Machine Design

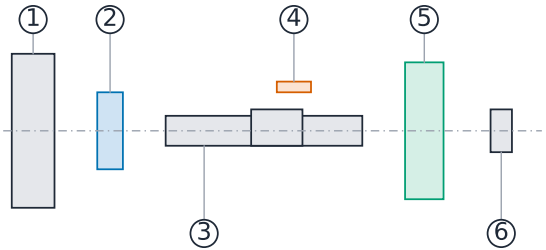
Curated undergraduate study track (not accredited, no external exam). Original explanations and practice only, following the reviewed course handout.

Designing the pump drive

- The ninth course: a 1440 rpm motor, an 8:1 spur-gear stage, the 300 N · m output shaft, its bearings and the housing bolts.
- C45 steel ($S_{ut} = 630$, $S_y = 530$ MPa) and catalogue bearing and bolt data, stated where used.
- Unit 9.1 writes the design down; 9.2-9.3 set the rules; 9.4-9.5 size the parts; 9.6 runs the project.

Exploded view, balloons, parts list

exploded along the axis: assembly order, left to right



parts list (rev B)

1 housing GJL-250
2 bearing 6206
3 shaft C45, Ø30
4 key 8×7×40
5 gear 136 T, m 3
6 nut M30 lock

Six parts from three suppliers stay consistent only through one BOM, one revision letter and dimensions driven by the bearing bore.

Design intent in one change

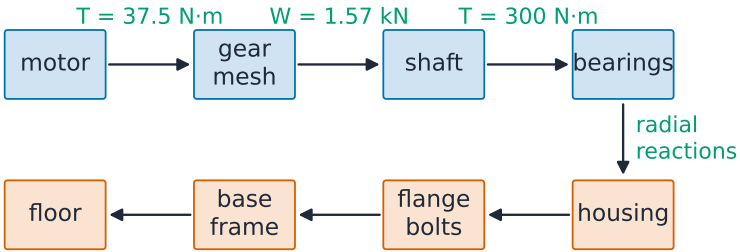
1. **Fixed key** Key drawn at 40 mm; hub shortened from 45 to 36 mm - the key is now longer than its hub.
2. **Related key** $L_{key} = L_{hub} - 5$ gives a 31 mm key automatically.
3. **Bearing change** 6206 $\rightarrow$ 6207 (30 $\rightarrow$ 35 mm bore) updates seat, shoulder (36 $\rightarrow$ 42 mm) and gear bore from one parameter.

Decision

Choose the driving dimensions by function, then let the rest follow.

The load path: motor to floor

every force needs a path to ground: trace it, then size each link



$T = \mathbf{37.5}$ N · m at the pinion, $W = \mathbf{1.57}$ kN at the mesh, $T = \mathbf{300}$ N · m on the output shaft - every arrow is a link to check.

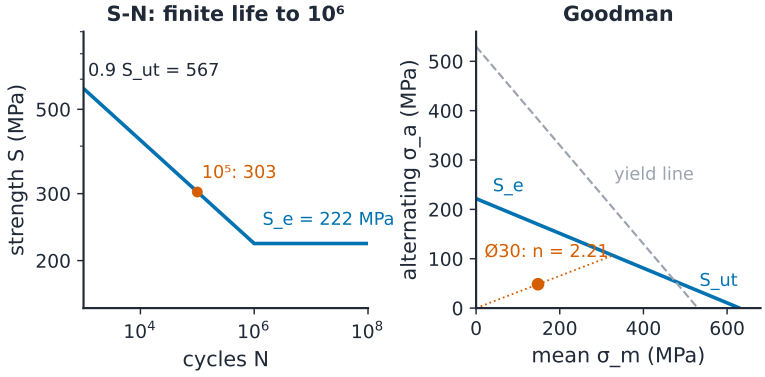
Duty cycle and mesh forces

1. **Duty cycle** 60% at 2 kN, 30% at 3 kN, 10% at 5 kN.
2. **Cube mean** $P_{eq} = (0.6 \cdot 2^3 + 0.3 \cdot 3^3 + 0.1 \cdot 5^3)^{1/3} = \mathbf{2.94}$ kN, not the average 2.6 kN.
3. **Mesh** $W_t = 2T/d = 2 \times 37.5/0.051 = \mathbf{1471}$ N; $W_r = W_t \tan 20^\circ = \mathbf{535}$ N.

Decision

Average loads underrate bearings; use the mean that matches the life law.

S-N curve and Goodman line



C45 machined, $d = 30$: $S_e = 0.817 \times 0.862 \times 315 = \mathbf{222}$ MPa; Goodman at the shoulder gives $n = \mathbf{2.21}$.

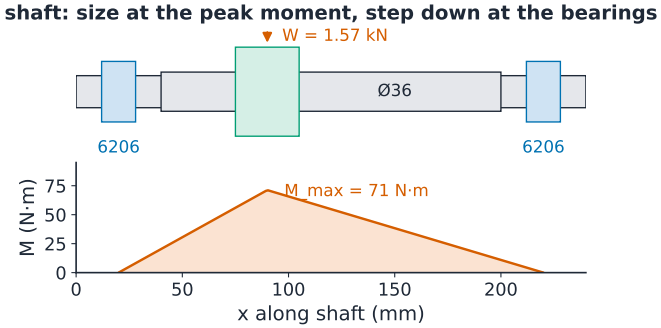
Goodman at the shoulder

1. **Notch** $K_t = 2.0$, $q = 0.8 \rightarrow K_f = \mathbf{1.8}$; torsion $K_{fs} = \mathbf{1.51}$.
2. **Stresses** $\sigma_a = K_f \cdot 32M_a/\pi d^3 = \mathbf{48.4}$ MPa; $\sigma_m = \sqrt{3}\,K_{fs} 16T_m/\pi d^3 = \mathbf{148.0}$ MPa.
3. **Goodman** $1/n = 48.4/222 + 148.0/630 \rightarrow n = \mathbf{2.21}$.
4. **Yield** $n_y = 530/\sqrt{48.4^2 + 148.0^2} = \mathbf{3.40}$ - **fatigue** governs.

