PROCESS CONTROL GAGING

Most often, this column addresses gaging as an element of the QA inspection process that occurs after a part is machined. This may be performed on the basis of SPC sampling, or 100-percent automated gaging. However, other approaches to dimensional gaging can serve other functions. Machine tool evaluation, for example, involves gaging the machine, to determine its potential for producing accurate parts. And in addition to mere inspection, post-process gaging can be used to maintain control over the process, either by manually compensating for observed drift, or through automatic feedback loops. Gaging can also occur in-process, to control the machine in "real time."

Process control gages actively participate in machine control, whether on a post-process, in-process, or even a pre-process basis. Process control gaging is typically used when variables exist that may affect the stability of the process and cause frequent out-of-tolerance conditions. Such variables can include: tool wear; growth or deformation of the machine tool or workpiece from internal "environmental" sources such as heat or vibration; and external environmental influences such as vibration from nearby machines. Process control gaging can help achieve tight tolerances in spite of such variables, and thus eliminate the need for intensive operator intervention, help improve productivity, and reduce scrap.

Where process drift tends to be gradual, post-process control gaging is often a practical approach. Under this regime, parts are fed directly from the machine tool into the gage. When the gage measures deviation away from the nominal specification and toward the upper or lower tolerance limit, it generates a feedback message, signalling the machine tool's NC controller to apply compensation, so that each successive part is brought closer to nominal.

Post-process control gaging may not provide sufficiently rapid response to some process variables. With grinding in particular, the tool may wear substantially during the production of a single part. Or a process may be inherently unstable, and thus unpredictable. In such cases, in-process gaging may be the best approach.

During in-process gaging, part size is monitored constantly to provide continuous, real-time control over the machine. Gaging is typically performed by electronic gage heads, which may be placed in direct contact with the workpiece, or may act against a moving part of the machine's drive mechanism that has a direct relation to part size—for example, the ram on a centerless grinder. The gage and machine controller can be programmed so that the machine initially runs at a rapid feed rate, then slows down to creep feed when most of the grind stock has been removed, and stops when the nominal dimension is reached.

In some instances, process variables resist even in-process control—for example if the part is subject to significant, unpredictable thermal expansion. Pre-process control gaging may be the answer in such cases. The part is gaged prior to machining, and the gage instructs the machine on how much material to remove before grinding begins.

The electronic gage heads used in process control applications are rugged, well shielded against contamination, and designed to work with coolant and chips flying all around. Even so, gage heads do become worn and damaged. Most process control gages therefore rely upon standard gaging components which are readily and economically replaced.

Contact-type gage heads may leave slight wear marks on some parts, particularly those made from aluminum or other soft materials. If such marks are unacceptable, either on cosmetic or functional grounds, air gaging can be used for in-process control. Air leaves no marks, and it offers the same potential for microinch accuracy as electronic gage heads.

The other main element in the control gage is the amplifier/controller. (Air gaging interfaces with electronic amplifiers through air-to-electronic converter modules.) Modern systems offer higher resolution and accuracy, and faster response than earlier versions, permitting very rapid machining rates on high precision parts. Some new systems also offer convenience features such as automatic zeroing and offset (tool wear compensation) capabilities, switchable inch/metric digital displays, and a choice of comparative or absolute size measurements.

Process control gaging has advanced spectacularly since the days of "snap-on" mechanical grinding gages, when the machinist would adjust feeds and speeds in "real time" according to the movements of the needle on a dial indicator. Even compared to the amplifier systems of just a few years ago, the new grinding gages are faster, more accurate, and easier to use. If your system predates the '90s, it may be time to look into an upgrade. And if you're not using process control gaging at all, check it out: it may be just the answer to a troublesome production problem.

AUTOMATED GAGING

Every shop should have this gaging "problem." A Tier 2 automotive supplier was required by his OEM customer to perform 100 percent inspection on parts for dimensional tolerances and several other characteristics. The parts were aluminum forgings for air conditioning compressor pistons, and the inspection requirements included dimensional tolerances for bend and twist, and checks for fill at four positions, presence of two radii, and flash removal at two positions. The problem was the size of the contract: the supplier was obligated to deliver, and thus to inspect, nearly 100,000 parts per day.

