Quality and Consistency of Machined Components and Products

Measurement Science and Standards in Forensic Firearms Analysis

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Quality and Consistency of Machined Components and Products

Delivering consistent value to customers for machined products

- Machining produces high geometric *accuracy* and low surface *roughness*, leading to high quality and value to the customer
- Increasing the quality or consistency of machined products increases their cost, which detracts from their value
- The quality, consistency, and cost of machining depends on a complex combination of the performance of process steps and equipment.
- Manufacturers manage this complex combination to increase value to customers while minimizing cost.

The Problem

Manufacturing of complex, high-value products are expensive and time consuming, requiring lengthy trial-and-error procedures and resulting in wasted resources due to uncertainties in:

- Material properties/behavior under manufacturing conditions
- Manufacturing processes
- Performance of manufacturing equipment

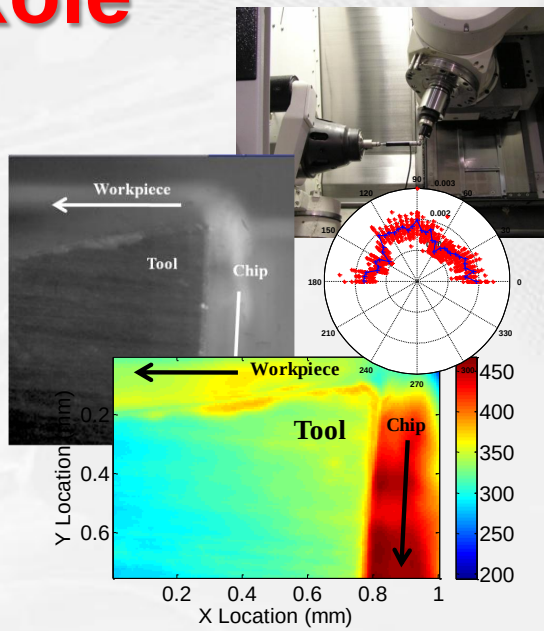
Resulting from:

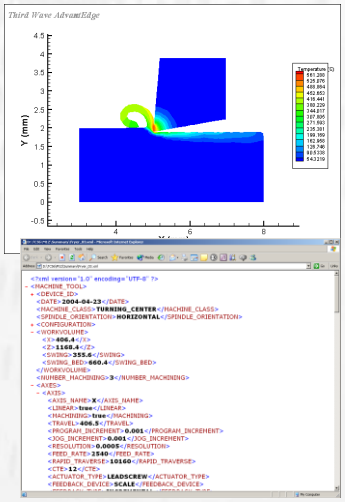
- Lack of strong metrology infrastructure
- Lack of robust and optimized process control technologies
- Variations in manufacturing system response due to varying manufacturing environmental conditions

Technical Approach - NIST Role

Develop/improve knowledge

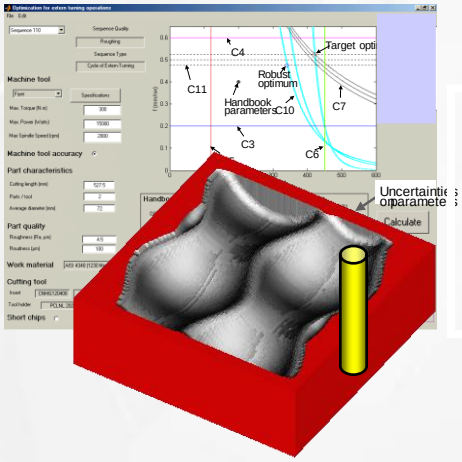
Performance Evaluation – Metrology – Data





