INDUSTRIAL Laser Solutions FOR MANUFACTURING

technology report

Minimizing circular path errors in laser machining

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MAKING BETTER CIRCLES IN HIGH SPEED LASER APPLICATIONS

Laser machining comprises a variety of processes, including laser drilling, cutting, marking, scribing, welding, and micromachining. While a great deal of industry experience exists with these processes, many challenges remain in performing them quickly, efficiently, and with the highest process quality. Many factors affect the ultimate part quality, including variations in gas pressure, laser power, material thickness, focusing of the laser head, and the motion system. However, tracking errors introduced by the motion system often contribute most significantly to the final part quality.

As with all manufacturing processes, minimizing part cycle times is critical. The motion system is relied upon to perform these complex patterns at high velocities while maintaining acceptable tolerances. Advanced motion controller features such as Aerotech's acceleration limiting coupled with multi-block look-ahead allow the user to maintain both high throughput and high quality.

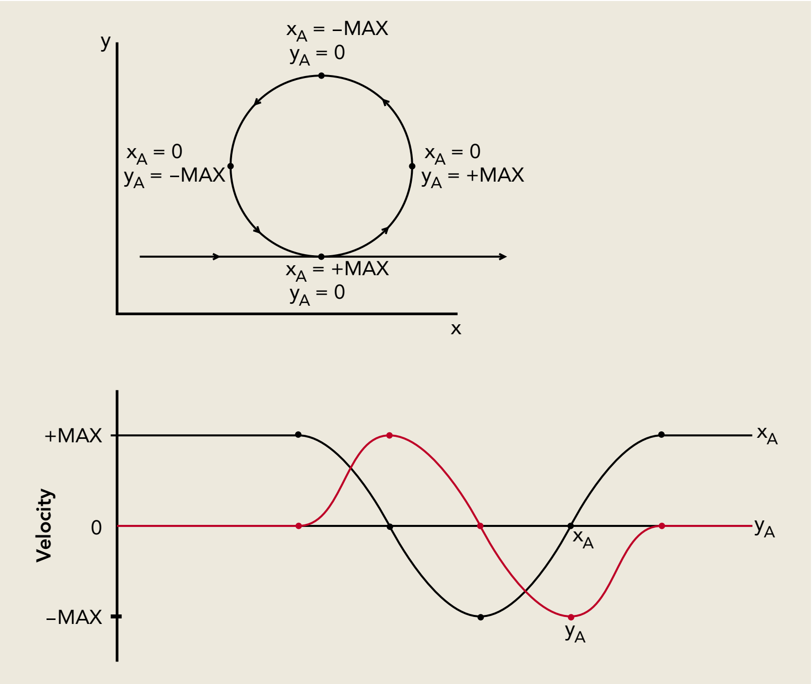

Figure 1. Ideal motion profile for a circle, illustrating the sinusoidal velocity profiles of the X and Y axes.

Acceleration limiting

Although tracking errors in a motion system can be attributed to a variety of factors, the greatest errors typically occur when the axes are accelerating or decelerating. This is because the position command changes faster than the system can react. It is important to remember that an axis is accelerating any time its velocity is changing. This occurs not only at the beginning and end of a move, but also any time the axes are moving in a curvilinear path.

Many laser machining motion systems consist of multiple single-axis stages connected together. Any complex cutting path is accomplished through careful coordinated interaction of these single-axis stages. During this interaction, it is common for one or more axes to constantly be changing velocity (accelerating). This is particularly the case when producing circles, as the velocity profiles of both axes are sinusoidal (see Figure 1), even if the path speed remains constant. During a circular move, the centripetal acceleration becomes the dominating factor in path error. Centripetal acceleration is defined by the rate of change of the tangential velocity (see Figure 2). It is equal to the square of this tangential velocity (v) divided by the radius (r) of the arc, represented by:

$$a = v^2/r$$

Examining this representation, one can see that in order to reduce the centripetal acceleration either the radius must be increased or the tangential velocity must be decreased. Because part paths are predetermined, the radius is often static and cannot be changed without altering the part. Therefore, the path speed must be reduced to maintain a centripetal acceleration below a predefined error threshold. Advanced controllers com-

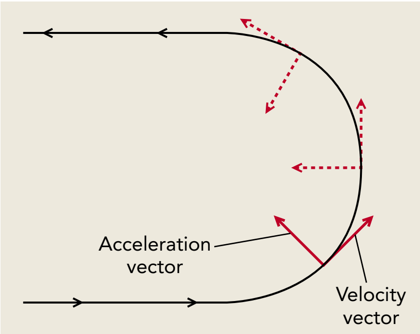

Figure 2. The velocity vector is constantly changing direction while cutting an arc. The centripetal acceleration vector is always perpendicular to the tangential velocity vector, pointing towards the center of the arc.

pare the centripetal acceleration of a move, before the move is executed, against a predefined threshold. When this value exceeds the threshold, the controller will decrease the tangential velocity, and thus the centripetal acceleration, to maintain part quality.

