


Achieving Your ACCURACY GOALS

by Matt Johnson

Tips for Avoiding Positioning System Speculation

Choosing the correct positioning technology for a motion application is often very frustrating, because the underlying terminology can be vague and confusing. Incorrectly specifying positioning requirements can lead to an overly expensive motion system or disappointing results. The challenge of correctly applying motion technology is often compounded by misconceptions about the inherent abilities of the components that make up the positioning system. This is “Part II” in a series of articles designed to help you “Determine the Positioning Performance Requirements for Your Applications”. Part I, “A Better Understanding of Repeatability and Accuracy” appeared in the previous issue of Ideas (Series A, Issue 2). Whenever you see the Issue 2 front cover icon  the associated topic is further detailed in “Part I” of the series. To get a copy of Issue 2, check the appropriate box on the attached fax back form. The goal of this series of articles is to provide some practical tips for avoiding speculation when applying positioning technology.

Overview


All motion systems have five fundamental performance requirements:

1. Load capacity (static, dynamic, impact, multi-axis related, etc.),
2. Movement characteristics (move profile, acceleration, velocity, etc.),
3. Quality of movement (accuracy, repeatability, resolution, etc.),
4. Physical limitations (physical dimensions, materials, special environments, etc.) and
5. System cost

All five of these fundamental requirements are interrelated. Optimizing any one objective forces trade-offs and compromises with the other objectives as well as increasing system cost. This series of articles qualitatively examines some of the chal-



lenges associated with optimizing the quality of movement, specifically accuracy. Although the overall focus of this series of articles will stress the performance of the entire system, this article begins with the drive systems, bearings and support structure.

Component Selection - Drive Systems

The drive system is the most critical component of a positioning system. Accuracy considerations really start with the drive system.  For a rigorous description of how accuracy is defined and measured, please consult ISO 230-2:1997(E) and ASME B5.54-1992.

Currently, there are three main drive options. For relatively high-speed, light-load, low-cost applications, belt drives are a popular choice (e.g., IDC's R Series belt driven rodless actuators). However, belt drives are not good choices for applications requiring high degrees of repeatability or accuracy.

Linear motors offer even higher speeds and repeatabilities than belt drives. Because linear motors are directly-driven, force-producing devices, they do not have the backlash and wear problems that plague traditional mechanically-driven systems. Almost all high-throughput applications could benefit from a linear motor drive. Unfortunately, linear motors, except for asynchronous induction linear motors, are not really designed for high-force applications. Depending on the type of linear motor technology, heat dissipation and loose magnetic field issues may be critical. Linear motors are also significantly more expensive than traditional mechanically-driven systems. As they continue to gain acceptance, more and more of the high-accuracy, high-throughput applications will be driven by linear motors in the next few years.

It is important to note that a linear servo motor requires a linear encoder for positioning as well as motor commutation. Some of these encoders have very fine resolutions (sometimes as fine as 0.25 microns). However, a fine-resolution encoder does not guarantee high system positional accuracy. The straightness and flatness of the surface that the encoder is mounted to can severely limit linear encoder accuracy. Any surface errors that prevent the encoder from achieving parallelism with the direction of travel will cause cosine errors. Linear encoders only measure accuracy in the direction of travel at the read head of the encoder. They cannot compensate for any angular errors  experienced at the carriage surface. Also, because the read head and the surface of the table are at different locations, Abbe error will also occur.  Finally, linear encoders cannot compensate for orthogonality or stack up errors in multi-axis applications. Linear encoders provide electrical resolution, but they do not guarantee accuracy.

Because the accuracy of a linear motor system is so dependent on the supporting mechanical components (support structure and bearings), linear motors can be used on everything from lower-accuracy, high-throughput applications (linear motor actuators like IDC's LM linear motor actuator shown in Figure 1) to sub-micron positioning applications (air bearings on a granite surface with laser interferometer feedback).

