

Specifying Part Positioning Equipment

Laser processing equipment usually integrates some kind of positioning equipment, and the specification of the positioning accuracy of this equipment can be a source of much confusion. Positioning equipment manufacturers themselves sometimes use conflicting terminology, and very few manufacturers supply all the information mentioned here.

A typical **positioning system** is composed of a number of **stages**, stacked on each other, and fixed to a rigid **frame** or **support**. Each individual linear stage consists of a **chariot** free to move in a single direction along **guideways** fixed to a **base**, and pushed in that direction by an **actuator** or **motor** acting through some kind of **drive system**. The **motor** is driven by a **motor drive unit**, receiving information from a **motion controller**, and possibly **feedback** information from a position **encoder**.

Traditionally, the drive system has been a motor driven screw or **ballscrew** & nut,- driven either by **stepper motor** or **servomotor** with feedback from either a **rotary encoder** measuring the motor shaft angle, or a **linear encoder** monitoring the actual chariot position.

For some applications, the trend is towards **linear motor** drive with encoder. Similarly, for some applications, ball or cylinder bearing guides are replaced by air bearings. This does not mean that such options are intrinsically 'better'; they are better for some applications, less good for others, irrelevant in most cases,- and always more costly. Another aspect of the problem arises from the fact that motion equipment manufacturers are generally specifying a single linear stage, whereas a workstation requires a number of stacked stages

Lead Performance

The **drive resolution** of the stage is the smallest programmable step in the drive direction; the **motion resolution** is the smallest step which will be reliably executed. The former, and usually quoted quantity, is determined by the drive system,- e.g. step size of a stepper motor drive-, or by the encoder resolution. The latter may be limited by mechanical linkages, constraints on the motion including rolling resistance etc., and ultimately by the roughness of the guideways. Thus, there is no difficulty in constructing a drive unit with vanishingly small electronic resolution, and manufacturers commonly quote sub-micronic resolution. However these figures are meaningless unless the chariot will actually move by this amount on a systematic basis, and in general drive resolution should be set to be on the same order or bigger than motion resolution. Motion resolution depends on the system construction, load etc. Ball guide stages have smoother guide motion than rollers, since a ball can push an obstacle aside, a roller must go over it (against this, cylinders have much greater load carrying ability). Note that the limit of roughness of the guideways can be overcome by well-designed air bearings, at the possible expense of **stiffness** of the system when used dynamically.

The **lead precision** of the drive system describes the linear error in the drive direction, assuming the motor to have perfect input information. This is commonly expressed either as maximum error over the total **travel**, or over some smaller fraction of this travel, or both. For a ballscrew drive without linear encoder, this is essentially the accuracy of the ballscrew pitch, usually with both cyclic and linear components; the latter being relatively simple to compensate using a multiplicative factor. Ballscrews come in different precision grades, selected at the factory, and linked to price. Thus, a very high precision ballscrew may have a precision of $1\mu\text{m}$ over 25mm, $10\mu\text{m}$ over 300mm. Note that for an encoder-based system with feedback the final precision is that of the encoder, rather than the drive system

The **repeatability** of positioning is a measure of the ability of the drive to return the chariot to the same nominal position. The **bidirectional repeatability** expresses this concept when the direction of approach varies. The difference between the two may be **play** in the drive, usually mostly eliminated by pre-loading, but always with an element due to rolling/wiper resistance and elastic deformation of the system components, which can also depend on both approach distance and speed of approach.

Finally, this positioning accuracy in one axis may be modified by static deformation of the stage due to **load**, the manner of mounting on the frame(or other table) including **orientation**, and, where dynamic performance is considered, by elastic deformations related to chariot acceleration etc. Tables designed for μm -scale positioning must be of a large, rigid section, and firmly mounted to an adequate support.

Guide Errors

So far we have only considered positioning accuracy in the lead axis, principally due to the drive system.

