MEASUREMENT AND INSPECTION

INTRODUCTION
Attributes versus Variables

STANDARDS OF MEASUREMENT
Linear standards (length, mass, time, temperature)
Length standards in industry - Gage block set
Standard measuring temperature (20° C)

ALLOWANCE AND TOLERANCE
Specifying tolerance and allowance (ANSI vs. ISO)
Accuracy vs. precision in process - example
Geometric tolerances (capability, linearity, repeat accuracy, stability, magnification, resolution)

INSPECTION METHODS FOR MEASUREMENT
Factors in selecting inspection equipment

MEASURING
Linear measuring instruments (machinist’s ruler ➔
toolmaker microscope)

INSTRUMENTS
Measuring with light and lasers (optical comparator ➔
interferometers)

VISION SYSTEMS FOR MEASUREMENT

COORDINATE MEASURING MACHINES

ANGLE MEASURING INSTRUMENTS

GAGES FOR ATTRIBUTES
Fixed - type gages
Deviation gages

SURFACE ROUGHNESS MEASUREMENT
PROCESS CAPABILITY AND QUALITY CONTROL

INTRODUCTION
Inspection to find defects vs. inspection to prevent defects

DETERMINING PROCESS
Making PC studies
What PC studies tell about the process

CAPABILITY
Process capability ratio $C_p$
Degree of bias $\beta$
Solutions for poor process control capability

INSPECTION AND QUALITY CONTROL
100% control
Statistical control
Sampling errors
Quality control charts
  X bar charts
  R charts
How to read a quality control chart
How to build the quality control charts

DETERMINING CAUSES FOR PROBLEMS IN QUALITY
Total quality control
House of quality
Fishbone diagram
INTRODUCTION

CUTTING TOOL MATERIALS

- Tool steels
- High speed steels
- Cast cobalt alloys
- Carbides or sintered carbides
- Ceramics
- Coated carbide tools
- TiN - coated high speed steel
- Cements
- Diamonds
- Polycrystalline cubic boron nitride (CBN)

TOOL GEOMETRY

TOOL FAILURE

TOOL LIFE

- Taylor tool life model - examples
- How to establish the tool life if a tool ($n \& C$ coefficients)

RECONDITIONING CUTTING TOOLS

ECONOMICS OF MACHINING

MACHINABILITY

CUTTING FLUIDS

SHAPING AND PLANING

- The cutting principle: the relative motion tool-workpiece
- Types of surfaces machined by shaping & planing
- Shaping machines: components, basic requirements, tool holder, ram, motions of the table and tool
- Workholding devices for shapers
- Planing machines: components, basic requirements, tool holders, motions of the table and tools, double housing planers, open sided planers
- Workholding devices for planers
METAL CUTTING

Definition: Removal of undesired material from a workpiece.

Kinematics: Relative motion of the tool and workpiece.

Cutting parameters: Single-point cutting tool: Material (cutting & physical properties)
Tool (geometry, material)
Process (speed, feed, chip thickness)
(cutting force, temperature, shear angle)

Cutting operations (SP): Turning, boring, facing, milling, drilling, shaping, planing;
Cutting operations (MP): Sawing, grinding, reaming, broaching;

Chip formation: Orthogonal machining, Oblique machining;

Kinematics of cutting: Chip ratio \( r_c \): Ratio of the removed thickness and the chip thickness \( t/t_c \)
Shear angle:
\[
\phi = \tan^{-1} \left( \frac{r_c \cdot \cos \alpha}{1 - r_c \cdot \sin \alpha} \right)
\]

Speed diagram and relationships:
\[
\begin{align*}
v_c &= \sin \alpha \\
v &= \cos(\phi - \alpha) \\
v_c &= \cos \alpha \\
v &= \cos(\phi - \alpha)
\end{align*}
\]

Shear strain:
\[
\varepsilon_s = \frac{\cos \alpha}{\sin \phi \cos(\phi - \alpha)} \quad (2 - 4 \text{ in/in})
\]

Three types of chips: discontinuous, continuous, continuous with build-up edge.

