Identifying Problems in Ballscrew Performance

As the demand for faster feedrates, tighter tolerances and better repeatability increases, annual and semiannual checks of ballscrew performance will remain a mold shop priority.

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Annual and semiannual checks of ballscrew performance are becoming more important as the demand for faster feedrates, tighter tolerances and better repeatability have increased. Nowhere is this more important than in the moldmaking industry.

The Maintenance Program

CNC programs depend on machine tools to follow their programmed tool path geometry accurately. When a ballscrew becomes worn or damaged and is no longer able to follow the toolpath with a high degree of accuracy and/or repeatability, a lot of time and materials can be wasted. A regular maintenance program, including laser calibration and ballbar analysis, can provide an accuracy check of the ballscrews and determine whether adjustments or repairs are necessary.

Laser calibration measures position accuracy and repeatability at specified increments along the entire length of the ballscrew. This information allows for adjustment, creation of compensation tables, and/or repair and replacement of worn ballscrews. *Ballbar analysis* checks the accuracy of the machine tool's circular interpolation and the data it provides is useful in tuning axis servomotors.

The mechanical issues affecting machine tool positioning accuracy are related to lost motion, which is caused by such issues as backlash, windup or deflection. Typically, backlash is the result of free play in the drive system along a linear axis. Backlash includes intentional play in the ballscrew coupling, looseness in the bearings or bearing mounting, end play of the screw, play between the screw and nut, looseness in the nut mounting and the effect of cocking of the machine slide (pitch and yaw). Windup and deflection are secondary sources of lost motion, affecting the machine tool positioning system like backlash.

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Windup is the angular twisting of rotary components under load such as shafts and screws. In the positioning system, deflection is linear compression, stretching or bending of a drive component. Machine tool manufacturers offset windup and deflection by increasing the stiffness of positioning components. Laser calibration and ballbar analysis can check machine tools for these factors and allow for compensation adjustments, repair or replacement. Understanding such issues as how to read a ballscrew survey provides the potential to reduce downtime, cost of repairs and scrap parts.

Ballscrew Operation

A ballscrew operates on the same principle as a screw with a nut. As the screw rotates, the nut moves. Clockwise or counter-clockwise rotation of the screw determines forward and reverse directions. Most machine tools utilize recirculating ballscrews in which the ball bearings provide the preload that reduces backlash.

Ball screws come with different diameters and thread pitch. These features determine the rotational speed, torque and

Figure 1

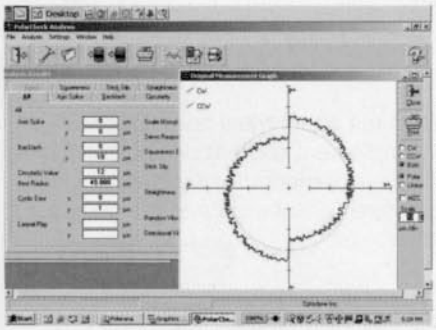


Figure courtesy of Optodyne Inc.

In this plot, the Y-axis has positive backlash—lost motion of 14.2 microns in both the positive Y-axis and the negative Y-axis. The plot shows an outward step that starts on an axis. Usually, the size of a step is unaffected by machine feedrate.

Figure 2A

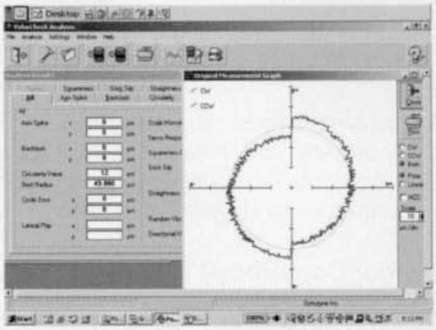
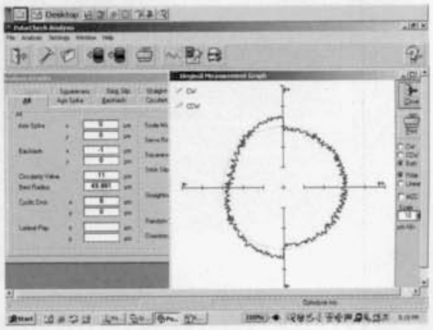


Figure 2B



Figures courtesy of Optodyne Inc.

The plot has either unequal backlash steps or, for machines with backlash compensation, backlash steps appearing in opposite directions on the same axis. In these plots, unequal backlash is shown in the Y-axis only.

