Introduction

This document has sample ballbar plots from machines with different geometric, dynamic and test hardware errors. Each sample includes a description of the error, the possible causes of the error, the effect that the error has on the machined part, and corrective action. When you do a ballbar analysis on a machine, compare your results to these sample plots to see what troubleshooting steps to do next.

Ballbar Analysis - Quick Check Mode

Click here for the procedure to do a BALLBAR ANALYSIS - QUICK CHECK MODE on a mill.

Compensation Parameters

The parameters that may need adjustment are listed below.

<table>
<thead>
<tr>
<th>AXIS</th>
<th>BACKLASH COMPENSATION</th>
<th>FRICTION COMPENSATION</th>
<th>LEAD COMPENSATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>13</td>
<td>138</td>
<td>229</td>
</tr>
<tr>
<td>Y</td>
<td>27</td>
<td>139</td>
<td>230</td>
</tr>
<tr>
<td>Z</td>
<td>41</td>
<td>140</td>
<td>231</td>
</tr>
</tbody>
</table>
Pitch, Roll and Yaw Definitions

Pitch [1] - An angular deviation possible in positioning systems, in which the table leading edge rises or falls as the table translates along the direction of travel. This represents rotation around a horizontal axis, perpendicular to the axis of travel.

Roll [2] - An angular deviation from ideal straight line motion, in which the positioning table rotates around its axis of travel as it translates along that axis.

Yaw [3] - An angular deviation from ideal straight line motion, in which the positioning table rotates around the vertical axis as it translates along its travel axis.
Backlash in the X Axis

Type of backlash: Positive = Lost motion

In this example, the X-Axis lost motion is at the reversal point, and causes the ballbar to extend. The steps on both sides of the reversal points are equal.

The machine feedrate usually does not affect the size of the step.

Probable Causes:

• A worn drive nut or ballscrew end float causes backlash in the drive system.
• Worn guideways cause dwell in the motion as the axis changes direction.
• Excessive strain in the ballscrew.

Effects on the Machined Part: A circular interpolated cutter path shows a short flat.

Corrective Action:

• Remove all backlash in the drive components for large backlash errors.
• Adjust the X-axis Backlash Compensation - Parameter 13 to correct for small backlash errors.

Note: Overcompensation (Parameter 13 set too high) shows as a step in the machined part.
Positive Backlash in the Y Axis

Type of backlash: Positive = Lost motion

In this example, the Y-Axis lost motion is at the reversal point, and causes the ballbar to extend. There are equal size steps on both sides of the reversal points.

The machine feedrate usually does not affect the size of the step.

Probable Causes:

- The drive nut or ballscrew end float is worn.
- Worn guideways cause dwell in the motion as the axis changes direction.
- Ballscrew wind-up causes too much strain in the ballscrew.

Effect on the Machined Part: A circular interpolated cutter path shows a short flat.

Corrective Action:

- For large backlash errors repair the drive components.
- For small backlash errors, adjust the Y-Axis Backlash Compensation - Parameter 27.

Note: Overcompensation (Parameter 27 set too high) shows as a step in the machined part.
Unequal Backlash in the Y Axis

Type of backlash: Unequal (bottom step is smaller than the upper step)

You must take into account the configuration of the machine.

In this example, the Y-Axis lost motion is at the reversal point, and causes the ballbar to extend. There are equal size steps on both sides of the reversal points.

Possible Causes:

- Too much strain causes the ballscrew to twist. This causes an angular motion error.
- Damage to a drive component causes pitch/yaw.

Corrective Action: Inspect the drive components.
Reversal Spikes in the X Axis

There is a delay in motion at the reversal points. Unlike backlash, the controller recognizes the delay in motion and compensates.

In this example, the X Axis had a delay in motion and compensated.

The size of the step often varies with the machines feedrate.

Possible Causes:

- Tight way covers bind and cause friction.
- There is initial torque on the ballscrew at the reversal point. An inadequate amount of torque was applied by the axis drive motor at the axis reversal point. It causes the axis to stick momentarily, as the frictional forces change direction.
- The servo response time of the machine is inadequate on Backlash Compensation. This means that the machine is unable to compensate for the backlash in time. This causes the axis to stop while the machine absorbs the slack.
- There are loose bearings.
- There is twist on the ballscrew.
- There is a problem with the axis lubrication system.

Note: Before you use the Friction Compensation parameter to remove the problem, remove all other possible causes.

Effect on the Machined Part: The effect of a reversal spike is that a circular interpolated cutter path shows a small flat followed by an inward recovery step.
Reversal Spikes in the Y Axis

There is a delay in motion at the reversal points. Unlike backlash, the controller recognizes the delay in motion and compensates.

In this example, the Y Axis had a delay in motion and compensated.

The size of the step often varies with the machines feedrate.

