Save by Calibrating Your Machine

By Charles Wang, Ph.D, courtesy Optodyne

There are two major reasons to calibrate machine tools and they both have to do with cost reduction. First, parts will be more accurate, so there is less time spent getting to the first part and less scrap. Second, regular scheduled calibration will enable problems with the machine tool to be detected early and allow for maintenance without interrupting a critical production run. If your machine tool cuts the part accurately on the first try, you've reduced production time and scrap, both of which are costly. And the downtime costs of a machine tool, especially when it's in the middle of rush job for your best customer, can cost a lot more than the rush job.

Out of Tolerance Equipment

What happens when a machine tool is out of tolerance and hasn't been calibrated?

The following example begins when an offline-generated program, in this situation a CAM system, is downloaded to the machine's control through DNC. The axes are homed, zero point on the part is located, tool and zero offsets are set and the first part is cut. The customer for this part is in the medical industry and requires that the part meet specific tolerances, so it was checked on a CMM (coordinate measuring machine) to identify dimensional errors. The part was out of tolerance in two critical areas, sent to the scrap pile and the part program was adjusted. Another part was cut, inspected, found to be within tolerance and production was able to begin.

If the part was still out of tolerance, it would indicate an error in the program or repeatability is out of tolerance. The latter is an indication of excessive backlash attributed to wear in the transmission or ballscrew which had better be checked soon, to avoid additional damage to the machine, more scrap parts or the machine tool out of service during critical production runs.

Advantage of Regular Calibration

Regular calibration of the machine tool eliminates a high percentage of program adjustments and reduces the time it takes to get to the first production part. It becomes more important with machining of prototypes, short production runs or difficult-to-cut materials, such as titanium. Measuring the machine tool before there's a problem can determine geometric configuration, identify bad bearings, servos, slip-stick conditions and whether it's out of squareness, etc.

Numerous factors can cause a machine tool to make inaccurate parts. Many of these errors can be measured with laser systems; examples include linear displacement, repeatability, straightness, angular error, squareness and parallelism of the axis.

Online Inspection

Online-inspection is the name of the process that a machine tool performs by inspection with a spindle-mounted probe of a part that has just been machined. Online inspection has become more commonplace, because it saves time by immediately verifying the part dimensions. But if the machine tool isn't calibrated regularly and is out of tolerance, then the part will be out of tolerance and online inspection will be inaccurate.

Machine tool standards, such as the B5 standard, were partially developed to allow the machine tool to be used in place of a CMM to check parts. For a machine tool to qualify for offline inspection it must be thoroughly checked and evaluated for all the errors that can cause an error in measurement. Testing a machine tool completely requires a large number of tests as specified in the standard, but a large percentage of machine tool errors can be identified with more limited tests. For example, basic machine tool performance evaluation can be made with environmental, displacement accuracy, spindle and contouring accuracy tests.

Types of Errors Detected

Displacement accuracy tests can be performed with laser calibration systems. For example, linear displacement accuracy for each of the machine axes is measured through the center of the work zone. The displacement accuracy should also be measured along diagonal lines that go through the center of the machine's work zone. This allows the maintenance staff to see all the possible errors of a 3axis machine with one measurement.

There are six possible errors per linear axis, including positioning, pitch, yaw, vertical straightness, horizontal straightness and roll. Diagonal tests performed by the laser calibration system will reveal an error on any of the axes. For large aspect ratio machine tools, such as gantry machining centers, a step-wise diagonal measurement technique has been developed using the Laser Doppler Calibration System offered by Optodyne.

Today, many of the controls in practical use can correct errors; the most common is pitch error compensation. Originally it was designed to correct for imperfections in the ballscrew by using encoders mounted directly to the ballscrew or the feed motor itself. Often problems developed, because there was no way to compensate for phenomena such as thermal ballscrew growth. An encoder is unable to correct for thermal growth, which causes positioning errors. Depending on the machine, types of cycles, and the thermal expansion coefficient of the ballscrew errors can be well over 100 microns.