Decision

Check both; the lower factor sets the design.

The shaft and its moment diagram



Gear 70 mm from the left bearing on a 200 mm span: $R_1 = \mathbf{1.02}$ kN, $M_{max} = \mathbf{71.2}$ N · m at the gear seat.

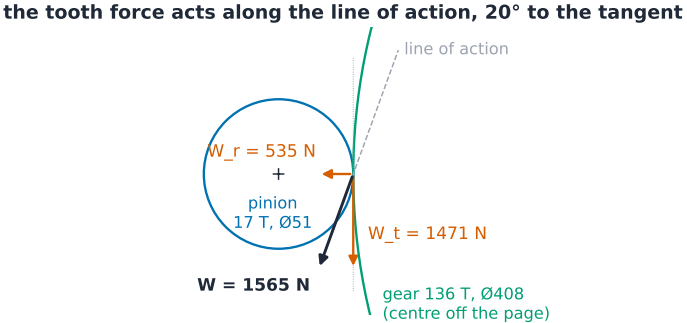
Sizing the seat and choosing the bearing

1. **Diameter** DE-Goodman with $n = 2$ gives $d = \mathbf{29.0}$ mm $\rightarrow$ choose $\mathbf{30}$ mm ($n = 2.21$).
2. **Life** 180 rpm $\times$ 60 $\times$ 20 000 h $= \mathbf{2.16 \times 10^8}$ rev.
3. **Rating** $C_{req} = 2.94 \times 216^{1/3} = \mathbf{17.6}$ kN.
4. **6206** $C = 19.5$ kN $\rightarrow$ $L_{10} = \mathbf{27\,000}$ h on the 30 mm seat.

Decision

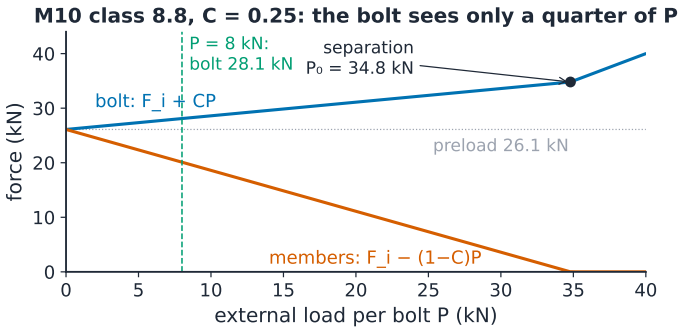
One bearing meets both the bore and the life, with 35% margin.

Spur gears: force on the line of action



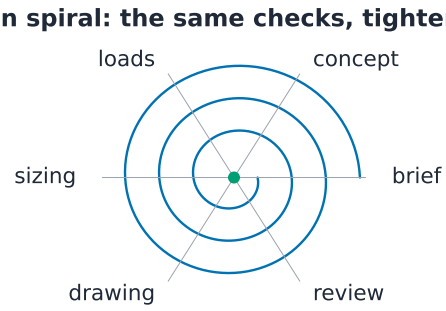
Module 3, 17/136 teeth: Lewis $\sigma = K_v W_t/(FmY) = \mathbf{87.9}$ MPa; contact $\sigma_c = \mathbf{633}$ MPa governs.

Bolted joint: preload carries the load



M10 8.8: $F_i = \mathbf{26.1}$ kN; at $P = 8$ kN the bolt carries $\mathbf{28.1}$ kN; the joint separates at $\mathbf{34.8}$ kN.

The design spiral



Brief → concept → loads → sizing → drawing → review, then round again with better numbers.

Choosing the concept

Concept	Cost, size, efficiency, maintenance (1–5)	Weighted score
A spur gears	4, 3, 4, 3	3.60
B belt drive	5, 2, 3, 3	3.45
C gearmotor	3, 4, 4, 5	**3.80**

The design file

1. **Shaft** Ø30 C45, Goodman $n = 2.21$, yield $n = 3.40$.
2. **Bearing** 6206, $L_{10} = 27\,000$ h against 20 000 h.
3. **Bolts** M10 8.8, load factor 4.35, separation 34.8 kN.
4. **Gears** Bending 87.9 MPa; contact 633 MPa $\rightarrow$ through-hardened, about 300 HB.

Decision

Limits stated: no shock loads, no deflection or key check yet, lubrication assumed.

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Check yourself

- The safety factor and the duty cycle? ($1.2 \times 1.15 \times 1.1 = 1.52$; cube mean 2.94 kN.)
- The **endurance limit** and the shoulder? (222 MPa; Goodman n = 2.21, yield 3.40.)
- The seat and the bearing? (29.0 $\rightarrow$ 30 mm; C 17.6 kN needed, 6206 gives 27 000 h.)
- The bolt and the pinion? (26.1 kN **preload**, 28.1 kN at 8 kN, separation 34.8 kN; 87.9 and 633 MPa.)