Possible Causes:

- Tight way covers bind and cause friction.
- There is initial torque on the ballscrew at the reversal point. The axis drive motor does not apply enough torque at the axis reversal point. It causes the axis to stick momentarily, as the frictional forces change direction.
- The servo response time of the machine is inadequate on backlash compensation. This means that the machine is unable to compensate for the backlash in time. This causes the axis to stop while the machine absorbs the slack.
- There are loose bearings.
- There is twist on the ballscrew.
- There is a problem with the axis lubrication system.

Note: A Friction Compensation parameter adjustment may get rid of the problem, but everything else must be ruled out.

Effect on the Machined Part: A reversal spike causes a circular interpolated cutter path to show a small flat followed by an inward recovery step.
Plot Rotation Error

Reversal spikes that occur at 45° are most likely caused by tester error since both axes are at the same speed at those points and there is no change in direction.

**Probable Causes:**

- There is a test error.
- The ballbar hardware is loose.

**Corrective Action:** Inspect the hardware and do the test again.

Spiral Errors

These types of errors start to appear as backlash in only one side or unequal backlash.

True backlash mirrors the plot when performing two runs.

If the ballbar hardware is worn, loose or dirty, you cannot repeat the plot.

**Probable Causes:**

- There is a test error or hardware error.
- Loose ballbar hardware. The sphere may be moving within the cup, this changes the position of the center.

**Corrective Actions:** Inspect the hardware and do the test again.
Squareness Error

The plot displays an oval peanut shape distorted at the 45° or 135° diagonal.

The axis of distortion is the same for both directions of the run (CCW and CW). The amount of distortion is unaffected by the feedrate.

Probable Causes:

- The ballscrew may be bent locally or there may be an overall axis misalignment in the machine.
- The machine is not level. A machine that is not level shows a symmetrical, flat-sided plot in the shape of an oval, or peanut, tilted at a 45° angle.
- The axes of the machine droops. This causes the axis to mis-align at certain locations.

Corrective Actions:

- Repeat the test at various locations on the machine to find out whether the squareness error is local to a certain area on the machine or if it affects the whole machine.
- If a squareness error affects the whole machine, then realign the machine axes if possible. If the guide ways are worn they may require replacement.
Servo Mismatch

Servo mismatch is quantified as the time in milliseconds by which one of the machine's axis servos leads the other.

Probable Causes:

- The servo loop gains of the axes are mismatched. This causes one axis to lead over the other, which shows an oval plot. The leading axis is the axis with the higher loop gain.
- Poor drive performance
- The linear guide trucks do not move freely.

Corrective Action: Adjust the machine controller to balance the loop gains of the axis servos. Either turn up the gain of the axis which is lagging, or turn down the gain of the axis which is leading.

Squareness and Servo Mismatch Error

In run two, both errors cancel each other and the resulting plot in Run 2 may look OK.

Probable Causes: Refer to the Squareness Error and Servo Mismatch error descriptions.

Corrective Action: Refer to the Squareness Error and Servo Mismatch error descriptions.
Scaling Mismatch

To calculate the scaling mismatch, the plot subtracts the X-Axis diameter from the Y-Axis diameter.

The temperature of the machine effects scaling mismatch plots.

Probable Causes:

- A ballscrew that is damaged or too hot causes a pitch error.
- The axis linear guides are not straight.
- The ballbar is not calibrated correctly.

Note: To identify the actual cause, it is a good idea to do another plot.

Corrective Actions:

- Adjust the axis Lead Compensation parameter.
- Do the test with the tester elevated above the table. If the mismatch gets worse, then the error is caused by pitch.
- Do the test at a different location on the table, if the mismatch gets worse, then the error is caused by yaw.

Squareness and Scaling Mismatch

Note the angle of the oval shape, the axis of the shape is not at the 45°. The scaling mismatch causes the angle to lean towards the longer axis.

Probable Causes: Refer to the Scaling Mismatch error descriptions.

Corrective Action: Refer to the Scaling Mismatch error descriptions.
The plot has three distinct lobes in its general shape. These lobes may change size and orientation between adjacent clockwise and counter-clockwise runs. A tri-lobe plot has sharp transitions between lobes; a straightness error plot has more gradual transitions.

This is a test error.

**Probable Causes:**

- The hardware is loose.
- The ball may be moving on the holding cup.

**Corrective Action:** Inspect the ballbar hardware and do the test again.
The plot has three distinct lobes in its general shape. These are not affected by feedrate or direction but may change with the location at which the test is performed on the machine bed. A straightness type plot can be distinguished from a Tri-lobe test error type plot by its smoother transitions between lobes and better repeatability.

**Probable Causes:**

- The number one cause for straightness error is roll.
- The linear guides are bent.
- Overall linear guide misalignment.
- A foundation that is not stable causes the machine to distort.

**Corrective Actions:**

- Check for loose ballbar hardware and do the test again, if the error does not repeat it is not a straightness error.
- Inspect the machine's linear guides.
- Use a granite standard to determine which axis has the error.
X-Axis Straightness on Y-Axis Error

The plot has three distinct lobes in its general shape. These are not affected by feedrate or direction but may change with the location at which the test is performed on the machine bed. A straightness type plot can be distinguished from a Tri-lobe test error type plot by its smoother transitions between lobes and better repeatability. The number one cause for straightness error is roll.