Represent knowledge

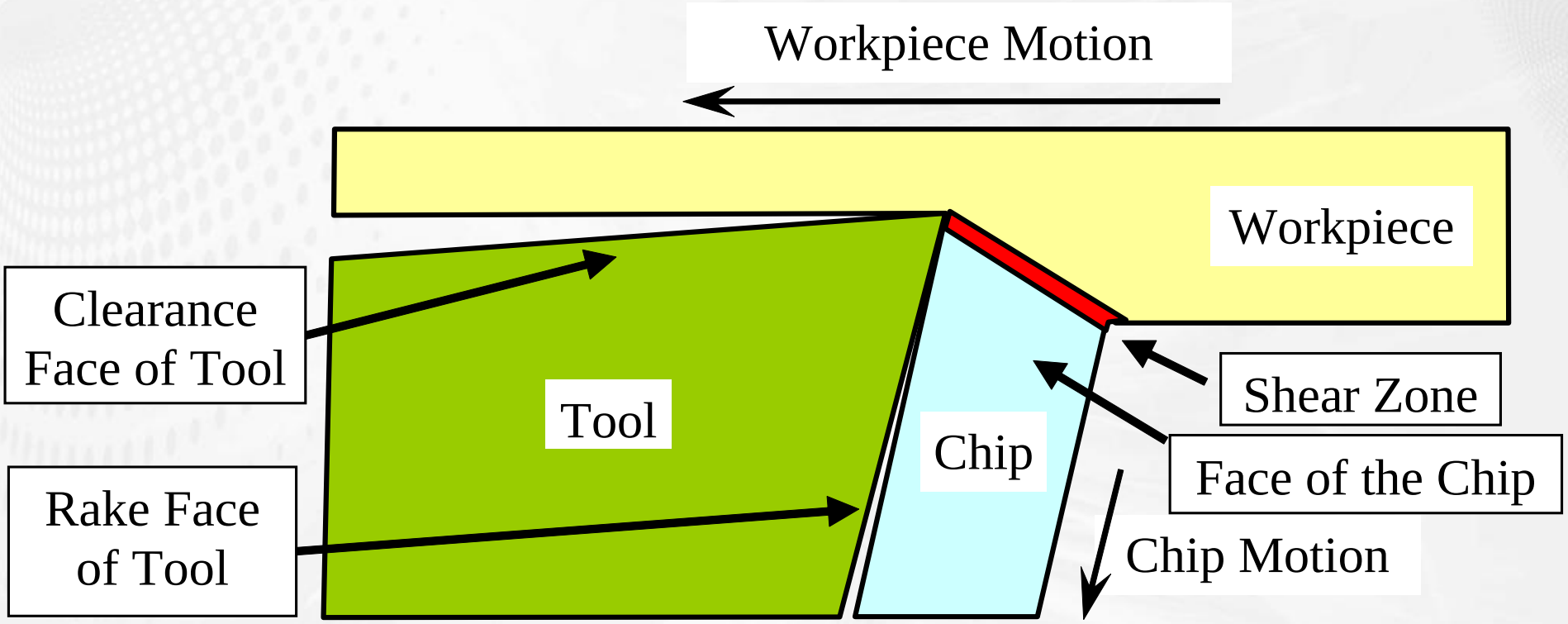
Models – IT – Standards



Integrate/use knowledge

Manufacturability Analysis – Optimization – Control - Diagnosis

Basic Machining Process

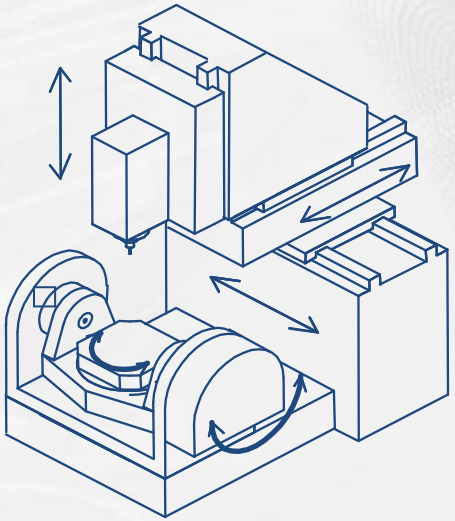


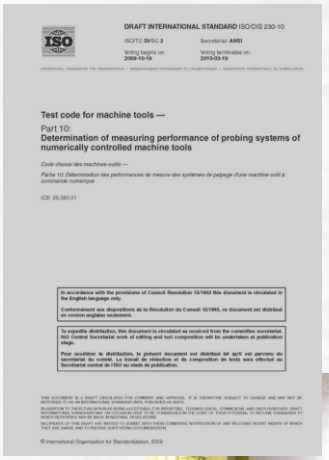
Schematic of an image of an orthogonal cutting process. The equipment produces the relative motion between the workpiece and the tool. The process removes material in the form of a chip, creating an accurate and smooth surface on the workpiece.

Machining Equipment Metrology

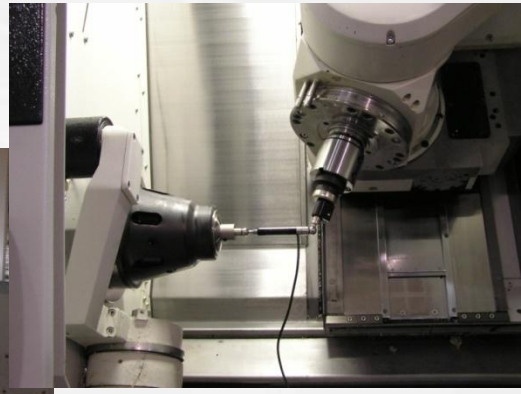
- **Machine Tool Performance Standards –** provide consistent measures of motion errors, which enables manufacturers to evaluate production quality limits.

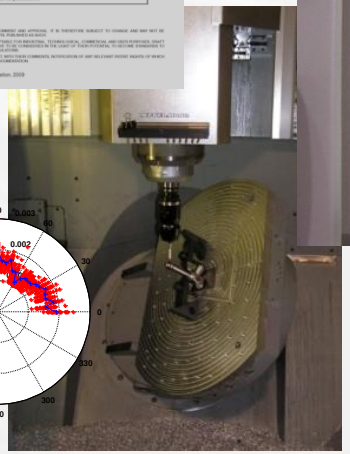
- **On-machine metrology –** enable complex part certification by assessment of measuring capability (uncertainty) of machine tools through development of relevant ISO standards

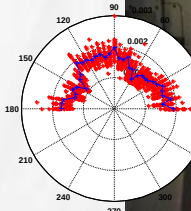



DRAFT INTERNATIONAL STANDARD ISO/DIS 230-10

Test code for machine tools —
Part 10:
Determination of measuring performance of probing systems of numerically controlled machine tools

