

# Gear design basics

The gear vocabulary and the numbers behind it — types, the module and pitch geometry, ratio and torque, tooth strength, quality and backlash, and the failure modes.

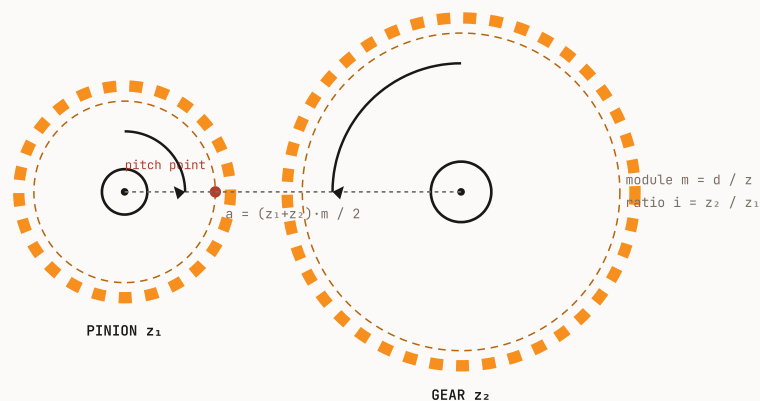
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## ABSTRACT

Gears transmit rotation and multiply (or divide) torque between shafts. The design starts with geometry — the module sets tooth size and centre distance, the tooth counts set the ratio — then checks tooth strength (bending and surface durability) and chooses a quality grade and lubrication.

Section 1 covers gear types and terms. Section 2 is geometry and the module. Section 3 is ratio, speed and torque. Section 4 is tooth strength and sizing. Section 5 is quality, backlash and lubrication. Section 6 is selection and failure modes.

## SPUR GEAR MESH — PITCH CIRCLES & CENTRE DISTANCE



TWO GEARS MESH ON THEIR PITCH CIRCLES; THE CENTRE DISTANCE IS SET BY THE MODULE AND TOOTH COUNTS. GET THE MODULE, PRESSURE ANGLE AND RATIO RIGHT FIRST — STRENGTH AND QUALITY FOLLOW.

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## 1. Gear types and terms

The shaft arrangement (parallel, intersecting, skew) and the ratio largely pick the type:

TYPE	SHAFT AXES	RATIO / STAGE	EFFICIENCY	NOTES
Spur	parallel	up to ~6–8	98–99%	Simplest, cheapest; noisier at speed
Helical	parallel (or crossed)	~6–10	97–98%	Quiet, smooth; produces axial thrust
Bevel	intersecting (usually 90°)	~1–5	97–98%	Right-angle drives
Worm	non-intersecting 90°	5–100	50–90%	Very high ratio, compact, can self-lock
Rack & pinion	rotary ↔ linear	—	~98%	Converts to linear motion
Planetary	coaxial	3–10 / stage	high	High torque density, compact

Module $m$	Tooth size = pitch diameter / number of teeth (mm). Two meshing gears must share a module.
Pressure angle	Angle of the tooth flank line of action — 20° is the modern standard
Pitch diameter $d$	The "working" diameter where gears effectively roll: $d = m \cdot z$
Addendum / dedendum	Tooth height above / below the pitch circle (1· $m$ / 1.25· $m$ standard)
Backlash	Clearance between mating teeth — needed for lubrication and thermal expansion

## 2. Geometry and the module

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Everything keys off the **module m** and tooth count **z**:

- Pitch diameter  $d = m \cdot z$
- Centre distance  $a = (z_1 + z_2) \cdot m / 2$  (for external gears at standard centres)
- Addendum =  $m$ , dedendum =  $1.25 m$ , so outside diameter =  $m(z + 2)$
- Standard pressure angle  $20^\circ$ ; standard addendum proportions per ISO 53 / DIN 867.

Pick a **standard module** (...1, 1.25, 1.5, 2, 2.5, 3, 4, 5...) for available cutters and stock gears, then set tooth counts for the ratio and centre distance. Keep the pinion above the minimum tooth count ( $\approx 17$  at  $20^\circ$  for no undercut, fewer with profile shift).

### 3. Ratio, speed and torque

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- Ratio  $i = z_2 / z_1 = n_1 / n_2$

the pinion (small) drives the gear (large) to reduce speed and multiply torque.

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- Torque scales with ratio and efficiency:  $T_2 \approx T_1 \cdot i \cdot \eta$ .
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- Pitch-line velocity  $v = \pi \cdot d \cdot n$  sets noise, lubrication and quality needs (faster  $\rightarrow$  quieter helical, higher quality, oil).
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- Keep per-stage ratio sensible ( $\approx \leq 6-8$  for spur/helical); cascade stages or use planetary/worm for big reductions.

## 4. Tooth strength and sizing

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Two independent checks — size for the **worse** of them:

- **Bending (tooth root):** the classic Lewis equation and its modern form (ISO 6336 / AGMA 2001) check the root doesn't fatigue. Bending capacity rises with module, face width and material strength.
- **Surface durability (pitting):** Hertzian contact stress at the tooth flank must stay below the material's contact limit, or the flanks pit. Surface-hardened teeth resist this far better.

Practical levers: increase **module** (bigger teeth), **face width** (8–12 × module typical), or **material/heat-treat**. Materials run from acetal/nylon (light, quiet, low load) through through-hardened steel to **case-hardened** steel (≈58–62 HRC) for high power density. Pair with the *Fatigue primer* and *Hertz contact* references.

## 5. Quality, backlash and lubrication

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- **Quality grade (ISO 1328 / AGMA) sets tolerance on tooth form and spacing**  
higher grade = quieter, smoother, costlier. Match grade to pitch-line velocity and noise spec.
- **Backlash is designed-in clearance; too little binds and overheats, too much adds noise and lost motion. Set it via tooth thinning or centre distance.**
- **Lubrication by speed: grease for slow/intermittent, splash oil for moderate, forced/jet oil for high speed. Worm gears need EP oil (high sliding); check yellow-metal compatibility.**

## 6. Selection and failure modes

FAILURE	CAUSE	FIX
<b>Pitting (surface fatigue)</b>	contact stress too high	harder/case-hardened flanks, larger gears, better lube
<b>Tooth bending fatigue</b>	root stress too high	bigger module, wider face, stronger material, root fillet
<b>Scoring / scuffing</b>	lube film breakdown (speed/load/heat)	EP oil, lower temp, better finish
<b>Abrasive wear</b>	contamination, poor lube	filtration, sealing, correct lubricant
<b>Excess noise / whine</b>	low quality, backlash, misalignment	helical teeth, higher quality, alignment

**Selection checklist:** shaft arrangement → type · required ratio (single vs multi-stage) · input torque/speed → module + tooth counts + face width · check bending and contact (size for the worse) · pick material/heat-treat · set quality grade, backlash and lubrication for the pitch-line velocity.