MECH2400 Assignment D PART 1 *SID: 490440906*

The number of teeth on the pinion is 23.
The number of teeth on the super gear is 67.

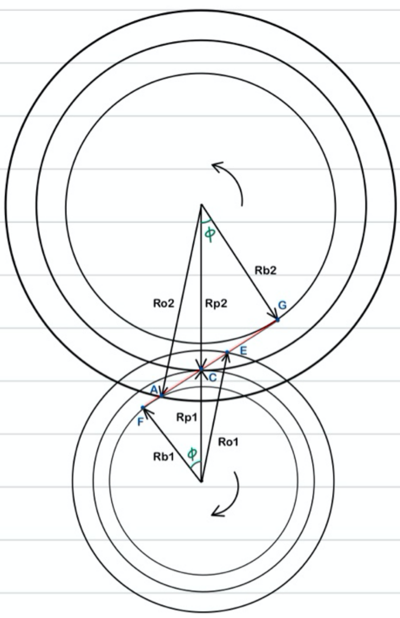
Given:
Module m = 15mm
Pressure angle Ø = 20˚
Addendum a = 15mm
Dedendum d = 18.75mm

1. Addendum diameter
   For the pinion, d_{o1}= d_{P1}+ 2*a = 345 + 2*15 = 375.0000mm
   For the super gear, d_{o2}= d_{P2}+ 2*a = 1005 + 2*15 = 1035.0000mm

2. Pitch diameter (Briozzo, 2020)
   For the pinion, d_{P1}= m*N = 15 *23 = 345.0000mm.
   For the super gear, d_{P2}= m*N = 15 *67 = 1005.0000mm

3. Base diameter
   For the pinion, d_{b1}= 2*R_{P1}*cos ϕ = 2 *(345/2) * cos 20˚ = 324.1939mm
   For the super gear, d_{b2}= 2*R_{P2}*cos ϕ = 2 *(1005/2) * cos 20˚ = 944.3911mm

4. Dedendum diameter
   For the pinion, d_{r1}= d_{P1}– 2*d = 345 – 2*18.75 = 307.5000mm
   For the super gear, d_{r2}= d_{P2}– 2*d = 1005 – 2*18.75 = 967.5000mm



$Ro1 = \frac{375}{2} = 187.5\,mm \quad Ro2 = \frac{1035}{2} = 517.5\,mm$

$Rb1 = \frac{324.1939}{2} = 162.0969\,mm \quad Rb2 = \frac{944.3911}{2} = 472.1955\,mm$

$Rp1 = \frac{345}{2} = 172.5\,mm \quad Rp2 = \frac{1005}{2} = 502.5\,mm$

$$AC = \sqrt{Ro2^2 - Rb2^2} - \sqrt{Rp2^2 - Rb2^2}$$
$$= \sqrt{517.5^2 - 472.1955^2} - \sqrt{502.5^2 - 472.1955^2}$$
$$= \sqrt{44837.6598} - \sqrt{29537.6598}$$
$$= 211.7490 - 171.8652$$
$$= 39.8838\,mm$$

$$EC = \sqrt{Ro1^2 - Rb1^2} - \sqrt{Rp1^2 - Rb1^2}$$
$$= \sqrt{187.5^2 - 162.0969^2} - \sqrt{172.5^2 - 162.0969^2}$$
$$= \sqrt{8880.8450} - \sqrt{3480.8450}$$
$$= 94.2382 - 58.9987$$
$$= 35.2395\,mm$$

$$AE = AC + EC = 39.8838 + 35.2395 = 75.1233\,mm$$

5. Tooth width (arc length) (Briozzo, 2020)
   For the pinion, pitch diameter d_{P1}= 345mm.
   Pitch circumference = π*d_{P1} = π * 345 = 1083.8495mm.
   1083.8495/pinion teeth number = 1083.8495/23 = 47.1239mm per tooth.
   The tooth thickness is (47.1239/2) = 23.5619mm.

For the super gear, pitch diameter d_{P2}= 1005mm.
Pitch circumference = π*d_{P2} = π * 1005 = 3157.3006mm.
3157.3006/pinion teeth number = 3157.3006/67 = 41.1239mm per tooth.
The tooth thickness is (41.1239/2) = 23.5619mm.