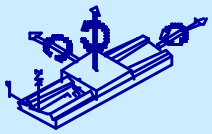




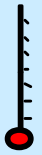


Standards Enable Error Segregation

Many error sources with complex task-specific effects

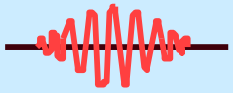


Geometric Errors



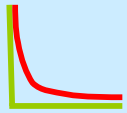
Thermal Errors

Stiffness & Hysteresis



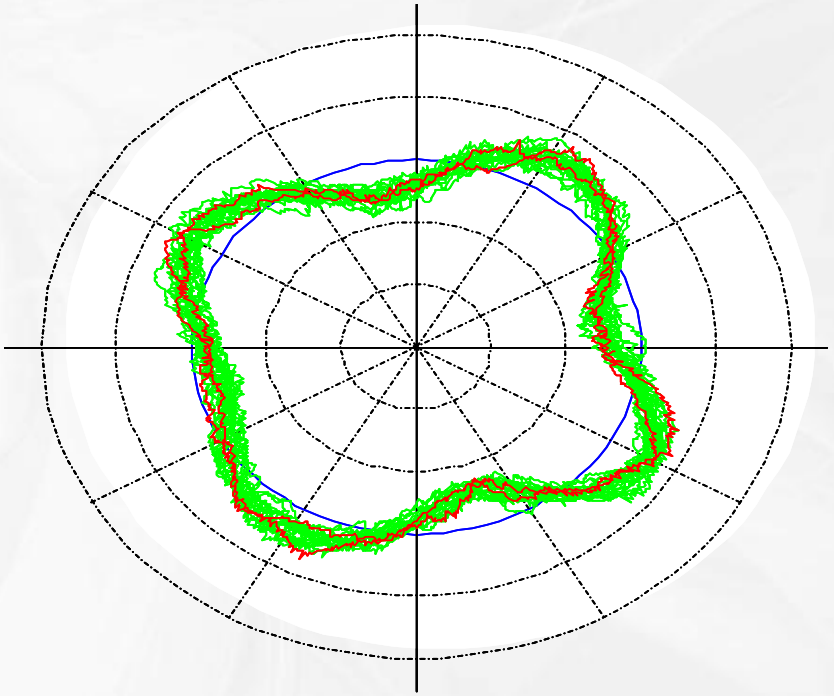
Machine Dynamics

Axis of Rotation

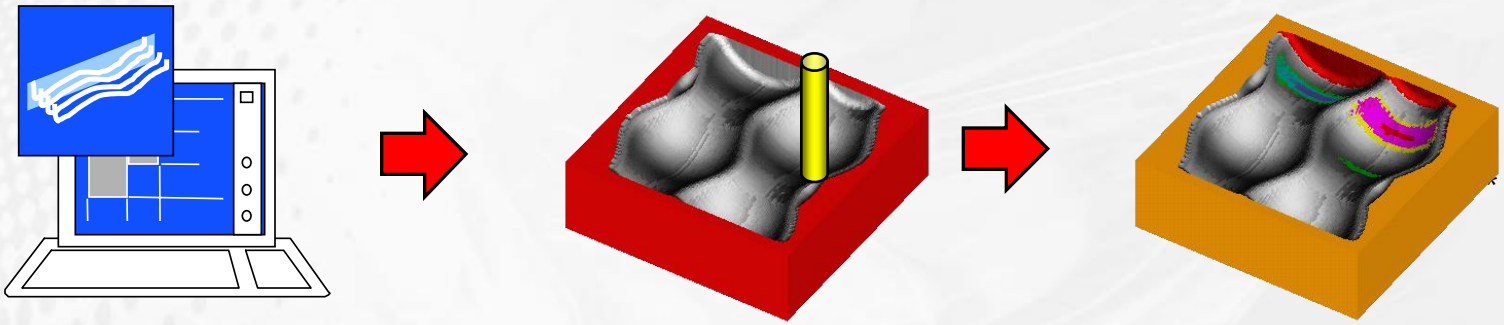


Contouring

Spindle Error Motion



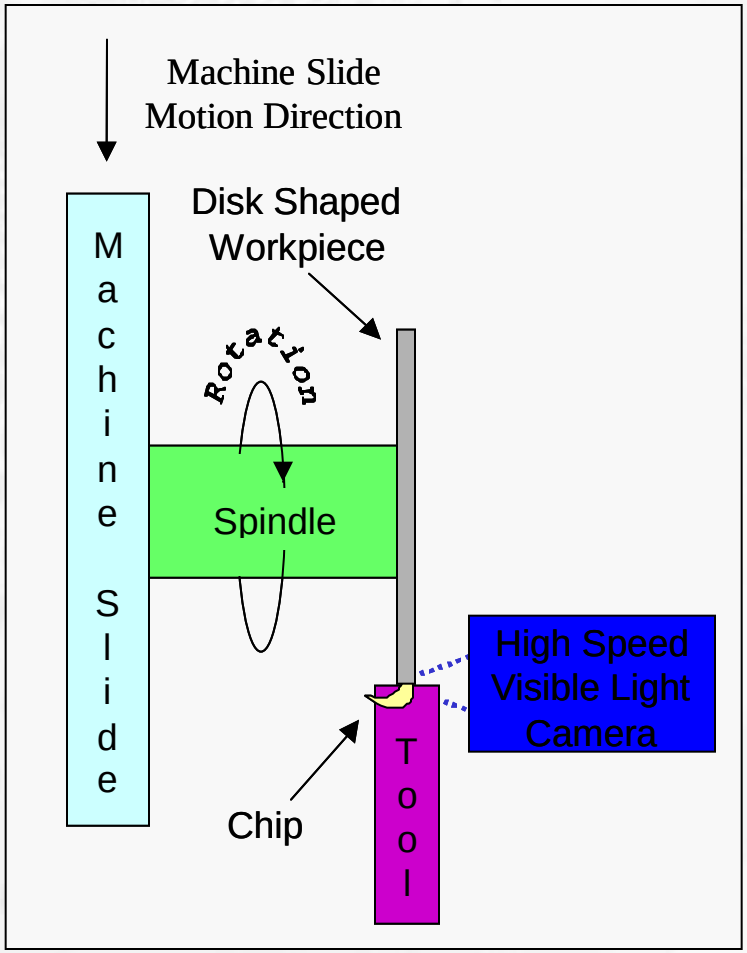
Predicting machining tolerances

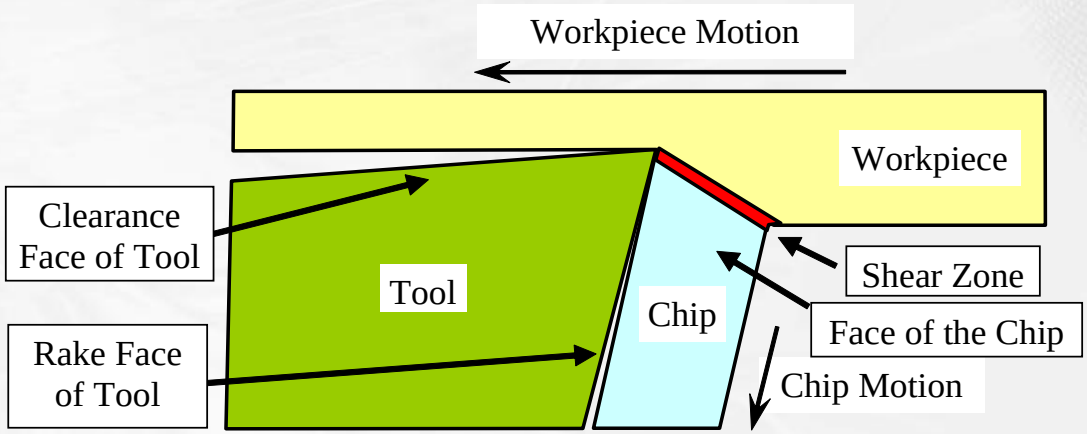


Design & Plan | Virtual Machining | Virtual Inspection

- Aggregating the measured errors provides a threshold for achievable tolerances
- Variations in process performance degrade tolerances from this theoretically achievable threshold

