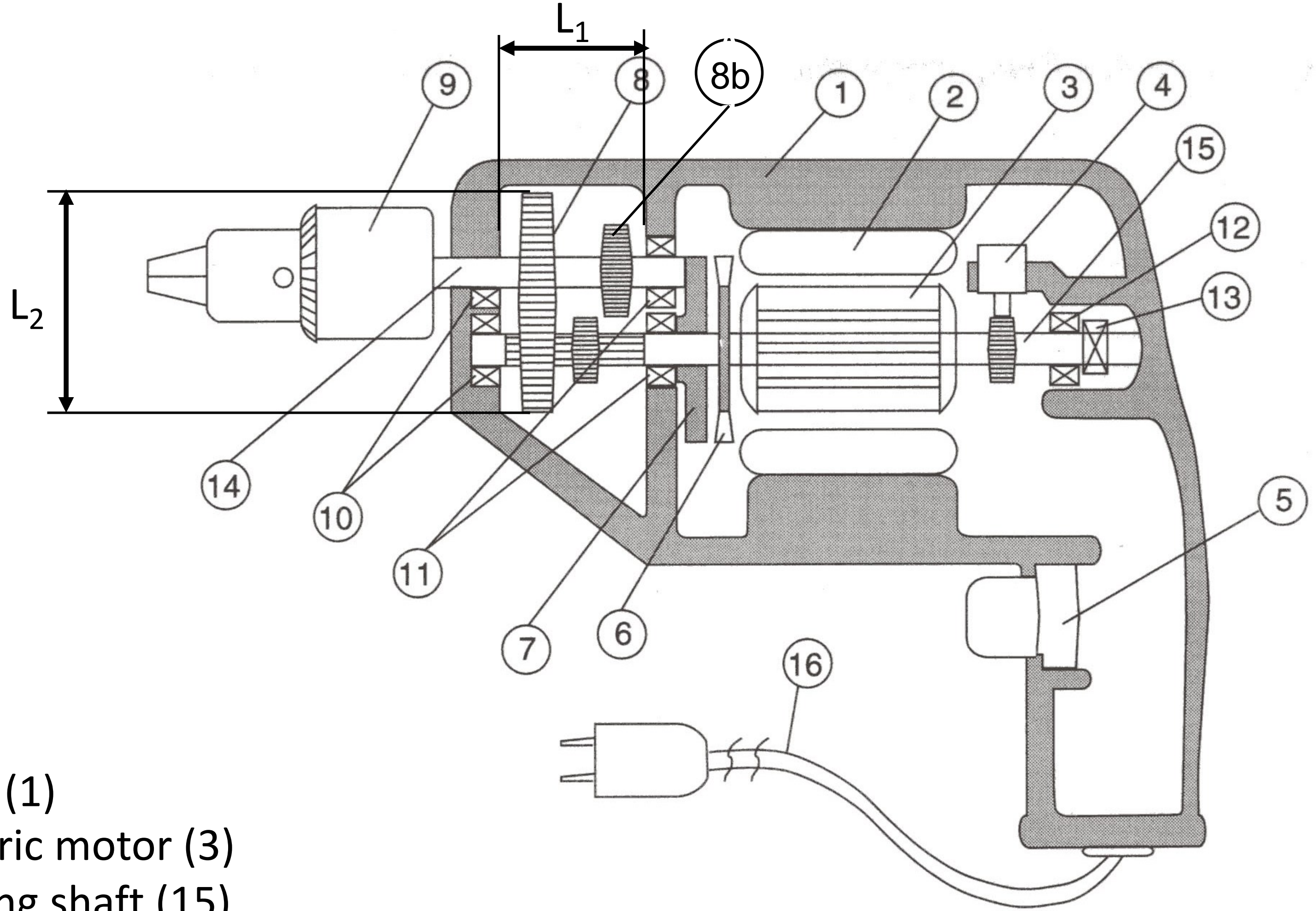
Course of Mechanical Design and Machine Elements

Homework 2, part A: Design and verification of the driven shaft of an electric drill



Legend:

- Case (1)
- Electric motor (3)
- Driving shaft (15)
- Driven shaft (14)
- Chuck (9)
- Spur gearset (8), (8b)
- Ball bearings (10)
- Roller bearings (11)
- Cam drive (7)

