VIVA PREPARATION · BUILT FROM YOUR LAB FILE

Machine Tools & Metrology Lab

Notes, formulas and 200+ likely viva questions with answers for all nine experiments in your record, plus the lab-file mistakes to fix before you walk in.

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BEFORE YOU START

How to use this tonight

1. **Pass 1 (about 60 min):** read the notes for each experiment. Don't memorise yet, just understand why each thing happens.
2. **Pass 2 (about 60 min):** cover the answers and say each viva answer out loud. Mark any you miss.
3. **Pass 3 (about 20 min):** formula sheet (page 3), then redo only the marked questions.
4. **Morning (15 min):** the "30 must-know answers" on the last page.

Examiners usually open with *"What was the aim of this experiment?"*, then *"What is the principle?"*, then *"What is the least count / formula?"*, then one twist (*"Why not above 45°?"*, *"Why ratchet?"*). Every experiment below is written in that order.

Fixes to your lab file

These are slips in the handwritten record. If the examiner flips through your file and asks about them, you'll already know the right answer.

1. **Exp 7 (micrometer):** "semiconductor frame" should be a **semicircular, U- or C-shaped frame** (forged steel or malleable cast iron).
2. **Exp 5 (cutting power):** `P = Fc·V / 60000 kW` needs **V in m/min**, not m/s. If V is in m/s, use `P = Fc·V / 1000 kW`.
3. **Exp 2 (Taylor):** your file says n "depends on material of steel". The exponent **n depends mainly on the tool material** (HSS ≈ 0.1–0.15, carbide ≈ 0.2–0.4, ceramic ≈ 0.5–0.7). **C** depends on the work material, tool material and conditions. C is the cutting speed that gives a tool life of 1 minute.
4. **Exp 8 (bevel protractor):** the apparatus list (sine bar, height gauge, angle plate) was copied from Exp 9. The real apparatus is a **universal bevel protractor, the specimen and a surface plate**. The least count is **2 main-scale divisions − 1 vernier division = 2° − 23/12° = 1/12° = 5 minutes**.
5. **Exp 9 (sine bar):** "less than 5 pr" should read: used when an angle must be checked to an accuracy **better than about 5 minutes of arc**.
6. **Exp 3 (capstan):** the six tools sit on the **hexagonal turret** (on the ram). The **square turret is on the cross-slide** and holds 4 tools. The feed stroke is the ram moving **towards the headstock** (right to left as you face the machine).
7. **Exp 4 (strain gauge):** resistance change in a metallic gauge comes mainly from the change in the wire's length and area (geometry). Semiconductor gauges use the true piezoresistive effect. Formula: $\Delta R/R = GF \cdot \varepsilon$, with GF ≈ 2 for metal foil gauges.
8. **Missing scans:** notebook page 3 (lathe and milling theory) and the first page of Exp 6 (vernier aim and apparatus) aren't in your PDF. Both are fully covered in this guide.

ONE PAGE

Formula & numbers sheet

Quantity	Formula	Notes
Cutting speed (lathe, drill, mill)	$V = \pi DN / 1000$	V in m/min, D in mm, N in rpm
Taylor's tool life	$V \cdot T^n = C$	Comparing two speeds: $V_1T_1^n = V_2T_2^n$
Extended Taylor	$V \cdot T^n \cdot f^a \cdot d^b = K$	f = feed, d = depth of cut
Cutting power (turning)	$P = Fc \cdot V / 60000$ kW	Fc in N, V in m/min
Resultant force (turning)	$R = \sqrt{(Fc^2 + Ff^2 + Fr^2)}$	The three components are mutually perpendicular
Chip thickness ratio	$r = t_1 / t_2 < 1$	t_1 = uncut, t_2 = chip thickness
Shear angle	$\tan \varphi = r \cos \alpha / (1 - r \sin \alpha)$	α = rake angle
Merchant's relation	$\varphi = 45° + \alpha/2 - \beta/2$	β = friction angle, μ = tan β = F/N
Friction & normal force on rake face	$F = Fc \sin \alpha + Ft \cos \alpha$ $N = Fc \cos \alpha - Ft \sin \alpha$	Ft = thrust force (orthogonal)
Shear & normal force on shear plane	$Fs = Fc \cos \varphi - Ft \sin \varphi$ $Fn = Fc \sin \varphi + Ft \cos \varphi$	
MRR, turning	$MRR = V \cdot f \cdot d$	V in mm/min gives mm^3/min
MRR, drilling	$MRR = (\pi d^2/4) \cdot f \cdot N$	f in mm/rev
Drilling power from torque	$P = 2\pi NT / 60$ W	T in N·m (1 kgf·m = 9.81 N·m)
Strain gauge	$\Delta R/R = GF \cdot \varepsilon$	GF ≈ 2 for metal foil gauges
Least count (vernier)	$LC = 1$ MSD $- 1$ VSD $=$ MSD $/ n$	1 mm / 50 = 0.02 mm
Vernier / micrometer reading	$MSR + (VSC \times LC) \pm$ zero error	Zero error with its sign
Least count (micrometer)	$LC =$ pitch $/$ thimble divisions	0.5 / 50 = 0.01 mm
Least count (bevel protractor)	$LC = 2° - 23°/12 = 1/12°$	= 5 minutes
Sine bar	$\sin \theta = h / L$	h = slip-gauge height, L = roller centre distance
Sine bar error	$d\theta = dh / (L \cos \theta)$	Error grows as θ → 90°, so keep θ ≤ 45°
Indexing (dividing head)	turns of crank $= 40 / N$	N = number of divisions

Key numbers

- Drill point angle: **118°** (general); helix angle ≈ **30°**; lip clearance **8–12°**; chisel edge angle **120–135°**
- Chisel edge produces about **50–60% of the thrust** but little torque
- HSS 18-4-1 = 18% W, 4% Cr, 1% V; hot hardness up to about **600 °C**
- Flank wear tool-life criterion: VB ≈ **0.3 mm** average (0.6 mm max)
- Capstan hexagonal turret: **6** tools, indexes **1/6 rev (60°)**

Least counts

- Steel rule: 0.5–1 mm
- Vernier caliper: **0.02 mm** (also 0.05, 0.1 mm models)
- Micrometer: **0.01 mm** (0.001 mm with a vernier on the sleeve)
- Bevel protractor: **5′**
- Dial indicator: 0.01 mm (0.001 fine)
- Sine bar: angle accuracy ≈ **a few seconds to minutes**, set by the slip gauges

EXPERIMENT 01

Study of machines in the lab

Aim: To study the different machine tools in the lab: lathe, milling machine, drilling machine and grinding machine.

A **machine tool** is a power-driven machine that shapes metal by removing material as chips, using a cutting tool, under controlled relative motion between tool and work. Every machine tool has two motions: a **primary (cutting) motion** that removes metal and a **secondary (feed) motion** that brings new material to the tool.

Machine	Cutting motion	Feed motion	Tool
Lathe	Work rotates	Tool moves linearly	Single-point
Drilling	Drill rotates	Drill moves axially	Multi-point (2 lips)
Milling	Cutter rotates	Work (table) moves	Multi-point
Grinding	Wheel rotates (very high speed)	Work or table moves	Abrasive grains (multi-point, random geometry)
Shaper (for contrast)	Tool reciprocates	Work moves intermittently	Single-point

1. Lathe (centre lathe / engine lathe)

The "mother of all machine tools". The work is held and **rotated**, and a single-point tool is fed against it to produce cylindrical, conical, flat and threaded surfaces.

Main parts

- **Bed:** heavy cast-iron base with accurate guideways (V and flat). Aligns headstock, tailstock and carriage.
- **Headstock:** left end. Holds the hollow **spindle** (live centre or chuck) and the speed gearbox.
- **Tailstock:** right end, slides on the bed. Holds the **dead centre** to support long work, or a drill or reamer.
- **Carriage:** carries the tool. Made up of the **saddle** (slides on bed), **cross-slide** (moves across), **compound rest** (swivels for short tapers), **tool post**, and the **apron** (front, holds the feed gears, half-nut and hand wheels).
- **Lead screw:** used only for thread cutting (engaged through the half-nut).
- **Feed rod:** drives ordinary longitudinal and cross feeds.

Operations

Turning (straight, step, taper), facing, chamfering, knurling, thread cutting, drilling, boring, reaming, grooving, parting-off, forming.

Taper turning methods

Compound rest swivelling (short, steep tapers), tailstock set-over (long, gentle tapers between centres), taper-turning attachment, form tool.

Specification of a lathe

Height of centres above the bed, **swing over bed** (max diameter), **distance between centres** (max length), swing over cross-slide, spindle bore, speed range, motor power.

Work holding

3-jaw (self-centring) chuck, 4-jaw (independent) chuck, collet, between centres with a lathe dog, faceplate, mandrel.

2. Milling machine

Removes metal with a rotating **multi-point cutter** while the work, clamped on the table, is fed past it. Cutting is **intermittent**: each tooth cuts and then cools. Produces flat surfaces, slots, steps, gears and contours.

Parts (column-and-knee type)

- **Base:** foundation; often holds the coolant reservoir.
- **Column:** vertical housing for the spindle drive.
- **Knee:** slides **vertically** on the column (raised by the **elevating screw**). Gives depth of cut.
- **Saddle:** on the knee, moves **crosswise** (in and out).
- **Table:** on the saddle, moves **longitudinally**. Has T-slots for clamping.
- **Spindle:** drives the cutter. Horizontal machines add an **arbor** and **overarm**.

Types

Horizontal, vertical, universal (table swivels, used for helical work), plus planer-type, bed-type and CNC.

Up-milling vs down-milling

	Up (conventional)	Down (climb)
Cutter vs feed	Opposite	Same direction
Chip thickness	Zero → max	Max → zero
Force on work	Tends to lift it	Presses it down
Finish, tool life	Poorer	Better
Needs	Works on any machine	Backlash eliminator

Operations & cutters

Plain/slab, face, side, straddle, gang, slot, keyway (Woodruff), T-slot, form, gear cutting, end milling, slitting (saw).

Dividing head

Worm and worm wheel at 40:1. Simple indexing: crank turns = 40/N. For example, a 6-sided nut needs 40/6 = 6⅔ turns.

3. Drilling machine

Principle (from your file): the drill rotates at high speed and is fed **axially** into the work. Its two cutting lips remove material as chips and produce a round hole.

Types

- **Portable:** hand-held, small holes.
- **Sensitive / bench:** light work, holes up to about 12–15 mm. The operator "feels" the feed through the hand lever.
- **Upright / pillar:** medium work, power feed.
- **Radial:** large, heavy work. The arm swings and the head slides, so the drill is moved to the work (Exp 4).
- **Gang, multi-spindle, deep-hole, CNC:** production types.

Bench drill parts (your diagram)

Base, column, table with table clamp, spindle head, spindle, drill (in a drill chuck), drill-feed handle, step-cone pulley, belt and motor.

Operations

- **Drilling:** making a hole.
- **Reaming:** finishing an existing hole to an accurate size and smooth finish.
- **Boring:** enlarging a hole with a single-point tool.
- **Counterboring:** stepped, enlarged end (for a bolt head).
- **Countersinking:** conical enlargement (for a countersunk screw).
- **Spot facing:** flat seat around a hole.
- **Tapping:** cutting internal threads.