Mechanics of machining: Orthogonal machining - two force system.
The resultant force \( R \) acts @ the tool-chip interface contact area;
\[
R = \sqrt{F_c^2 + N^2} = \sqrt{F_c^2 + F_t^2} = \sqrt{F_c^2 + F_f^2}
\]
\[
\beta = \tan^{-1} \mu = \tan^{-1} \frac{F}{N}
\]
\[
F_c = F_i \sin \alpha + F_i \cos \alpha \\
N = F_i \cos \alpha - F_i \sin \alpha
\]

Fc and Ft - measurable forces
\[
F_i = F_i \cos \phi - F_i \sin \phi \\
F_n = F_i \sin \phi + F_i \cos \phi
\]

the shear stress:
\[
\tau_s = \frac{F_i}{A_j} \quad A_j = \frac{tw}{\sin \phi}
\]
\[
\tau_s = \frac{F_i \sin \phi \cos \phi - F_i \sin^2 \phi}{tw} \quad \text{psi} \quad \text{constant of material}
\]

Energy and power: Oblique machining:

F_c - primary cutting force
F_f - feed acting force \( (1/2 F) \)
F_t - thrust force \( (1/2 F_i) \)
cutting power: \( P = F_c V \quad [\text{HP} = F_c V/33,000] \)
unit of specific power : \( \text{HP}_s = \text{HP}/\text{MRR} \)

Energy: shear and friction: total energy:
\[
U = \frac{F_i}{F_i \cdot t}
\]

Engine power:
\[
\text{HP}_w = \frac{\text{HP}_s \times \text{MRR} \times \text{CF}}{E}, \quad \text{CF} - \text{correction factor; E - efficiency}
\]

Maximum depth of cut: power dependent
Heating and temperature: sources of heating, distribution of heat.
CUTTING TOOLS (C.T.) FOR MACHINING

Materials: Carbon steels, low/medium alloy steels, high-speed steels, (cast cobalt alloys), cemented carbides, coated alloys and carbides, ceramics, sintered polycrystalline cubic boron nitride (CBN), sintered polycrystalline diamond, single crystal natural diamond.

Selection: Inputs (work material, type of cut, part geometry & size, lot size, machinability data, required quality, experience of the decision maker), Constraints (manufacturing practice, condition of the MT, workholding devices, process time), Outputs (selected tools, cutting parameters), Availability.

Characteristics: Hardness, resistance to abrasion, wear, toughness, hot hardness, strength to deformation, chemical stability, thermal properties, elastic modulus, tool life, geometry & surface finish.

High speed alloy: 18-4-1 W-Cr-Va - exhibit good hardness @ high temperatures.
Sintered carbides: Powder cemented WC - based clusters with 3 to 13% Co binder - high stiffness and better hardness, but brittle (more expensive): the bits are brazed on the tool mountings; operate @ higher speeds than the rapid steels (up to 300 m/min).
Ceramics: sintered clusters of Al2O3 - similar to carbide tools, do not need coolant and more brittle; edge chipping, mainly for Al and Ti materials.
Coated steels & carbides: the polished material is coated by thin TiN, TiC or Al2O3 films (5 µm) by Physical Vapor Deposition (PVD) or Chemical Vapor Deposition (CVD) reduce the early wear by hardening the surface of the tool (4 times longer life).
Diamonds: synthetic sintered and natural single crystal - highest toughness and Cubic boron nitrides: CBN: low chemical reactivity, work @ up to 5 times higher speeds, hard and brittle; requires high precision and power machine tools.

Tool geometry: Back rake angle: -5° to + 20°. Relief angles: 5° to 10°.

Tool failure (tool life): Two mechanisms: (i) slow death and (ii) sudden death mechanisms. The wear limit given by the depth of the crater: 0.025 - 0.03 in. Tool wear follows normal distribution. Tool life can be expressed in effective cutting time, removed volume of material or number of certain pieces made.

Taylor's tool life model: \[ T = \frac{\text{const}}{f_x V_y} \] or \[ VT^n = C \]
with \( n \) - constant depending on material (tool & work), cutting conditions and environment.