Probable Causes:

- The linear guides are bent.
- Overall linear guide misalignment.
- A foundation that is not stable causes the machine to distort.

Corrective Actions:

- Check for loose ballbar hardware and do the test again, if the error does not repeat it is not a straightness error.
- Inspect the machine's linear guides.
Straightness Error

The plot has three distinct lobes in its general shape. These are not affected by feedrate or direction but may change with the location at which the test is performed on the machine bed. A straightness type plot can be distinguished from a Tri-lobe test error type plot by its smoother transitions between lobes and better repeatability. The number one cause for straightness error is roll.

Probable Causes:

- The linear guides are bent.
- Overall linear guide misalignment.
- A foundation that is not stable causes the machine to distort.

Corrective Actions:

- Check for loose ballbar hardware and do the test again, if the error does not repeat it is not a straightness error.
- Inspect the machine's linear guides.
Cyclic Error on X Axis

Cycles are more pronounced as the faulty axis approaches the reversal point. They will appear smaller at the point where the faulty axis moves at maximum speed and the frequency does not change. Measure the cycles and determine the pitch for each component in the drive system.

Probable Causes:

- The ballscrew is off-center.
- The ballscrew is damaged.
- The motor mount is defective.
- The coupler is damaged.
- The bearing pack is damaged.

Corrective Actions:

- Adjust the off-center ballscrew in the faulty axis.
- Adjust or replace the faulty motor mounts.
- Replace the faulty coupler.
- Replace the bearing pack.
Cyclic Error on Y Axis

Cycles are more pronounced as the faulty axis approaches the reversal point. They will appear smaller at the point where the faulty axis moves at maximum speed and the frequency does not change. Measure the cycles and determine the pitch for each component in the drive system.

Probable Causes:

- The ballscrew is off-center.
- The ballscrew is damaged.
- The motor mount is defective.
- The coupler is damaged.
- The bearing pack is damaged.

Corrective Actions:

- Adjust the off-center ballscrew in the damaged axis.
- Adjust or replace the damaged or defective motor mounts.
- Replace the damaged coupler.
- Replace the bearing pack.

Offset Change

The center of each plot is at a different location.

Probable Causes:

- There is a tester error.
- The ballbar hardware is loose.

Corrective Action: Inspect the ballbar hardware and do the test again.
Different Diameter Plots

The center for each plot is at the same location, but the diameter of the plots are different.

Probable Causes:

- There is a tester error.
- The ballbar hardware is loose.

Corrective Action: Inspect the ball bar hardware and do the test again.

Stick Slip on Y-Axis

This error will appear on the 90° of the axis that has it as it travels at low federate.

Friction forces are greater as the axis slows down.

Probable Causes:

- The quantity of lubrication is not sufficient.
- The linear guides do not move freely.

Corrective Action: Inspect and repair the components that cause friction.
Odd Shapes

Worn, damaged, loose or chip-covered ballbar components cause distorted plots.

The wrong feedrate causes a plot that does not meet at the beginning and the end.

In most cases, a false reading is obvious. Be aware, however, that dirty equipment or a component that has worn down to the point where it is just marginal, produces plots that appear to be normal but are actually out of round or flat-sided.
Other Plots from Tested Machines
Other examples of distorted plots from machines with bad ballbar or other components are shown below:
<table>
<thead>
<tr>
<th>PLOT</th>
<th>CAUSE</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Graph 1" /></td>
<td><strong>Cause:</strong> The servo amplifier is bad.</td>
</tr>
<tr>
<td><img src="image" alt="Graph 2" /></td>
<td><strong>Cause:</strong> The X-Axis motor housing is bad.</td>
</tr>
</tbody>
</table>
Cause: The Y-Axis servo motor is bad.

There is noise on the top and the bottom of the plot at or near the transition point.

Cause: The motor or the amplifier is bad.

Corrective Action: Change the Low Pass Filter Setting to ON to verify that the problem is electrical.
**Cause:** The Y-Axis ballscrew is tight near the motor.

**Corrective Action:** Realign the Y-Axis ballscrew.

**Cause:** The X-Axis Servo Motor is bad.
Cause: Backlash errors in Y axis. There is drag in the way covers and the linear guides are misaligned.

Cause: There is an electrical problem with the ballbar equipment. The ballbar equipment is not correctly grounded or there is a bad connection.
Cause: There is excessive friction on the way covers [1]. There is backlash in the linear guides in both X and Y axes [2].

Corrective Action: Change the Y-axis bearing pack.

Cause: There is backlash in the Y-axis bearing pack.

Corrective Action: Change the Y-axis bearing pack.
Cause: The pre-load is not adjusted correctly. The nut on end of ballscrew is not tight.

Cause: There is a loose ballbar component. The coupler nut is loose.