Figure 3

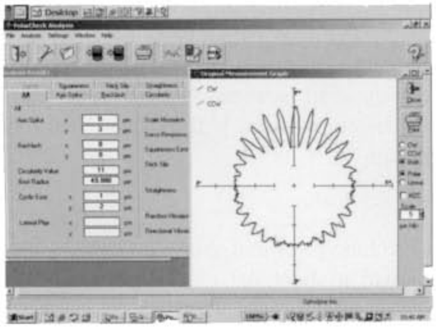


Figure courtesy of Optodyne Inc.

The plot has a cyclic sinusoidal error, varying in both frequency and amplitude around the plot. *Dy*, the wavelength as measured along the Y-axis, is approximately constant around the circle.

Figure 4A

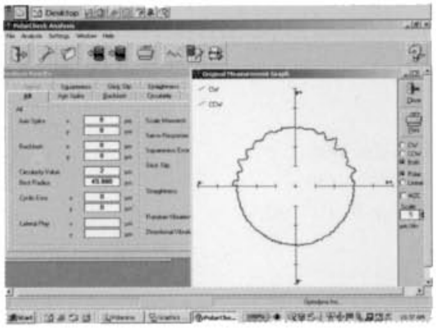
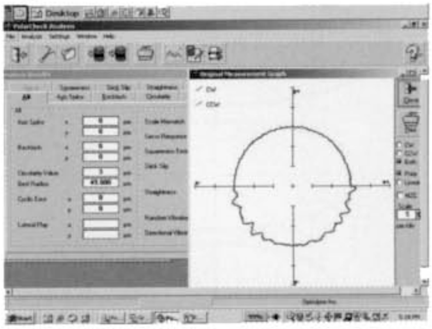


Figure 4B



Figures courtesy of Optodyne Inc.

The counterbalance problem is clearly shown as only one half of each plot (clockwise and counter-clockwise) exhibits a cyclic error.

horsepower the axis motor must deliver to move the table at a given feedrate and thrust. A ballscrew with a coarse pitch turns fewer times to move the same distance as a ball screw with a finer fine pitch, but delivers less thrust, or requires a larger, higher horsepower motor to achieve the same result.

Pitch is a definition used to identify a ballscrew's performance based on the distance the nut moves with one rotation of the screw. Fine threads on a ballscrew provide higher accuracy, but move slower than coarse threads on a ballscrew. Conversely, coarse threads move faster, but are not as accurate. However, an encoder with very high resolution will deliver high accuracy, even if the threads are coarse. Larger diameter ballscrews have a higher load rating and can produce higher axis thrusts with less wear than smaller diameter ballscrews.

Ballscrew Wear

Eventually, all ballscrews will show signs of wear. Premature ballscrew wear is caused by a number of issues, including speed/duty rating, friction (causes heat leading to thermal expansion), lack of lubrication, misalignment in mounting, loose ballscrew and repetitive motion over an extended period.

Ballscrew Problems Identified with Ballscrew Survey

When exceeding the rated speed of a ballbar, harmonic vibration (resonance) can result, reducing repeatability and causing a poor surface finish, as well as premature wear. Exceeding the rated speed of the ballscrew for an extended period, especially during long rapids and sharp corners, may result in wear and damage to the ball track, metal fatigue and wear on the bearing, damaged threads, ball wear/breakage and surface brinelling (damage to the raceway).

Another issue of concern is the ballscrew duty rating supplied by its manufacturer. After integrating the ballscrew with the machine tool, the builder will specify the percentage of duty rating at which the ballscrews will operate. If the machine tool manufacturer specifies a high percentage duty rating the ballscrew will experience more wear. For example, a ballscrew operating at 70 percent of its duty rating usually will experience less wear and outlast one operating at 100 percent duty rating.

Friction causes heat. Heat causes thermal growth, leading to an inaccurate workpiece. Ballscrews are the components most affected by thermal growth. Heat develops within the ballscrew nut depending on preload within the nut, ball size, number of circuits, ball nut design and screw diameter. The type and amount of lubrication utilized also may affect heat buildup. Additionally, some ballscrews are gun-drilled, allowing coolant to flow through them.

According to tests conducted by an independent testing firm, when ballscrew temperatures rise 1°C (1.8°F) in a 20-inch long ball screw, it will grow 0.00023-inch, based on the expansion coefficient of steel, which is 0.00001134-inch per degree Celsius per inch. If there is a 35°C-temperature change, growth in the same ballscrew will be 0.008". Thermal growth eventually can lead to loss of preload and excessive metal-to-metal contact—resulting in excessive wear requiring ballscrew replacement.