Most contemporary positioning systems utilize a ballscrew or leadscrew drive. These systems offer a good balance between load, speed, accuracy, and cost. Leadscrews are typically lower-cost, lower-accuracy devices that offer smooth motion and low noise. However, there are also some very high-precision, high-cost leadscrews whose accuracy can be as high as 0.25 microns per revolution

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and 2.5 microns per 300mm. Both types of leadscrews can be used in positioning systems; however, most typical commercial leadscrews are not really appropriate for high-accuracy applications (only the high-precision leadscrews are really appropriate). The main limitations of leadscrews are duty cycle (typically 60%) and wear. Leadscrews are often used in vertical-power transmission applications, because the increased surface contact area of their threads prevents back-driving.

Ballscrews are typically higher-cost, higher-accuracy choices that offer high-power transmission efficiency. Ballscrews can be preloaded to eliminate backlash and can be run at a 100 percent duty cycle. Their rolling contact reduces the wear associated with leadscrews. There are three types of ballscrews. Commercial rolled ballscrews (lead accuracy worse than 200 microns per 300mm) are very low-cost and primarily used in power transmission applications (actuators). They are not appropriate for positioning applications. This has lead manufacturers of precision positioning systems, like IDC to eliminate commercial rolled ballscrews from their standard products.

Ground ballscrews are significantly more expensive than rolled ballscrews; however, these types of ballscrews offer several advantages. First, ground ballscrew accuracy (between 50 microns per 300mm and 3.5 microns per 300mm) is classified according to one of two internationally recognized standards (JIS 1192 and DIN 69051). This clarifies and standardizes performance specifications. Second, ground ballscrews offer smooth, uniform motion throughout the entire range of travel. This is a key advantage for increasing system resolution (less stiction), achieving quicker settling times and better performance in contouring applications. Ground ballscrews are usually the best choice for positioning systems. This is why IDC recommends the G and MG screws in precision table applications.

The third type of ballscrew is the high-precision, rolled ballscrew (e.g.,

IDC's P screws). Their accuracy range falls in between the commercial rolled and ground ballscrews (200 microns per 300mm to 25 microns per 300mm). Their other performance specifications also fill the gap between ground and commercial rolled ballscrews. High-precision, rolled ballscrews are good choices for some lower-accuracy positioning applications. However, ground ballscrews are usually more appropriate for accurate positioning applications.


All screw-driven systems have some additional physical limitations. One limitation is critical speed. At the critical speed, a screw starts to resonate at its first natural frequency (whipping). The critical speed is proportional to the diameter of the screw and inversely proportional to distance between the screw supports squared. Critical speed is also strongly affected by how well the screw is supported. Except for very long, slender screw-driven applications, most critical speeds are well above 2500 rpm. Column loading is not usually an important consideration, because positioning systems are not usually used as thrust producing devices.

It is important to note that a finer-lead, higher-resolution leadscrew or ballscrew will not become more accurate because of its finer lead. For example, a JIS C3 ballscrew with any lead (e.g., 2mm or 20mm) is allowed a maximum error of 6 microns per revolution. For applications that require high accuracy and high resolution, the actual screw lead error should be mapped. Some controllers can use the error mapping information to compensate for the actual lead error.

To reiterate, the fundamental accuracy of the positioning system is largely determined by the drive components. The drive system is largely responsible for errors in the direction of travel. The additional system components add error, both in the direction of travel and perpendicular to the direction of travel, to the fundamental errors attributable to the drive components. As previously stated, linear encoders can only compensate for positional

errors in the direction of travel at the encoder read head, not at the carriage surface (Abbe error). Therefore, it is important to select the sufficiently accurate drive components. The next section covers another source of errors, the support structure and bearings.

Component Selection - Support Structure and Bearings

In addition to the drive components, the support structure and bearings can also be an important source of errors. These errors are expressed as angular deviations (roll, pitch and yaw), planar deviations (straightness and flatness) or total deviation from a theoretically perfect straight line (straight-line accuracy).  For a detailed description of how angular errors are defined and measured, please consult ASME B5.54-1992.

First it is important to consider the role of the structure. Positioning system accuracy is constrained by the structural materials as well as all the machining and assembly tolerances. The fundamental straightness and flatness of each positioning system axis is determined by how well the base of each axis is manufactured. Ground or lapped surfaces are critical for systems with low angular error requirements. Poorly machined surfaces also contribute to cosine error (straightness and flatness errors between a linear encoder and the direction of travel), which limits the accuracy of linear encoders.