Machining Process Metrology

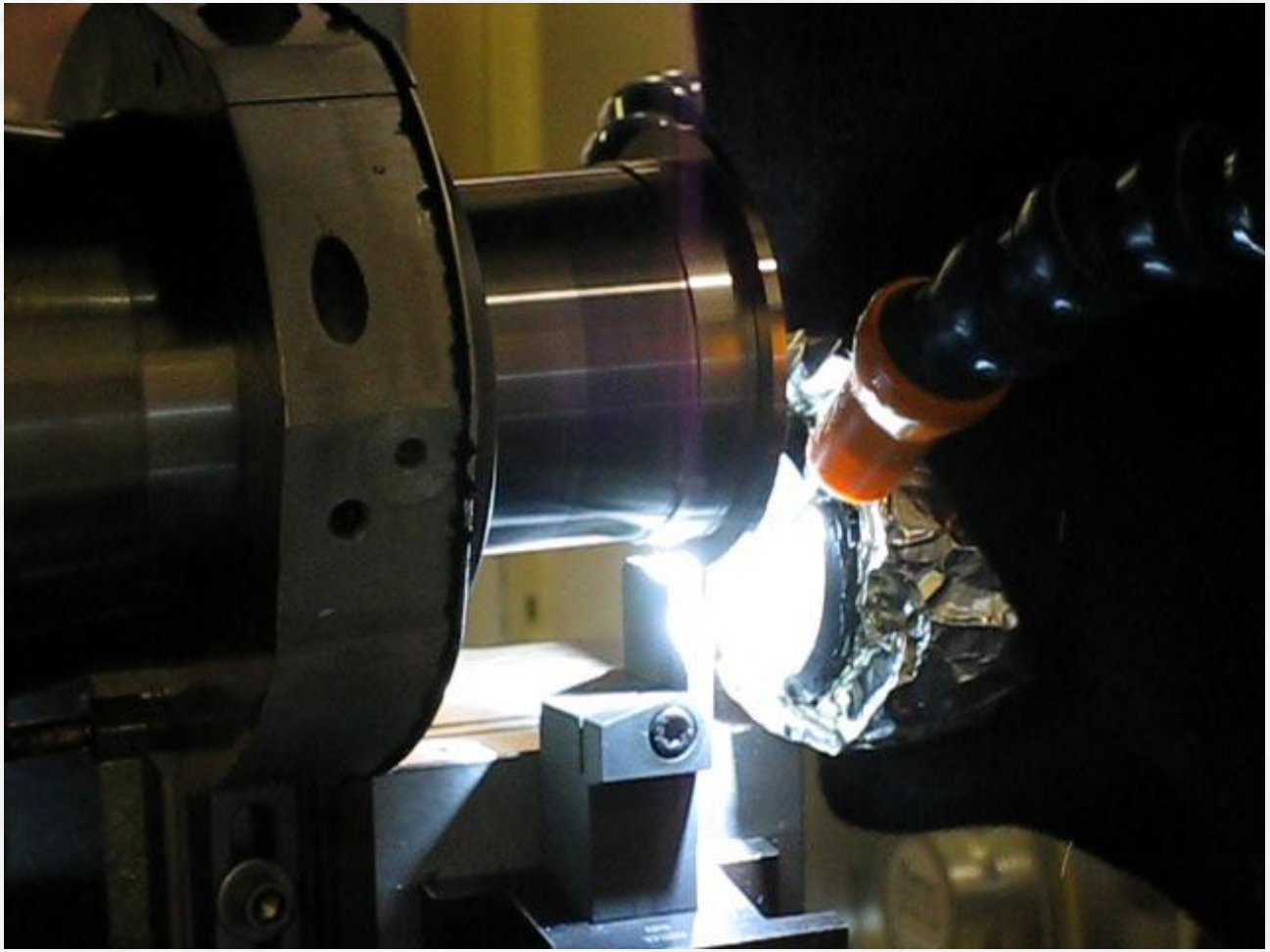




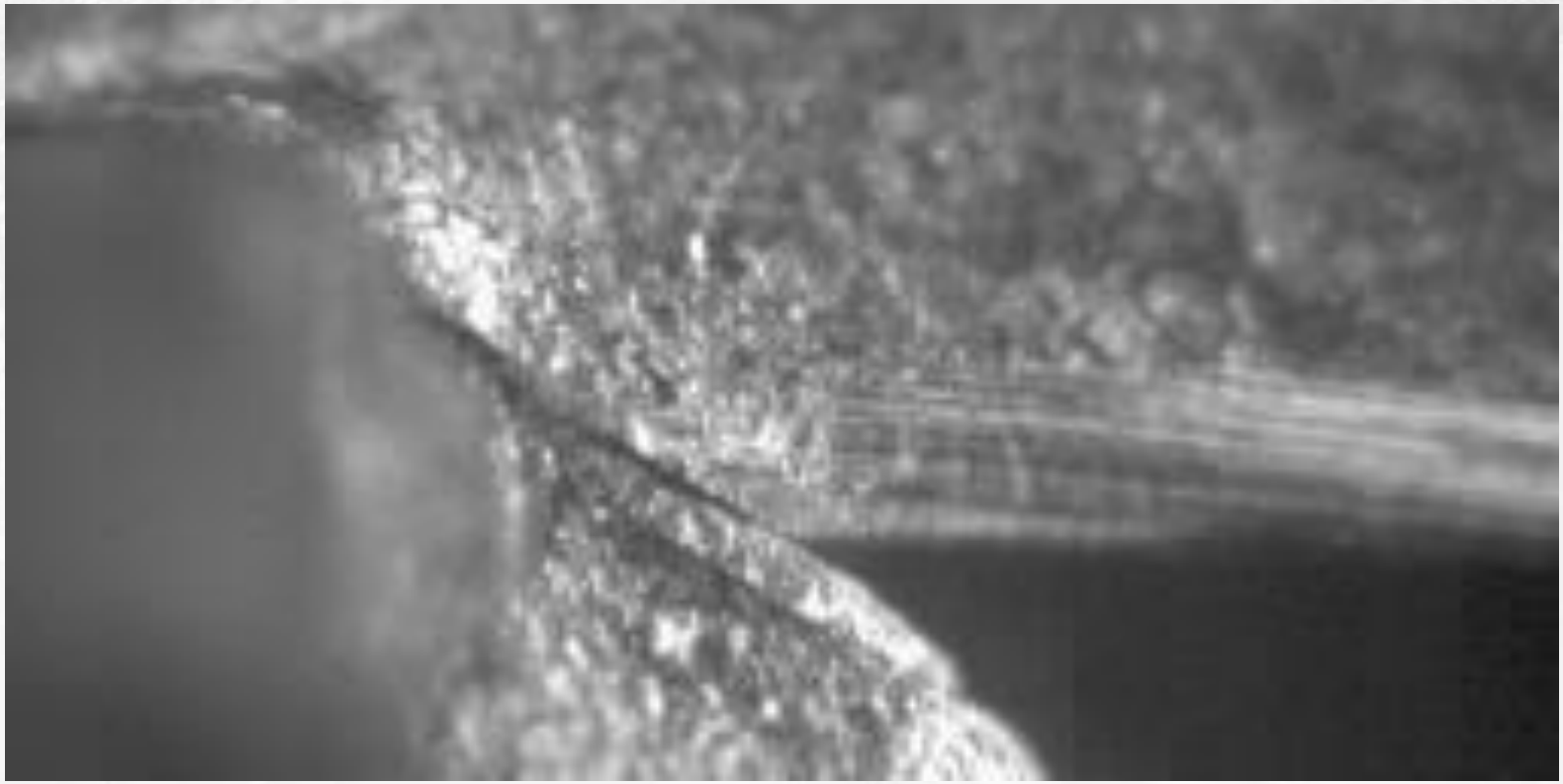
Schematic of an image of an orthogonal cutting process.