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The figure illustrates the schematic layout of an electric hammer drill. The main shaft is driven by an electric motor and the rotary motion is transmitted to a driven shaft through one of two spur gearsets. The chuck carrying the drill bit is mounted on the driven shaft through a tapered press fit. The impact loading is provided by a cam drive imparting an oscillatory axial motion to the driven shaft. The two gearsets are used to permit the drill to function at two distinct angular speeds (slow and fast speed). A spline is used on the main shaft to switch from one speed to the other. The outer ring of the ball bearing is hosted in a seat with axial clearance adequate to permit the oscillatory impact motion. The present project is focussed on the driven shaft and its machine elements only. In particular, it is requested to:

1) design the two pairs of spur gears
2) design the constraining system of the driven shaft (included the axial clearance) and select the rolling bearings
3) design the keys for gear/shaft couplings
4) design the driven shaft for strength (safe life) and stiffness
5) design the tapered press fit between chuck and shaft
6) prepare a detailed drawing of the shafts, including indications about tolerances, surface finish, material and heat treatment

Feel free to select material, surface finish, quality index, lubricant and non-specified dimensions.

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Data:

Nominal power of the electric motor: W_{motor}=800 W

Angular speed of the electric motor: n_{motor}= 1400 rev/min

Impact energy: E_k = 1.6 J

Impact rate: n_{impact}= 5600 impacts/min

Oscillating mass: m_{osc} = 600 g

Service factor: K_s=1.6

Transmission ratio of the fast gearset: τ_{fast}=0.64

Transmission ratio of the slow gearset: τ_{slow}=0.3

Maximum internal distance between supports: L_1= 60 mm

Maximum diametrical envelope of the gearsets: L_2 = 120 mm

Maximum contact pressure on the tapered press fit: p_{all} = 150 MPa

Service life: 1,000 h Reliability 99%

If the fatigue SN curve of the shaft material is not available, take:

$$\sigma_{\lim} = \sigma_{2\cdot 10^6} = 0.45\sigma_R$$

$$\sigma_{10^4} = 0.75\sigma_R$$

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Hints:

In general stiffness requirements are more demanding than strength requirements. Try to design first for stiffness and then verify the strength (safe life)

Slope and deflections can be calculated analytically or using a 2D beam software (remember to combine vectorially deflections and slopes estimated on the two transversal planes). See for instance:

- Beam 2D Stress Analysis, Orand Systems, Inc., available from the web
- FrameDesign, LetsConstruct, available from Google store

Usual stiffness requirements:

$$f_{\max} \leq \frac{l}{3000} \qquad f_{\max}: \text{ maximum deflection} \qquad l: \text{shaft length}$$

$$\theta / l \leq 0.044/1000 \quad rad/mm \ \text{ maximum torsional deformation}$$

Maximum slope tolerated by bearings depend on the bearing type (see catalogues)

module	Max gear deflection
m > 6 mm	0.25 mm
3 < m < 6	0.125 mm
1< m < 3 mm	0.075 mm

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Hints:

- Make sure that both gearsets have the same centre distance
- Assume the cam drive to impart a sinusoidal trajectory to the driven shaft
- Determine the amplitude of the sinusoidal motion from the impact energy
- The range of the motion plus a reasonable clearance determines the axial length of the seat of the outer ring of the ball bearing
- Verify the shaft for both speed regimes independently
- Neglect the effect of the axial (impact) load on the shaft strength
- Select a shaft material of adequate toughness

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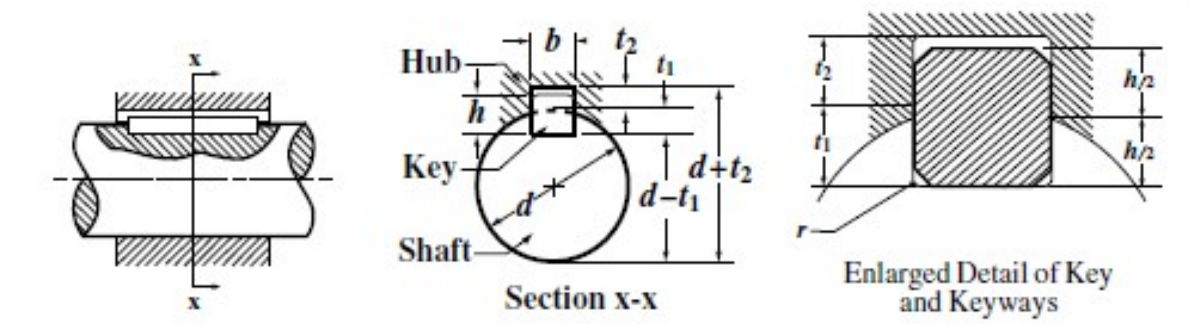