Ballscrew lubrication according to the manufacturer's recommendations will minimize excessive metal-to-metal contact that causes premature wear. The result may include a decrease in accuracy, increase in scrap parts and loss of production time during replacement of the ballscrew.

Misalignment of the ballscrew causes tension loads, compression loads and/or bending. Tension loads, caused by a force pulling on the bearing, results in premature ball wear, worn or broken nut, damaged threads, and uneven wear and damage to the ball track. A compression load is another result of thermal expansion, causing the ballscrew to bend, which affects accuracy and repeatability, and can cause a bent shaft.

Repetitive motion over an extended time creates wear at a specific location on the ballscrew. Laser calibration may not be able to compensate for this wear, because it is not consistent over the length of the ballscrew.

Figure 5

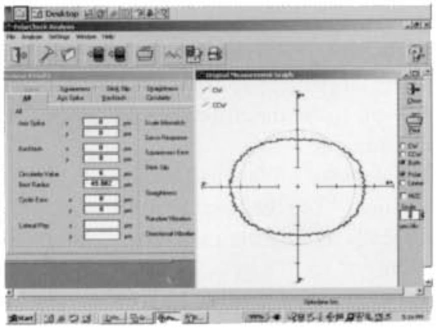


Figure courtesy of Optodyne Inc.

The plot has an oval or peanut shape distorted along the 0° or 90° axis. The axis of distortion is unaffected by the direction of data capture (i.e., clockwise or counter-clockwise). The amount of distortion caused by scaling error is usually unaffected by machine feedrate.

Diagnosing the Ballscrew

Many symptoms can indicate a worn ballscrew. For example, when using circular interpolation to machine a hole that turns out egg-shaped,

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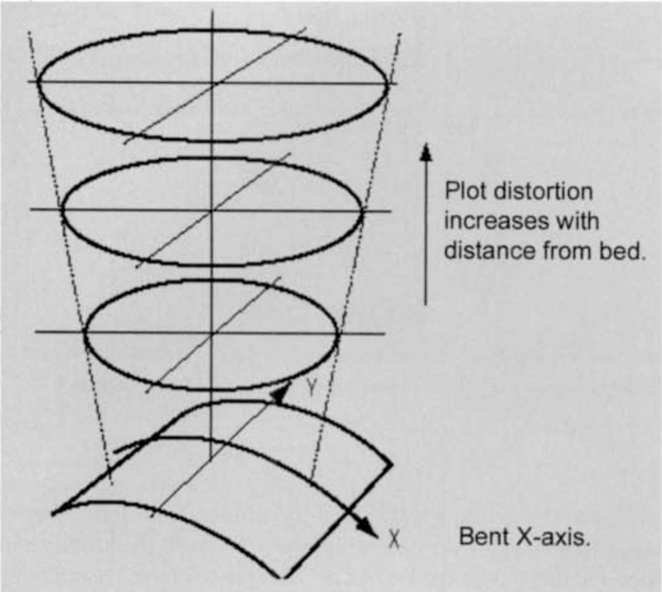
Figure 6



The Abbe effect causes the distortions demonstrated.

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trapezoid, oblong or parallelogram (angled on the 45s), instead of round. Flat spots or dimples at the 90s are caused during circular interpolation when the axis motors change direction at the 90-degree point when cutting a circle or arc. Hole position varies—either too close, too far or a combination of both—over the length of the part. Still other symptoms include loss of accuracy, repeatability and flatness, as well as poor surface finish.

Laser calibration can determine if the ballscrew is worn, where it is worn and if it is serviceable or needs to be replaced. Laser calibration measurements determine the difference between the laser measurement and the position indicated on the control. Generally, importing the measurements into a graph makes them faster and easier to understand. The line on the graph should be linear, if not it indicates wear. If the line is sporadic and multiple measurements of the same axis are not repeating, then the ballscrew is worn out and must be replaced. If the line is linear, but averages more than 0.0003" per inch, then the ballscrew is worn, but adjustments can be made to compensate for the difference. For example, wear caused by misalignment of the ballscrew, slop or tightness on the gibs, and wear in the thrust-bearing mount can be compensated for with adjustments.

A technician performs analysis of the ballscrew with either a laser or mechanical ballbar. The ballbar analysis measures circular interpolation. Typically, tuning the axis servomotors will adjust circular interpolation.