Machining Process Metrology

High speed cameras acquire gigabytes in a second



Machining Process Metrology

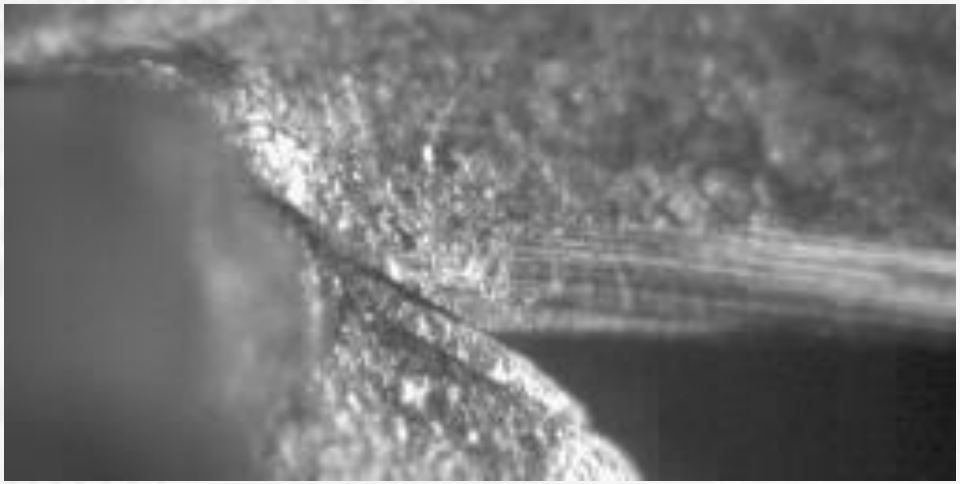


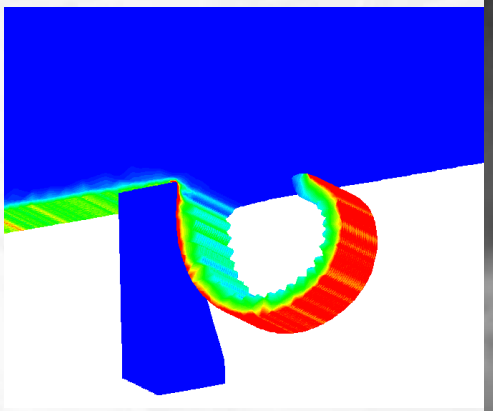
- Imperfections in process performance include surface deformation, tool deflection, and wear

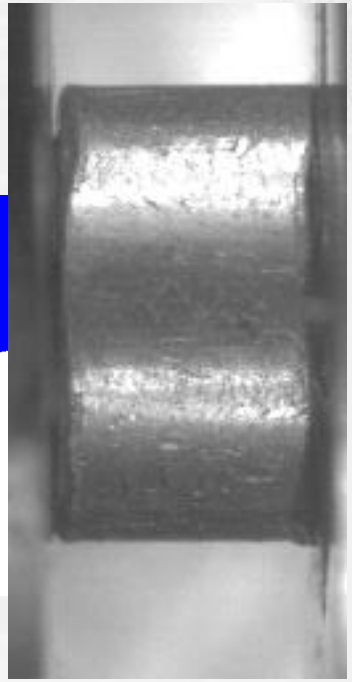
Machining Process Metrology

Advancing competitiveness of generalized scientific process models requires:

- Advanced simulation tools
- *Data on phenomena during material processing*
- *Material properties under manufacturing conditions*







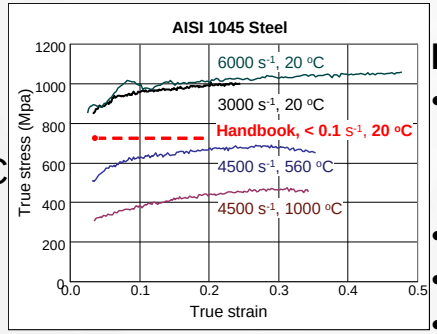
Process characteristics:

Strain 200 % to 2000%

Strain rates: 10^3 to 10^7 s^{-1}

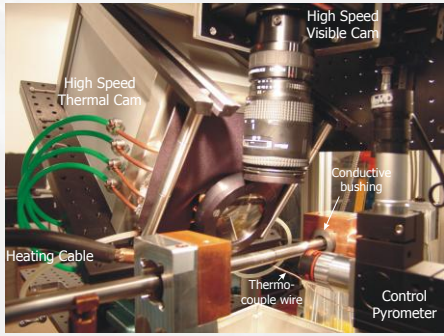
Temperatures: 100 to 1000 C

Heating rate: up to 10^6 C/s

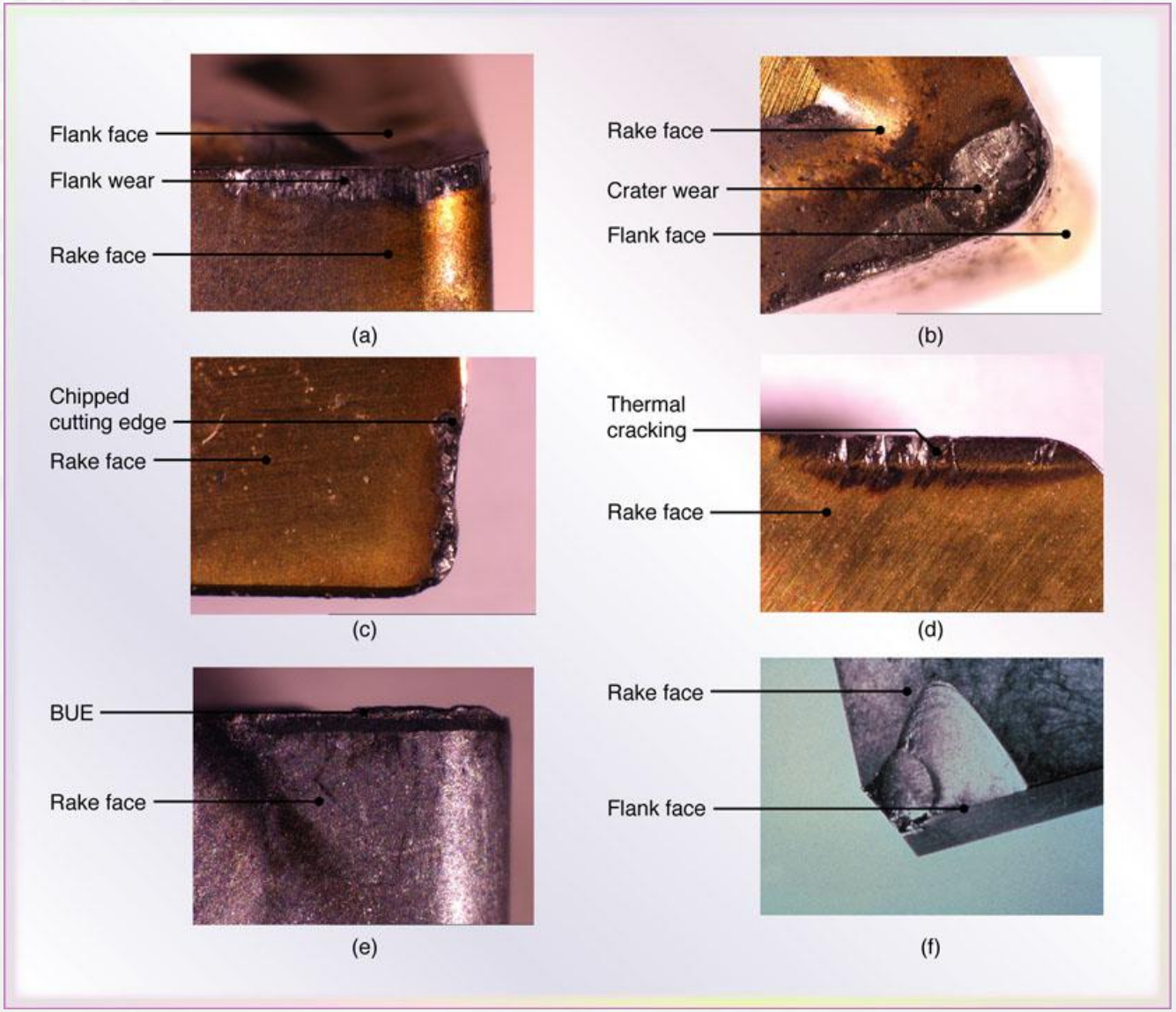


NIST Pulse-heated Kolsky Bar

- Unique capability to heat sample to 1200 K in less than 0.5 s
- Strains up to 50%
- Strain-rates up to 8000 s^{-1}
- Thermal camera
- High-speed visual camera

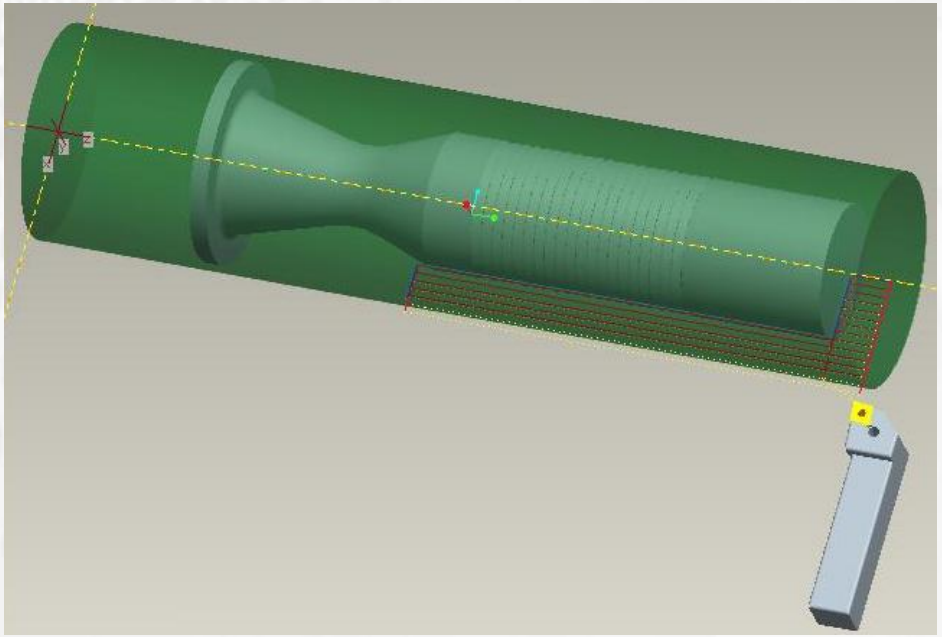


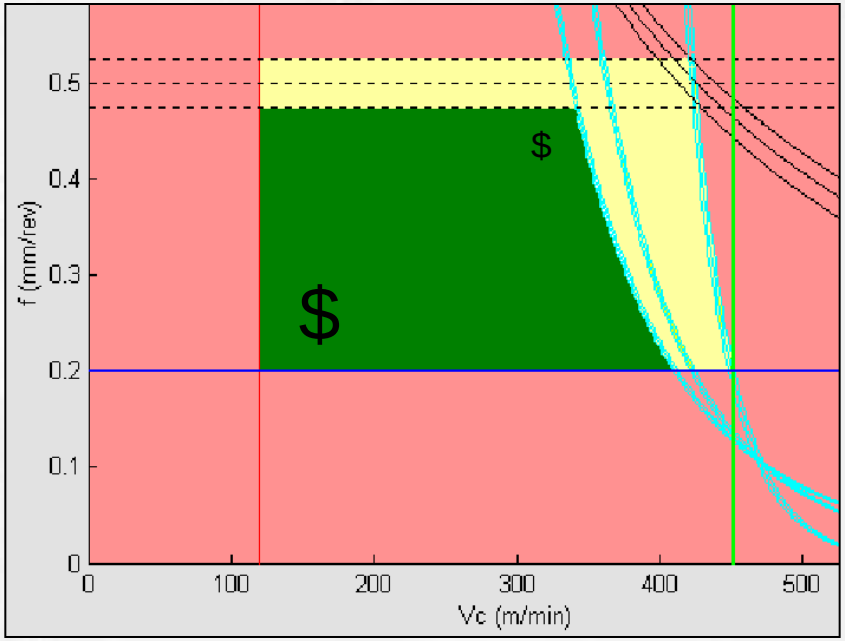
Worn tools degrade surface quality



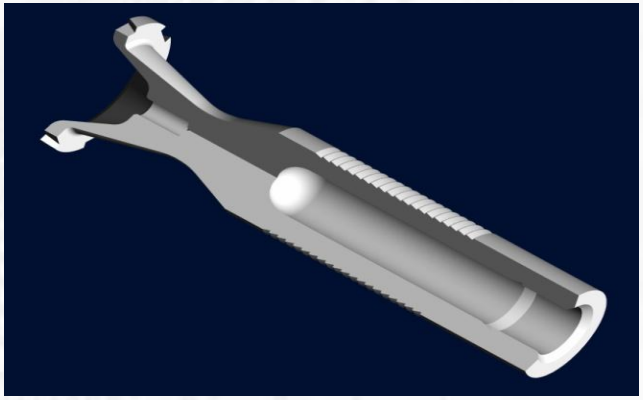
Fundamental Metrology for Material Processing

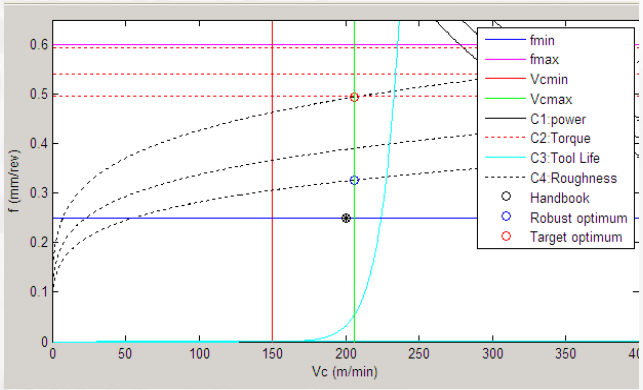
- Industry uses process planning and modeling to *produce parts to specification*