C - constant which depends on the input parameters, mainly feed.

Tool life variability factors: work hardness variability, geometry and material of the C.T., vibrations in machine tool, changing surface characteristics.

Reconditioning: To lower the cost of machining. Purpose: (1) to re-establish the geometry of the tool, (2) to re-achieve the initial quality of the surface.

The main paradox of machining: @ higher speeds, the material removal is more efficient, but the tool wears out faster.

Optimal problem: what is the best decision.

C1 - Machining cost/piece
C2 - Tool cost/piece
C3 - Tool change cost/piece
C4 - non-productive cost

Machinability: Ease or difficulty with which a metal can be machined. Defined by the relative speed, for the same performances compared to a standard workpiece material cut with the same tool, when the life and wear of the tool will be the same (ISO 3685 - 30 min and 0.33 mm flank wear). In definition, certain affinities must be also specified; (ex: Ti and Al).

Cutting fluids: Multiple functions: (1) reduce the contact temperature, (2) lubricate the cutting point, (3) helps chip removal. Improves the life of the cutting tool. Environmental issue.
TURNING, BORING, AND RELATED PROCESSES

INTRODUCTION

FUNDAMENTALS OF TURNING, BORING AND FACING

Turning
Boring
Facing
Parting
Drilling
Reaming
Knurling
Turning and boring tapers
Special attachments
Dimensional accuracy

LATHE DESIGN AND TERMINOLOGY

Lathe design
Size designation of lathes
Types of lathes
Turret lathes
Vertical turret lathe
Automatic turret lathe
Single-spindle
Automatic screw
Machines
Multiple spindle
Automatic screw
Machines

TYPES OF BORING MACHINES

Vertical boring and turning machines
Jig borers
Horizontal boring machines
Mass production boring machines
Boring machine precision

CUTTING TOOLS FOR LATHES

Lathe cutting tool
Form tools
Turret lathe tools

WORKHOLDING IN LATHES

Workholding devices for lathes
Lathe centers
Mandrels
Lathe chucks
Collets
Face-plates
Mounting work on carriage
Steady and follow rests
DRILLING AND RELATED HOLE-MAKING PROCESSES

INTRODUCTION

FUNDAMENTALS OF THE DRILLING PROCESS
CT, MRR

TYPED OF DRILLS
Nomenclature and geometry of the conventional twist drill
Materials
Types of drills

TOOL-HOLDERS FOR DRILLING
Chucks

WORKHOLDING DEVICES FOR DRILLING
Jigs and fixtures

MACHINE TOOLS FOR DRILLING
Bench, Upright, Radial, Gang, Multi-spindle, Deep-hole, Transfer

CUTTING FLUIDS FOR DRILLING
Functions

DEEP BPRING, COUNTERBORING, COUNTERSINKING, AND SPOT FACING

DRILLING PRACTICES
Improper drill grinding, Cutting speed, Chip removal
AND PROBLEMS
Helix angle vs. work-material, life of the drill

REAMING
Types of reamers
Reaming practice
# THREAD MANUFACTURING

**Introduction**
- Thread geometry, (straight, tapered), screw vs. thread
- Standardization (UN, ISO)
- Nomenclature
- Types of screws and threads
- Thread classes
- Thread designation: 3/8’ -16 UNC - 2A
  
  M6x0.75 -5g6g

**Thread cutting:**
- Cutting threads on lathe - threading dial
- Cutting threads on CNC Lathe - chasers
- Cutting threads with dies
- Self-opening die heads

**Internal thread cutting:**
- Collapsing taps
- Hole preparation
- Machine tapping
- Tapping cutting time: $CT = \pi DLn / 8V$
- Special threading and tapping machines
- Common tapping problems
- Tapping high strength materials
- Cutting fluids for tapping

**Thread milling**

**Thread grinding**
- Center type with axial feed
- Center type with infeed
- Centerless thread grinding

**Thread rolling**
- Flat dies
- Cylindrical dies
  - Three roll die
  - Planetary two rollers
- Chipless tapping

**Machining vs. thread forming.**
# Milling

## Fundamentals of milling process
CT, MRR, kinematic relationship feed - speed, geometric relationship work - tool, chip thickness variation, cutting force variation