Acceleration limiting can also be used to eliminate errors between two non-tangential line segments, or corners, when the path speed must be held constant. In these situations, the controller calculates the acceleration required to negotiate the move at the speed, comparing it to a predetermined value, and adjusts if necessary.

For example, Aerotech's Automation 3200 controller (see Figure 3) has three acceleration limiting parameters for users to define. One parameter is used for circular motion, the second is for line-to-line contours, and the third is for corners between rotary axes.

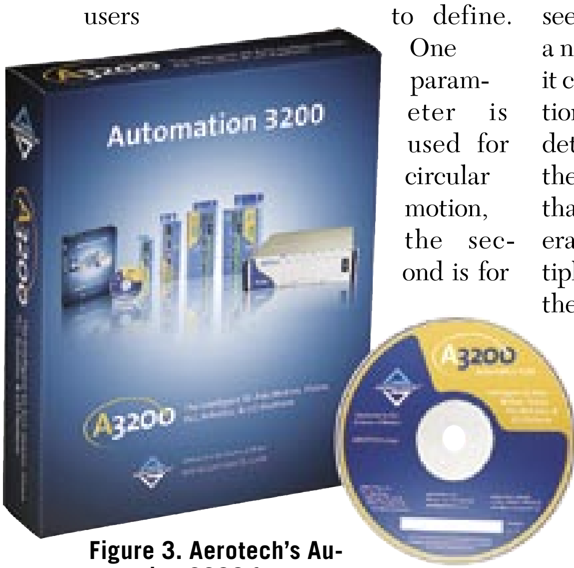

Figure 3. Aerotech's Automation 3200 features both acceleration limiting and multi-block look-ahead in a software-based controller.

For acceleration limiting to be most effective, the controller must analyze future path commands. The further out the controller can analyze these moves, the greater the time it will have to react. Multi-block look-ahead allows the controller to analyze these future moves.

Look-ahead

Look-ahead is the ability of a motion controller to identify and correct conditions that will likely cause motion system errors, before they occur. Traditional single-block look-ahead algorithms are only capable of analyzing the move immediately following the currently executing move. While helpful in reducing errors, this feature often does not allow enough time for the motion system to overcome the system momentum and adjust for potential problems. Multi-block look-ahead allows the motion controller to look at multiple future moves beyond the one currently executing. As a result, the motion system will compensate, when necessary, over multiple moves, allowing sufficient time to take any corrective action needed to minimize errors (see Figure 4).

Typical multi-block look-ahead actions include acceleration limiting, as described above, and feed-rate limiting. In other words, if the controller sees that the path will encounter a curve a number of moves ahead of where it is, it can calculate the centripetal acceleration and compare this result to the predetermined parameter (threshold). If the move requires acceleration greater than the parameter setting, it will decelerate at a predetermined rate over multiple moves so that it enters the curve at the proper speed. It will also automatically accelerate back to the original desired path speed at the end of the curve.

This feature is especially useful for profiles consisting of short moves, where the length of the move is not long enough to decelerate to the required speed at the predetermined rate. It is also useful during dwell commands and at the end of motion, as it allows the controller to proactively decelerate and not overshoot the end point.

Additionally, multi-block look-ahead allows the user flexibility in choosing feed rates by using the acceleration limiting, allowing selection of a much higher limit value than needed. This is because the controller will automatically use the greatest feed rate possible that does not violate the acceleration parameters.

Part quality and throughput are both essential to an efficient and successful laser process. However, these characteristics do not need to be exclusive. By taking advantage of advanced features in today's motion controllers, such as acceleration limiting and multi-block look-ahead, throughput may still be maximized while maintaining tight part tolerances.

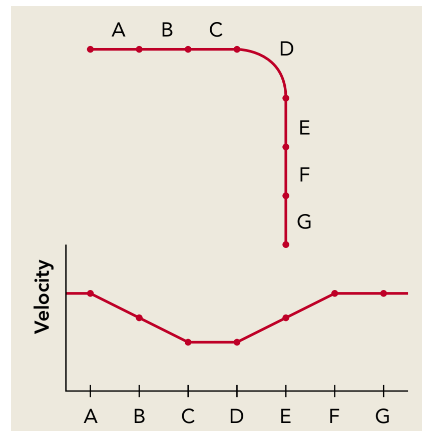

Figure 4. An example of a velocity profile utilizing multi-block look-ahead.

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