Shaft		Key	Keyway											
Nominal Diameter d			Width, b						Depth				Radius r	
				Free Fit		Normal Fit		Close Fit	Shaft t_1		Hub t_2			
Over	Up to and Incl	Size, $b \times h$	Nominal	Shaft (H9)	Hub (D10)	Shaft (N9)	Hub (J_S9)[a]	Shaft and Hub (P9)	Nominal	Tolerance	Nominal	Tolerance	Max.	Min.
				Tolerances										
Keyways for Square Parallel Keys														
6	8	2 × 2	2	+0.025	+0.060	−0.004	+0.012	−0.006	1.2		1		0.16	0.08
8	10	3 × 3	3	0	+0.020	−0.029	−0.012	−0.031	1.8		1.4		0.16	0.08
10	12	4 × 4	4						2.5	+0.1 0	1.8	+0.1 0	0.16	0.08
12	17	5 × 5	5	+0.030 0	+0.078 +0.030	0 −0.030	+0.015 −0.015	−0.012 −0.042	3		2.3		0.25	0.16
17	22	6 × 6	6						3.5		2.8		0.25	0.16
Keyways for Rectangular Parallel Keys														
22	30	8 × 7	8	+0.036	+0.098	0	+0.018	−0.015	4		3.3		0.25	0.16
30	38	10 × 8	10	0	+0.040	−0.036	−0.018	−0.051	5		3.3		0.40	0.25
38	44	12 × 8	12						5		3.3		0.40	0.25
44	50	14 × 9	14	+0.043	+0.120 +0.050	0 −0.043	+0.021 −0.021	−0.018 −0.061	5.5		3.8		0.40	0.25
50	58	16 × 10	16						6		4.3		0.40	0.25
58	65	18 × 11	18						7	+0.2 0	4.4	+0.2 0	0.40	0.25
65	75	20 × 12	20						7.5		4.9		0.60	0.40
75	85	22 × 14	22	+0.052	+0.149 +0.065	0 −0.052	+0.026 −0.026	−0.022 −0.074	9		5.4		0.60	0.40
85	95	25 × 14	25						9		5.4		0.60	0.40
95	110	28 × 16	28						10		6.4		0.60	0.40
110	130	32 × 18	32						11		7.4		0.60	0.40
130	150	36 × 20	36						12		8.4		1.00	0.70
150	170	40 × 22	40	+0.062	+0.180 −0.080	0 −0.062	+0.031 −0.031	−0.026 −0.088	13		9.4		1.00	0.70
170	200	45 × 25	45						15		10.4		1.00	0.70
200	230	50 × 28	50						17		11.4		1.00	0.70
230	260	56 × 32	56						20	+0.3 0	12.4	+0.3 0	1.60	1.20
260	290	63 × 32	63	+0.074	+0.220 +0.100	0 −0.074	+0.037 −0.037	−0.032 −0.106	20		12.4		1.60	1.20
290	330	70 × 36	70						22		14.4		1.60	1.20
330	380	80 × 40	80						25		15.4		2.50	2.00
380	440	90 × 45	90	+0.087	+0.260	0	+0.043	−0.037	28		17.4		2.50	2.00
440	500	100 × 50	100	0	+0.120	−0.087	−0.043	−0.124	31		19.5		2.50	2.00

[a] Tolerance limits J_S9 are quoted from BS 4500, "ISO Limits and Fits," to three significant figures.

All dimensions in millimeters.

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1) Typical values of the notch fatigue factor introduced by the keyseat into the shaft are 3 in bending and 2 in torsion.
2) Typical key material is steel C45 (p_{all} = 150 MPa, τ_{all} = 75 MPa).
3) Check if the selected bearings have width and fillet radii compatible with the shaft designed in part A and, if necessary, update the shaft layout to accommodate the bearings.
4) Prepare a constructive drawing that shows the mounting of bearings, in particular how inner and outer rings are fixed radially and axially.

For bearing selection, you can consult any manufacturer catalogue, for instance:

http://www.skf.com/binary/77-121486/SKF-rolling-bearings-catalogue.pdf

http://www.skf.com/it/knowledge-centre/engineering-tools/skfbearingcalculator.html

http://www.fag.de/content.fag.de/en/products_services/rotativ_products/index.jsp