Machining Process Models

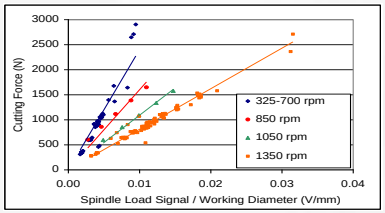




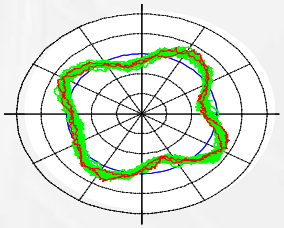
Model-based optimization optimize for:

- Tool path
- Tool selection
- Feeds/speeds
- Coolant strategy
- Sequence

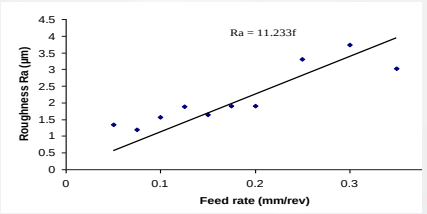
Power and Forces



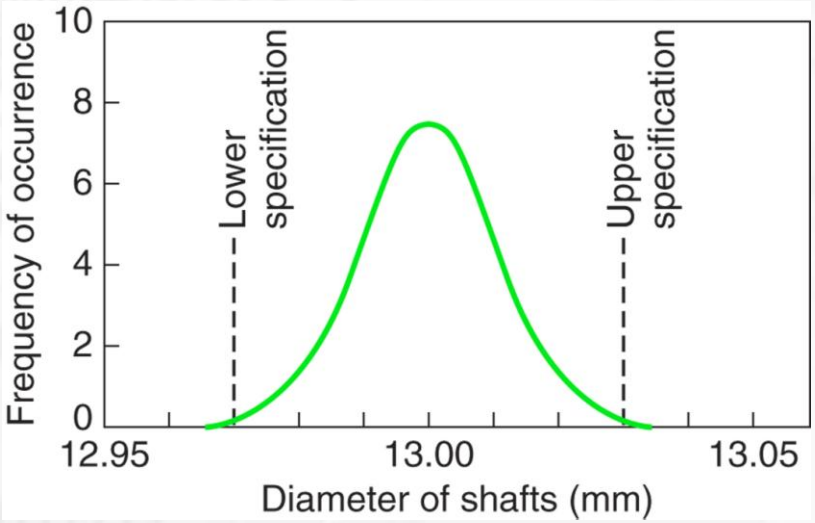
Spindle Error Motion

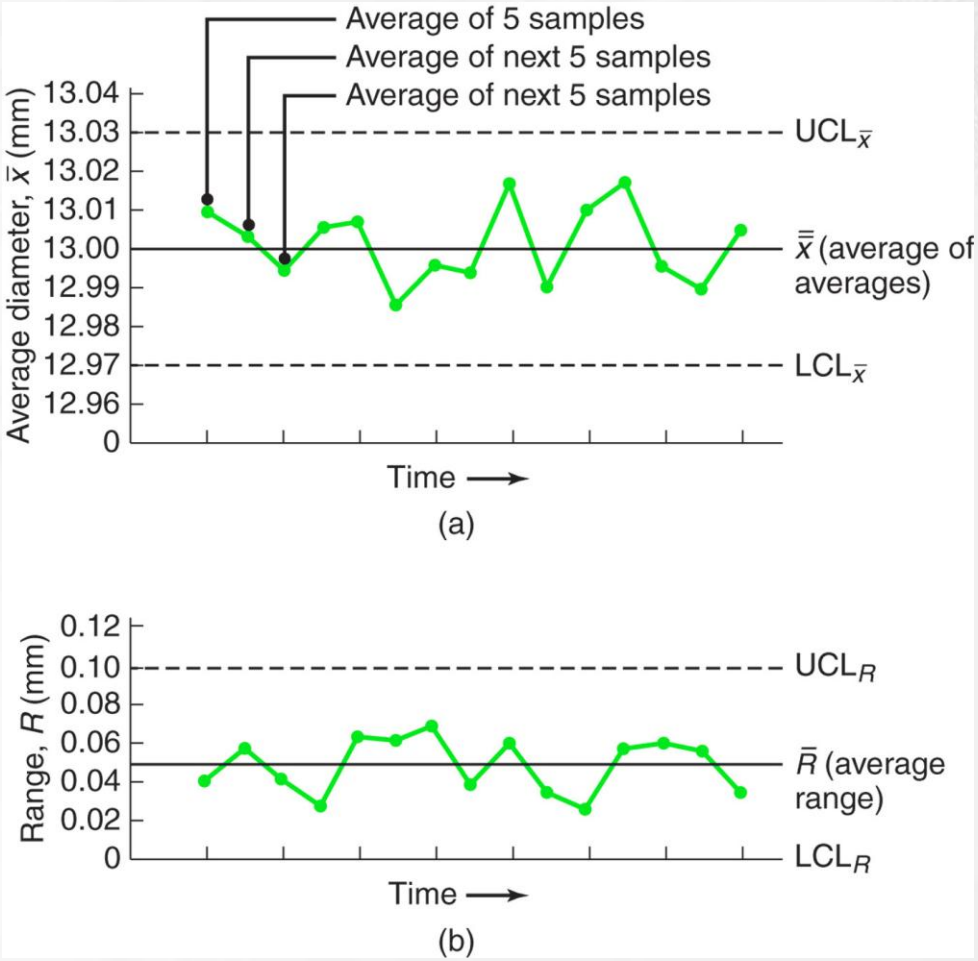


Surface Roughness



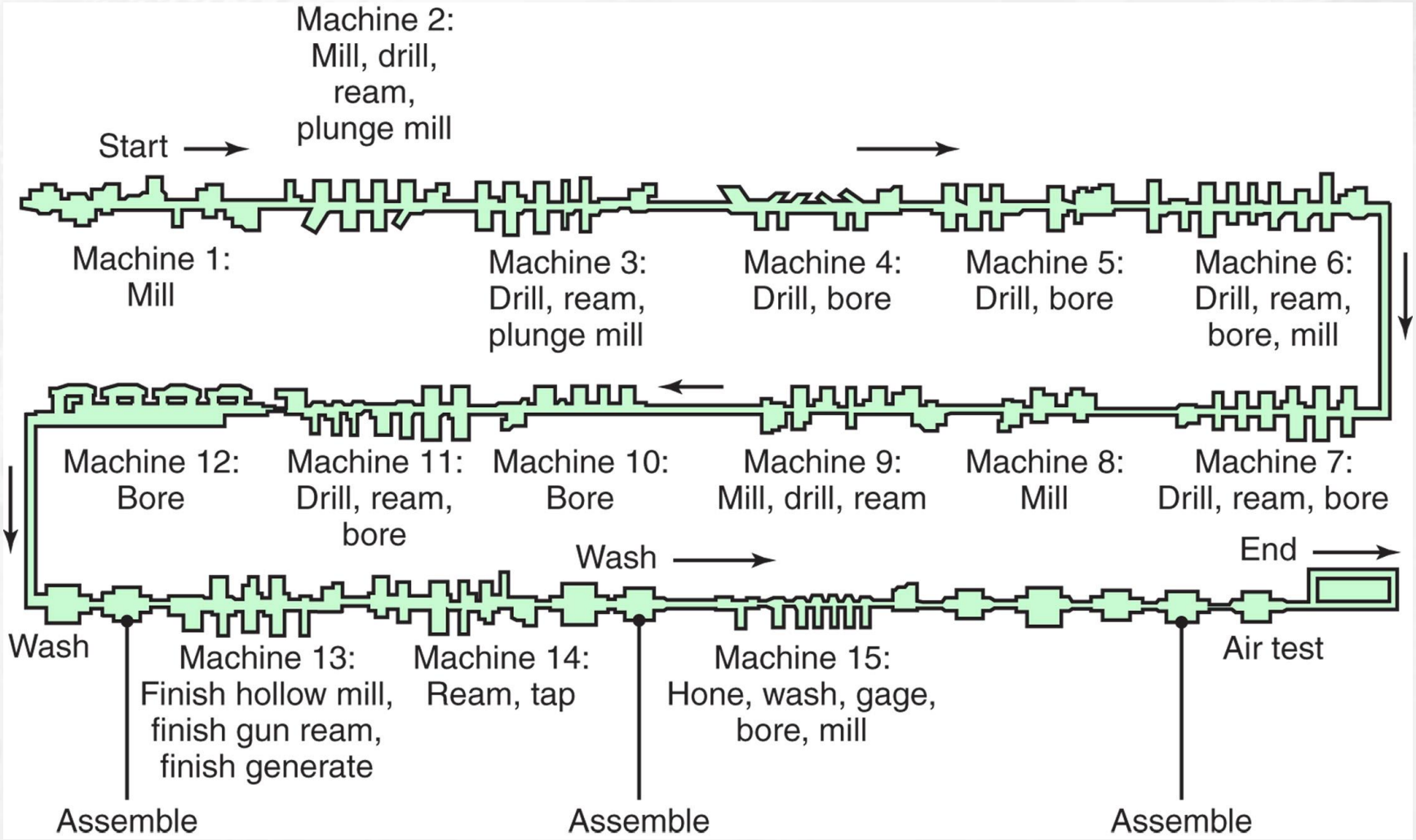
Quality Control of One Process Step



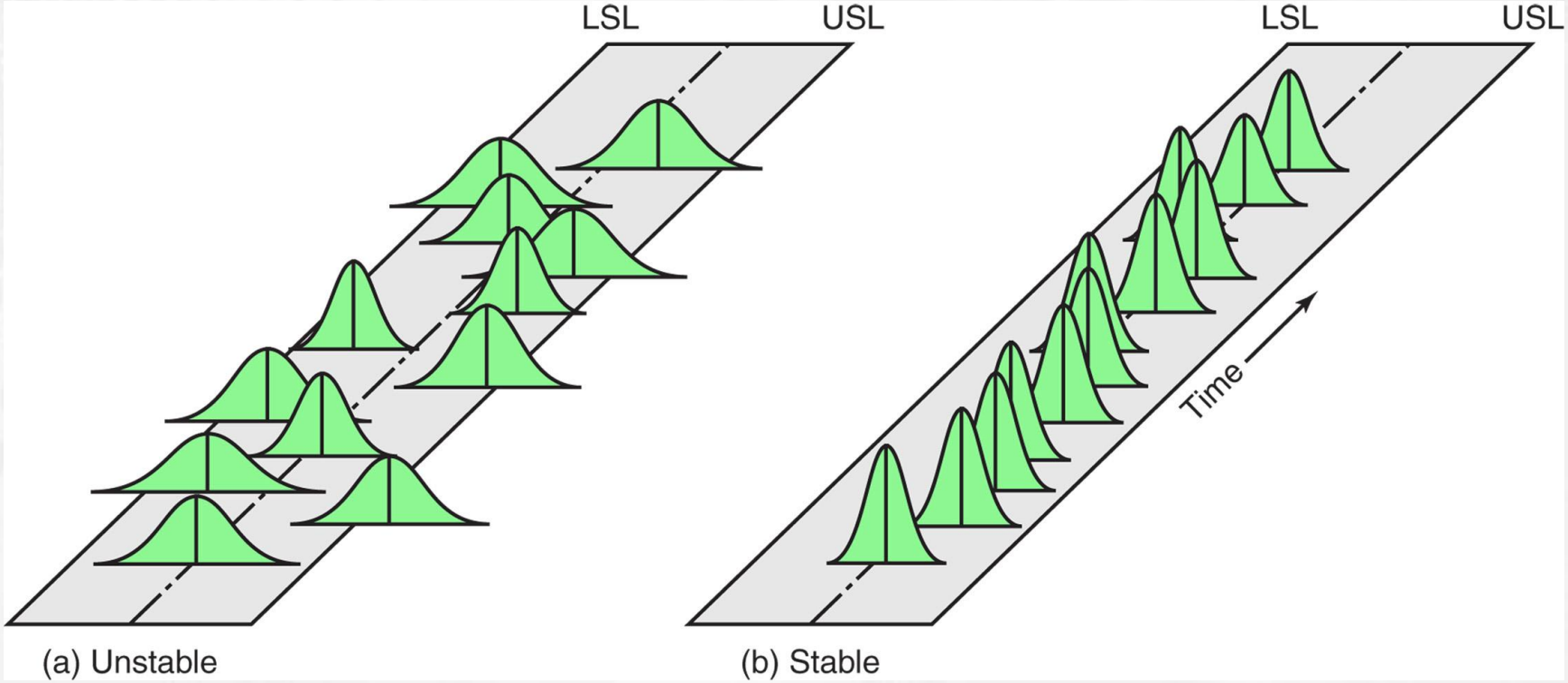


Manufacturing Engineering and Technology, Sixth Edition
Serope Kalpakjian and Steven R. Schmid

Products Need Many Process Steps



Aggregate Control of Quality



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Forensics of Machined Components and Products

Manufacturers manage this complex combination to increase value to customers while minimizing cost.

- Changes in process steps and equipment to maintain quality and consistency focus on aspects related to the product function
- Any aspects of product characteristics *related to forensics but unrelated to function* may or may not be controlled

Questions and Discussions