Drill holding

Small drills: straight shank in a **drill chuck**. Large drills: **Morse taper** shank fitted directly in the spindle (self-holding taper), removed with a drift.

4. Grinding machine

Definition (from your file): a machine tool used for **finishing** and obtaining **high dimensional accuracy** by removing very small amounts of material with a rotating abrasive wheel. **Principle:** abrasive machining. The wheel contains thousands of abrasive grains, and each grain acts like a tiny cutting tool.

Types

- **Surface grinder:** flat surfaces. Work held on a **magnetic chuck** on a reciprocating table.
- **Cylindrical grinder:** external round surfaces. Work held between centres in the headstock and tailstock. Your diagram shows the plain cylindrical grinder: headstock, grinding wheel, wheel head, tailstock, lower table, bed.
- **Centreless grinder:** no centres. The work rests on a **work-rest blade** between the **grinding wheel** and a rubber-bonded **regulating wheel**. The regulating wheel controls rotation and, when tilted, gives through-feed. Used for high-volume pins and rods.
- Others: internal, tool-and-cutter.

Grinding wheel specification

For example, `A 46 K 5 V` = abrasive · grain size · grade · structure · bond.

- **Abrasive:** A = aluminium oxide (steels); C = silicon carbide (cast iron, non-ferrous, carbides); CBN and diamond are superabrasives.
- **Grain size:** coarse 10–24, medium 30–60, fine 70–180, very fine 220–600.
- **Grade** (bond strength): A (soft) to Z (hard).
- **Structure:** 1 (dense) to 15 (open).
- **Bond:** V vitrified (most common), B resinoid, R rubber, E shellac, S silicate, M metal.

Rule: hard work material → soft wheel; soft work material → hard wheel.

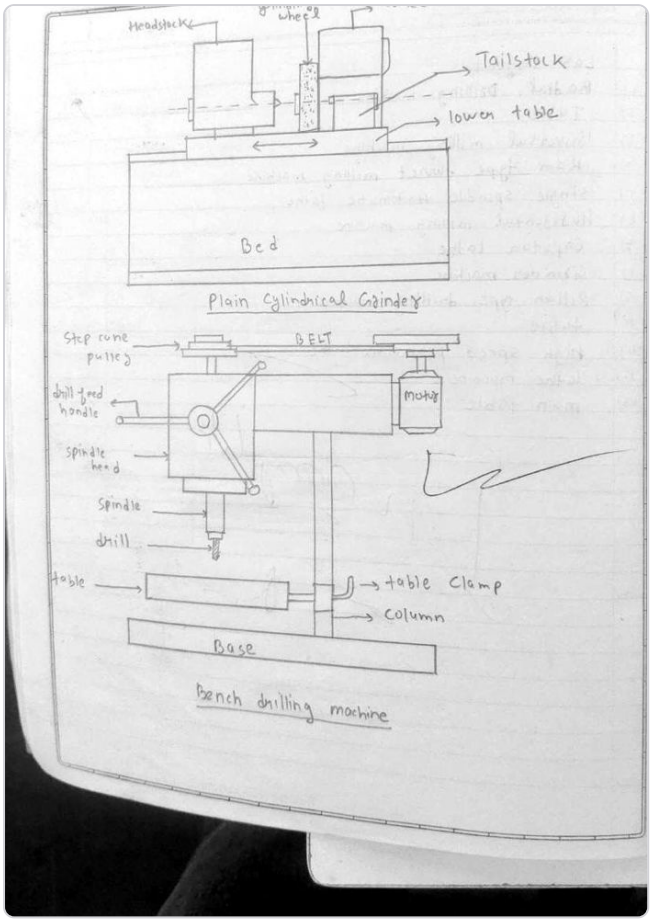
Glazing vs loading

Glazing: grains go dull but are not released (wheel too hard or too slow). The face looks shiny. **Loading:** chips clog the pores between grains (soft, ductile work such as aluminium).

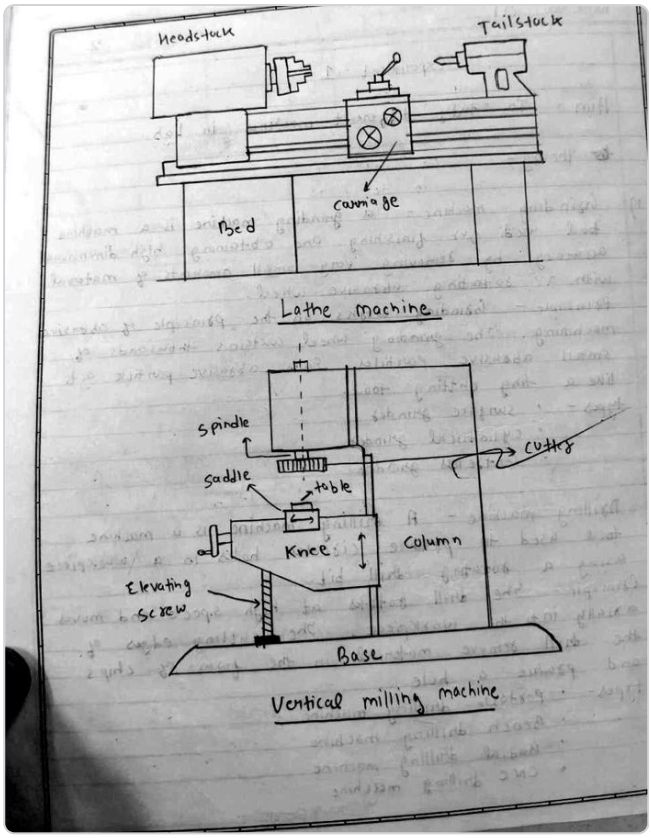
Dressing vs truing

Dressing: removes the dull or clogged layer to expose sharp grains. **Truing:** restores the wheel's true shape and makes it concentric with the spindle. A diamond dresser can do both.

Your diagrams from the file (practise drawing and labelling these)



Plain cylindrical grinder and bench drilling machine (file p. 1)



Lathe and vertical milling machine (file p. 2)

Viva questions: Experiment 1

1 **What is a machine tool?**
A power-driven machine that removes material as chips with a cutting tool, through controlled relative motion between tool and work, to give the required shape, size and finish.

2 **Difference between a machine and a machine tool?**
A machine converts energy into useful work (for example, a pump). A machine tool is a specific kind of machine that cuts or shapes material. Every machine tool is a machine, but not every machine is a machine tool.

3 **Why is the lathe called the mother of machine tools?**
It was one of the earliest machine tools and can do many operations (turning, threading, drilling, boring). The precise lead screws and spindles of other machine tools were originally made on lathes.

4 **Name the main parts of a lathe.**
Bed, headstock, tailstock, carriage (saddle, cross-slide, compound rest, tool post, apron), lead screw, feed rod, and legs or cabinet.

5 **What material is the lathe bed made of, and why?**
Grey cast iron. It has good vibration damping, is rigid in compression, is easy to cast into complex shapes, and its free graphite gives good sliding properties on the guideways.

6 **Lead screw vs feed rod?**
The lead screw is used only for
thread cutting
; it gives a positive, exact feed through the half-nut. The feed rod drives normal turning and facing feeds through the apron gears, which saves wear on the lead screw.

7 **How is a lathe specified?**
By swing over the bed (maximum diameter), distance between centres (maximum length), height of centres, spindle bore, speed range and motor power.

8 **Live centre vs dead centre?**
The live centre sits in the headstock spindle and rotates with the work. The dead centre sits in the tailstock and stays still (unless it is a revolving centre).

9 **3-jaw vs 4-jaw chuck?**
3-jaw: self-centring, all jaws move together. Quick for round or hexagonal bars, but less accurate. 4-jaw: each jaw moves independently. Holds irregular shapes and can be centred very accurately, but is slower to set up.

10 **Name the methods of taper turning.**
Swivelling the compound rest, tailstock set-over, taper-turning attachment, form tool, and (on CNC machines) combined feeds.

11 **Define cutting speed, feed and depth of cut.**
Cutting speed: relative surface speed between tool and work, $V = \pi DN/1000$ m/min. Feed: distance the tool advances per revolution of the work (mm/rev). Depth of cut: thickness of metal removed in one pass, measured perpendicular to the machined surface, $(D - d)/2$ in turning.

12 **What is knurling?**
Pressing a diamond or straight pattern onto a surface with knurling rolls to give grip (for example, on tool handles). It is a forming operation, not a cutting one.

13 **Basic principle of milling?**
A rotating multi-point cutter removes metal while the work is fed past it. Each tooth cuts intermittently.

14 **Up-milling vs down-milling?**
Up: cutter rotation opposes the feed and chip thickness goes from zero to maximum. Down (climb): rotation is in the same direction as the feed, chip thickness goes from maximum to zero, finish is better, and a backlash eliminator is needed.

15 **Name the parts of a column-and-knee milling machine.**
Base, column, knee (vertical movement via the elevating screw), saddle (cross movement), table (longitudinal movement), spindle, and on horizontal machines the arbor and overarm.

16 **Horizontal vs vertical milling?**
In horizontal milling the spindle is horizontal and cutters sit on an arbor (slab, side and face, gang milling). In vertical milling the spindle is vertical and uses end mills and face mills (slots, pockets, faces).

17 **What is a universal milling machine?**
A horizontal machine whose table can also be swivelled in the horizontal plane, typically up to 45°. Used with a dividing head for helical milling (helical gears, twist drills).

18 **What is indexing? Give the simple-indexing formula.**
Dividing the work periphery into equal parts. Dividing-head ratio is 40:1, so crank turns = 40/N. For N = 8, the crank turns 5 times.

19 **Principle of drilling?**
A rotating twist drill is fed axially into the work, and its two lips cut the metal into chips to produce a round hole.

20 **Name the types of drilling machines.**
Portable, sensitive (bench), upright (pillar), radial, gang, multi-spindle, deep-hole, CNC.

21 **Why is it called a sensitive drilling machine?**
The feed is by hand, so the operator can "sense" the cutting resistance. Useful for small drills that break easily.

22 **Drilling vs boring vs reaming?**
Drilling makes a new hole. Boring enlarges an existing hole with a single-point tool and corrects its position or straightness. Reaming finishes a hole to an exact size and smooth finish, removing very little material.

23 **Counterboring vs countersinking?**
Counterboring gives a cylindrical stepped recess for a socket-head bolt. Countersinking gives a conical recess (usually 90°) for a flat-head screw.

24 **Why is the Morse taper used?**
It is a self-holding taper (about 1:20). Friction alone holds the drill in the spindle, and it gives good centring.

25 **What is grinding and why is it used?**
Material removal by abrasive grains on a rotating wheel. Used for finishing, high accuracy (about ±0.0025 mm), good surface finish, and machining hardened materials that ordinary tools can't cut.

26 **Name the types of grinding machines.**
Surface, cylindrical (external), internal, centreless, tool-and-cutter.

