

## Why Go Metric?

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The U.S. is a multi-lingual country, in its measurement units as well as its language. The rest of the world, however, uses one language for measurement, and that is metric. This makes the U.S. the only industrialized country that has not standardized on this system, even though it has had over 200 years in which to join the rest of the world. And this presents a few problems. For example, in 1999, NASA engineers launched their Mars Climate Orbiter, a \$125 million spacecraft designed to explore the surface of the red planet. For nine months, engineers monitored the spacecraft's flight and altered its trajectory as needed. The engineers knew that two crucial programs spoke in different units of measure, one in metric and the other in English units. And a simple conversion check was set up to ensure that the data from one program was compatible with the other. However, that simple conversion check was not done. It was overlooked.

In calculating the thrust of rocket firings, engineers used feet per second. The spacecraft's program, however, interpreted those instructions in the metric measure of thrust, Newtons per second. The difference between the two measures of unit is 4.4 feet per second. Therefore, each time engineers ordered a rocket firing, the spacecraft's orbiting error increased, resulting in a critical problem – NASA lost the spacecraft. After months of analysis to determine what happened, engineers discovered the conversion problem and concluded that the Climate Orbiter either flew too low and crashed into the planet or it glanced off into outer space. Either way, they have not heard from it since.

This is an example of what can happen when metric and English units are mixed without proper conversion. But it's not an isolated example, simply a reported one. Such errors occur in business more often than many want to admit. One solution is to be more careful with conversions, however, that still leaves room for errors, as NASA discovered. Another solution is for all U.S. engineers and designers to choose compatibility with the rest of the world and standardize on the Systeme Internationale (SI) metric system.

## The Metric Push . . .

The metric system of measurement emerged in 1790 when French scholars defined standard units of measure. In fact, the guillotine blades used during the French Revolution were measured in centimeters, not inches. Napoleon and his soldiers, along with the need for common units used in European commerce helped carry this new system throughout Europe.

In 1789, however, the First Congress of the U.S. debated on a system of weights and measures. Thomas Jefferson, serving as the First Secretary of State, submitted a proposal for a decimal-based system with a mix of units. His basic unit of measure for distance was the foot, which was slightly less than the traditional foot. It was divided into 10 inches. Each inch was divided into 10 lines, and each line into 10 points. Other interesting measures in his proposal included the decade, which equaled 10 feet; the rood -- 100 feet; the furlong, -- 1000 feet; and the mile -- 10,000 feet. After some debate, Congress took no action, leaving the U.S. with a system consisting of carryovers from English weights and measures.

It wasn't until 1866 that Congress legalized the use of the metric system. But businesses did not convert. In 1975, the Metric Conversion Act was established to help jump start businesses to voluntarily adopt this system. Few did. In 1988, Congress tried again with the Omnibus Trade and Competitiveness Act, which mandated that all federal agencies specify metric when purchasing materials and equipment. In 1991, President Bush issued an Executive Order on the use of metric within the U.S. Now, U.S. law requires businesses to convert to metric. However, throughout U.S. industry, there's a mix of equipment for use here and overseas built to both units of measure.

One problem caused by maintaining a mix of units: No manufacturer wants to have two production lines, one English and one metric. This setup means that tools, machinery and parts must be stored and inventoried separately, increasing the burden on record keeping and warehouse space. Procedures must be instituted to prevent accidentally shipping metric parts with units built to inches and feet. When such an error happens, more paperwork is needed to correct it. The bottom line on trying to please two masters is that costs add up, decreasing companies' bottom line.

A related problem involves overseas customers. Every other country is demanding that more U.S. products be built and labeled to metric standards. Even European Union countries, that have long been good U.S. customers, no longer want our non-metric products. In turn, they don't want to supply the U.S. with non-metric products anymore because of the additional cost. Then, there's the problem of competitiveness. U.S. businesses can produce a lot of product, more than can be consumed within the fifty states. Companies must sell overseas to stay in business. But as the only hold out for the non-metric system, U.S. corporations face stiff competition from others already standardized on metric.

### **. . . Is Incomplete**

The metric system offers benefits. For one, thinking in metric units allows a company to communicate with the rest of the world without hindrance, a fact such high tech industries as semiconductor and medical know well. Plus, use of metric implies greater technical sophistication.

Until recently, the availability of metric sized components has been low because demand was

low. Now, however, that situation is changing, especially in the world of motion control components, where engineers can readily find such products.

People avoid using metric because of familiarity with inches and pounds, and the confusion that comes from converting back and forth between the systems. Until people can build a similar familiarity with metric, reluctance to use it may continue.

### **Hard Metric Versus Soft Metric**

Because of the U.S. Executive Order, U.S. engineers and designers are often faced with converting components built in English units to metric units, particularly when bidding on various Federal contracts.

