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Precision Measurement Solutions for Manufacturers

**Improve your machines and manufacturing processes:
*Increase your profits!***

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Introduction

We live in a global economy with competition from all parts of the world. The toughest competition comes from the low cost provider with the flexibility to win work with lower prices and generate higher profits with better margins. Are you a low cost provider? Low cost providers also beat the competition with shorter lead times and higher quality standards. How do they do it? They reduce or eliminate the non value-added activities that consume time and resources creating waste and inefficiency, and they reduce variation in their manufacturing processes that results in repair, rework, and lost profits. You can do it too!

Two general categories of actions characterize the steps necessary to achieve low cost provider status. Likewise, two methodologies answer the question how. Reducing and eliminating waste and variation, the enemies of productivity and profit, are the required actions. How do you do it? Implement Prevention-based Manufacturing practices and begin Predictive Maintenance programs on your machines.

Reducing Waste

Given a comparable product, your customers care about two things: lead-time and price. Eliminating waste gives you an advantage in both, and provides an opportunity for greater profits. There are three primary ways to eliminate waste: (1) automate non value-added tasks such as tool setting and work-piece set-up; (2) inspect parts while they are being machined so you can accept them directly off the machine; and (3) Establish machine performance capabilities before you begin making parts.

If you automate machine set-up and machining processes, reduce your inspection costs, and create the ability to accept parts right off your machines, you will increase shop throughput, reduce machine downtime, create shorter lead times, improve the dependability of your production schedules, and reduce or eliminate scrap and rework. This means higher productivity and more profits!

Time-consuming Set-up Activities on CNC Machines	
<ul style="list-style-type: none">• Measuring tools and updating offsets• Mounting and indicating parts and fixtures• Identifying and updating machine work offsets• Cutting a second part	<ul style="list-style-type: none">• Adjusting rough and finish tools to specification• Inspecting first-off parts to verify set-up Adjusting work offsets• Repeating inspection of altered process parameters

Table 1

Attacking cycle time is a very effective way to eliminates waste and increase profits. Cycle time includes set-up time, parts movement time, all waiting time (e.g., waiting for a machine, operator attention, or inspection), inspection time, and rework time. It is well understood that the greatest profits are generated when you create good parts at lower costs. However, it is not as widely understood what affect reduced cycle time has on costs. Studying the effects of machine tool probing systems helps. When you realize you could save days of wasted time and resources by reducing set-up times and eliminating machine downtime through automated process feedback directly on the machine, it starts to

become clearer. Machine tool probing systems attack cycle time by eliminating the non value-added activities that add costs to your machining processes, activities that unnecessarily devour time and resources.

$$\text{Cycle time} = \frac{\sum (\text{Set-up time} + \text{machining time} + \text{certification time})}{\text{Number of good parts produced}}$$

According to Renishaw, in a traditional manufacturing environment, 5 out of 10 vertical machining centers are in a waiting state at any one time, and 3 out of 7 horizontal machining centers are waiting.¹ You are only adding value when you are machining a part to specification. Waiting is a waste of manufacturing resources, and the numbers presented by Renishaw indicate it is a huge waste. By minimizing the non value-added activities (e.g., inspection, set-up, adjustments, waiting time, parts movement, etc. plus the time spent machining bad parts, performing rework, responding to tool breakage, etc.) you are maximizing productivity and profits.

Reducing Variation

Controlling and reducing variation in your manufacturing processes also reduces waste, thereby improving productivity and profits. Variation is inherent in your process inputs. People, machines, measurement, materials, methods, and environment supply variation and affect productivity and profit.

People introduced variation can be found in three primary areas: (1) operators, (2) setup, and (3) maintenance. Operators introduce variation with manual measurement, manual calculations, application offsets (the number one source of crashes, rework, scrap, and broken tools)² and the manual application of offsets to correct for machine geometry. While your set-up people can run their own jobs, have fewer quality problems, and are more productive, they (conversely) are paid more money, the shop stops when they aren't available, and when they can't keep up you end up with bottlenecks. As they help less experienced operators, they ramp down on one problem and ramp up on the next, so two machines and two operators sit idle. When a problem is encountered that your setters can't fix they call maintenance. What needs to be done to solve the problem? Different people have different ideas, and while they decide or try various solutions, the machine isn't producing parts. Throughout, your production processes, different people give you different results and it is likely affecting your profits in a negative manner.

Prevention-based Manufacturing

Prevention-based manufacturing reduces life cycle costs by shifting and transforming repetitive non value-added expenditures to one-time costs in the production design phase. Prevention-based manufacturing methods can reduce or eliminate non value-added activities that devour resources in the later phases of the production or product life cycle by nearly 45 percent.³ Probing systems enable the implementation of value-added prevention-based processes. They are value-added because they contribute to the *making* of good parts. Inspection is an example of a non value-added activity, either because it produces machine idle time or (if the machine is allowed to continue) allows the production of potential scrap. Using machine tool probe systems to implement prevention-based manufacturing can

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eliminate or reduce this type of non value-added activity by shifting efforts to value-added one-time programming costs that enable automated parts setting, tool setting, and critical features control. The result: machines create more good parts per shift with increased productivity and profits because of reduced downtime, waste, and manual intervention.