27 **How does centreless grinding work?**
The work rests on a work-rest blade between the grinding wheel and a regulating wheel. The regulating wheel controls the work's speed and, when tilted a few degrees, feeds it axially (through-feed). No centres are needed, so it is fast and suits mass production of pins and shafts.

28 **Explain A 46 K 5 V.**
A = aluminium oxide abrasive, 46 = medium grain size, K = medium-soft grade, 5 = medium-dense structure, V = vitrified bond.

29 **Al_2O_3 vs SiC wheels?**
Aluminium oxide is tougher, so it is used for steels and other high-tensile materials. Silicon carbide is harder but more brittle, so it is used for cast iron, brass, aluminium, carbides and other low-tensile materials.

30 **Why is a soft wheel used on hard material?**
Hard material dulls grains quickly. A soft bond releases the dull grains so fresh sharp ones are exposed (self-sharpening), which avoids glazing.

31 **Glazing vs loading?**
Glazing: dull grains stay in place and the wheel face becomes shiny (wheel too hard). Loading: metal chips clog the wheel pores (soft, ductile work).

32 **Dressing vs truing?**
Dressing sharpens the wheel by exposing fresh grains. Truing restores its geometric shape and concentricity.

33 **Why are grinding speeds so high?**
Each grain removes a tiny chip. A high wheel speed (about 25–35 m/s) means many grains cut per second, giving a reasonable material removal rate and a fine finish.

34 **Why is coolant essential in grinding?**
Grinding generates intense heat in a tiny zone. Without coolant you get burns, cracks, loss of temper, thermal distortion and wheel loading. Coolant also flushes away chips.

EXPERIMENT 02

Tool life of an HSS tool

Aim: To determine the tool life of a given HSS tool. **Apparatus:** centre lathe, HSS single-point cutting tool, microscope (toolmaker's), vernier calipers, stopwatch.

Theory

Tool wear is the gradual loss of material from the cutting tool due to its interaction with the workpiece and chips. As the tool wears, its cutting ability falls, cutting forces and temperature rise, and the surface finish gets worse.

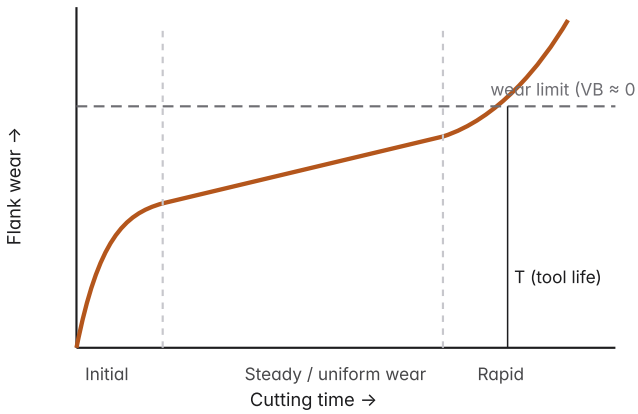
Tool life is the total cutting time for which a tool performs satisfactorily before it needs regrinding or replacing. It can be expressed as cutting time (minutes), volume of metal removed, or number of components produced.

Types of wear (from your file, expanded)

- **Flank wear (VB):** on the flank (clearance) face, from **rubbing between the tool and the newly machined surface**. Mainly abrasion. It affects size and finish, so it is the usual tool-life criterion.
- **Crater wear (KT):** a depression on the **rake face** where the hot chip slides over it. Mainly diffusion and adhesion at high temperature. It weakens the edge.
- **Nose wear:** at the tool nose radius. It affects finish.
- **Chipping:** small pieces of the edge break off (brittle tools, interrupted cuts, vibration).
- Also: notch wear at the depth-of-cut line, and plastic deformation of the edge.

Wear mechanisms

Abrasion (hard particles in the work scratch the tool), adhesion (welding and tearing, built-up edge), diffusion (atoms migrate at high temperature, causing crater wear), oxidation, and chemical wear.



Typical tool-wear curve: rapid initial (break-in) wear, a long steady region, then rapid failure. Your result matches the first two zones.

Your readings (cumulative wear, inches): 0.003 → 0.004 → 0.005 → 0.006 → 0.008 after 1, 2, 3, 4 and 5 minutes. The big first step (0.003 in the first minute) is the **initial rapid wear**. After that it grows by about 0.001 per minute, which is the **steady-state zone**.

Taylor's tool life equation

$$V \cdot T^n = C$$

Symbol	Meaning
V	Cutting speed (m/min) = πDN/1000
T	Tool life (min)
n	Taylor exponent. Depends mainly on the **tool material**: HSS ≈ 0.08–0.2 (take 0.125), carbide ≈ 0.2–0.5 (take 0.25), ceramic ≈ 0.5–0.7
C	Taylor constant: the cutting speed that gives a 1-minute tool life. Depends on the tool–work pair, feed, depth and fluid

- On a **log–log plot**, log V + n log T = log C is a straight line with slope −n. Two tests at different speeds give n and C.
- **Speed has the strongest effect on tool life**, then feed, then depth of cut. That's why the extended form is $V \cdot T^n \cdot f^a \cdot d^b = K$ with a > b.
- **Worked example:** HSS tool, n = 0.125. At 30 m/min, T = 60 min. What speed gives T = 30 min? $V_2 = 30 \times (60/30)^{0.125} = 30 \times 1.0905 \approx$ **32.7 m/min**. Halving the tool life only allows about a 9% speed increase.
- Conversely, with n = 0.125, **doubling the speed cuts tool life by 2^(1/0.125) = 256 times**.

Procedure (your file)

1. Note the initial tool-wear reading under the microscope.
2. Machine on the lathe for 1 minute and note the wear reading.
3. Repeat for 2 minutes and record.
4. Repeat for 3, 4 and 5 minutes.
5. Calculate wear and cumulative wear (inches) for each reading.
6. Plot cumulative time against cumulative wear.

Result

Tool wear was comparatively high in the initial stage, then the wear rate became comparatively steady in the secondary stage.

Precautions

1. Hold the workpiece properly in the chuck.
2. Clamp the HSS tool properly, at centre height.
3. Take readings accurately.
4. Set the measuring instrument to zero before taking readings.
5. Follow lathe safety precautions.

Single-point cutting tool: what they love to ask

- **Rake face:** the surface the chip flows over. **Flank:** the surface facing the machined work.
- **Rake angle:** inclination of the rake face. Positive rake means lower force and a better finish but a weaker edge. Negative rake gives a strong edge (used on carbides and ceramics).
- **Clearance (relief) angle:** stops the flank rubbing on the work. About 5–8°.
- **Nose radius:** strengthens the tip and improves finish. Too large a radius causes chatter.
- **Cutting edge angles:** the side cutting edge angle (approach angle) spreads the load; the end cutting edge angle avoids rubbing.
- **Tool signature (ASA):** back rake – side rake – end relief – side relief – end cutting-edge angle – side cutting-edge angle – nose radius. For example, `8-14-6-6-6-15-1`.
- **HSS 18-4-1:** 18% tungsten, 4% chromium, 1% vanadium, about 0.7% carbon. Hot (red) hardness up to about 600 °C. Tough and easy to regrind.
- **Tool material order** (increasing hot hardness): carbon steel → HSS → cast alloy (Stellite) → cemented carbide → ceramic → CBN → diamond.

Viva questions: Experiment 2

1 **What is tool life?**
The time a tool cuts satisfactorily between two consecutive regrinds, that is, until it reaches a set wear criterion.

2 **What are the different ways of expressing tool life?**
Cutting time in minutes, volume of metal removed per regrind, or number of components produced per regrind.

3 **State Taylor's tool life equation.**
$VT^n = C$, where V is cutting speed, T is tool life in minutes, n is an exponent that depends mainly on the tool material, and C is a constant.

4 **What is the physical meaning of C?**
The cutting speed at which the tool life is exactly 1 minute.

5 **Typical values of n?**
HSS ≈ 0.1–0.15, carbide ≈ 0.2–0.4, ceramic ≈ 0.5–0.7. A higher n means tool life is less sensitive to speed.

6 **How do you find n and C experimentally?**
Find T at two or more speeds, then plot log V against log T. The slope is −n and the intercept (at T = 1 min) gives C. Or solve $V_1T_1^n = V_2T_2^n$.

7 **Which factor affects tool life most?**
Cutting speed, then feed, then depth of cut. Speed raises the cutting temperature most strongly.

8 **What other factors affect tool life?**
Tool material and geometry, work material (hardness, inclusions), feed and depth of cut, cutting fluid, rigidity of the machine and setup, and type of cut (continuous or interrupted).

9 **Name the types of tool wear.**
Flank wear, crater wear, nose wear, chipping, notch wear, and plastic deformation of the edge.

10 **What causes flank wear, and why is it the usual tool-life criterion?**
Abrasion from rubbing between the flank and the machined surface. It directly affects the dimension and surface finish of the job and is easy to measure, so VB ≈ 0.3 mm (average) is used as the criterion.

11 **What causes crater wear? Where does it occur?**
It occurs on the rake face, a little behind the cutting edge, where the hot chip slides. It is mainly caused by diffusion and adhesion at high temperature, and is serious in carbide tools cutting steel at high speed.

12 **Explain the three zones of the wear curve.**
(1) Initial or break-in: rapid wear as the sharp edge rounds off. (2) Steady state: slow, uniform wear, which is most of the useful life. (3) Rapid or catastrophic: temperature rises and wear accelerates, and the tool fails.

13 **What did you observe in your experiment?**
Wear was high at first (0.003 in after 1 minute), then increased steadily by about 0.001 in per minute. The tool was in the initial and steady-state zones.

14 **What was used to measure wear?**
A toolmaker's (or tool wear) microscope, which measures the flank wear land width. A vernier was used for dimensions and a stopwatch for cutting time.

15 **What is HSS? Composition?**
High-speed steel, 18-4-1: 18% W, 4% Cr, 1% V. It keeps its hardness up to about 600 °C, can cut at roughly 2–3 times the speed of carbon steel tools, and is tough.

16 **What is hot (red) hardness?**
The ability of a tool material to keep its hardness at high temperature.

17 **Why do HSS tools cut at lower speed than carbides?**
HSS softens above about 600 °C, while carbides keep their hardness up to about 1000 °C.

18 **What is a built-up edge (BUE)?**
Work material welds onto the tool tip under high pressure at low speed. It changes the effective tool geometry, spoils the finish, and when it breaks away it can chip the tool. Higher speed, positive rake and coolant reduce it.

19 **What are the functions of cutting fluid?**
Cooling (longer tool life), lubrication (less friction and BUE), flushing chips away, better finish, and corrosion protection.

20 **What is machinability?**
The ease with which a material can be machined. It is judged by tool life, surface finish, cutting forces or power, and chip form.

21 **If speed is doubled with n = 0.125, what happens to tool life?**
$T_2/T_1 = (V_1/V_2)^{(1/n)} = (1/2)^8 = 1/256$. Tool life falls about 256 times.

22 **Why is a graph of cumulative time against cumulative wear plotted?**
To show the wear rate (the slope) in each zone and to read off the tool life where the curve crosses the wear limit.