Some gages lend themselves to faster throughput than others. Generally, the more specific the gage's purpose, the more quickly it can be operated. For example, fixed-size bore gages (i.e, plug gages) are quicker than adjustable (rocking) bore gages. If the task is more complex—for example, inspecting multiple diameters on a part such as a crankshaft— then a purpose-built fixture gage will allow faster throughput than a selection of snap gages, or the use of surface plate methods. But there comes a point when even the most narrowly focused, manually operated gage must give way to automation. It's either that, or hire a whole roomful of inspectors to keep up with production.

Automated gaging is usually cost-justified in applications where a part must be inspected every 45 seconds or less. This figure includes not just gage operation, but the entire gaging cycle. While the part measurement itself may take only three seconds, the complete cycle includes at minimum: placing the part in the gage; operating and reading the gage; and removing the part from the gage. Other required actions may include: recording the measurement; sorting parts into appropriate categories by size; and removing rejects from the lot.

Many additional variables influence the speed at which a part can be measured, and hence influence any gaging setup, whether manually operated or automatic. These include: the number of features to inspect; the need for a dimensional reading versus simply go/no-go results; how measurement data will be used (e.g., for export to SPC, or for direct process feedback); the level of accuracy required; and whether gaging occurs in-process or post-process.

With so many variables in play, it is hardly surprising that automatic gages can rarely, if ever, be bought "off the shelf." In the case of the Tier 2 supplier, we custom-engineered a fully automatic gage, capable of inspecting one part every 3.5 seconds (i.e., 1,030 parts per hour, or 24,720 parts per day). Four identical units were built and installed, providing total throughput of 98,880 parts per day.

Reliable parts handling was obviously one of the most important engineering considerations. Accordingly, the gage was designed to make use of the most reliable parts-handling mechanism ever developed: gravity. Parts feed in at the top of the machine, sliding down a 45° chute to a dead stop, where a proximity switch senses the part and triggers a locking mechanism. An air-driven cylinder then raises the holding fixture, and a nest of electronic gage heads descends until it contacts the part. The gaging device traverses the part, checking for true position, material fill, flash, and the presence of radii. Bend and twist are checked as independent features by comparing position and diameter measurements at opposite ends of the piston.

When the inspection is complete, the holding fixture descends and the part is released to drop down the exit chute. Out-of-spec readings trigger an escapement, which diverts bad parts into a reject bin, while good parts pass straight through to the next production process.

Gage head signal conditioning, data processing, and data storage are controlled by a gaging computer, from which measurements are downloaded daily. Programmable logic controllers (PLCs) control all of the gage's logic functions. The systems have proven to be extremely reliable, operating around the clock for months between downtime for preventive maintenance.

To equal the throughput of the automated gage, the Tier 2 supplier would have to keep 13 human operators working around the clock, at a minimum throughput of one part every 45 seconds per person. Even at minimum wage, and assuming no coffee breaks or sick days, it wouldn't take long before those human operators, each with a manually operated gage and a master, started to look pretty expensive.

Few machine shops face throughput requirements even close to this, but any shop involved in a large production run can usually benefit from some form of specialized gaging, to make inspection easier and faster. And for larger shops where throughput requirements are very high, and the production run will last for a year or more, customized, automated gaging may be the only practical approach to inspection.

MACHINE COMPENSATION

Ever since electronics first made their way onto machine tools, machine builders and users have been seeking ways to integrate gaging results, to achieve some level of "automatic" process control. Certain causes of dimensional variation in machined parts --tool wear, for instance-- occur gradually. Measuring parts for variation provides a means to efficiently adjust the machine's position settings, to "compensate" for tool wear and other changes.

In the first use of electronics for compensation, parts were gaged by hand, then the operator would press a button on a stepper control attached to the machine tool. One button moved the machine a fixed amount in one direction, while another moved it the same amount in the opposite direction.

The next generation, which integrated electronic gages, took the concept further with automatic feedback control. When the gage sensed that a part had reached or exceeded an approach tolerance, it would send a signal to the machine's controller to compensate. Again, the compensation was a fixed amount each time, and this was known as incremental compensation.