Probing systems enable automated tool setting with work-piece set-up that is faster and more repeatable than manual methods; eliminating human error, preventing defects, and eliminating manual cut and measure. Tools are set while rotating, eliminating errors that are caused by run-out and insert height variations. You will no longer need to update offsets manually as the probing software updates tool and work offsets automatically, eliminating human error and reducing tool and part damage. Probing solutions eliminate manual alignment of complex fixtures, as the probe finds the part and its orientation in seconds, eliminating the manual clocking of fixtures and allowing you to machine parts right the first time. Eliminate offline pre-setters by setting tools in place at normal cutting speeds for greater accuracy.

Accepting parts off machines is a growing trend. Imagine the possibilities if 100% of your parts were good the first time. When production and automated on-machine inspection processes allow you to accept parts off the machine you have less parts handling and delay, shorter manufacturing lead times, and less work-in-process. There is no waiting for inspection if you establish machine performance before you start machining parts. You can measure critical features on the machine before you perform finishing cuts, and you can correlate measurements between the machine tool and your CMM (your traceable measurement standard). Eliminate operator intervention as you automatically measure and document your parts, and automatically feedback process parameters (offset changes) to ensure your parts continue to meet specifications.

You can attack and eliminate variation with probing solutions that provide repeatable and automatic feedback of your process parameters; monitor your tools and control part dimensions in cycle; and monitor machine performance and accurately diagnose errors. Probing is faster than manual measurement, and it adds precision and repeatability to the process. Automate the measurement of your parts to eliminate manual calculation and keystroke errors. Probing systems allow your programs to check for broken tools before they create scrap, update offsets to adjust for process drift because of tool wear or thermal effects, provide valuable information to your statistical process control programs, and they reduce the need for operator intervention once a batch is running.

Predictive Maintenance

So how do you make good parts the first time and know your parts are correct so you can accept them off the machines? One key is to know your machines are capable of producing parts to specification before you start machining. Secondly, you need to prove to your customers that your machines have the capability to meet standards such as ASME B5.54, B5.57, ISO 230, etc., by implementing process control to traceable standards and certifying the capability of your machines. Establishing machine performance capabilities allows you to characterize machine tool accuracy; pick the right machine for the right job based on part tolerance requirements; and identify deteriorating machine performance before it begins to affect quality.

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Predictive maintenance programs allow you to zoom-in on exactly what is wrong with your machine. You can machine in confidence, eliminate guesswork, and plan your maintenance with reliable information. Good information allows you to remove geometry errors at the source and avoid compensating for their effects; spot declines in the condition of your machines before they affect quality; and eliminate guesswork by identifying the source of your errors. Ballbar checks quickly tell you what is wrong with your machine, while alignment and calibration laser systems align and calibrate your machines to OEM specifications and international standards. Understanding the capabilities of your machines allows you to assign the right machine to the right job, avoiding scrap and rework.

The sources of geometric error in your machine tools include the linear accuracy and repeatability of an axis; the angular pitch and yaw of an axis; the straightness of an axis; the squareness between axes; rotary axis angular position; and machine dynamic characteristics. While most machines allow linear and rotary axis errors to be compensated in the CNC, other errors need to be eliminated or minimized at the source with proper alignment and calibration. Proper diagnosis, alignment, and calibration with laser alignment, laser calibration, and ballbar systems allows you to quickly and accurately baseline and certify the resolution, repeatability, and accuracy of your machines.

There are six steps (see Table 2) required to improve the capability of your machines.

Six Steps for Improved Machine Capability	
1. Determine the accuracy you need	4. Eliminate or calibrate the errors
2. Establish a baseline	5. Establish a new baseline
3. Identify and rank the sources of error	6. Monitor the health of your machine

Table 2

Your specifications, drawings, and blueprints determine the machine accuracy that is required. To perform steps 2 through 6 you will need a ballbar (as called for in ASME and ISO standards). You will also need laser and other electronic calibration systems or services such as those offered by Morley.

Partial List of Metrology Equipment Utilized by Morley	
- Faro [®] Laser Tracker XI	- Renishaw [®] RX 10 Rotary Calibrator
- Hamar L-743 Ultra-Precision Triple Scan [®] Laser	- Talyvel 4 Electronic Level
- Renishaw [®] XL 80 Laser Interferometer	- AA Davies Ultradex Rotary Index Table
- Renishaw [®] QC20 Wireless Ballbar	- Davidson Autocollimator

Table 3

The ballbar is used to establish the baseline of the machine. The machine is directed to moves in a circular path and the ballbar detects minor deviations and presents the positioning errors in a graphical and data format. Depending on the results, you may need to level, adjust, or repair the machine. If the machine is capable of producing parts to specification, you can start cutting parts. The Renishaw[®] ballbar software is an excellent tool for diagnosing machine tool errors, enabling the inspection of 20 machine parameters. Once errors have been identified, you can rank them and begin eliminating the most severe. Table 4 shows the corrective action for several errors.