23 **What is the extended Taylor equation?**
$VT^nf^ad^b = K$. It includes the feed and depth-of-cut effects (a > b, because feed affects tool life more than depth).

24 **What is economic tool life?**
The tool life that minimises the total cost per component. It balances machining cost, which falls with higher speed, against tool cost, which rises with higher speed.

25 **Define rake angle and clearance angle.**
Rake angle: inclination of the rake face from the reference plane. It controls chip flow and cutting force.
Clearance angle: the angle between the flank and the machined surface. It prevents rubbing.

EXPERIMENT 03

Capstan lathe

Aim: To study the capstan lathe.

A capstan lathe is a **semi-automatic, special-purpose production lathe** for **mass and batch production** of small and medium-sized identical parts. It is a modified centre lathe in which the **tailstock is replaced by a hexagonal turret** carrying several tools. All tools are set once. After that a semi-skilled operator simply brings each tool into position in sequence, so the parts come out identical and quickly.

It is called a **capstan** lathe because the hexagonal tool head (turret) is moved by a **capstan wheel** with spokes, like a ship's capstan.

Main parts

1. **Bed:** robust base that carries the headstock and turret saddle, and aligns the carriage and turret parallel to the spindle axis.
2. **Headstock:** a large casing at the left end. Types: step-cone-pulley driven, direct electric-motor driven, all-geared, or preselective. Usually has a **collet chuck** for bar work.
3. **Cross-slide and saddle:** on small capstans these are hand-operated and clamped on the bed at the required position. They carry a **square (front) turret** with 4 tools and a **rear tool post** for parting-off and forming.
4. **Turret saddle and auxiliary slide (ram):** the turret saddle bridges the two bedways and is clamped. Its accurately machined top carries the **auxiliary slide (ram)**, and the **hexagonal turret** is mounted on the ram. When the ram is pulled back after an operation, the turret **indexes automatically** to the next tool.

Mechanisms

1. Turret indexing mechanism. At the end of the return (withdrawal) stroke the turret rotates automatically by **1/6 of a revolution (60°)**, bringing the next tool into line. The turret head, index plate, bevel gear and ratchet sit on the same vertical spindle in the saddle. A **spring-loaded plunger** locks the index plate, so the turret can't rotate while cutting. On the return stroke a cam (a pin fitted to the plunger) lifts the plunger, the indexing pawl engages the ratchet and rotates the turret, then the plunger drops into the next slot to lock it.

2. Bar feeding mechanism. The bar is fed without stopping the machine. The bar passes through the hollow spindle and is gripped by a **collet**. A bar chuck (fixed to the bar with set screws) rotates in a sleeve on a sliding bracket. A **chain with a suspended weight** pulls the bar chuck towards the headstock. When the collet opens, the weight pushes the bar forward until it butts against the **bar stop** held in the turret. Then the collet is closed.

3. Stops: adjustable stop rods, one for each turret face, limit the ram travel, so every part gets exactly the same length.

Capstan lathe vs turret lathe vs centre lathe

Feature	Capstan lathe	Turret lathe
Turret mounted on	Ram (auxiliary slide) that slides on a saddle clamped to the bed	Saddle that moves directly on the bed
Stroke	Short	Long
Work size	Small and light, bar work (up to about 60 mm)	Large and heavy, chucking work
Operation	Easy, because the ram is light	Tiring, because the whole saddle moves
Rigidity	Less (ram overhang)	More
Speed	Faster for small parts	Slower but handles heavier cuts

Feature	Centre lathe	Capstan / turret lathe
Tailstock	Yes	Replaced by the hexagonal turret
Tools set at once	1 (or 4 in a square post)	Up to 6 + 4 + 1 (rear)
Thread cutting	Lead screw	Die head or tap, or a chasing attachment
Operator	Skilled	Semi-skilled (after tool setting)
Suited to	One-off, repair, toolroom	Batch and mass production

Advantages (your file)

1. A tool-post turret carries about 6 tools, plus a rear tool post for an inverted (parting) tool.
2. No lead screw: die heads are used to cut threads.
3. No tailstock. A slide and a (generally hexagonal) turret hold the tools instead.
4. Quick-acting back gear.
5. Adjustable stops limit the saddle motion.

Disadvantages

1. Limited to relatively small and medium-sized workpieces.
2. Not suitable for very heavy or large jobs, because of its construction.
3. Higher initial cost than a centre lathe.
4. Needs skilled tool setting and a long setup time, so it isn't economical for small batches.
5. Tooling cost is high.

Viva questions: Experiment 3

1 **What is a capstan lathe?**
A semi-automatic production lathe in which the tailstock is replaced by a hexagonal turret holding 6 tools. Used to make many identical small parts quickly.

2 **Why is it called "capstan"?**
The turret is moved by a spoked capstan wheel, like the capstan used on ships to wind ropes.

3 **Main difference between a capstan and a turret lathe?**
In a capstan lathe the turret is on a **ram** that slides on a **clamped saddle** (short stroke, light work). In a turret lathe the turret is directly on a **saddle that moves along the bed** (long stroke, heavy work).

4 **Why does a capstan lathe have no tailstock?**
The hexagonal turret takes its place. Drilling, reaming and centring tools held in the turret do the jobs the tailstock would do.

5 **How many tools can be mounted at once?**
6 on the hexagonal turret, 4 on the square front turret on the cross-slide, and 1 on the rear tool post, so up to 11.

6 **By how much does the turret index?**
1/6 of a revolution (60°) per stroke for a hexagonal turret.

7 **Explain the turret indexing mechanism.**
On the return stroke of the ram, a cam lifts the spring-loaded locking plunger out of the index plate. A pawl then engages the ratchet and rotates the turret 60°, and the plunger drops into the next slot to lock it. Indexing is automatic.

8 **What is the purpose of the locking plunger?**
It holds the turret rigidly in position during cutting so it can't rotate under cutting forces.

9 **Explain the bar feeding mechanism.**
The bar passes through the hollow spindle and is held by a collet. A weight on a chain keeps pushing the bar forward. When the collet is released the bar moves forward until it hits the bar stop in the turret, then the collet is closed. The machine doesn't need to stop.

10 **Why is a collet chuck used for bar work?**
It grips round bar concentrically, opens and closes very quickly, and lets the bar feed through.

11 **What is the function of adjustable stops?**
They limit the travel of the ram or saddle for each tool, so every component is machined to the same length without measuring each time.

12 **How are threads cut on a capstan lathe?**
With a self-opening die head (external threads) or a tap (internal threads) held in the turret. There is usually no lead screw, although some have a thread-chasing attachment.

13 **What is tool layout?**
Planning the sequence of operations and deciding which tool goes in which turret or tool-post station, to minimise the machining time per piece.

14 **Name some typical capstan lathe tools.**
Bar stop, centre drill, twist drill, roller steady turning tool, box tool, knee tool, reamer, die head, tap, chamfering tool, parting tool (rear post).

15 **What are the types of capstan headstock?**
Step-cone-pulley driven, direct electric-motor driven, all-geared, and preselective.

16 **Is a capstan lathe automatic?**
It is semi-automatic. The operator loads the work and moves the turret, while indexing, stops and bar feed are automatic. Fully automatic lathes (single- or multi-spindle automats) do everything by cams.

17 **When would you use a capstan lathe instead of a CNC lathe?**
For medium batches of simple parts where it costs less, or where CNC isn't available. CNC is preferred for complex profiles and frequent changeovers.

18 **Why isn't a capstan lathe economical for small batches?**
Setting up the tools takes a long time. That setup time is only worth it when spread over many parts.

19 **What does the turret saddle do?**
It bridges the gap between the two bedways and provides an accurately machined bearing surface for the auxiliary slide (ram).

20 **Why is a capstan lathe faster than a centre lathe?**
All tools are preset, tool changes take seconds (by indexing), stops remove the need to measure, bar feeding is quick, and several tools can cut at once (turret and cross-slide together).

EXPERIMENT 04

Thrust & torque in drilling

Aim: To study the effect of changes in cutting speed, feed and drill diameter on the thrust and torque while drilling on a radial drilling machine. **Apparatus:** radial drilling machine, different drills, drill chuck, drill dynamometer.

Radial drilling machine

Intended for drilling **medium to large and heavy workpieces**. It has a heavy, round vertical **column** on a large **base**. The column supports a **radial arm** that can be **raised and lowered** (by an elevating screw) to suit work of different heights, and **swung** to any position over the work bed. The **drill head**, containing the mechanism for rotating and feeding the drill, slides **horizontally** along guideways on the arm. To drill several holes in a large workpiece, you move the arm and head, not the work.

Specification: column diameter, length of arm (maximum radius at which a hole can be drilled), maximum drill diameter, spindle travel, speed and feed ranges, motor power. **Types:** plain (arm moves up, down and round), semi-universal (the head can also tilt), and universal (the arm can also rotate about its own axis, for angled holes).

Twist drill geometry and nomenclature

Element	Description	Typical value
Shank	Cylindrical (straight) or tapered (Morse) end held in the spindle or chuck	—
Tang	Flat end of a taper shank. Drives the drill and is used to knock it out	—
Body	The part between shank and point	—
Flutes	Helical grooves that form the cutting edges, carry chips out and let coolant in	2
Point angle (2θ)	Included angle between the two cutting lips	118° general; 135–140° hard steel; 90° plastics
Helix angle (ψ)	Angle between the flute's leading edge and the drill axis. It gives the effective **rake angle**	≈ 30° (20–32°)
Lip clearance angle	Relief ground behind the lips to stop the body rubbing on the bottom of the hole	8–12°
Chisel edge	Short edge across the web at the centre. It doesn't cut cleanly: it **indents and extrudes** material	Chisel edge angle 120–135°
Web	Central metal between the flutes. Gets thicker towards the shank	—
Margin / land	Narrow full-diameter strip along the flute. Guides the drill and sizes the hole	—
Body clearance	Reduced diameter behind the margin. Lowers friction with the hole wall	—

Forces in drilling

- **Thrust force (Fz):** axial force acting parallel to the drill axis. Notably, **50–60% of the total thrust comes from the chisel edge**, because of its non-shearing, indenting action (very negative rake).
- **Torque (T):** the rotational moment resisting spindle motion. It comes **mainly from the cutting lips**, with a small contribution from friction at the margins.

That's why a **pilot hole** (or web thinning) sharply reduces thrust: it removes the chisel edge's work.

Dynamometer types

Dynamometers convert the mechanical strain caused by machining forces into measurable electrical (or hydraulic) signals.

1. **Strain gauge:** metal foil gauges bonded to an elastic body. Versatile, rugged and cheap, for both static and dynamic forces. This is the type used in the lab.
2. **Piezoelectric:** quartz crystals release electric charge in proportion to the applied force. High stiffness and high natural frequency, so excellent for dynamic forces, but expensive.
3. **Hydraulic:** force is sensed through fluid displacement and pressure gauges. Simple, but limited to low-speed static tests because of slow response.

