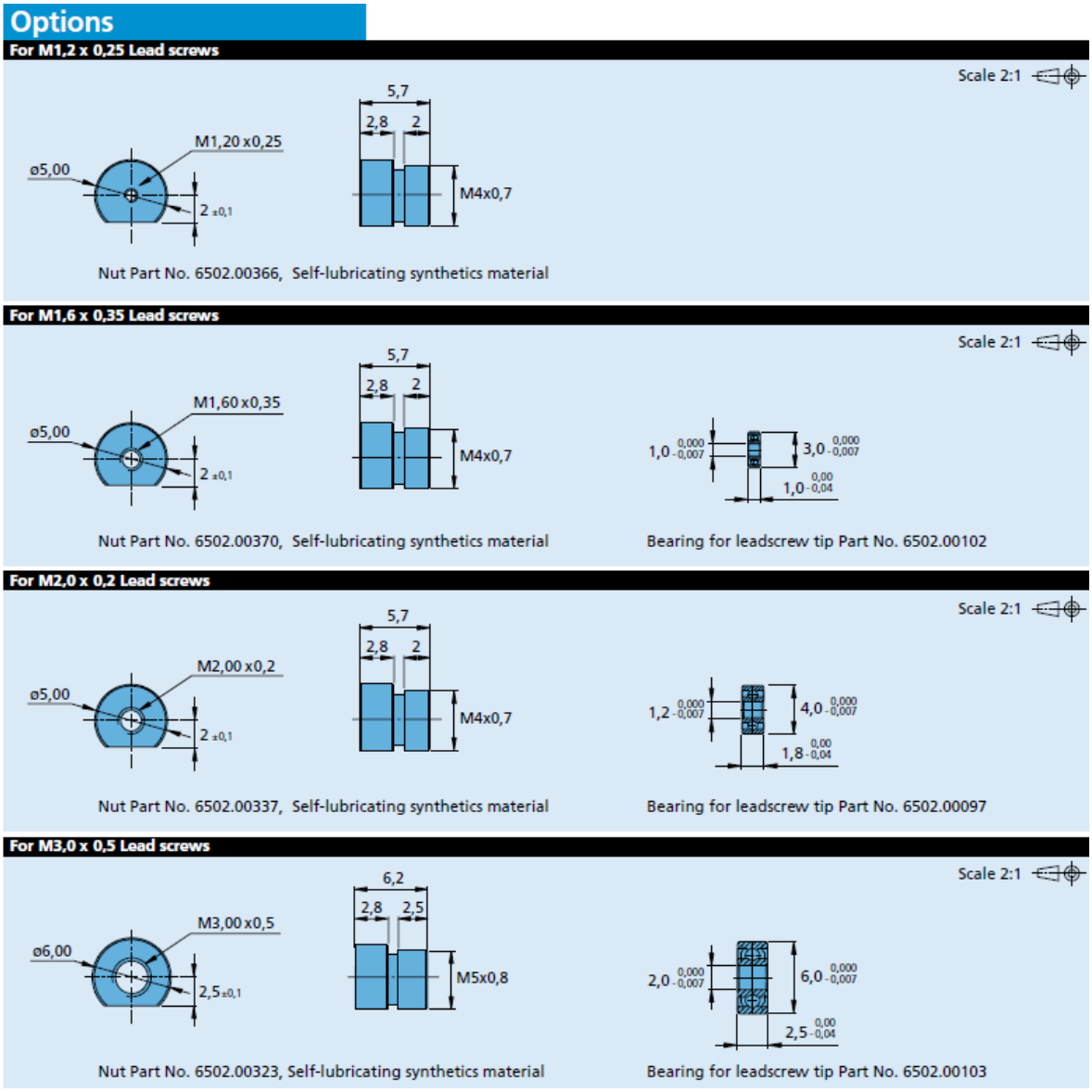

Figure 2 : Nut and ball bearing drawings from the datasheet.

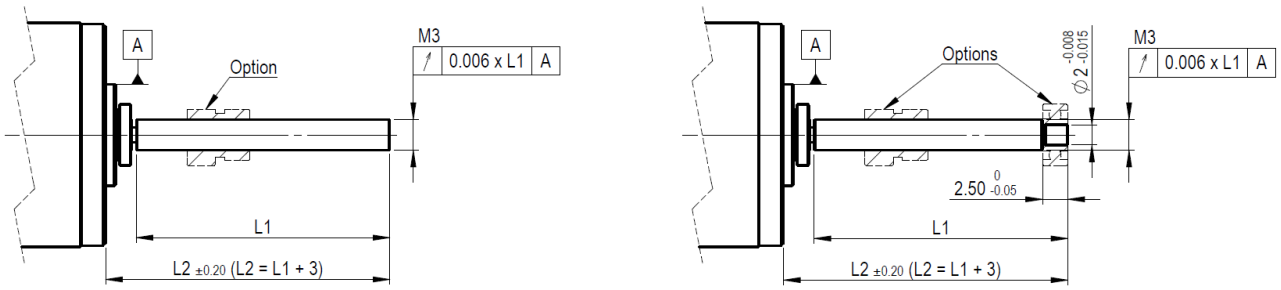

Figure 3 : Drawings of a lead screw assembled on a stepper motor (left) without tip, (right) with tip.