6. Tooth width with a 0.01 mm backlash (in mesh) (Briozzo, 2020)
   Only consider half of the backlash per tooth.
   For the pinion, 23.5619 – (0.01/2) = 23.5569mm.
   For the super gear, 23.5619 – (0.01/2) = 23.5569mm.

7. Contact ratio
   The line of contact AE = 75.1233mm (Briozzo, 2020)
   For the pinion, P_{b1} = 2*π*R_{b1}/ pinion teeth number = 2*π*(324.1939/2)/23 = 44.2820mm.
   m_{C1} = Z/P_{b1} = 75.1233/44.2820 = 1.6965
   For the super gear, P_{b2} = 2*π*R_{b2}/ gear teeth number = 2*π*(944.3911/2)/67 = 44.2820mm.
   m_{C2} = Z/P_{b2} = 75.1233/44.2820 = 1.6965

8. Length of line of access
   AC = 39.8838mm.

9. Length of line of recess
   EC = 35.2395mm.

10. Length of line of single tooth contact
    AE = 75.1233mm

Reference

Briozzo, P. (2020). *MECH2400 9400 Mechanical Design 1: Gear Part 1* [Lecture PowerPoint slides].

MECH2400 Assignment D PART 2 *SID: 490440906*

Given:
Speed = 2880 RPM
The gearbox starts and stops 10 to 20 times a day.
DG = BG = 50mm, CG = AG = 106/2 = 53 (based on the last two digits of SID)
The number of teeth on the pinion N_p = 23.
The number of teeth on the super gear is N_g = 67.
Efficiency for each gear = 98%

Shaft Design:

Assume the shaft diameter is 20mm.
The volume of shaft AB:

$$V_{AB} = \frac{\pi d^2}{4} \cdot length = \frac{\pi(0.02)^2}{4} \cdot (0.05 + 0.053) = 3.2358 \cdot 10^{-5} m^3$$

Based on the data sheet of hot rolled steel, the density of shaft AB is $\rho_{steel} = 7872 kg/m^3$.
The weight of shaft AB:

$$W_{AB} = \rho_{steel} \cdot V_{AB} \cdot 9.81 = 7872 \cdot 3.2358 \cdot 10^{-5} \cdot 9.81 = 2.4989N$$

For calculating the weight of gear, use pitch circle diameter of pinion which is 345mm.
The volume of pinion:

$$V_p = \frac{\pi(D^2 - d^2)}{4} \cdot length = \frac{\pi(0.345^2 - 0.02^2)}{4} \cdot 0.025 = 232.9196 \cdot 10^{-5} m^3$$

Consider the pinion material is the same as the shaft, then the density of pinion is $\rho_{steel} = 7872 kg/m^3$.
The weight of pinion:

$$W_p = \rho_{steel} \cdot V_p \cdot 9.81 = 7872 \cdot 232.9196 \cdot 10^{-5} \cdot 9.81 = 179.8706N$$

The gear is turning with 20˚ pressure angle, and the vertical force caused by 20˚ pressure angle is pulling the super gear and the pinion away from each other. However, the input torque is transmitted in a clockwise direction and consider some loss of torque due to 98% of pinion efficiency.
The actual torque has applied on the pinion:

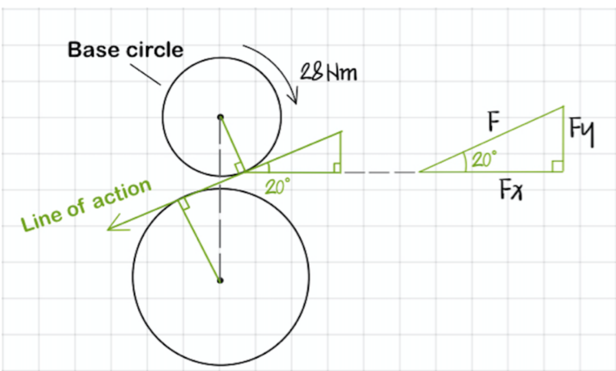
$$\tau_p = 0.98 \cdot 28Nm = 27.44Nm$$

The base diameter of pinion is 324.1939mm.
The resultant force caused by torque and 20˚ pressure angle:

$$F = \tau_p / r_b = 27.44/(324.1939 \cdot 10^{-3}/2) = 169.2814N$$

The vertical force: $F_y = F \cdot \sin 20^\circ = 169.2814 \cdot \sin 20^\circ = 57.8977N$

The horizontal force: $F_x = F \cdot \cos 20^\circ = 169.2814 \cdot \cos 20^\circ = 159.0725N$



The shaft AB has been pushed upward by the application of torque, while the weight of shaft AB and the weight of pinion are acting downward.