Working principle: strain gauge drill dynamometer

- It measures **thrust (Fz) and torque (T) at the same time**. It is a two-component dynamometer.
- **Sensing element:** a hollow cylindrical steel elastic element mounted under the workpiece stage.
- **Gauge layout:** thrust gauges are mounted **parallel to the cylinder axis** to sense axial strain. Torque gauges are mounted at **45° to the axis**, because torsion produces its maximum principal strain at 45°.
- **Resistance change:** the electrical resistance change ΔR relates directly to the strain ε: $\Delta R/R = GF \cdot \varepsilon$ ($GF \approx 2$).
- **Signal:** the resistance changes unbalance a **Wheatstone bridge**, which outputs millivolt signals. These are amplified and recorded through a DAQ (data acquisition) system.

Procedure

1. Secure the workpiece on the strain gauge dynamometer.
2. Set the required cutting speed, feed and drill diameter on the radial drill.
3. Drill while varying **one parameter at a time** and keeping the others constant. Record thrust and torque.
4. Repeat for other combinations and tabulate the values.

Results: effect of each parameter

Increase in	Thrust	Torque	Why
Feed (f)	↑	↑	Thicker uncut chip. F, T ∝ f^0.7–0.8
Drill diameter (d)	↑↑	↑↑↑	Longer cutting edge. Torque also has a longer lever arm (T roughly ∝ d^2)
Cutting speed (N)	slight ↓	slight ↓	Higher temperature causes thermal softening of the work

Your file's margin tables show three torque sets (kgf·m): 1.1 / 0.4 / 1.1, then 1.1 / 2.3 / 7.5, then 1.1 / 1.0 / 1.2. The column labels weren't visible in the scan. The sharply rising set matches feed or diameter, and the nearly flat set matches speed. Check your own page before the viva.

Viva questions: Experiment 4

1 **What is the aim of this experiment?**
To find how cutting speed, feed and drill diameter affect the thrust force and torque in drilling, measured with a drill dynamometer on a radial drilling machine.

2 **Why use a radial drilling machine?**
For large, heavy work that can't be moved easily. The arm swings, rises and falls, and the head slides, so the drill can reach any point.

3 **Name the parts of a radial drill.**
Base, column, radial arm, elevating screw, drill head, spindle, feed mechanism, and work table.

4 **How is a radial drill specified?**
By arm length (maximum radius), column diameter, maximum drill size, spindle travel, and speed and feed ranges.

5 **What forces act in drilling?**
Thrust force (axial, along the drill axis) and torque (resisting rotation). There are also small radial forces, which cancel out if the lips are symmetric.

6 **What contributes most of the thrust?**
The chisel edge, about 50–60%. It doesn't shear the metal but pushes and extrudes it, because of its large negative rake.

7 **What contributes most of the torque?**
The two cutting lips (main cutting edges), with a small contribution from margin friction.

8 **How can thrust be reduced?**
Drill a pilot hole, thin the web, use a split-point drill, reduce the feed, or use a sharp drill with coolant.

9 **Effect of feed on thrust and torque?**
Both increase, roughly in proportion to f^0.7–0.8, because the uncut chip thickness increases.

10 **Effect of drill diameter?**
Both increase. Thrust rises roughly with d. Torque rises more steeply (roughly d^1.8–2), because the cutting edge is longer and the lever arm is larger.

11 **Effect of cutting speed?**
A slight decrease in thrust and torque, because the higher temperature softens the work material. The effect is much smaller than that of feed or diameter.

12 **What is the standard point angle? When is it changed?**
118° for general steel. 135–140° for hard or tough materials (stronger point). About 90° or less for plastics, wood and soft materials.

13 **What is the helix angle and its effect?**
The angle of the flutes to the axis, about 30°. It gives the effective rake angle. A high helix suits soft materials such as aluminium (better chip flow); a low helix suits brass and hard materials.

14 **Why is lip clearance needed?**
So the flank behind the lip doesn't rub on the bottom of the hole. Too little clearance means rubbing and heat. Too much means a weak edge.

15 **What is the chisel edge?**
The short edge across the web at the drill centre. It indents rather than cuts, and causes high thrust.

16 **What is the margin for?**
A narrow strip at full diameter that guides the drill in the hole and sizes the hole. The body clearance behind it reduces friction.

17 **What is a dynamometer?**
An instrument that measures force or torque (here, cutting forces) by converting the strain or deflection into an electrical or hydraulic signal.

18 **What are the requirements of a good dynamometer?**
High stiffness (so the deflection doesn't disturb cutting), high sensitivity, high natural frequency (for dynamic forces), no cross-talk between components, linearity, and stability.

19 **Types of dynamometers?**
Strain gauge, piezoelectric, hydraulic, plus mechanical, pneumatic and capacitive types.

20 **Principle of a strain gauge?**
When a conductor is strained, its resistance changes: $\Delta R/R = GF \cdot \varepsilon$. Gauges bonded to an elastic element sense the strain produced by the force.

21 **What is the gauge factor?**
The ratio of the fractional change in resistance to the strain: $GF = (\Delta R/R)/\varepsilon$. About 2 for metal foil and about 100+ for semiconductor gauges.

22 **Why are torque gauges at 45°?**
Pure torsion produces maximum principal (tensile and compressive) strains at ±45° to the shaft axis, so gauges there are most sensitive to torque and insensitive to axial load.

23 **Why use a Wheatstone bridge?**
It turns very small resistance changes into a measurable voltage. A full bridge also compensates for temperature and boosts sensitivity.

24 **Piezoelectric vs strain gauge dynamometer?**
Piezo (quartz): very stiff, high natural frequency, best for dynamic and fast forces, but expensive and with charge drift over long static periods. Strain gauge: cheaper, rugged, good for static and moderate dynamic forces.

25 **Why vary only one parameter at a time?**
So the change in thrust or torque can be attributed to that one parameter alone.

26 **How do you calculate drilling power from torque?**
$P = 2\pi NT/60$ watts, with T in N·m and N in rpm. Convert kgf·m to N·m by multiplying by 9.81.

27 **What is the MRR in drilling?**
$MRR = (\pi d^2/4) \times f \times N$ mm³/min.

28 **What materials are drills made of?**
HSS (most common), cobalt HSS, solid carbide, and carbide-tipped. Often coated with TiN (gold colour).

EXPERIMENT 05

Cutting forces in turning

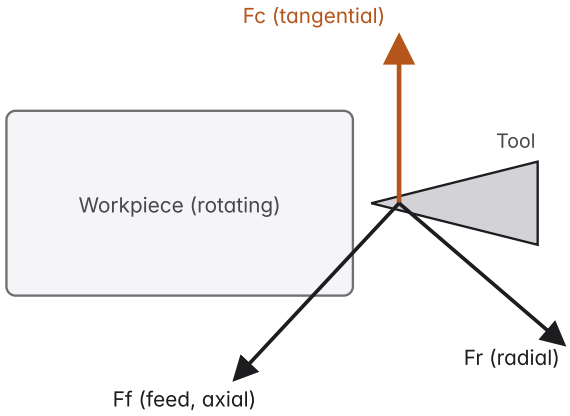
Aim: To study the forces developed during turning on a lathe and understand their measurement and analysis using a tool dynamometer.

In turning, forces arise from (i) **shearing** of the work material in the shear zone, (ii) **friction** between the chip and the rake face, and (iii) contact between the tool flank and the machined surface. Force analysis helps estimate cutting power, choose machining parameters, design machines and fixtures, and improve tool life and surface finish.

Three force components

1. **Cutting (tangential) force, Fc:** acts tangentially to the rotating work, opposing the cutting motion. It is the **largest component** and is used to calculate **cutting power**.
2. **Feed (axial) force, Ff:** acts parallel to the feed direction, along the work axis in longitudinal turning. It comes from the feed motion and the tool–chip interaction.
3. **Radial (thrust) force, Fr:** perpendicular to the machined surface. It tends to push the tool and work apart, which can cause **deflection, vibration (chatter) and dimensional errors**.

Rough proportion: **Fc : Ff : Fr ≈ 1 : 0.4–0.5 : 0.2–0.3** (it varies with tool geometry).



The three mutually perpendicular force components on a turning tool (schematic, as felt by the tool).

Measurement of lathe cutting forces

A **lathe tool dynamometer** is fitted between the cutting tool and the tool post. It measures one or more force components during turning. In a **strain gauge** dynamometer the elastic deformation becomes a change in electrical resistance. In a **piezoelectric** dynamometer the force generates electric charge. The signals are calibrated and displayed as force readings. Three-component lathe dynamometers measure Fc, Ff and Fr together.

Common methods: (1) direct measurement with a tool dynamometer; (2) indirect estimation from cutting power or spindle torque (the wattmeter method); (3) measuring tool or work deflection and inferring the force through calibration.

Analysis of turning forces

Cutting power

$$P_c = F_c \cdot V / 60000 \text{ kW}$$

Fc in N, V in m/min. This is the ideal power at the tool. Motor input is higher because of machine and drive losses: P_motor = Pc / η.

Cutting speed

$$V = \pi D N / 1000$$

V in m/min, D in mm, N in rpm.

Resultant force

$$R = \sqrt{F_c^2 + F_f^2 + F_r^2}$$

Valid because the three measured components are mutually perpendicular.

Worked example: D = 50 mm, N = 400 rpm, so V = π×50×400/1000 = 62.8 m/min. With Fc = 800 N: Pc = 800×62.8/60000 = **0.84 kW**. If Ff = 350 N and Fr = 200 N, then R = √(800² + 350² + 200²) = **895.8 N**.

Orthogonal cutting and Merchant's analysis

In the simplified **orthogonal** model the cutting edge is perpendicular to the cutting velocity, so there are only two forces: **Fc** (cutting) and **Ft** (thrust). These are resolved into forces on the **tool rake face** and on the **shear plane**. The model explains chip formation. Practical turning is usually **oblique**: the edge is inclined at an angle λ, and there are three forces.

Let α = rake angle, φ = shear angle, β = friction angle.

Friction force on rake face	$F = Fc \sin\alpha + Ft \cos\alpha$
Normal force on rake face	$N = Fc \cos\alpha - Ft \sin\alpha$
Shear force on shear plane	$Fs = Fc \cos\varphi - Ft \sin\varphi$
Normal force on shear plane	$Fn = Fc \sin\varphi + Ft \cos\varphi$
Coefficient of friction	$\mu = \tan\beta = F / N$
Chip thickness ratio	$r = t_1 / t_2$ (< 1)
Shear angle	$\tan\varphi = r\cos\alpha / (1 - r\sin\alpha)$
Merchant's relation	$\varphi = 45° + \alpha/2 - \beta/2$
Shear strain	$\gamma = \cot\varphi + \tan(\varphi - \alpha)$
Shear plane area	$As = b \cdot t_1 / \sin\varphi$

t_1 = uncut chip thickness, t_2 = chip thickness after cutting. Merchant's relation rests on simplifying assumptions, so it is an approximation rather than a universal law.

Merchant's assumptions

- The tool is perfectly sharp (no flank contact).
- Shear happens on a single thin plane.
- The chip is continuous with no built-up edge.
- Plane strain: the width of cut is much larger than its depth.
- Uniform stress on the shear plane, constant friction coefficient.
- The work material shears at the angle that minimises the energy needed.