Error Type	Compensate with ballbar	Compensate with laser	Repair
Servo mismatch	X		
Reversal Spikes	X		
Backlash	X	X	
Cyclic Error		X	X
Scale		X	
Straightness			X
Squareness			X
Lateral play			X

Table 4

A laser interferometer that meets international standards can be used to calibrate out significant error sources, and (assuming other factors are acceptable) laser compensation will remove positioning error, providing a renewed machine with accurate and repeatable capabilities. With errors corrected, a new ballbar test will establish a new baseline. After the new baseline is established, monitor the machine to identify any new errors that develop and show a deviation from the baseline. Keep track of the results on each parameter, and plot them on a graph to spot trends and determine when maintenance is required.

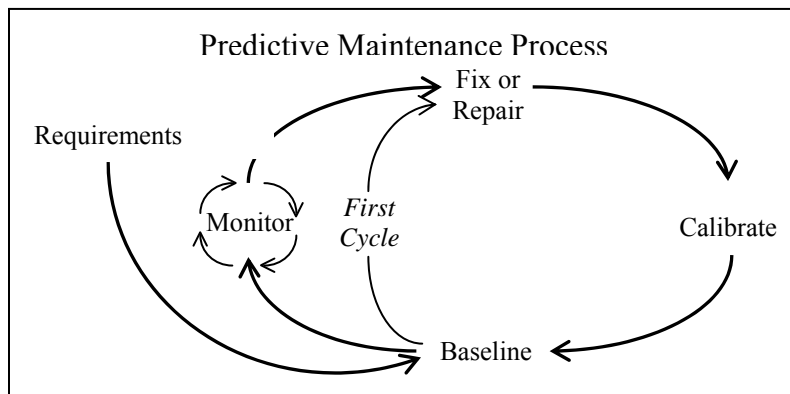


Figure 1

Applied in a systematic manner, the six steps listed in Table 2 provide a predictive maintenance process (see Figure 1 above) that (1) maintains and improves the capabilities of your machine, (2) eliminates judgment calls on which machine to use, (3) eliminates bottlenecks, (4) transforms operational expenditures into investments in your processes, (5) increases machine up-time, (6) eliminates unnecessary movement of parts, and (7) provides traceable documentation of your machine and process capabilities

Proving your parts are correct

While probing solutions have the ability to prove a part is correct, that isn't why you would implement probes on your machines. You already have processes and procedures that prove the parts are correct. The reason for a probing solution is to reduce cycle time. By reducing set-up time, reducing certification time (including waiting and move time), and reducing scrap with automated in-cycle feedback, cycle time is reduced, money is saved, and profits are increased.

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Still, you may be asking yourself how machines can be trusted to measure their own work. The answer is inspecting parts to a traceable standard (knowing the measurement uncertainty of your machines), and providing certified documentation demonstrating control of the process. By using probes and tool setting systems to monitor and control the machining processes and by introducing traceability through artifact comparison and baselines, you can derive the volumetric measuring performance of your machines, thereby meeting the B5 standards.

Now that you have implemented your predictive maintenance process, and your machines are stable, introduce in-cycle process control to compensate for short-term variations, and accept the parts off the machine. Because CMM and machine tool structures are very similar (both are calibrated to national and international standards), and even though a machine tool is subject to additional sources of error, it can still measure its own parts. Establish an on-machine measurement process with a known and low level of uncertainty (e.g., in-cycle probing for traceable process control).

Thermal growth and distortion (transient and changing) is an example of a machine tool error that would prevent traceability if not corrected. Because machines are generally not in temperature-controlled environments, ambient temperature affects the machine and the part, and temperature differences can cause distortion in both the parts and the machine. Machine tools also generate heat, (e.g., the spindle motor heat can affect the Z-axis, and axis drive motors and friction in bearings can affect ball screw length. Some machine geometric errors (consistent and/or underlying) may be compensated for in the CNC, but others remain (squareness, straightness, angular).

Summary

Becoming a low cost provider increases opportunities and profits. Eliminating waste and variation in your manufacturing processes is the key. Prevention-based manufacturing practices and predictive maintenance programs give you the ability to significantly reduce cycle time and variation; and open the door to the reality of accepting parts off your machines. Cycle time is reduced further as machines measure their own parts, reducing the workload on the CMM that traditionally provides the final say on the acceptance of parts. The result is a production environment with much lower costs and much higher profits.

¹ Renishaw, "Manufacturing Process Improvement", August 17, 2001, <[http://resources.renishaw.com/details/Manufacturing+process+improvement\(6328\)](http://resources.renishaw.com/details/Manufacturing+process+improvement(6328))> (May 7, 2010): 14

² Renishaw, 34

³ Renishaw, 16,22