UNIT X · LESSON 02

Machine Tools, Machining, CNC & NDT

cutting mechanics · tool life · lathe · drilling · milling · shaper/planer · grinding · machining time · unconventional machining · CNC & part programming · NDT

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questions in Unit X
Casting · Machining · PPC · OR

MECHANICS METAL CUTTING

- **Orthogonal** (edge ⊥ velocity, 2-D) vs **oblique** (inclined edge, 3-D, practical)
- Chip thickness ratio **$r = t/t_c = l_c/l < 1$**; shear angle **$\tan\varphi = r\cos\alpha/(1 - r\sin\alpha)$**
- **Merchant**: $2\varphi + \beta - \alpha = 90° \rightarrow \varphi = 45° + \alpha/2 - \beta/2$ (β = friction angle, α = rake)
- Shear strain $\gamma = \cot\varphi + \tan(\varphi - \alpha)$; chip velocity $V_c = rV$; shear velocity $V_s = V\cos\alpha/\cos(\varphi - \alpha)$
- Forces from dynamometer: cutting F_c, thrust F_t; $\mu = (F_t + F_c\tan\alpha)/(F_c - F_t\tan\alpha)$
- Power $P = F_cV$; specific energy $u = F_c/(bt)$
- Chips: **continuous** (ductile, high speed, +rake), **with BUE** (built-up edge, low speed), **discontinuous** (brittle, CI), serrated
- Heat: ≈ 80 % to chip, 10–15 % tool, rest workpiece
- Example: $t = 0.5$, $t_c = 1.0$ mm, $\alpha = 10° \rightarrow r = 0.5$, $\tan\varphi = 0.492/0.913 \rightarrow \varphi \approx$ **28.3°**

TAYLOR TOOL LIFE

- **Taylor's equation $VT^n = C$**; n ≈ 0.1–0.15 (HSS), 0.2–0.4 (carbide), 0.4–0.6 (ceramic)
- Extended: $VT^n f^a d^b = C$; speed affects life most, then feed, then depth
- Example: n = 0.25, C = 300 m/min; V = 150 → $T = (300/150)^4 =$ **16 min**
- Wear: **flank wear** (tool-life criterion VB ≈ 0.3 mm), **crater wear** (rake face, diffusion), notch, chipping
- **Machinability index**: free-cutting steel (AISI 1112) = 100 %
- Tool materials (increasing hot hardness): carbon steel → **HSS** (18-4-1, 600 °C) → cast alloy (Stellite) → **cemented carbide** (WC–Co, coated TiN/TiC/Al_2O_3) → **ceramics** → **CBN** (hardened steel) → **diamond** (non-ferrous only)
- Tool signature (ASA): back rake, side rake, end relief, side relief, end cutting edge, side cutting edge, nose radius
- Cutting fluids: cool & lubricate (soluble oil, straight oil, synthetic)

TURNING LATHE

- Parts: bed, headstock, tailstock, carriage (saddle, cross-slide, compound rest, tool post, apron), lead screw, feed rod
- Size: swing over bed and distance between centres
- Operations: facing, turning, step/taper turning, **threading**, knurling, drilling, boring, reaming, parting, chamfering, grooving
- **Taper**: compound rest (short, steep), **tailstock set-over** (offset = L(D − d)/(2l)), taper-turning attachment, form tool
- Thread cutting: lead-screw drive; change gears driver/driven = pitch of job / pitch of lead screw
- Work holding: 3-jaw (self-centring), 4-jaw (independent), collet, face plate, centres, mandrel
- Capstan & turret lathes, automats (Swiss type) for mass production
- **Cutting speed V = πDN/1000** m/min; turning time **T = L/(f N)** per pass
- Example: D = 50 mm, V = 31.4 m/min → N = **200 rpm**; L = 100 mm, f = 0.25 mm/rev → T = **2 min**
- MRR (turning) = π D f d N (mm^3/min) ≈ V f d (×1000)

MULTI-POINT MILLING (CONTD.)