Merchant's circle

A force diagram in which Fc and Ft, F and N, and Fs and Fn are all drawn as pairs of components of the same resultant R, so they lie on one circle whose diameter is R. It lets you find all the forces graphically from the two measured ones.

Chip types

Continuous (ductile material, high speed, positive rake, which is good). **Continuous with BUE** (ductile material, low speed, high friction). **Discontinuous** (brittle materials such as cast iron, low speed). **Serrated** (hard-to-machine metals such as titanium).

Procedure

1. Secure the workpiece in the chuck and clamp the cutting tool properly.
2. Mount the dynamometer and zero it according to the instrument instructions.
3. Select a suitable spindle speed, feed and depth of cut.
4. Perform a short turning pass.
5. Record the cutting, feed and radial force readings once they stabilise.
6. Repeat for other conditions, changing one parameter at a time.
7. Calculate the cutting speed, resultant force and cutting power.

Precautions

1. Clamp the workpiece firmly.
2. Calibrate the dynamometer before taking readings.
3. Don't overload the dynamometer.
4. Keep cutting conditions steady during each reading.
5. Never touch the rotating workpiece.

Result

The principal force components developed during lathe turning, and their analysis, were studied. The resultant force and cutting power can be found from the measured force components and the machining parameters.

Viva questions: Experiment 5

1 **What are the three force components in turning?**
Cutting (tangential) force Fc, feed (axial) force Ff, and radial (thrust) force Fr.

2 **Which is the largest, and why does it matter most?**
Fc. It acts in the direction of cutting velocity, so it alone does almost all the work: power = Fc × V.

3 **Why do Ff and Fr consume almost no power?**
Power is force times velocity in that force's direction. The feed velocity is tiny and there is no radial velocity, so their power is negligible.

4 **What problems does the radial force cause?**
It pushes the tool and work apart, causing deflection (especially in long, slender work), chatter and dimensional (taper) errors.

5 **What is a tool dynamometer?**
A device fitted between the tool and the tool post that measures the cutting force components, usually with strain gauges or piezoelectric crystals.

6 **Name the types of lathe tool dynamometer.**
Mechanical, hydraulic, pneumatic, strain gauge (most common in labs), and piezoelectric (Kistler type).

7 **Why should a dynamometer be stiff?**
So its deflection under load doesn't change the depth of cut or cause vibration, which would alter the very forces being measured.

8 **Why zero or calibrate the dynamometer before cutting?**
To remove the offset caused by the tool's weight, clamping and temperature, so the readings reflect only the cutting forces.

9 **Formula for cutting power?**
$P_c = F_c \cdot V / 60000$ kW, with Fc in N and V in m/min.

10 **Why is motor power greater than cutting power?**
Because of losses in the gears, belts, bearings and motor. $P_{motor} = P_c / \eta$.

11 **Orthogonal vs oblique cutting?**
Orthogonal: the cutting edge is perpendicular to the cutting velocity, there are 2 force components, and the chip flows along the rake face. Oblique: the edge is inclined at angle λ, there are 3 force components, and the chip flows sideways. Most real turning is oblique.

12 **What is the shear plane and shear angle?**
The plane along which the work material shears to form the chip. The shear angle φ is the angle between this plane and the cutting velocity direction.

13 **Define chip thickness ratio.**
$r = t_1/t_2$, uncut chip thickness divided by chip thickness. It is always less than 1 because the chip thickens. Its reciprocal is the chip reduction coefficient.

14 **How is the shear angle found experimentally?**
Measure the chip thickness (or chip length) to get r, then use $\tan \varphi = r \cos \alpha / (1 - r \sin \alpha)$.

15 **State Merchant's relation.**
φ = 45° + α/2 − β/2. A higher rake angle or lower friction gives a larger shear angle, a thinner chip and lower forces.

16 **What is Merchant's circle?**
A graphical construction in which the resultant force R is the diameter of a circle and three pairs of components (Fc and Ft, F and N, Fs and Fn) are drawn inside it. It relates the measured forces to the forces on the shear plane and the rake face.

17 **State Merchant's assumptions.**
Sharp tool, shearing on a single plane, continuous chip with no BUE, plane strain, uniform stress, constant friction, and minimum energy.

18 **Effect of rake angle on cutting force?**
Increasing the (positive) rake angle lowers the cutting force, because the shear angle increases and the chip deforms less. But the edge becomes weaker.

19 **Effect of feed and depth of cut on Fc?**
Both increase Fc, roughly in proportion to the chip area (f × d). Depth has a nearly linear effect; feed has a slightly less than linear effect.

20 **Effect of cutting speed on Fc?**
A slight decrease at higher speeds, due to thermal softening, a lower friction coefficient and less BUE.

21 **What is specific cutting energy (pressure)?**
The energy needed to remove a unit volume of material: u = Fc / (f·d) in N/mm² (= J/mm³). It is a property of the work material.

22 **Name the types of chips.**
Continuous, continuous with built-up edge, discontinuous, and serrated (segmented).

23 **When are discontinuous chips formed?**
When machining brittle materials (cast iron, brass) or at low speeds with large feeds.

24 **Why is the resultant found by √(sum of squares)?**
Because the three components act along mutually perpendicular axes.

25 **Indirect ways of finding cutting force?**
From power drawn by the motor (wattmeter): Fc = 60000·P·η / V. Or from spindle torque, or from tool deflection with calibration.

26 **Why is a single-point tool used for turning?**
It cuts with one main edge, which is simple to grind and set, and suits the continuous cut of a rotating workpiece.

27 **What is the friction angle?**
β, where tan β = μ = F/N on the rake face. It is the angle between the resultant force and the normal to the rake face.

EXPERIMENT 06

Vernier caliper

Aim: To measure the dimensions of a given specimen with a vernier caliper.
Apparatus: vernier caliper, specimen. (The first page of this experiment isn't in your scan, so this is the standard aim.)

Vernier principle

When two scales whose divisions differ slightly in size are used together, the difference between them can be used to improve the accuracy of measurement. Invented by **Pierre Vernier** (1631).

Construction

- **Main scale:** a long, thin, graduated steel strip with a fixed jaw at one end.
- **Vernier scale:** a graduated strip with a movable jaw that slides over the main scale.
- **Lower (outside) jaws** measure external dimensions. **Upper (inside) jaws** measure internal dimensions such as bore diameter.
- **Depth probe (depth bar):** a long, thin strip attached to the back of the vernier. It measures the depth of holes, cylinders and hollow tubes.
- **Locking screw** and a **fine-adjustment screw**.

Least count

The smallest measurement that can be recorded accurately with the instrument.

The vernier has **50 divisions** covering the same length as **49 divisions** on the main scale (1 MSD = 1 mm).

$$1\ \text{VSD} = 49/50 = 0.98\ \text{mm}$$

$$\text{LC} = 1\ \text{MSD} - 1\ \text{VSD} = 1 - 0.98 = 0.02\ \text{mm}$$

Or: LC = value of one main-scale division ÷ number of vernier divisions = 1/50 = 0.02 mm.

Reading

$$\text{Reading} = \text{MSR} + (\text{VSC} \times \text{LC}) - (\text{zero error})$$

Example: the vernier zero is just past 24 mm on the main scale (MSR = 24), and the 17th vernier line coincides (VSC = 17). Reading = 24 + 17 × 0.02 = **24.34 mm**.

Zero error

Close the jaws. If the vernier zero is **to the right** of the main-scale zero, the zero error is **positive**: subtract it. If it is **to the left**, the zero error is **negative**: add its magnitude. Corrected reading = observed − (± zero error).

Advantages and limitations (your file)

Advantages: large measuring range on one instrument (up to about 2000 mm), and it measures external, internal and depth dimensions. **Limitations:** accuracy only 0.02 mm. The line of measurement isn't in line with the scale (it **doesn't obey Abbe's principle**). The jaws can spring. Jaw length limits measurements far from the end of the part. No adjustment for wear. Reading depends on skill (feel and parallax).

Viva questions: Experiment 6

1 **What is the principle of a vernier?**
Two scales with slightly different division lengths are used together. The small difference between one main-scale division and one vernier division gives the fine reading.

2 **Define least count.**
The smallest measurement an instrument can read accurately.

3 **What is the LC of your vernier and how did you get it?**
0.02 mm. 50 vernier divisions = 49 main-scale divisions, so LC = 1 MSD − 1 VSD = 1 − 49/50 = 0.02 mm.

4 **What other least counts exist?**
0.1 mm (10 divisions), 0.05 mm (20 divisions), 0.02 mm (50 divisions). Digital calipers have 0.01 mm resolution.

5 **What can a vernier caliper measure?**
Outside dimensions (lower jaws), inside dimensions (upper jaws), depth (depth bar), and steps.

6 **What is zero error? How do you correct it?**
A non-zero reading when the jaws are closed. Positive error (vernier zero to the right): subtract it. Negative error: add it. Corrected = observed − zero error (with sign).

7 **What is parallax error and how is it avoided?**
A reading error caused by viewing the scale at an angle. Keep your eye perpendicular to the scale at the line of coincidence.

8 **What is Abbe's principle? Does a vernier obey it?**
The line of measurement should be in line with the scale axis. A vernier caliper does **not** obey it, because the jaws are offset from the scale, so any tilt of the jaw gives an error. A micrometer does obey it.

9 **Why is the caliper made of steel? Why stainless?**
For rigidity, wear resistance and low thermal expansion. Stainless steel resists corrosion.

10 **What are the limitations of a vernier caliper?**
Accuracy limited to about 0.02 mm, Abbe error, jaws can spring, depends on the operator's feel, and no wear adjustment.

11 **What are the locking screw and fine adjustment for?**
The lock holds the reading so the caliper can be removed and read. The fine adjustment allows a precise final setting.

12 **What are vernier height gauges and depth gauges?**
Instruments using the same vernier principle: the height gauge measures or marks heights from a surface plate, and the depth gauge measures depths of holes and slots.

13 **Accuracy vs precision?**
Accuracy is closeness to the true value. Precision is repeatability, meaning how close repeated readings are to each other.

14 **Why take several readings and average them?**
To reduce random errors and account for non-uniformity (ovality, taper) of the specimen.

15 **Who invented the vernier?**
Pierre Vernier, a French mathematician, in 1631.

EXPERIMENT 07

Micrometer

Aim: To measure a specimen with the help of a micrometer. **Apparatus:** micrometer, specimen.

Function

A precision instrument that measures size to an accuracy of **0.01 mm**. Different types measure external and internal dimensions as well as depths and heights.

Principle

Uses an accurately cut **screw and nut**. When a screw turns in a fixed nut, it advances by one **pitch** per revolution. Dividing one revolution into many parts gives a very fine linear reading. (Screw-and-nut principle.)

Parts

1. **Frame:** U- or C-shaped (semicircular). Rigid and often insulated so hand heat doesn't expand it.
2. **Anvil:** fixed, hardened (often carbide-tipped) measuring face.
3. **Spindle:** moving measuring face. One end of the accurate screw.
4. **Sleeve (barrel):** fixed to the frame. Carries the datum line and main scale, and acts as the nut.
5. **Thimble:** rotates with the spindle and carries the circular scale (50 divisions).
6. **Ratchet stop:** slips at a set torque, giving **uniform measuring pressure**.
7. **Lock nut:** locks the spindle to hold a reading.

