Importance of Lifecycle Management

• US not producing high accuracy machine tools
  – our knowledge base is eroding
• Advancing machine complexity increases Cost and Schedule
• Push older machines to produce with as-new capability
• Capability maintenance is sacrificed to lower cost
Stages of Machine Tool Lifecycle

1. Vendor Selection
2. Installation and Run-off
3. Production Application
4. Rebuild or Retire

Modeling Tools improve management of the Machine Tool Lifecycle

Modeling and Management Tools

A. Process Error Budget Model consisting of:
   – Part Measurement Budget
   – Manufacturing Practices Budget
   – Environmental Thermal Budget
   – Internal Thermal Budget
   – Machine Error Budgets
Modeling and Management Tools

B. Error Control Tools, consisting of:
   - ISO Test Codes for Machine Tools
   - Data Acquisition and Analysis Systems

Modeling Tools Improve Vendor Selection

• By matching multiple Part Feature Tolerances with Machine Capability
• By establishing Standardized Capability requirements for vendor purchase agreement
Modeling Tools Improve Installation and Run-off

- Machine Capability is proven at vendor site
- Machine Capability is verified at customer site

Modeling Tools Improve Production Application

- Models identify Critical Process and Machine Parameters
- Focused plans can be developed to maintain Critical Parameters
- Maintenance of Critical Parameters leads to >20% improvement in machine availability.
Modeling Tools Improve Rebuild or Retire Decisions

- User has more knowledge of machine condition
- Rebuild decisions are focused on Critical Parameters
- Rebuilder can focus on specific requirements
- Machines can be Retired to tasks that match current Capability

Modeling Tool Application

A Comprehensive Process Error Budget model is the **KEY** to success since it combines all factors impacting Feature Tolerance into an easily understood framework...
Process Error Budgets

- Each of the five Process Error elements must be allocated a percentage of the total tolerance
- Allocation should be based on the best engineering/science practices
- For simplicity, this presentation will focus on the machine
Machine Error Budget Steps

1. Identify Critical to Manufacturing Features and Processes (CTMs)
2. Create Machine Full Volume Error Models
3. Create multiple Part Feature Models from Full Volume Models
4. Perform GAP analysis between Actual (existing or offered) and Optimized Machine and Process Performance

Step 1: Identify CTMs

• Identify CTMs (Critical To Manufacturing) features and tolerances
  – that are most difficult to manufacture within a specific part, part family or operation
Step 1: Identify CTMs

- Review CTM manufacturing process details (actual or proposed)
  - to define machine, tooling, active axes, part orientation, etc.
Step 1: Identify CTMs

- Part Feature Tolerance
  - limited by a machine’s capability to produce that tolerance over a given distance
- Calculate Feature Unit Tolerance
  - determined by dividing the feature tolerance bandwidth by the distance over which it is applied

Step 1: CTM Feature Assessment

- **CTMs** are Features having the smallest Unit Tolerance for:
  - Size
  - Form
  - Profile
  - Location
  - Orientation or
  - Run-out
Step 1: CTM Feature Identification

Step 2: Machine Full Volume Model

- The weighted summation of all position errors related to the Machine Parametric Errors for the Full Travel of all the motion axes.
Step 2: 5-Axis Vertical Machining Center Model

- A 5-Axis Machine has 35 Degrees of Freedom and 50+ identifiable Parametric Errors

Step 2: 3-Axis Machine Full Volume Model
Step 3: Feature Model Development

The development of a Feature Model from the Machine Full Volume Model involves:

- Use of the CTM feature dimensions to determine the machine axes moved and how far they travel from datums.