Based on the FBD of shaft AB, calculate the total reaction force at point G.

$$F_{Gy} =- W_{AB} - W_p + F_y =- 2.4988 - 179.8706 + 57.8977 =- 124.4718N$$

For vertical plane, use F_y calculate the corresponding reaction force at point A and point B.

$$\sum M_B = 0\,,\ A_y = F_{Gy} \cdot \frac{0.05}{0.05 + 0.053} = 124.4717 \cdot \frac{50}{103} = \ 60.4232N$$

$$\sum F_y = 0, B_y = F_G - A_y = 124.4717 - 60.4232 = \ 64.0486N$$

For horizontal plane, use F_x calculate the corresponding reaction force at point A and point B.

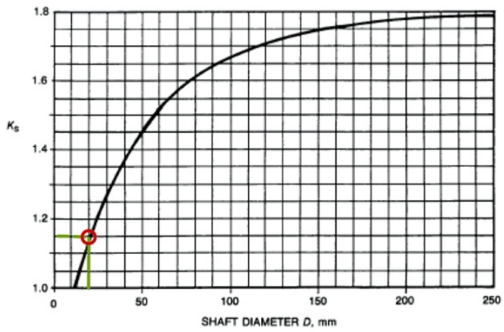
$$F_{Gx} = F_x = 159.0725N$$

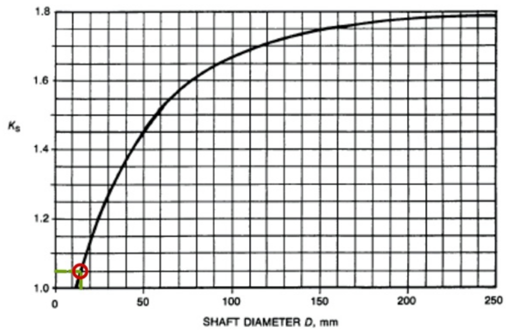
$$\sum M_B = 0\,, A_y = F_{Gx} \cdot \frac{0.05}{0.05 + 0.053} = \ 159.0725 \cdot \frac{50}{103} = \ 77.2197N$$

$$\sum F_y = 0, B_y = F_{Gx} - A_y = \ 159.0725 - 77.2197 = \ 81.8528N$$

Max bending moment: $M_{Max\ Bending} = \sqrt{3.2024^2 + 4.0926^2} = 5.1967\ Nm$

The ultimate tensile strength of hot rolled steel is 325MPa.
The endurance limit $F_R = 0.45 \cdot F_{uf} = 146.25MPa$.





Based on the figures above (Committee ME-005, 2004), at $D = 20mm$, size factor $K_s = 1.15$.

The equivalent torque: $T_E = 1.15\sqrt{{M_q}^2 + 0.75{T_q}^2} = 1.15\sqrt{5.1967^2 + 0.75 \cdot 28^2} = 28.5192\ Nm$

The trial diameter:

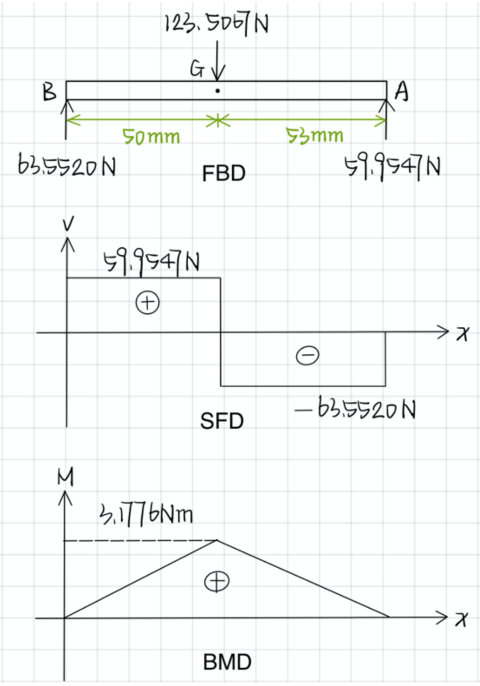
$$D^3 = \frac{12000K_s}{F_R} \cdot T_E = \frac{12000 \cdot 1.15}{146.25} \cdot 28.5192, \qquad D = 13.91\ mm$$

The value of trial diameter is much lower than the assumed diameter. Therefore, try 14 mm as shaft diameter.
According to AS1403(Committee ME-005, 2004), at $D = 14mm$, size factor $K_s \approx 1.15$.