Construction

A semicircular frame with a cylindrical extension at its right end and a hardened anvil inside at the left end. The screw is attached to the spindle and turned by the thimble. The barrel, fixed to the frame, acts as the nut that engages the screw threads, which are made accurately with a pitch of 0.5 mm. Each revolution of the thimble advances the screw by one pitch. The barrel has a datum line and two sets of division marks (whole mm above, half mm below).

Least count

One full turn of the thimble moves the spindle 0.5 mm along the main scale. The thimble has 50 divisions.

$$LC = \text{pitch} / \text{divisions} = 0.5 / 50 = 0.01\ \text{mm}$$

Reading

$$\text{Reading} = MSR + (TSR \times LC) - \text{zero error}$$

Example: the sleeve shows 7 mm plus a visible half-mm line (MSR = 7.5), and thimble division 28 is on the datum line. Reading = 7.5 + 28 × 0.01 = **7.78 mm**.

Zero error: close the faces with the ratchet. If the thimble zero is **below** the datum line, the error is positive: subtract it. If it is **above**, the error is negative: add it.

Procedure

1. Find the least count.
2. Check for zero error.
3. Place the part between the measuring faces.
4. Advance the spindle slowly by turning the thimble.
5. As the spindle is about to touch the object, use the ratchet stop for the final movement and contact pressure.
6. Read the barrel and thimble to get the size.

Sources of error

1. Anvil faces may not be truly flat.
2. Lack of parallelism and squareness of the anvils.
3. Inaccurate zero setting.
4. Inaccurate readings after the zero position.
5. Inaccurate fractional divisions on the thimble.
6. Also: backlash, excess pressure, temperature.

Precautions

1. Avoid parallax and zero error.
2. Hold the part in the left hand and the micrometer in the right.
3. Never put an instrument down violently or with a jerk.
4. Clean instruments thoroughly, oil them, and store them in dust-free covers.
5. Always use the ratchet; never over-tighten.

Viva questions: Experiment 7

1 **On what principle does a micrometer work?**
The screw and nut principle. A screw advances by one pitch per revolution, and dividing the revolution on the thimble gives fine readings.

2 **What is the pitch of a metric micrometer screw?**
0.5 mm.

3 **Least count, and how?**
0.01 mm = pitch 0.5 mm ÷ 50 thimble divisions.

4 **Why is the micrometer more accurate than a vernier?**
It has a finer LC (0.01 against 0.02 mm), obeys Abbe's principle (the measurement axis is in line with the screw), and the ratchet gives constant measuring pressure.

5 **What does the ratchet stop do?**
It slips at a preset torque, so the measuring force is the same every time. This prevents over-tightening, which would deform the part or the frame, and makes the reading independent of the operator.

6 **What is the lock nut for?**
It clamps the spindle so a reading isn't disturbed while the micrometer is removed and read.

7 **What is backlash error?**
Lost motion between the screw and nut when the direction of rotation is reversed. Avoid it by always approaching the reading in the same direction.

8 **Positive vs negative zero error in a micrometer?**
With the faces closed: thimble zero below the datum line means positive error (subtract). Above the line means negative error (add).

9 **What is the range of a micrometer?**
Usually 25 mm per instrument: 0–25, 25–50, 50–75 mm, and so on. Larger sizes need a different frame.

10 **Name the types of micrometers.**
Outside, inside, depth, screw-thread (with pointed and V anvils), tube, blade, V-anvil, digital, and vernier micrometer (LC 0.001 mm).

11 **Why is the frame U-shaped, and why insulated?**
The U shape gives clearance for the work while staying rigid. Insulating pads stop body heat from expanding the frame and changing the reading.

12 **Why are anvil faces hardened or carbide-tipped?**
To resist wear, so the measuring faces stay flat and parallel.

13 **How do you check the flatness and parallelism of the faces?**
Flatness with an optical flat (count the interference fringes). Parallelism with optical parallels of different thicknesses.

14 **How do you get LC 0.001 mm?**
A vernier micrometer has a vernier scale on the sleeve, where 10 vernier divisions equal 9 thimble divisions. That gives 0.01/10 = 0.001 mm.

15 **Why hold the micrometer by the frame (insulated part)?**
To avoid heat transfer and thermal expansion, which causes errors at the micron level.

16 **Is the micrometer a line or an end standard?**
It measures between two faces (end measurement), but the reading comes from line graduations on the sleeve and thimble.

EXPERIMENT 08

Universal bevel protractor

Aim: To measure a specimen with the help of a bevel protractor. **Apparatus:** universal bevel protractor, specimen, surface plate.

Function

Used for **measuring and laying out angles**, from 0° to 360°, with an accuracy of 5 minutes.

Construction and working principle

- A **base plate (stock)** attached to the main body, and an **adjustable blade** attached to a circular plate (turret) carrying the **vernier scale**.
- The adjustable blade can **rotate freely** about the centre of the main scale engraved on the body, and can be **locked** in any position.
- An **acute-angle attachment** at the top is used to measure acute angles.
- Main scale: degrees, in four quadrants (0–90–0–90). The blade is usually 150 or 300 mm long.
- Also a blade-clamp nut, a turret-lock nut, and (on some models) a fine adjustment.

Least count

The fixed scale is in degrees. The vernier is graduated so that **12 vernier divisions equal 23 main-scale divisions (23°)**.

$$1\ \text{VSD} = 23°/12 = 1°55'$$

$$\text{LC} = 2\ \text{MSD} - 1\ \text{VSD} = 2° - 1°55' = 5'$$

So **LC = 1/12° = 5 minutes**. The vernier reads up to 60′ on each side (12 × 5′), so it can be read in either direction.

Reading

$$\text{Angle} = \text{MSR}\ (°) + \text{VSC} \times 5'$$

Example: the vernier zero is past 42° and the 7th vernier line coincides. Angle = 42° + 7 × 5′ = **42°35′**. Read the vernier in the **same direction** as the main scale is increasing.

Procedure

1. Study the bevel protractor and identify its main parts.
2. Insert the adjustable blade in the slot of the body and clamp it with the knob in a convenient position.
3. Place the working edge of the stock on one surface of the job, and rotate the turret holding the blade until the blade's working edge coincides with the other surface.
4. Measure the angles of the sample and record the readings.

Sources of error

1. Base plate and adjustable settings.
2. Blade and stock not parallel to the surfaces of the sample, which gives a wrong angle.
3. Marking errors on the instrument.
4. Parallax, and a loose lock nut.

Precautions

1. Use the instrument with care.
2. When reading, keep your eyes directly in front of the matching lines.
3. Lock the blade before removing the protractor.
4. Clean the blade and job surfaces.

Viva questions: Experiment 8

1 **What is a bevel protractor used for?**
Measuring and laying out angles between two faces of a component, from 0° to 360°.

2 **What is its least count and how is it derived?**
5 minutes. 12 vernier divisions = 23°, so 1 VSD = 1°55′. LC = 2° − 1°55′ = 5′ (1/12°).

3 **Why 23 divisions and not 11?**
Spreading the vernier over 23° (instead of 11°) makes it longer and its divisions wider, so it is easier to read. The LC is still 5′.

4 **Name its parts.**
Body (stock/base plate), main scale (degrees), turret or dial with vernier, adjustable blade, blade-clamp nut, turret lock nut, acute-angle attachment.

5 **What is the acute-angle attachment for?**
It provides a working edge that makes it easier to measure acute angles (less than 90°).

6 **How do you read an obtuse angle?**
Read the acute value shown, then subtract it from 180° depending on how the blade and stock are placed. For example, if 42°35′ is shown but the angle is obtuse, the answer is 137°25′.

7 **Bevel protractor vs sine bar?**
Bevel protractor: direct reading, fast, LC 5′. Sine bar: indirect (uses slip gauges and trigonometry), much more precise (to seconds), but slow and best below 45°.

8 **What is an optical bevel protractor?**
One with a glass circle read through a magnifier. LC about 2′.

9 **What are the sources of error?**
Blade or stock not seated flat on the surfaces, parallax, a loose lock, worn or graduated-scale errors, and a dirty blade.

10 **Name other angle-measuring instruments.**
Sine bar, sine centre, angle gauges, spirit level and clinometer, autocollimator, combination set (protractor head), and dividing head.

11 **How many minutes in a degree? Express 5′ in degrees.**
60 minutes. 5′ = 0.0833°.

EXPERIMENT 09

Sine bar

Aim: To measure the angle of a specimen with the help of a sine bar. **Apparatus:** sine bar, slip gauges, surface plate, height gauge with dial indicator, specimen.

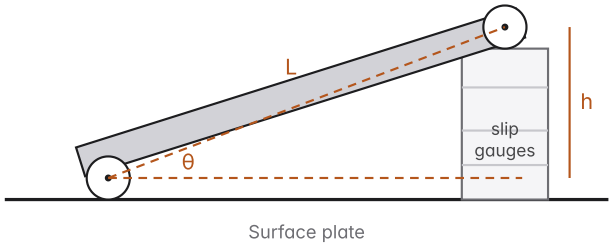
Working principle

- A sine bar is used when an angle must be checked, or work positioned at an angle, to an accuracy **better than about 5 minutes**.
- It is a precision steel bar with **two cylinders (rollers) of equal diameter** fastened near the ends.
- The axes of the two rollers are parallel to each other and to the top surface. The line through their centres is exactly parallel to the working edge of the bar.
- It is used on a surface plate. Any desired angle is set by raising one end of the bar to a calculated height with **slip gauges** (gauge blocks).

$$\sin\theta = h / L$$

L = centre distance between the rollers (the size of the sine bar: 100, 200, 250 or 300 mm). h = height of slip gauges under one roller.

Material: high-carbon, high-chromium corrosion-resistant steel, hardened, ground, lapped and stabilised.



Sine bar on a surface plate. One roller rests on the plate and the other on slip gauges of height h, so sin θ = h / L.

Worked example: L = 200 mm, θ = 20°, so h = 200 × sin 20° = **68.404 mm**. Build it from slip gauges (M112 set), always choosing the smallest decimal block first: 1.004 + 1.40 + 6.0 + 60.0 = 68.404 mm.

Procedure (measuring the angle of a specimen)

1. Clean the surface plate.
2. Clean the sine bar.
3. Clean the workpiece and make sure there are no burrs on its surface.
4. Clean the surface height gauge properly.
5. Mount the dial indicator on the height gauge.
6. Note the reading of the dial indicator and the height gauge scale.
7. Calculate the difference between two height gauge readings. This gives the height of one roller relative to the other.
8. The centre distance between the two rollers is known for a standard sine bar. Calculate $\theta = \sin^{-1}(h/L)$.

Alternative method: set the sine bar at the nominal angle with slip gauges, put the work on it, and run the dial indicator along the top. If the dial reading differs by δ over a length l, the angle error is about δ/l radians. Adjust h until the dial reads the same at both ends.

Why not above 45°?