However, the chariot is also subject to lateral errors in the guideways, and these are expressed as **straightness**, i.e. in the plane in which the guideways lie-, and **flatness**,- perpendicular to this plane. These two quantities are usually expressed in a similar way to the drive precision.

Clearly, if a Y stage is stacked on top of an X stage, then the X guide errors appear directly as **cross errors** in the lead direction of Y, and vice versa.

Further, errors in the guideways also lead to angular movements of the chariot in the three orthogonal axes, **roll**, **pitch**, and **yaw**(RPY errors). These lead to positioning errors for all points vertically displaced from the guide plane, and therefore become increasingly important where one table is mounted upon another, and can lead to large errors in overall positioning accuracy when acting over a long distance,- i.e. at the limits of table travel or when several stages are stacked.

Stacking Stages

When two or more tables are mounted together the concept of **squareness** also becomes important. In theory, squareness could be perfectly eliminated, but at the lower limit inevitably becomes anyway confused with straightness since the true stage axes can no longer be defined.

Thus in a practical system the static **overall positioning error** OPE of a complete positioning system is the error, due to all causes above, in the position of a particular point in the X,Y plane, relative to a fixed coordinate system. Of the various errors discussed, most motion controllers allow compensation of the linear component of the drive error. With this compensated, for SMALL displacements, relative OPE is usually determined by either non-linear drive errors, or bidirectional repeatability, and in a good system will be comparable to the motion resolution.

However the OPE of an X,Y system over the FULL travel range is usually determined by guide & mounting errors rather than lead precision, and may easily be an order of magnitude or more greater than the quoted drive resolution or lead precision. In this situation, discussion of the relative merits of different drive systems misses the important point that the major part of the OPE in a practical stacked system does NOT arise from lead precision, but from guide and mounting errors, including RPY. Caveat emptor.

DMC

Dynamic Matrix Correction aims to characterize and correct the OPE directly, without attempting to determine its origins. Laser processing workstations which include a TTL vision system are ideally suited to this approach, where a suitable calibration standard is used to determine OPE, and the resulting corrections applied to all subsequent moves. The principal advantage of DMC is its ability to compensate for guide & mounting errors, including RPY errors and squareness.

Steppers vs Servos

The two commonest types of stage encountered in laser processing are stepper motor driven ballscrew drives, and servomotor with rotary encoder, or servomotor motor drives with linear encoder; the latter include also linear motors. Stepper motors have an obvious appeal for point to point applications, and are generally simpler and more reliable. Loss of steps due to motor stalling is rarely an issue where motors are correctly dimensioned for the task, whilst stalling offers a simple approach to mechanical overload.

Since linear encoders can be made in higher precision grade than ballscrews, there is no doubt that the lead precision of linear encoder-based systems can be superior, especially over long distances. However, as pointed out above, lead precision is often not the controlling factor on overall performance of a practical system.

Dynamics

Thus in a practical case, one has to study carefully the trade-offs in performance/price etc against real benefits of any particular system. At this point the specific requirements of the application generally need to be considered. Horses for courses.

Dynamic contouring accuracy of a system is the deviation from a mathematically defined contour, and includes dynamic parameters proportional to loads and accelerations. In particular the feedback loop parameters of servodrives become determining factors.

Mechanical drive systems and guideways are subject to **wear**, depending on conditions of use, which ultimately degrade accuracy as play develops in the system.

It is important to grasp clearly the difference between the various parameters defined here, to have an appreciation of what is possible, not to overspecify, to study the claims of manufacturers critically,- and to understand the essential difference between the quoted precision of the different components of a positioning system, and the performance of the resulting complete system.

For example;- a single axis positioning table with sub- μm resolution is available at low cost. Single axis positioning with $1\mu\text{m}$ repeatability is possible at moderate cost. Dual axis positioning with 2-3 μm accuracy requires the use of linear encoders and look-up tables, and careful selection of components and design of the frame. Contouring accuracy to 10 μm is attainable at a cost, and limited speed, depending on the load to be moved.