As microprocessors and computers were incorporated into both gaging and machine tools, the simplicity of incremental compensation was replaced by the sophistication of absolute compensation, in which the machine's position is adjusted by the exact amount that is optimum for the process. If desired, compensation can be triggered when part dimensions are drifting just a little bit off nominal, rather than waiting for them to approach tolerance limits.

Computers or microprocessors run algorithms that determine the present level of the process, and look for trends, steps, or other statistical features. While there are a number of different statistical schemes, all use size data from a number of consecutively machined workpieces to establish the current level of the process. A popular, basic scheme is to simply take the average size of the most recent parts. Averaging a large number of parts tends to minimize the influence of normal part-to-part variation, and reduces the number of compensations performed. Small sample lots, on the other hand, allow the machine to respond faster to process changes. Other algorithms, which may be based on any known method of statistical process control, can be far more sophisticated.

There are two basic hardware options for modern, automated machine tool compensation. Microprocessor-based CNC/gage interfaces accept input from a variety of electronic gages and gaging amplifiers, and communicate with the CNC via RS232. These are usually panel-mount devices that are pre-programmed to perform a wide range of standard gaging/control actions, with integral keypads that allow users to set approach and tolerance limits, select algorithms, define actions, and so on. The second option is a gaging computer, which offers higher-level capabilities to store or modify algorithms, analyze and utilize data simultaneously from a larger number of inputs, program more complex actions, and store and communicate data. They can be readily interfaced with most modern CNCs and other production equipment.

For example, a large agricultural equipment manufacturer uses a gaging computer to maintain control over gear blank production in fully automated workcells. A robot loads a part into an NC lathe, then removes the half-turned part, turns it around, and loads it into another lathe, which turns the other half. The robot then places the part on an automated gage which measures several ID and OD dimensions. After gaging, the robot stacks the parts on pallets.

All gage functions are controlled by the gaging computer, which allows the manufacturer to switch instantly between eight different part numbers. The computer compensates the lathes based on the average deviation from the three most recent parts, and shuts down the cell instantly should any dimension fall out of tolerance. The computer also accepts data from temperature sensors in the gage, and performs additional machine compensation for thermal influences.

The use of gages for automatic machine compensation can improve overall quality and productivity, reduce scrap, and minimize manpower requirements. It should be seriously considered for all long-running automated or semi-automated applications where dimensions must be maintained within close tolerances.

SEMI-AUTOMATICS — THE IN-BETWEEN GAGES

The faucet has been opened a little and you've just received a long-awaited contract to produce 10,000 large trunnion caps for a manufacturer of earth moving equipment. Despite the joy, you realize you have a problem. The machines will be in place and ready to run the part shortly, but you haven't given much thought to the gaging.

Manual gaging is not going to cut it because it is too slow. Operator-introduced variation may be too large for the tolerance, and there are too many parts to inspect over a relatively short period. On the other hand, the size of the job just won't justify the expense of a fully automatic gage.

There is something in between that can solve the problem: a semi-automatic gage—one that makes multiple checks, classifies the part, and can mark or stamp it for identification.

These are frequently, manually loaded/unloaded, but can also incorporate a disposal system.

In certain applications, these features offer the user a number of distinct advantages. Since part of the gaging cycle is automatic, semi-automatic gages are much faster than completely manual, individual gages. And, when manually loaded, they can handle workpieces that may be difficult and costly to feed or orient manually. Manual loading of the part also permits visual inspection for scratches, discoloration and unclean finishes prior to the gaging process.

Semi-automatic gages will check a relatively large volume of parts quickly and accurately, enabling the inspector to keep up with production by taking over the gaging function. Many manually loaded gages can be operated at speeds close to one part per second. Disposal is automatic, eliminating operator interpretation or sorting errors. Most semi-automatic gages are controlled by a small gaging computer that takes over the complete gaging function—positioning gage heads, moving the part, collecting data, marking the part, and disposing of it in the correct class. Operator fatigue and misclassification can be a big problem when handling many parts. Since the semi-automatic gage is tireless and consistent in its decision-making, many of the operator-influenced problems go away.

Today there are many choices in semi-automatic gages, and design time is not as long as is sometimes perceived. A semi-automatic, built with off-the-shelf gaging components and supplemented with motion control and gaging computers, can be designed quickly and delivered ready to meet its gaging challenge.

Now if we could only get it to put the parts in boxes and deliver them to ……