Determinism In Manufacturing

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What is Determinism?

Simply stated, the deterministic philosophy predicts that machine tool errors obey cause-and-effect relationships, and do not vary randomly without reason.

Determinism contradicts the notion that non-repeatable machine tool or machining errors can be random.

The term "random" to describe non-repeatable errors implies that:

- the cause of the error cannot be determined
- nothing can be done about the causes of the variations
- the best one can do is try to statistically assess the range of variation.

At the error levels we are dealing with *"...we see statistics as, at best, a distraction and, at worst, a cloak of respectability for bad metrology."*

– R. R. Donaldson

Determinism allows us to divide machine tool errors into two categories:

Repeatable:	Those errors that recur as a machine goes through its motions.
Non-repeatable:	Those errors which are not directly related to machine motions, even though source and error follow a cause-effect relationship.

We find that non-repeatable errors often mask the inherent accuracy of even conventional machine tools.

Determinism gives the machine tool designer or user rational tools for optimizing the performance of his equipment:

- Stored error compensation
- Predictive error compensation (thermal errors)

- Post-process gaging with feedback
- Parametric testing for error source isolation
- Error budgeting
- Parametric machine specifications

An Example Of Applied Determinism: Dual Transducer Gage Error Budget

An error budget was formulated that took into account effects of systematic errors:

- weight-shift induced errors
- manufacturing/assembly errors

These were tempered by past experience.

Error budget for systematic errors before mapping:

	Y	Z	
Y Slide			
Guidebars	N/A	N/A	
Granite Straightness	N/A	27.00	]
Granite Parallelism	N/A	17.00	] Y-Slide
Weight Shift	N/A	14.00	] Z-Straightness
Z Slide			
X Straightness	N/A	N/A	
Y Straightness	42.00	N/A	] Z-Slide
Y Guidebar Parallelism	26.00	N/A	] Y-Straightness
Squareness of Z to Y Travel	20.00	20.00	
Squareness of C to Y Travel	20.00	20.00	
Total Machine Errors, μinches	**108.0**	**98.0**	

We will use error mapping to reduce systematic machine errors:

- Multiple measurements will reduce effects of random error components and isolate systematic error components.
- Limits to the accuracy to which systematic errors may be reduced will be dictated by errors in the mapping process.

Our approach to mapping machine errors is based on that used by nbs to calibrate LODTM

- Straightness, Spindle Squareness:
  reference straightedge, reversal technique
- Y-Z Axis Squareness:
  45 degree interferometer method

By using multiple measurements to reduce the effects of non-repeatable errors, we estimate that we can obtain a reduction of systematic errors comparable to the reduction obtained on LODTM.

Error budget for systematic errors with mapping:

	Before Mapping		After Mapping	
	Y	Z	Y	Z
Y Slide				
Guidebars	N/A	N/A		
Granite Straightness	N/A	27.00		
Granite Parallelism	N/A	17.00		
Weight Shift	N/A	14.00		4.00
Z Slide				
X Straightness	N/A	N/A		
Y Straightness	42.00	N/A		
Y Guidebar Parallelism	26.00	N/A	4.00	
Squareness of Z to Y Travel	20.00	20.00	6.00	6.00
Squareness of C to Y Travel	20.00	20.00	4.00	4.00
Total Machine Errors, µinches			**14.00**	**14.00**

We have analyzed the repeatability of the machine during the actual part measurement process.

Error Source	Magnitude, Pv µinches Y	Z
Position Interferometers		
Laser Vacuum Wavelength Stability	0.8	0.8
Opticalelectronic Factors	0.5	0.5

Thermal Effects On The Structure		
0.1 Deg. F Gradiant In Z Direction	6.9	4.1
Machine Repeatability	**8.2**	**5.4**

The absolute accuracy of the dual transducer gage will be dictated by:

Mastering Accuracy	14.0	14.0
Machine Repeatability	8.2	5.4
Total Accuracy	**22.2**	**19.4**

Maximum Error = $\sqrt{22.2^2 + 19.4^2} = 29.5\ \mu$inches PV

Deterministic Manufacturing

Determinism can also be applied to machining/manufacturing operations to:

- Enhance accuracy/productivity
- Reduce or eliminate final part inspection/certification

Deterministic manufacturing, real-time and near-real-time measurements are used to monitor the status of a process:

Dimensional measurements

- Tool-setting
- Selected features
- In-process
- Process-intermittant

Equipment monitoring

- Temperatures
- Following error
- Vibration, etc.

Process monitoring

- Tool wear, breakage
- Spindle torque
- Tool force

Measured variables can be compared against a process model to assess the condition of the process and/or predict its failure:

- Equipment failure
- Tool breakage, wear

Dimensional data can be used to maintain process accuracy:

- Tool wear
- Thermal drift

Implementation of a deterministic manufacturing system implies the need for:

- An automated process
- Data bases and models appropriate for the process
- Large enough production runs to provide economic justification

Artificial intelligence would be a useful tool for optimizing a deterministic manufacturing process.

Ultimately, as confidence is gained in the accuracy of a deterministic manufacturing system, final inspection could arguably be:

- Eliminated
- Reduced
- Replaced with spot sampling for process monitoring

Thus deterministic manufacturing offers us the opportunity to move from part certification to process certification.