Federal rules promoting the use of metric have, unfortunately, complicated the matter. Contracts require bidders to use metric products measured in rounded units, for example, 300 mm rather than 304.8 mm. The 304.8 mm is the exact conversion of 12 inches. Because of the government requirements, however, components will physically be less than a foot to meet the rounding requirement. According to some bidding groups, this rule is imposed only to achieve rounded numbers. Rounded measures are known as hard metric.

Soft metric, on the other hand, is simply the mathematical conversion of English units to metric units. The converted component is not taken to the next level (hard) and physically altered to a rounded dimension.

One problem with hard metric is that it can force manufacturers to retool and invest in new capital equipment to meet the requirements. But it can speed the process of learning and accepting the metric system.

One problem with soft metric is that users must know the correct conversion factor. For example, the SI system has specific values for converting weight (or mass) and force. Also, engineers may introduce accuracy into a value it didn't have during the conversion.

### **Designing in Metric**

In general, there are no functional differences in designing with metric or English-dimensioned motion control components. With most metric lead screws, for example, the screw is in metric dimensions. Some screws also have the mounting threads measured in metric dimensions. Be sure to check the manufacturers' catalogs.

Some manufacturers offer unique features in their metric components, largely because they are new designs, that engineers can take advantage of. For example, some metric lead screws have a modified thread design that maximizes performance with plastic nuts because it reduces stress concentrations on leads, particularly on high leads.

A factor engineers will want to note is the accuracy used to produce a metric motion control component. Continuing with the example of metric lead screws, the main gage of accuracy for lead screws is lead error. Most metric lead screws offer an accuracy of 300 micron/300 mm. Newer offerings, though, have accuracies to 75 micron/300 mm.

As long as engineers remember to keep their units straight, the same design principals apply. Here's a look at some of the factors to examine for metric lead screws.

Know the efficiency required by an application. Efficiency is usually defined as the ratio of work in to work out and it must be known to calculate torque. In lead screws, efficiency is a function of the Helix angle and the friction coefficient and can be found through the equation:  $e = \frac{\tan(\theta)}{\tan(\theta + \arctan f)}$ , where  $\theta$  is the Helix angle and  $f$  is the friction coefficient.

Torque is the function of Force, Lead and efficiency and can be found using the following equation:  $T = FL/2\pi e$ , where  $T$  is torque,  $F$  is force and  $L$  is lead and  $e$  is efficiency.

And pressure velocity indicates allowable load and speed limits. Use the following:  $PV = (\text{load/projected area}) \times \text{velocity}$ .

## **Changing**

With laws in place, and with most engineers having some familiarity with metric, the only obstacles left to overcome is a lack of component available in metric units in sufficient quantities and our own resistance to change. The first obstacle is being overcome with the increasing number of available products. The rest is up to engineers.

### What's New in Metric Lead Screws

Many engineers are turning to metric lead screws when designing scanning equipment, wafer handling systems, data storage devices, as well as semiconductor and medical equipment. These quiet devices are ideal for light to medium loads of less than 650 N, while offering fast and precise movement. And because there are no recirculating balls, there's no vibration.

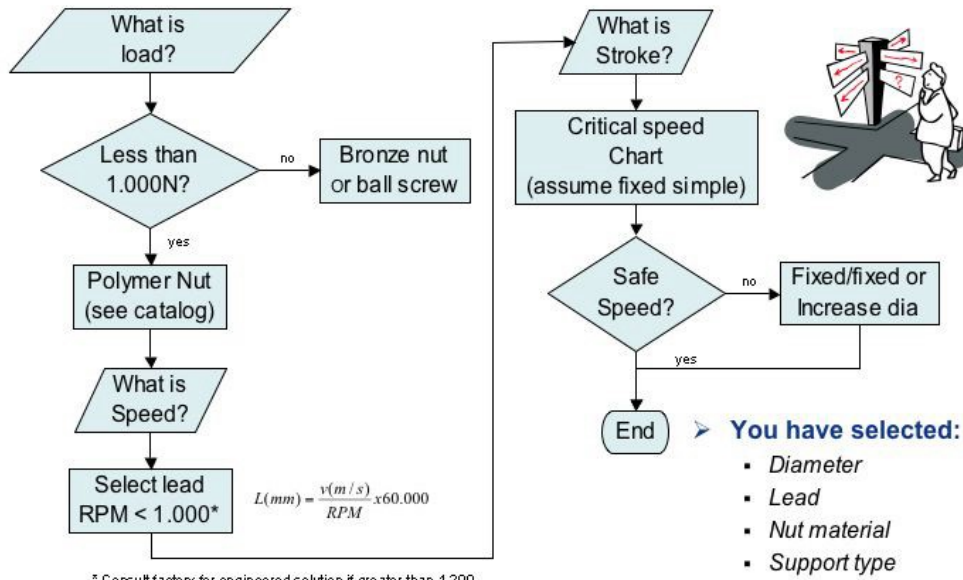
Lead screws also offer efficiencies that typically range from approximately 30 to 80%, depending on the lead (helix) angle. Many lead screws are also self-locking at low leads, eliminating the need for brakes.