Differentiating h = L sin θ gives $d\theta = dh / (L \cos \theta)$. Any error in the slip gauges or roller size (dh) produces an angle error that grows as cos θ falls. Above 45° the error rises rapidly, and near 90° the sine bar is useless. It is **reliable up to 45°** and not recommended above 60°. For larger angles, measure the complement (90° − θ) or use angle gauges.

Sources of error

1. Improper cleaning of the instrument or workpiece.
2. Damaged instrument.
3. Damaged workpiece surface.
4. Improper setting of the instrument.
5. Initial error in the measuring instrument.
6. Wrong measurement of height in the gauge.
7. Uneven pressure at the two points of reading.
8. Also: rollers unequal or not parallel, wrong centre distance L, and slip gauges not properly wrung.

Precautions

1. Clean all instruments properly.
2. Remove any burrs or damage on the workpiece surface.
3. Check and correct zero error in the instrument.
4. Take readings carefully.

Viva questions: Experiment 9

1 **What is a sine bar?**
A precision hardened steel bar with two equal rollers at a fixed centre distance. With slip gauges, it is used to measure or set angles accurately using sin θ = h/L.

2 **Principle of the sine bar?**
Trigonometry. The bar forms the hypotenuse (L) of a right triangle and the slip gauges form the opposite side (h), so sin θ = h/L.

3 **How is a sine bar specified?**
By the centre distance between the rollers: 100 mm, 200 mm, 300 mm (or 5 in, 10 in).

4 **Why is it called a "sine" bar?**
Because the angle is obtained from its sine: sin θ = h/L.

5 **Why is it not used above 45°?**
dθ = dh/(L cos θ). As θ increases, cos θ falls, so small errors in h or L cause large angle errors. Accuracy is poor above 45°, and above 60° the sine bar is impractical.

6 **What are slip gauges?**
Rectangular hardened steel (or ceramic) blocks with two flat, parallel faces of precise thickness. Also called gauge blocks or Johansson gauges. They are combined (wrung) to build any length.

7 **What is wringing?**
Sliding two clean, flat slip gauges together with slight pressure so they adhere. This is due to molecular attraction and a very thin film of moisture or oil, and gives a negligible gap.

8 **Rule for building a slip-gauge stack?**
Use the minimum number of gauges, and start by eliminating the smallest decimal place first.

9 **What are the M87 and M112 sets?**
Standard metric slip-gauge sets with 87 and 112 pieces respectively.

10 **Why is the dial indicator used?**
To check whether the top surface of the work is parallel to the surface plate after setting. Equal readings at both ends mean the set angle equals the work angle.

11 **What is the surface plate made of, and why?**
Close-grained cast iron (seasoned and scraped) or granite. It provides a flat datum reference surface. Granite doesn't rust or burr and is thermally stable.

12 **What conditions must a sine bar satisfy?**
The rollers are of equal diameter, their axes are parallel to each other and to the top face, and the centre distance is exactly the nominal value.

13 **What are a sine centre and a sine table?**
A sine centre is a sine bar with centres, for holding conical work. A sine table is a wide sine bar or plate for heavier work.

14 **Height needed for 30° with a 100 mm sine bar?**
h = 100 × sin 30° = 50 mm.

15 **Slip gauges give h = 34.20 mm on a 100 mm bar. What is the angle?**
θ = $\sin^{-1}(0.342) \approx 20°$.

16 **How do you measure angles larger than 45° with a sine bar?**
Measure the complementary angle (90° − θ) by turning the work, or use angle gauges or a bevel protractor.

17 **Is the sine bar a direct or indirect measuring instrument?**
Indirect. The angle is calculated from linear measurements (h and L).

18 **What limits its accuracy?**
The accuracy of the slip gauges, the centre distance and roller size, the flatness of the surface plate, the angle size (best below 45°), cleanliness and temperature.

CROSS-TOPIC

General & rapid-fire questions

Examiners often throw in a few basics that cut across experiments. Know these cold.

Metrology basics

1 **What is metrology?**
The science of measurement. In engineering it covers dimensional measurement, standards, instruments and inspection.

2 **Accuracy vs precision?**
Accuracy is closeness to the true value. Precision is closeness of repeated readings to each other. An instrument can be precise but not accurate (consistent offset).

3 **Least count vs resolution vs sensitivity?**
Least count: smallest graduated value. Resolution: smallest change the instrument can detect. Sensitivity: output change per unit input change.

4 **Systematic vs random error?**
Systematic errors are consistent and correctable (zero error, calibration error, instrument wear). Random errors vary unpredictably (operator, environment), and are reduced by averaging.

5 **What is calibration?**
Comparing an instrument's reading with a known standard and adjusting or correcting it.

6 **Line standard vs end standard?**
Line standard: length is the distance between two engraved lines (steel rule, scale). End standard: length is the distance between two flat end faces (slip gauges, micrometer anvils). End standards are more accurate.

7 **State Abbe's principle.**
The axis of measurement should coincide with the axis of the measuring scale. The micrometer obeys it; the vernier caliper doesn't.

8 **What is the standard temperature for measurement?**
20 °C.

9 **What is a dial indicator? What is its LC?**
A comparator that magnifies the plunger movement through a rack and gears onto a dial. LC is usually 0.01 mm. Used for comparison, run-out and flatness checks.

10 **What is a comparator?**
An instrument that compares a dimension with a standard and shows the deviation (it doesn't measure absolute size). Types: mechanical, optical, electrical and pneumatic.

11 **What is a height gauge?**
A vernier (or digital) instrument on a heavy base, used on a surface plate to measure heights or mark lines.

12 **Tolerance vs allowance?**
Tolerance: permitted variation in the size of one part (upper limit – lower limit). Allowance: the intentional difference between mating parts (minimum clearance or maximum interference).

Machining basics

1 **Units of cutting speed, feed and depth of cut?**
Cutting speed in m/min, feed in mm/rev (turning and drilling) or mm/min (milling table), depth of cut in mm.

2 **What is MRR?**
Material removal rate: the volume of metal removed per unit time. For turning, MRR = V·f·d.

3 **Single-point vs multi-point tools, with examples?**
Single-point: lathe, shaper and boring tools. Multi-point: drill (2 lips), milling cutter, grinding wheel, broach, reamer.

4 **Order tool materials by hot hardness.**
Carbon steel < HSS < cast cobalt alloy (Stellite) < cemented carbide < ceramic < CBN < diamond.

5 **Why isn't diamond used for cutting steel?**
Carbon from the diamond diffuses into iron at high temperature, so it wears rapidly. CBN is used for hardened steel instead.

6 **What is the most important cutting parameter for surface finish?**
Feed, together with the nose radius. Theoretical roughness is Rmax ≈ $f^2/(8r)$.

7 **What is chatter?**
Self-excited vibration between the tool and work. It leaves wavy marks and shortens tool life. Reduce it with a rigid setup, less overhang, lower depth of cut or a speed change.

8 **Why is cast iron machined dry?**
Its free graphite acts as a lubricant, and its chips are powdery (discontinuous). Coolant would form a sludge.

9 **Name common cutting fluids.**
Water-soluble (emulsion) oils, straight cutting oils, synthetic and semi-synthetic fluids, and air or mist.

10 **What safety precautions apply in the machine shop?**
Wear safety goggles and fitted clothing (no loose sleeves or ties). Remove the chuck key before starting. Never touch rotating work or remove chips by hand. Clamp work firmly. Stop the machine before measuring.

11 **Why remove the chuck key immediately?**
If the machine starts with the key in the chuck, the key is thrown out at high speed and can cause serious injury.

12 **Why should the tool be set at centre height?**
Above centre, the effective rake increases and the clearance decreases, causing rubbing. Below centre, the work may climb over the tool. Both spoil the finish and accuracy.

MORNING REVISION

The 30 must-know answers

If you remember nothing else, remember these.

#	Question	Answer
1	Cutting speed formula	$V = \pi DN/1000$ m/min
2	Taylor's equation	$VT^n = C$. n for HSS ≈ 0.125, carbide ≈ 0.25. C = speed for a 1-minute life
3	Most important factor for tool life	Cutting speed (then feed, then depth)
4	Flank vs crater wear	Flank: on the clearance face, abrasion, the tool-life criterion. Crater: on the rake face, diffusion at high temperature
5	Three zones of the wear curve	Initial (rapid), steady (uniform), rapid failure
6	HSS composition	18-4-1: W-Cr-V. Hot hardness to about 600 °C
7	Capstan vs turret lathe	Capstan: turret on a ram, saddle clamped, short stroke, light work. Turret: turret on a saddle that moves along the bed, heavy work
8	Capstan tools and indexing	6 on the hexagonal turret, 4 on the square turret, 1 rear. Indexes 1/6 rev (60°) automatically on the return stroke
9	Bar feed	Collet opens, a weight and chain push the bar to the bar stop, the collet closes. No need to stop the spindle
10	Forces in drilling	Thrust (axial) and torque
11	Source of most of the drilling thrust	The chisel edge (50–60%), because it indents and extrudes
12	Effect of f, d and N on drilling forces	Feed ↑ and diameter ↑ increase both. Speed ↑ gives a slight decrease
13	Drill angles	Point 118°, helix about 30°, lip clearance 8–12°
14	Strain gauge equation	$\Delta R/R = GF \cdot \varepsilon$, GF ≈ 2. Wheatstone bridge, then amplifier, then DAQ
15	Why torque gauges are at 45°	Maximum principal strain in torsion is at 45°
16	Three forces in turning	Fc (tangential, largest, sets power), Ff (feed, axial), Fr (radial, causes deflection)
17	Cutting power	$P = Fc \cdot V/60000$ kW (V in m/min)
18	Resultant force	$R = \sqrt{(Fc^2 + Ff^2 + Fr^2)}$
19	Merchant's relation	$\varphi = 45° + \alpha/2 - \beta/2$
20	Shear angle from chip ratio	$\tan \varphi = r \cos \alpha / (1 - r \sin \alpha)$, $r = t_1/t_2 < 1$
21	Orthogonal vs oblique	Edge ⊥ to velocity (2 forces) vs edge inclined (3 forces)
22	Vernier LC	1 MSD − 1 VSD = 1 − 49/50 = 0.02 mm
23	Micrometer LC	Pitch / divisions = 0.5/50 = 0.01 mm
24	Micrometer principle and ratchet	Screw and nut. The ratchet gives uniform measuring pressure
25	Abbe's principle	Measurement axis in line with the scale. Micrometer obeys it, vernier doesn't
26	Bevel protractor LC	12 VSD = 23°, so LC = 2° − 23°/12 = 5′
27	Sine bar formula	$\sin \theta = h/L$. L = roller centre distance (100, 200 or 300 mm)
28	Why a sine bar isn't used above 45°	$d\theta = dh/(L \cos \theta)$. Error grows as cos θ falls
29	Zero error correction	True reading = observed − (zero error with sign)
30	Grinding wheel rule	Hard material → soft wheel; soft material → hard wheel. A for steel, C for cast iron and non-ferrous

If you blank on a question

Fall back on the structure: **"The principle is..., the formula is..., in our experiment we observed..."** Linking the answer back to what you actually did in the lab (your readings, your graph) always earns marks. Good luck tomorrow.