## Milling cutters
- types of milling cutters:
  - plain
  - helical
  - side
  - interlocking
  - staggered-tooth
  - slitting saw
  - angle
  - form
  - end
  - plain end
  - shell end
  - hollow end
  - T - slot
  - Wodruff keyseat
  - fly

## Milling machines
- Basic (general purpose)
  - column-and-knee (plain, universal, vertical, turret type)
- Manufacturing
  - bed type (simplex, universal, triplex)
- Planer type (large work only)
- Special (rotary table, drum type, profile, duplicators)

## Milling machine construction
- DOF of the table
- DOF of the spindle

## Accessories
- Vertical attachment
- Universal dividing head

## Workholding devices
- vise
- fixtures
- T slots of the table

## Precision and accuracy
- $\pm 0.0005$ in
- $R_a \geq 60 - 150 \mu in.$
ABRASIVE MACHINING PROCESSES

INTRODUCTION, DEFINITION

ABRASIVES  Abrasive Grain Size and Geometry

GRINDING:  Grinding Wheel Structure and Grade
G Ratio
Bonding Materials for Grinding Wheel
Abrasive Machining
Snagging
Low stress Grinding
Dressing and Truing
Grinding Wheel Identification
Grinding Wheel Geometry
Balancing Grinding Wheels
Safety in Grinding
Use of Cutting Fluids in Grinding

GRINING MACHINES:  Cylindrical Grinding
Centerless Grinding
Tool-Post Grinders
Surface Grinding Machines
Creep Feed Grinding Machines
Disk Grinding Machines
Tool and Cutter Grinders
Mounted Wheels and Point Coated Abrasives

DESIGN CONSIDERATIONS IN GRINDING

HONING:  Honing Stones

SUPERFINISHING

LAPPING
## METAL FORMING PROCESS

### INTRODUCTION

### HOT WORKING PROCESS

#### CLASSIFICATION OF DEFORMATION PROCESSES

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROLLING</td>
<td>Basic rolling processes, Rolling temperatures, Rolling mill configurations, Ring rolling, Characteristics, quality and precision of hot rolled products, Flatness control and rolling defects, Thermomechanical processing and controlled rolling</td>
</tr>
<tr>
<td>FORGING</td>
<td>Open die drop hammer forging, Impression die drop hammer forging, Design of impression die forging, Press forging, Upset forging, Automatic hot forging, Roll forging, Roll forging, Swaging, Net shape and near-net shape forging</td>
</tr>
<tr>
<td>EXTRUSION</td>
<td>Extrusion methods, Extrusion of hollow shapes, Metal flow in extrusion</td>
</tr>
<tr>
<td>HOT DRAWING OF SHEET AND PLATE</td>
<td>Butt-welded pipe, Lap-welded pipe</td>
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</tbody>
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### PIERCING

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COLD WORKING PROCESS

SQUEEZING
Cold rolling

PROCESSES
Cold-rolled shapes
Thread rolling
Swaging
Cold forging
Cold extrusion (impact extrusion)
Hydrostatic extrusion
Continuous extrusion
Roll extrusion
Sizing
Riveting
Staking
Coining
Hubbing
Surface improvement by cold working

BENDING
Angle bending
Design for bending
Air bend vs. bottoming dies
Roll bending
Draw bending and compression bending
Cold-roll forming
Seaming and flanging
Straightening

SHEARING
Simple shearing
Slitting
Piercing and blanking
Tools and dies for piercing and blanking
Design for piercing and blanking

DRAWING AND SHEET METAL FORMING
Rod, bar and tube drawing
Wire drawing
Spinning
Shear forming
Stretch forming
Sheet metal drawing (Deep drawing, shell drawing and shallow drawing)
Forming with rubber tooling or fluid pressure
Drawing on a drop hammer
High energy rate forming
Ironing
Embossing
Forming
Design hints for sheet metal forming

PRESSES
Classification of presses
Types of press frame
Special types of presses