- Gear manufacture: form milling, **hobbing** (fast, accurate), shaping, broaching; finishing by shaving, grinding, lapping

HOLES DRILLING & BORING

- Twist drill point angle **118°** (general), helix 30°; chisel edge
- Machines: bench/pillar, **radial** (large work), gang, multi-spindle, deep-hole (gun drilling)
- Operations: drilling, **reaming** (finish, accuracy), **boring** (enlarge, true), counter-boring, counter-sinking, spot-facing, **tapping**
- Drilling time T = (L + 0.3D)/(f N) (allowance for point)
- MRR = ($\pi D^2/4$) f N
- Tap drill size ≈ major diameter − pitch

MULTI-POINT MILLING

- **Up (conventional) milling**: cutter rotates against feed; chip thin → thick; tends to lift work; safer on old machines
- **Down (climb) milling**: rotation with feed; thick → thin; better finish, longer tool life; needs **backlash eliminator**
- Machines: horizontal (column-and-knee), vertical, universal (swivel table — helical milling), planer-type, CNC machining centres
- Cutters: plain/slab, side & face, end mill, face mill, form, **T-slot**, slitting saw, fly cutter, gear (involute) cutters
- Table feed $\mathbf{f_m = f_t \times z \times N}$ (mm/min)
- Example: z = 10, f_t = 0.1 mm/tooth, N = 200 → f_m = **200 mm/min**
- **Indexing** (dividing head 40:1): simple indexing crank turns = **40/N**; N = 24 → 1⅔ turns (1 turn + 12 holes on an 18-hole circle); differential, compound indexing

RECIPROCATING SHAPER, PLANER, SLOTTER & BROACHING

Machine	Moves	Use
Shaper	tool reciprocates, work fed	small flat surfaces, keyways; **quick-return** (Whitworth / crank & slotted link)
Planer	work reciprocates, tool fed	large heavy flat surfaces
Slotter	vertical shaper	internal keyways, slots
Broaching	multi-tooth broach, one pass	internal splines, keyways; **mass production**, high accuracy, costly tool

- Shaper cutting time $T = (B/f)\cdot L(1 + m)/(1000V)$, m = return/cutting time ratio

NON-TRADITIONAL UNCONVENTIONAL MACHINING

Process	Mechanism	Material / use
AJM (abrasive jet)	abrasive in air jet	brittle, glass, deburring
USM (ultrasonic)	abrasive slurry, tool vibrates ≈ 20 kHz	**hard brittle** (glass, ceramics)
WJM / AWJM	high-pressure water (± abrasive)	soft materials / any

ABRASIVE GRINDING & FINISHING

- Abrasives: **Al_2O_3** (steels), **SiC** (cast iron, non-ferrous, carbide), CBN, diamond
- **Wheel designation** (e.g. A 46 K 8 V 23): abrasive – grain size – **grade (hardness of bond)** – structure – bond – maker's code
- Bonds: **vitrified (V, most common)**, resinoid (B), rubber (R), shellac (E), silicate (S), metal (M)
- Rule: hard material → **soft wheel**; soft material → hard wheel
- **Dressing** (sharpen, re-expose grains) vs **truing** (restore shape); glazing & loading
- Types: surface, cylindrical, **centreless** (no centres, regulating wheel), internal, tool & cutter
- Superfinishing: **honing** (bores, cross-hatch), **lapping** (flatness), superfinishing, buffing, polishing
- Surface roughness achievable: turning 0.8–6.3 µm → grinding 0.1–1.6 µm → lapping 0.05–0.4 µm Ra

NON-TRADITIONAL UNCONVENTIONAL MACHINING (CONTD.)

Process	Mechanism	Material / use
ECM (electro-chemical)	anodic dissolution (Faraday's law), no tool wear	**hard conductive**, turbine blades, no residual stress
EDM (electric discharge)	sparks in dielectric (kerosene); tool = cathode (Cu, graphite)	**hard conductive**, dies, moulds; wire-EDM for profiles
LBM (laser)	thermal; CO_2, Nd:YAG	small holes, cutting any material
EBM (electron beam)	in vacuum	micro holes
PAM (plasma arc)	≈ 10 000–30 000 °C plasma	cutting thick steel
CHM (chemical milling)	etchant + maskant	aerospace panels

- ECM: MRR = I A/(ρ F Z) (cm^3/s); EDM: needs electrically conductive work, recast layer, overcut
- Choice: mechanical (AJM, USM, WJM), electrochemical (ECM), thermal (EDM, LBM, EBM, PAM), chemical (CHM)