How to read the datasheet?

Figure 4 illustrates the datasheet of an M2x0.2 lead screw. From there, one can read the pull and push force in function of speed. These graphs are also very dependent of the torque curves from the stepper motor, which explains why there are 3 different curves depending on the supply voltage provided.
The force is limited by the preload of the ball bearing in pull mode but exceeding the preload in pull mode will not damage the motor, it will only cause the shaft to move for a few hundreds of micro-meters (approximately 200µm). It is recommended to refer to the technical information downloadable on the FAULHABER website for more information.
Please note that a safety factor of 40% is applied in the calculations leading to those results.

Series M2 x 0,2 x L1

Ordering information	L1 (mm) =	15	25	28/30	Custom	
Order code (no bearing tip)		M2x15	M2x25	M2x30	M2xL1*	
Order code (with bearing tip)		M2x15T	M2x25T	M2x28T	M2xL1*T	
Nominal diameter	2,0					mm
Pitch	0,2					mm
Material	Stainless steel					

* For custom length, please inquire with your point of sales

For combination with Stepper Motors AM0820, AM1020, DM1220, AM1524

Important notes
The thrust curves include already a safety factor for the use of the stepper motor.
Please read the "Technical information" for a better understanding of the curves.

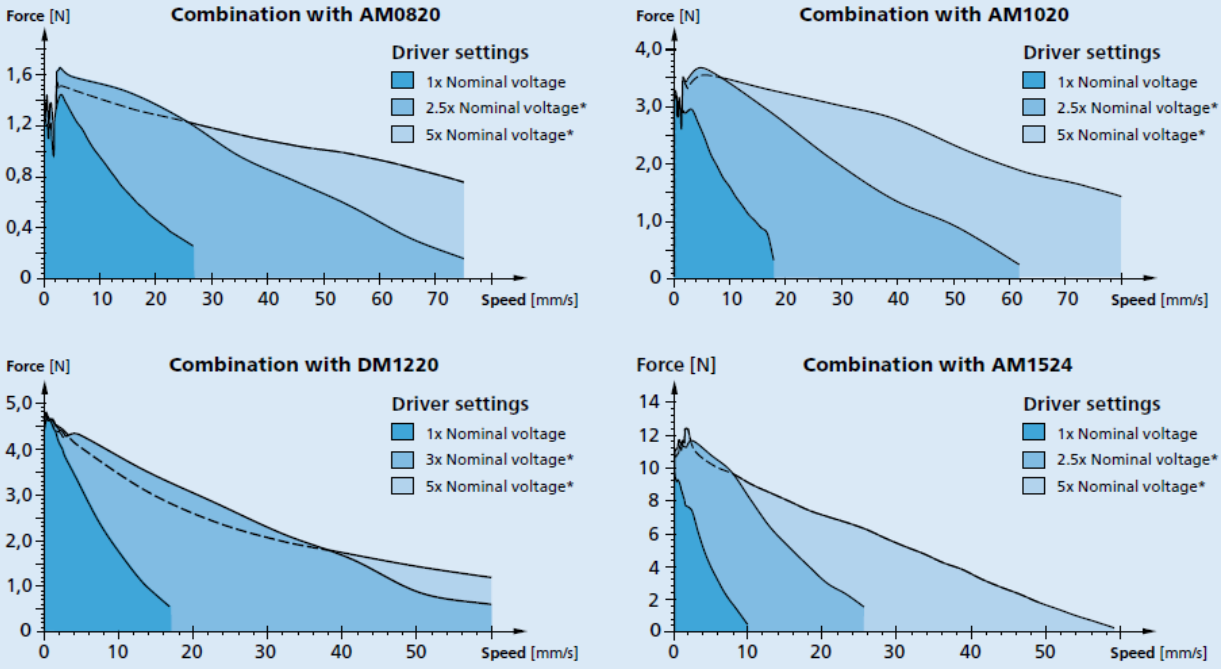

Figure 4 : Datasheet for a M2x0.2 lead screw.

Some calculation

Lead screw efficiency

The efficiency of a lead screw is given by the equation 1.

$$\eta = \tan\alpha \frac{\cos\left(\frac{\beta}{2}\right) - \mu \cdot \tan\alpha}{\cos\left(\frac{\beta}{2}\right) \cdot \tan\alpha + \mu} \qquad (1)$$

Where α is the helix angle, β the thread angle and μ the coefficient of friction. Due to friction, the efficiency of a lead screw is often situating between 10 and 30% which is quite low, as it can be observed in Figure 5. The coefficient of friction between the lead screw and the nut from FAULHABER is approximately 0.18.