Aluminum is a popular material for positioning system structures, because it is lightweight, corrosion resistant, easy to machine, and inexpensive. For applications where aluminum is not rigid enough, steel is usually chosen, because it is approximately three times stiffer than aluminum. However, steel is more expensive, more difficult to machine, and not as corrosion resistant. Stainless steel is sometimes used instead of steel, because it is corrosion resistant, but it is considerably more expensive

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and difficult to machine. Cast iron is usually used for systems where rigidity and vibration damping are important, such as machine tool applications. Granite is typically used with air bearings for systems with extremely low angular error and low stiction requirements, because it can be lapped to an extremely smooth, flat finish.

Bearings are also an important consideration for positioning applications. Traditional slide bearings, such as dovetail ways, have high load capacities and are very stiff. However, stiction and the wear produced by the metal-on-metal contact are important limitations. Most typical mechanical bearings are either

recirculating or non-recirculating. Recirculating bearings are best for higher-load, longer-travel or cantilevered-load applications (e.g., IDC tables RB4, RB6, LB8, RB8, RC6, and CE6). Figure 3 shows an IDC RC6 with recirculating guideway (ball) bearings. They can be highly preloaded for high stiffness or vertical applications. Most are designed with wipers to keep out contaminants; however, these wipers significantly add to the system stiction, which reduces system resolution.

Non-recirculating bearings are best for lighter-load, smooth-motion applications (e.g., IDC tables CP3, CP8, HM and PB4). Figure 2 shows an IDC CP3 with non-recirculating ball bearings. They are typically very economical and have no wiper stiction. Because they are typically point-contact mechanisms, non-recirculating bearings are not designed to handle moment or impact loading.

Both types of bearings can utilize ball or cross roller elements. Cross roller bearings are stronger because of their increased load bearing surface area. Both types of bearings are rated to a B10 bearing life, which is the life (a linear distance, typically 50km), under a specified load (dynamic load), at which 90% of the contact elements will maintain geometric integrity. Both

types of bearings can be used in positioning applications requiring straight-line accuracies up to 1 micron per 25mm. However, the ability to achieve these straight-line accuracies is dependent on both the positioning system structure and the bearings. For example, typical precision-grade bearings can achieve a cumula-

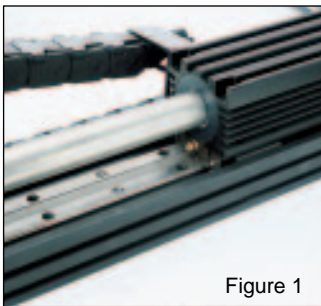


Figure 1

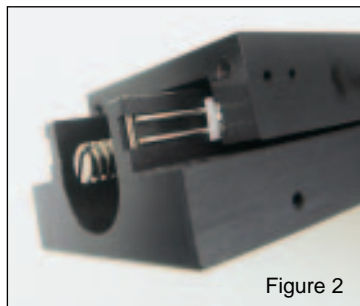


Figure 2

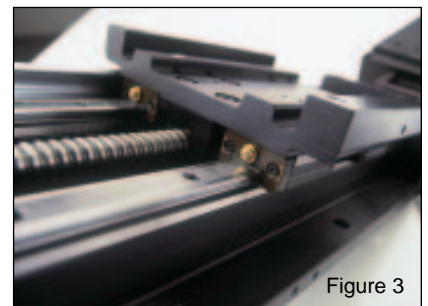


Figure 3

tive running parallelism error of 10 microns over a 1 meter length, provided that the bearings are installed on a sufficiently straight and flat base. Poorly machined surfaces will cause errors far greater than the errors caused by the bearings alone. For applications with more demanding straight-line accuracy or low-stiction requirements, air bearings are necessary.

In this article we've looked at some of the major drive and bearing issues that affect system accuracy. Future articles will examine other important considerations. For more information about achieving your accuracy goals, watch for our next newsletter or contact IDC or your local distributor.