To correct this problem, many machine tool builders have switched to glass scales. Laser Doppler scales have also been used to correct for this type of error, because they do not rely on the ballscrew for positioning accuracy of the machine tool. In fact, some machines have eliminated ballscrews. For example, high-velocity machining centers typically use linear motors to drive axes. With these machines, pitch error corrects for abbe errors, which are the angular positioning errors of the machine, multiplied by the offset of the machine-measuring device and the device used to check the machine.

Typically, the glass scale is mounted on one side of the machine tool, the scale for the X-axis of a machine is normally mounted on either the front or back of the machine. The laser head is placed in the center of the work zone for calibration, so if there is angular error, a positioning error results.

Other errors can also be compensated for in much the same way that CMM machines are mapped to reduce errors, provided that the machine tool's repeatability is within tolerance. For example, control manufacturers allow machine builders to correct for pitch or yaw errors. A machine axis is checked, then angular error, either in arc-second or microradians is loaded into the machine, the machine control now compensates for linear positioning error. The same is true for geometric errors such as squareness. Squareness compensation or comping one axis as a function of another. For example, the control moves a second axis when one axis is commanded to move. If there is a problem with the X Z squareness, on a vertical machine, the technician can comp the Z-axis as a function of the Xaxis. If the machine tool is commanded to move up in Z, the control will move the X-axis incrementally as the Zaxis moves.

Calibration Reduces Maintenance

Laser calibration systems also can be used as a maintenance tool to reduce machine tool downtime and assure quality. ISO 9000 has accelerated the trend toward predictive maintenance (PDM) programs to assure maximum performance and quality. The PDM program includes monitoring machine tools and collecting data with a variety of instruments. A historic comparison of the data is used to predict when a machine tool will require service and the scope of services that will be necessary.

Although PDM programs are designed to reduce machine tool downtime, when a machine tool is taken out of service for diagnostics, they also can cause downtime. A new trend in PDM programs integrates a quick check of machine tools with laser calibration. The technique is called a quick check because the new generation of laser calibration equipment can be mounted directly on the machine tool, so it doesn't have to be partially dismantled or covers removed. A quick check tests the machine tool's volumetric accuracy by making diagonal measurements with the laser. The quick check allows repairs and other maintenance to sustain machine tool performance and quality to be scheduled during time periods that least interfere with production.

Laser Doppler Calibration System

The Laser Doppler Calibration system utilizes a Laser Doppler Displacement Meter for machine tool calibration. The LDDM uses electro-optics, optical heterodyne techniques and phase-demodulators to obtain the position information of a movable corner-cube. This technology is based on 1950s' microwave radar technology and 1970s' laser technology. Polarization and stray light are non-issues, precision and special optics are not required. Windows can be inserted in the beam path and simple mirrors can be used to reflect the laser beam to any angle. The Laser Doppler Calibration System can be mounted on the machine tool to provide greater accuracy.

The differences between the Laser Doppler Calibration System and the laser interferometer calibration system are basic. The doppler system requires only two optics, a laser head and a retroreflector, while a laser interferometer system requires three optics, one of which, the laser head must be mounted on a tripod outside of the machine tool. So the laser doppler calibration system with only two optics to setup and align is much faster. Also, the Windows-based software supplied with the Doppler system supports automatic data collection, which cuts measurement time by up to 50 percent and reduces operator error.

Tips for Buying Calibration Instruments

Purchasing machine tool calibration equipment is much like purchasing other capital equipment, it needs to operate quickly and efficiently with a minimum of training and setup time. Following are a few tips to keep in mind when shopping for a laser calibration system:

1. Make sure the system performs all of the measurements required to calibrate all of your machine tools. Make a list of all your machine tools before shopping.

2. Define the accuracy or tolerance that the machine tools are required to maintain and make sure calibration instruments meet them.

3. Watch a demo on the most complex and the easiest-to-calibrate machine tools before a commitment is made.

4. Make sure that the equipment is easy to learn and that training is not too complex.

Machine tool calibration is a tool that saves costs in a variety of ways. By keeping the machine tool within tolerance, the number of scrap parts can be reduced, so when it cuts a part, the part is dimensionally accurate. Through PDM programs, maintenance and repairs can be scheduled during non-critical time periods. Also, calibration facilitates online inspection, which is another way of reducing production and inspection time. And with the new generation of laser calibration systems, it costs a lot less to own a system.