With either laser calibration or ballbar analysis, it is best to perform a push-and-pull test on the axes that is causing the problem. A push-and-pull test is crude but effective for confirming the amount of play that exists along a particular axis. However, it cannot identify the specific cause. A service technician performs a push-and-pull test by a mounting a dial indicator on a T-slot in the table and physically pulling the table in one direction and recording the measurement. The dial indicator is reset and the table is pulled in the opposite direction and the measurement is recorded. This tells the technician how much play or backlash is occurring in each axis for comparison with the machine tool manufacturer's specifications.

Positive Backlash

Positive backlash is a machine error that shows up as a circular interpolated cutter path with a short flat (**see Figure 1, page 50**). Causes include play in the drive system of the machine. For example, ballscrew endfloat or a worn drive nut; play in the guideways causing a dwell in motion during direction changes; wind-up caused by excessive strain on the ballscrew. Corrective action includes removing all play from the system, which may require replacing worn components. An alternative is controller backlash compensation.

Unequal Backlash

Unequal backlash is a machine error that shows up as a large difference in values in the positive and negative planes of a single axis or by both positive and negative backlash in the same axis (**see Figures 2A,B, page 50**). This results in inaccurate parts that change in magnitude depending on the position along the axis. Excessive windup in the ballscrew causes an unequal backlash effect. It depends on the position of the axis relative to the driven end of the ballscrew, which causes an unequal backlash type plot.

Machines with backlash compensation may be adjusted to average this difference, resulting in the opposing steps. The windup may be caused by a stiff or worn ballscrew, nut or guideway. This type of backlash is common in tests involving vertical movement, caused by counterbalancing effects. Removing any backlash compensation that has been applied to the machine will allow an assessment of the extent of the problem. The ballscrew and guideways should be checked and if necessary repaired or replaced. The counterbalance is likely to be the source of unequal backlash plots from tests involving vertical machine movement. This requires adjustment of the counterbalance system.

Cyclic Error

Cyclic error is a machine error where parts exhibit dimensional errors (**see Figure 3, page 51**). In this case, the Y-axis has a cyclic error problem caused by one of the following conditions:

- A drunk axis ballscrew thread causes the axis to move in a sinusoidal manner rather than at a uniform rate
- Encoder mountings may be eccentric
- Ballscrew mountings may be eccentric
- Poorly adjusted resolvers or inductosyns

If the cause is the axis ballscrew, the plot is unaffected by direction. Clockwise and counter-clockwise plots will appear similar or identical. If the cyclic error occurs in a vertical axis in one direction only when the axis is moving up or down, then the counterbalance mechanism of the machine most likely is the cause. If the cause is a faulty counterbalance, the plot will be affected by direction; causing a cyclic error when the machine moves forward in the positive Y-axis (i.e., vertically upwards from the machine bed).

The clockwise and counter-clockwise plots for a cyclic error caused by such a counterbalance problem may be as shown in

Figure 7

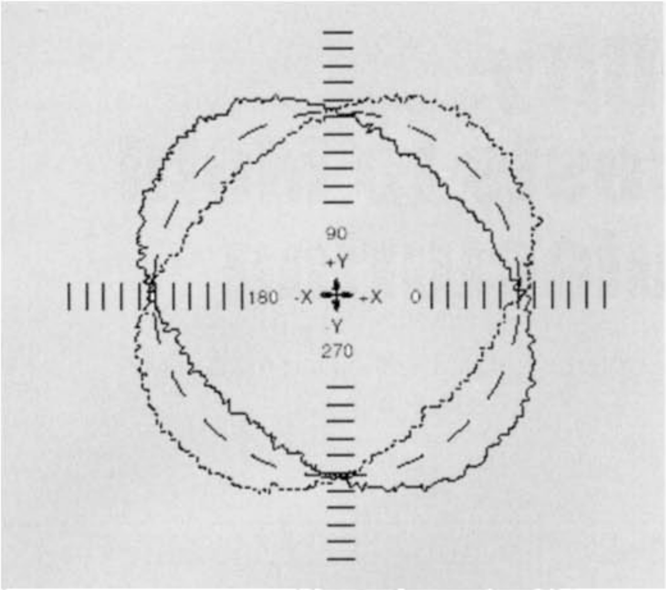
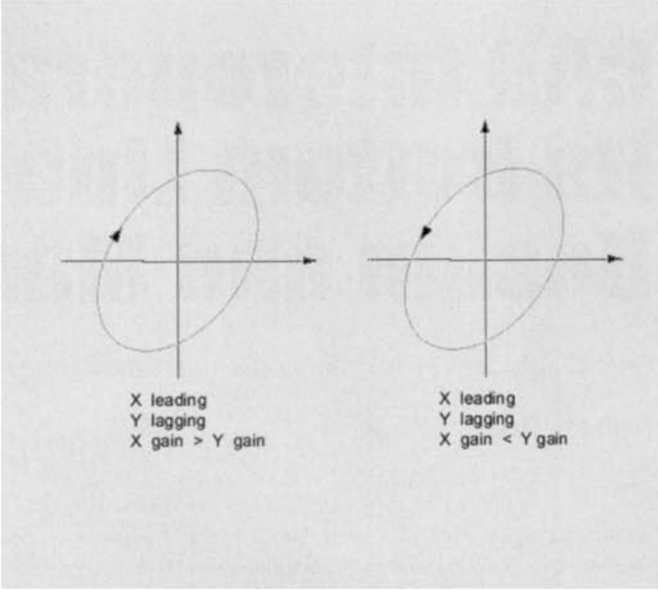