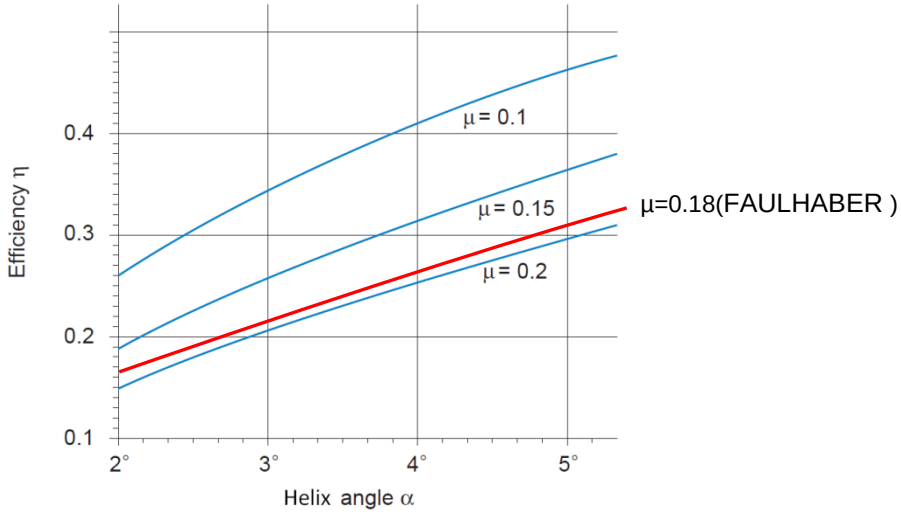

Figure 5 : Typical efficiency of a lead screw. [2]

Driving torque

The torque necessary to move a load can be estimated by equation 2.

$$T = \frac{F \cdot h}{2 \cdot \pi \cdot \eta} \qquad (2)$$

With *F* the axial load force (force along lead screw axis), *h* the pitch of the screw and *η* the efficiency of the screw.

Back driving / Lead screw reversibility

A motor fitted with a leadscrew transform a torque into an axial force. In some conditions, the load of application create an axial force which overcomes the friction torque of the nut/screw coupling and is transformed into a torque. This is called back driving and the back driving torque can be simply formulated as follows:

$$T_{bd} = \frac{F \cdot h \cdot \eta}{2 \cdot \pi} \qquad (3)$$

It's rather straightforward to predict if a leadscrew is reversible or not. The higher the thread angle, the more backdriving becomes possible. The following rule of thumb can be applied to determine whether back driving can occur or not for a given screw geometry.

$$h - \frac{d}{3} \begin{cases} < 0 & \text{back driving cannot occur} \\ > 0 & \text{back driving may occur} \end{cases}$$

With *h* the pitch of the screw and *d* its diameter (external diameter).
As a matter of fact, none of the lead screws proposed by FAULHABER is prone to back driving.

Characteristics of linear systems (accuracy, run out, axial play)

The lead screws are produced through a rolling technology that provides a good quality and repeatability of production. Depending on the motor and the lead screw selected, the characteristics of the assembly will be different. The aim of this section is to summarize the properties of the linear systems.

Table 3 : Characteristics of the FAULHABER lead screws.

Typical axial play between nut and screw	25µm
Typical motor axial play if preload is over-come	0.2mm (preload specified in the catalogue for each motor)
Run-out	Given by formula [mm] : Length of screw * 0.006 ⇨ 0.15mm up to lead screw of 25mm ⇨ 0.60mm up to lead screws of 100mm
Pitch accuracy (cumulative)	<2µm per pitch
Motor accuracy (non-cumulative)	±10% of a full step for AM technology ± 5% of a full step for DM0620 ± 3% of a full step for DM1220
Total accuracy	Lead screws are OK for positioning with ≥10µm accuracy between calculated discrete position. However, the accuracy is much better than 10µm for repetitive positioning (ex: back and forth motion between position A and B)

Zero backlash lead screw

If one wants to use a lead screw for a very precise positioning application, it could be useful to use a screw with zero backlash.
In standard, no zero-backlash solution is existing. If such kind of solution is requested, a customization project has to be started.

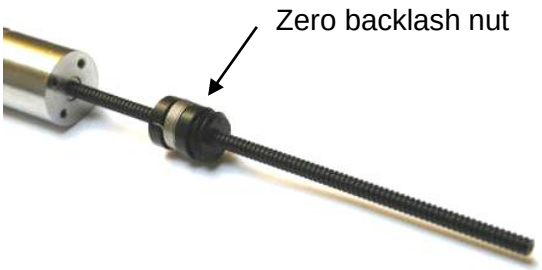

Figure 6 : Example of customization project: Screw with zero backlash on an AM1524 stepper motor.

Geared linear actuators

For certain motor sizes, another possibilities is to use a gear linear actuator. This product range allows to get high output forces and a large flexibility
For the AM2224 and AM3248, the geared linear actuators 22L and 32L are available. These come with either integrated leadscrews or integrated ballscrews with different pitch accuracy grades. Please refer to the datasheet of the geared linear actuators on the FAULHABER website for more details about the possible options, reduction ratios or screws.

Figure 7 : Geared linear actuator 22L with ballscrew

References

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