- Angular and orthogonal errors contribute to part error in a selected direction using tool and machine offsets

- Compute the weighted sum of all errors in a selected direction of a feature tolerance
Step 3: Feature Model Application

- Compare the weighted sum of all errors to the feature tolerance bandwidth, resulting in the FTP (Feature Tolerance Percentage)
Step 4: GAP Analysis and Optimization

- Perform **GAP** analysis between Actual (existing or offered) and Optimized Machine and Process Performance
  - to identify necessary corrective actions or modifications to design, machine or process specifications

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Step 4: GAP Analysis and Optimization

- **FTP** for all **CTMs** (Critical to Manufacturing Features) should not be greater than the percentage allocated for the machine in the Process Error Budget
- If an **FTP** is greater than the allocated percentage, Machine Parametric Errors must be Optimized by decreasing their allowable value
Step 4: GAP Analysis and Optimization

• Identify **CPPs** (Critical Performance Error Parameters) with greatest impact on **CTM** tolerance(s)
  – using **Optimized Machine Performance** and **Part Feature Error Models** to determine required machine specifications for success

Step 4: GAP Analysis and Optimization

• Calculate % contribution for each Parametric Error

• Errors with the greatest contribution to error sum become **CPPs** (Critical Performance Parameters)
Lifecycle Stage: Vendor Selection

• All Optimized Parametric Errors should be used in conjunction with ISO 230 Test code for machine tools when purchasing a high value machine tool
• For lower value machines, the Full Volume Model summation may be used to establish requirements for the ISO 230-6 Diagonal Displacement Tests

Lifecycle Stage: Installation and Run-off

• These Tools have been successfully applied to Machine Procurement Specifications for:
  – Heavy Machinery - Engines
  – Automotive - Power Train Parts
  – Navy Nuclear - Turbine Components
  – Army - Munitions Components
  – Aircraft - Composite Parts
  – Electronic Assembly System - Components
  – Communications - Fiber Optic Components
Lifecycle Stage: Production Application

- **CPP** Errors with the highest percentages should be monitored periodically to maintain control of the process.

Lifecycle Stage: Production Application

- Changes in machine condition can be monitored by:
  - Periodically probing a stable artifact representing the volume of the work piece(s)
  - Periodically applying the ASME B5.54 & B5.57 One Day Tests (Ball Bar, Laser Diagonals, Linear Displacement etc.)
Lifecycle Stage: Production Application

- These Tools have also been successfully applied for comparisons and diagnostics to:
  - Machine Tools - Competitor Comparison
  - Refrigeration - Rotary Pumps
  - Aircraft Engine - Components
  - Power Generation Mfg - Major Equipment Move
  - Refrigeration - Equipment Move
  - Automotive - Engine Block
  - NASA - Robotic Hand Parts

Conclusion

Applying Machine Tool Lifecycle Management Tools will:

- Renew US machine tool knowledge base
- Save millions of dollars in the lifecycles of machine tools
- Improve the capability of new and older machine tools
What’s Next

Prototype

Automated Process Error Model

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What the Prototype Does

• Estimates machine capability requirements of annotated 3D part models for all tolerated features in all possible machining orientations
• Optimizes machining orientations
How the Prototype Works

• Prototype divides the annotated 3D part model into pairs of toleranced Attributes and Features (AFPs)

How the Prototype Works

• The AFPs are then analyzed individually or in combination to determine the machine tool performance requirement for a user selected tolerance consumption targets
How the Prototype Works

• Prototype analysis uses 5 generic machine tool performance grades, representing the most common machine tool types (VMC & HMC)

• Prototype has been developed as an Add-in to a popular CAD system
Select File from drop-down list

Select Tools
Select Prototype Tool

Select Machine Sub-class
Review VMC Sub-class Image

Review HMC Sub-class Image
Analyze Machinability

View Most Difficult AFPs
View other AFPs

View more AFPs
View Minimum Orientations

Select AFP
Select Part Orientations

Select 2nd Orientation
Select 3rd Orientation

Select 5th Orientation
Select 6th Orientation

Where to go next?

- Extend rule set development to many machine subclasses
- Extend to multiple CAD systems
  - using STEP AP203 Part 2 or
  - custom CAD-proprietary interfaces (Original)
    META-iFAB Integrated Tool Chain
Thank you!

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