Figure 8



The plot has an oval or peanut shape, distorted along the 45° or 135° diagonal. The axis on which the plot is distorted switches if the feed changes from the clockwise direction to the counter-clockwise direction. Both directions are in Figure 8.

Figures 4A,B (page 51). Using diagnostic analysis, view the clockwise and counter-clockwise plots individually and identify whether the cause is a ballscrew problem or a counterbalance problem. If caused by the ballscrew, adjust the ballscrew and/or the encoder mountings. If the suspected cause of the cyclic error is the counterbalance mechanism, adjust the counterbalance.

Scaling or Mismatch Error

Scaling or mismatch error causes parts to exhibit dimensional errors (**see Figure 5, page 51**). Scaling errors occur when a machine axis over-travels or under-travels in relation to each other. Scaling error is the difference in the measured travels of the axes during the test. For example, if the machine is performing a circle in the XY plane; the X- and Y-axes should move over exactly the same distance. If they do not, the difference in their movements is the scaling mismatch error. In Figure 5, this is the difference between *a* and *b*.

A number of such issues cause scaling, including:

- Incorrectly set error compensation parameters
- Over-tensioned or under-tensioned axis scale
- Axis ballscrew faulty or overheating causing a pitch error
- The machine may be subject to an angular error, causing the X or Y axis to pitch out of the test plane as it moves, because the axis guideways are not straight or are not sufficiently rigid.

Scaling errors can be corrected by:

- Setting linear error compensation values correctly
- Correctly tensioned axis tape scales
- Ballscrew is in good condition and not overheating
- Machine guideways are straight and in good condition
- Angular errors can be identified by repeating tests at different locations on parallel planes. This identifies whether plot distortion increases with the distance the test is made from the machine bed, known as the Abbe effect (**see Figure 6**).

Servo Mismatch

Servo mismatch is a machine error whereby interpolated circles are not round **(Figures 7 and 8)**. Usually, the higher the feederate, the more oval-shaped the interpolated circle will be. Servo mismatch occurs when the servo loop gains of the axes are mismatched. This results in one axis leading the other, which causes an oval-shaped plot. The leading axis is the axis with the higher loop gain.

Adjusting the controller to balance loop gains of the axes servos corrects servo mismatch. Turn up the gain of the axis that is lagging, or turn down the gain of the axis that is leading. Additionally, use low feedrates when interpolating accurate arcs and circles as the effects of servo mismatch are minimized at lower feedrates.

Conclusion

The length of time that a ballscrew remains serviceable depends on the machine design, duty ratings, environment, types of cutting operations, materials cut, amount of travel over the screw, repetition of travels over the same section of the screw, and the amount of lubricant reaching the screw. Some shops have experienced ballscrews that last 15 years, such as shops specializing in prototypes. Other shops must replace ballscrews every two or three years, such as production shops running two or three shifts.

Scheduling regular maintenance with close attention to the ballscrews, ensuring ballscrew lubrication according to the manufacturer's specifications and protected from debris prolongs the life of a ballscrew. A preventive maintenance program that consists of calibration and inspection of the ballscrews can be very useful in identifying problems before they result in such substantial costs as scrap parts or lost production time waiting for replacement components.

MMT

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The Ins and Outs of Ballbar Calibration
This machine tool diagnostic device allows the detection of errors noticeable only while machine tools are in motion. Find a link to the article at http://www.moldmakingtechnology.com/articles/040306.html.