NUMERICAL CONTROL CNC

- **NC** (punched tape) → **CNC** (computer, stored program, editing) → **DNC** (direct/distributed NC, central computer feeds many machines)
- Elements: part program → **MCU** (machine control unit) → servo drives → machine tool; feedback (encoders, resolvers)
- **Open loop** (stepper motors, no feedback) vs **closed loop** (servo + feedback)
- Motion control: point-to-point (drilling), straight-line, **contouring (continuous path)** — interpolation linear/circular
- Axes (right-hand rule): **Z = spindle axis**, X horizontal (longest travel), Y; rotary A, B, C about X, Y, Z
- **Absolute (G90)** vs **incremental (G91)** dimensioning
- Ball screws (low friction, no backlash), recirculating ball, linear guides, ATC (automatic tool changer), APC (pallet changer)
- **Machining centre**: CNC milling + ATC; **turning centre**: CNC lathe + turret
- Advantages: accuracy, repeatability, complex shapes, flexibility, less lead time; limits: cost, skilled programmers

G & M CODES PART PROGRAMMING

Code	Meaning	Code	Meaning
G00	rapid traverse	M00	program stop
G01	linear interpolation	M02 / M30	program end (/ rewind)
G02	circular CW	M03	spindle ON clockwise
G03	circular CCW	M04	spindle ON CCW
G04	dwell	M05	spindle stop
G17/G18/G19	XY / ZX / YZ plane	M06	tool change
G20 / G21	inch / mm	M08 / M09	coolant ON / OFF
G28	return to reference	M98 / M99	subprogram call / return
G40/41/42	cutter radius comp. off / left / right		
G90 / G91	absolute / incremental		
G94 / G95	feed per min / per rev		

- Word address format: N10 G01 X50 Y20 F100 S800 T01 M03
- **Canned cycles**: G81 (drilling), G83 (peck drilling), G84 (tapping); G70–G76 (turning cycles, Fanuc)
- **APT** (automatically programmed tools) language; CAD/CAM generates G-code

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N10 G21 G90 G17
N20 M06 T01
N30 M03 S1000
N40 G00 X0 Y0 Z5
N50 G01 Z-2 F50
N60 G01 X40 Y0 F100
N70 G02 X60 Y20 R20
N80 G00 Z5
N90 M05
N100 M30
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INSPECTION NDT

Method	Principle	Detects
Visual / optical	eye, borescope	surface
Dye penetrant	capillary action, developer	surface-open cracks, non-porous material
Magnetic particle	leakage flux attracts iron particles	surface / near-surface, **ferromagnetic only**
Ultrasonic	0.5–25 MHz echoes (pulse-echo, through-transmission)	internal flaws, thickness; one-side access
Radiography	X / γ (Co-60, Ir-192) absorption on film	internal voids, porosity, inclusions; safety hazard
Eddy current	induced currents change coil impedance	surface cracks, conductivity, coating thickness
Acoustic emission	stress waves from growing cracks	active defects in pressure vessels
Thermography	IR imaging	delamination, hot spots
Leak testing	pressure / helium / bubble	leaks

- Metrology: limits, fits & tolerances (hole basis), gauges (Taylor's principle: GO checks all features, NO-GO one), comparators, CMM, slip gauges, surface roughness (Ra, Rz)

Q → A RAPID RECALL

Chip thickness ratio	t/t_c (< 1)
Merchant's relation	$2\varphi + \beta - \alpha = 90°$
Taylor's tool life equation	$VT^n = C$
Tool-life criterion wear	flank wear
Tool for non-ferrous only	diamond
Lathe cutting speed formula	πDN/1000
Standard drill point angle	118°
Milling with better finish (needs backlash eliminator)	down (climb) milling
Simple indexing crank turns	40/N
Wheel for hard materials	soft grade
Process for hard brittle non-conductors	USM
Process with no tool wear	ECM
Code for circular interpolation CW	G02
Code for spindle ON clockwise	M03
CNC Z-axis	along the spindle
NDT only for ferromagnetic parts	magnetic particle

TRAP EXAM TRAPS

- Cutting speed raises temperature and shortens tool life most strongly (n is small)
- Hard materials need **soft** wheels (grains must break away to stay sharp)
- EDM and ECM need conductive workpieces; USM works on non-conductors
- G90 / G91 change coordinate mode, not units (G20 / G21)
- Reaming finishes a hole; it does not correct hole position (boring does)