How much Tolerance does your machine tool consume?

by Michael A. Mariani

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When there is no obvious cause, diagnosing machining problems is difficult and costly with so many interrelated factors impacting feature tolerances: tooling, fixtures, cutter path, temperature, measurement accuracy, machine precision, etc. The list of potential problem areas is long and knowing where to focus is often an effort in trial and error.

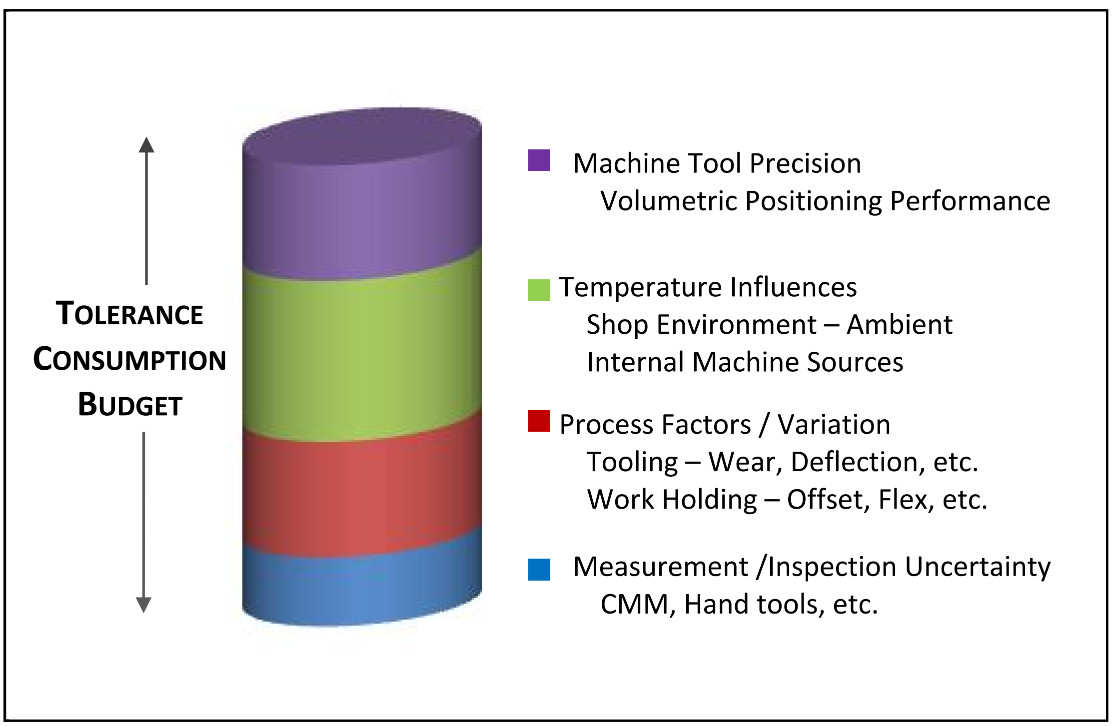
With so many deviation sources consuming tolerance, it's advantageous to group them into the following four major categories to define a "**Tolerance Consumption Budget**":

Machine Precision - How accurate the machine positions for this specific operation.

Thermal Influences - Ambient as well as Internal Machine Temperature changes during the operation.

Process Factors - Tooling Behavior (distortion during the cut, wear, etc.), Fixturing Effects (repeatability of location, flexure, part distortions, etc.), Cutter Path Errors (programmed path is not consistent with the desired surface), etc.

Measurement Uncertainties - Ensuring that your measuring device is at least four (4) times more accurate than the tolerance you are measuring.



Typical Tolerance Consumption Budget

The question is which one(s) can be improved to consume less tolerance? Experimentation is the most common way to answer this question.

So, place your bets on the consumption root cause and start spending resources.

If you think it's …

Measurement Uncertainty … Measure that part on the CMM and see if you get better results.

Tool Distortion … Use a stiffer tool and update the CNC program to use it for that "OP".

Machine Precision … Have maintenance laser compensate the machine.

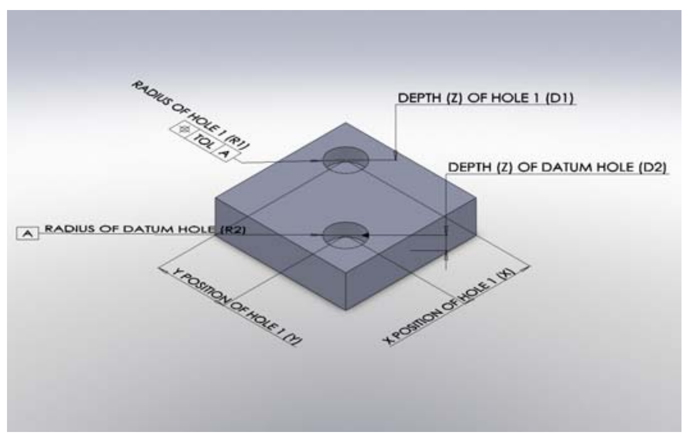
Thermal Influences … Monitor the shop temperature and see if there is significant variation.