The availability of metric lead screws is increasing. Engineers can find them with diameters ranging from 10 to 24 mm, with leads from 2 to 45 mm. Accuracy grades are standard and precise. The standard are accurate to 250 micron/300 mm. The precise are accurate to 75 micron/300 mm.



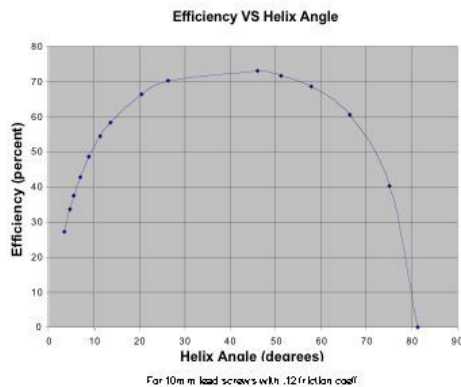
The availability and variety of motion control components in metric units of measure is increasing. These metric lead screws, from Thomson Neff, Danaher Motion for example, are available in 25 new lead screw sizes with diameters ranging from 10 to 24 mm.

## Sizing Process



Choosing metric components for an application, for example a lead screw, is no different than choosing an English components. As seen in the flow chart, the primary factors to know are load, speed and stroke. This information will help determine the metric lead screw diameter, lead, nut material and any support.

## Efficiency – Rotary to Linear



- ▶ Efficiency must be known to calculate torque
- ▶ Listed in catalog
- ▶ Efficiency is a function of:
  - Helix angle
  - Friction coefficient

$$e = \frac{\tan(\theta)}{\tan(\theta + \arctan f)}$$

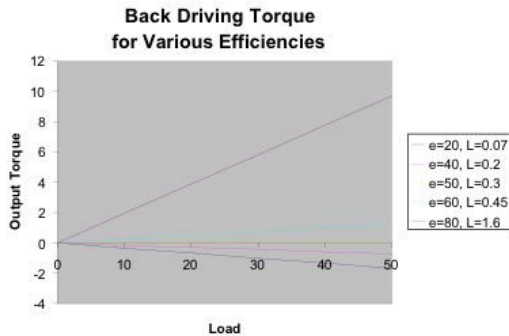
$\theta$  = helix angle

$f$  = friction coef

Definition: Efficiency is the ratio of work in to work out.

Most lead screw efficiencies are listed in the manufacturer’s catalogs, but engineers must know the needed efficiency for an application.

## Torque



- ▶ Torque is a function of:
  - Force
  - Lead
  - Efficiency
- ▶ Forward torque always positive
- ▶ Back driving torque changes

### Primary Equation

#### Forward Torque (Rotary to Linear)

$$T = \frac{FL}{2\pi e}$$

$T$  = torque  
 $F$  = force  
 $L$  = lead

#### Back Driving Torque (Linear to Rotary)

$$T_b = \frac{FP_d}{2} \tan(\theta - \arctan f)$$

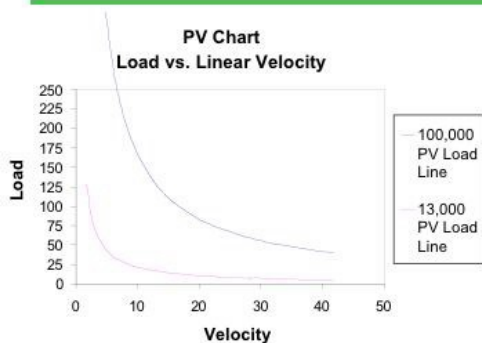
where

$P_d$  = Pitch Diameter

$\arctan f$  = friction angle

Whether metric or inch, forward torque is always positive, while back driving torque changes. The calculations would be the same when determining torque for a system in English units.

## PV (Pressure Velocity)



- ▶ PV determines allowable load and speed limits
- ▶ Wear inflection point
- ▶ Material property
- ▶ Typically expressed in MPa m/s

$$PV = \frac{\text{Load}}{\text{Projected Area}} \times \text{Velocity}$$

PV is usually expressed in Mpa m/s. It can indicate the wear inflection point of a chosen lead screw.



Metric lead screws and Inch lead screws handle the same applications. The only difference is in their dimensions, which in metric are usually labeled in mm and for English are usually labeled in inches. When working with metric, it's important for engineers to keep units straight when dealing with calculations of mass and force and torque.