No obvious source … Change the cutter path, and keep changing it to stay within tolerance.

Experimentation is expensive and all of the effort is "NON-VALUE ADDED".

There is a more efficient way to identify which factors to focus on based upon a deterministic approach. A simple framework exists for organizing each factor's potential tolerance consumption or "tolerance consumption budget" for a specific operation and machine.

Programs using this approach at national labs have proven to be very effective in improving machining processes and achieving high accuracy results. The success of these programs hinged on effort related to data gathering and analysis, which would far exceed practical industrial application.



True Position - Hole to Datum Hole

Reducing Non-Value Added effort is contingent upon rapidly identifying the root causes, i.e. the *key tolerance consumers* for an operation and only focusing on those that improve the process. Using a tolerance consumption budget focuses the diagnostic effort on the key tolerance consumers and identifies the largest consumers quickly.

Like triage, using a tolerance consumption budget helps to sort out those areas that are critical. In medicine, many tools and techniques have been developed to assess and sort patients; to identify those who can be helped and in which order. In triage, the objective is to focus on critical needs rapidly and not use limited resources where success is unlikely, only gathering enough information to determine where and when to apply resources.

In manufacturing, the same is true. There are many factors impacting the machining outcome. Focusing on those that are critical, in the right order saves both time and resources.

Rapidly estimating tolerance consumption can be a challenge given the sophistication of machining systems. Knowing enough to determine what is critical is the objective and understanding three of the four tolerance consumption categories ensures a good decision. Measurement Uncertainty and Thermal Influences can be estimated using gage calibration data and straight forward calculations using thermal expansion coefficients.

Separating tolerance consumption effects of process factors and machine precision presents more of a challenge. The sheer number of process elements can make estimating the tolerance consumption for each, anything but rapid. Machine positioning behavior is also complex considering multiple axes and structural configurations. Machine precision is typically defined by linear positioning of individual axes, which in practice has only a small impact on tolerance consumption for a specific operation.

Summing methods exist for estimating tolerance consumption of machine tools using deterministic methods. Until recently the issue has been the availability of modeling tools that make these methods easy to apply. IQL has developed and launched an easy to use web-based tool, www.locuscae.com, that provides tolerance consumption estimates in a matter of seconds.

Locus CAE is a tool that calculates tolerance consumption based upon details of the machining feature. The user selects the type of operation, i.e. size of a bore, width of a pocket, true position of a bore, etc., and inputs details of the feature and desired tolerance. Locus CAE then calculates the tolerance consumption for a given machine tool type (VMC, HMC), providing instant feedback regarding how much tolerance is being consumed by the machine tool alone.

True Position of Hole to Hole

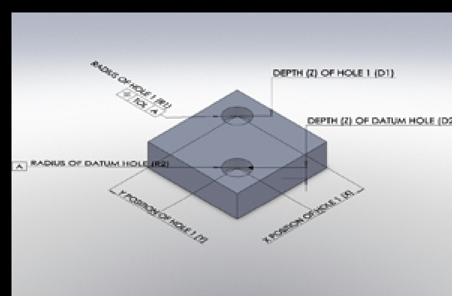
Analysis Results

Machine	Capability Index	Tolerance Consumed	PEN Analysis	
Haas VF2 Std	3.2	31 %	● (green)	Analyze
VMC YxyXxym_ZzxSt A	3.3	30 %	● (green)	Analyze
VMC YxyXxym_ZzxSt AA	6.9	15 %	● (green)	Analyze
VMC YxyXxym_ZzxSt B	1.9	54 %	● (red)	Analyze

Units Inch
Time 12/17/2010 1:38:46 PM

Comments

Back Done



Inputs

Input	Code	Value
Radius of Hole 1	R1	.5
Depth(Z) of Hole 1	D1	1
X Position of Hole 1	X	4
Y Position of Hole 1	Y	4
Radius of Hole 2	R2	.5
Depth(Z) of Hole 2	D2	1
Tolerance Bandwidth	Tol	.001
Tool Length	TLen	3
Tool Diameter	TDia	.5

Locus CAE Tolerance Consumption Results - True Position Hole to Datum Hole

Knowing the machine's consumption speeds the decision making process for corrective actions. If the machine is consuming less than 25% of the tolerance, the root cause is likely elsewhere. If it's consuming 50%, looking to minimize the effects of the other tolerance consumers is required. If it's consuming 80%, the machine could be optimized, the process could be shifted to a higher performance machine or perhaps a more appropriate process could be used (grinding, EDM, etc.).

In addition, knowing the machine tool's tolerance consumption prior to launching a part into production can help to identify issues before machining. This knowledge can help to shape the manufacturing strategy, identify new equipment or supplier needs as well as provide feedback into the design team to make the part easier to manufacture, given limited machining options.

Applying determinist tools like Locus CAE help to guide design and manufacturing strategy, and shorten machining diagnostics, which significantly reduces non-value added effort and shortens production cycle times.

Knowing how much tolerance the machine tool consumes can be invaluable!