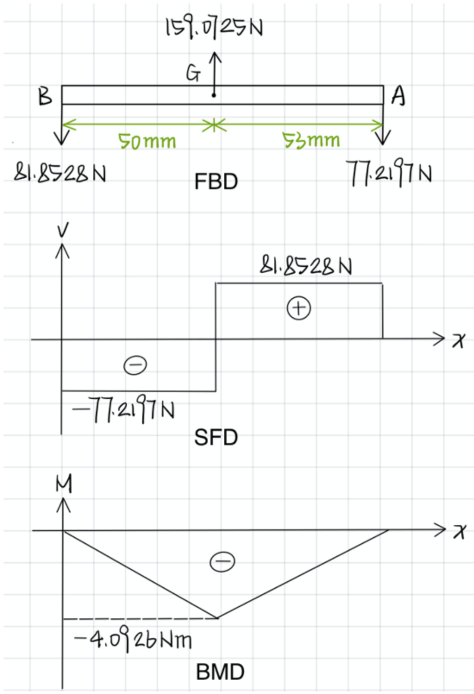
Shaft Diameter (m)	0.014	BG (m)	0.05	Ultimate tensile strength (MPa)	325
Shaft Volume (m^3)	1.58556E-05	AG (m)	0.053	Endurance limit (Mpa)	146.25
Shaft Weight (N)	1.224439328	Steel Density (kg/m^3)	7872	Ks	1.05
Pinion Pitch Diameter (m)	0.345	Efficiency	0.98	Trial Diameter (mm)	13.493315
Pinion Base Diameter (m)	0.3241939	Input Torque (Nm)	28		
Pinion width (m)	0.025	Gear Torque (Nm)	27.44	Max Bending moment (Nm)	5.1813949
		F (N)	169.28141		
Pinion Volume (m^3)	0.002333202	Fy (N)	57.897652	T(E)	28.515521
Pinion Weight (N)	180.1799	Fx (N)	159.07249		
				Vector sum of Force at G	201.39007
For vertical plane:				Vector sum of Force at A	97.762168
Resultant force at G (N)	-123.5066878	Max moment_y (Nm)	3.1775992	Vector sum of Force at B	103.6279
Reaction force at A (N)	59.95470279				
Reaction force at B (N)	63.55198496				
For horizontal plane:					
Resultant force at G (N)	159.0724903	Max moment_x (Nm)	-4.0926417		
Reaction force at A (N)	77.21965551				
Reaction force at B (N)	81.85283484				

The detail calculations about 14mm diameter of shaft are presented by Excel in the figure above. The result is fairly close to convergence, thereby the shaft diameter $D \approx 14mm$.

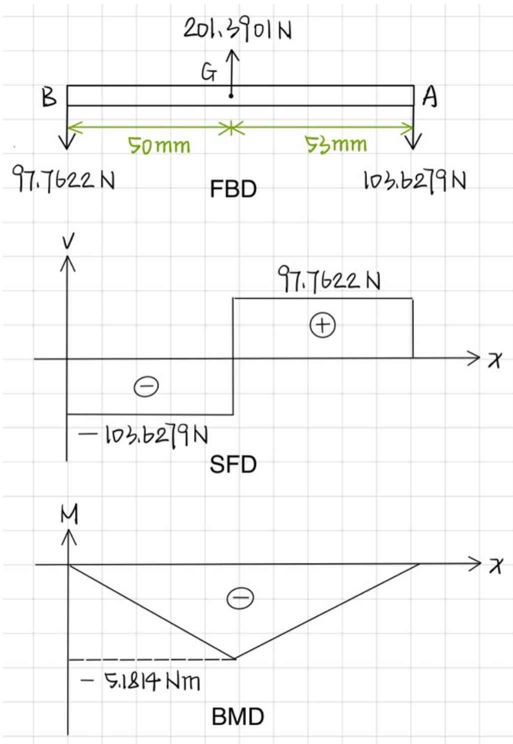
For vertical plane:



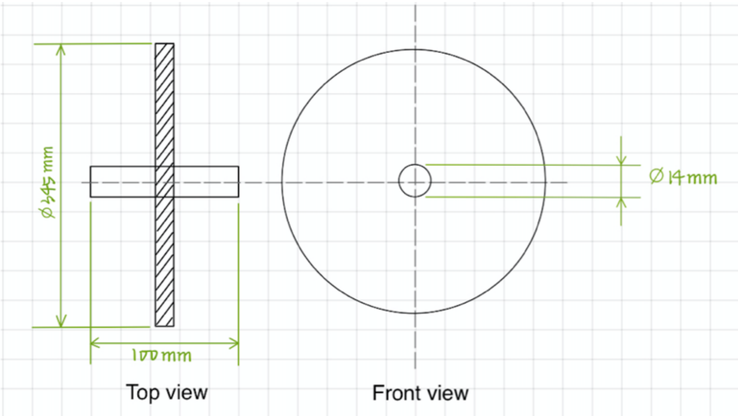
For horizontal plane:



Both planes with vector sum:



Overview Shaft and Pinion Diagram:



Use the standard formula (Committee ME-005, 2004) to calculate minimum diameter of shaft AB.

TABLE 2

FORMULAS FOR CALCULATING MINIMUM DIAMETER OF SHAFT D

Number of mechanism starts per year	Number of revolutions of shaft per year	Torque application conditions	Formula	Formulas
Application ≤600	≤900 Infrequent	Manually or power applied	$D^3 = \frac{10^4 F_S}{F_Y}\sqrt{\left(M_q + \frac{P_q D}{8000}\right)^2 + \frac{3}{4}T_q^2}$	1
	>900	Power applied	$D^3 = \frac{10^4 F_S}{F_R}\sqrt{\left[K_S K\left(M_q + \frac{P_q D}{8000}\right)\right]^2 + \frac{3}{4}T_q^2}$	2
>600	>900	Power applied torque reversals	$D^3 = \frac{10^4 F_S}{F_R} K_S K\sqrt{\left(M_q + \frac{P_q D}{8000}\right)^2 + \frac{3}{4}T_q^2}$	3
		Power applied, no torque reversals (see Note 1)	$D^3 = \frac{10^4 F_S}{F_R}\sqrt{\left[K_S K\left(M_q + \frac{P_q D}{8000}\right)\right]^2 + \frac{3}{16}\left[(1 + K_S K)T_q\right]^2}$	4

See Notes 2 and 3

NOTES:

1 Where the magnitude of the torque in one direction is not greater than 0.1 times the torque in the other direction, the torque application conditions may be considered as being non-reversing.

2 These formulas are extracted from a paper titled 'Shortcuts for Designing Shafts' by H.A. Borchardt, published in *Machine Design*, Vol. 45, No.3, 8 February 1973, pp 139-141.

3 The value of F_R is based on 10^6 stress cycles and is applicable for numbers of revolutions of shafts per year greater than 50 000.

4 For numbers of revolutions of shafts per year from 50 000 down to 900, formulas 2, 3 and 4 result in progressively more conservative values for the theoretical diameter of shaft.

5 The value of F_s is 2.0 for Formula 1 and 1.2 for Formulas 2, 3 and 4. Where severe injury, death or extensive equipment damage is likely to occur because of the failure of the shaft, higher factors of safety may be used.

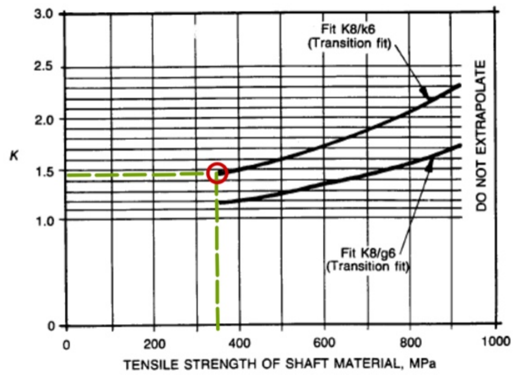
6 The values of K_s, K and the term P_q $D/8000$ may require the calculation of a 'trial' diameter (see Appendix A).

Given information indicates that the gearbox starts and stops 10 to 20 times a day across a working year. But no detail information about 'Number of revolutions of shaft per year' and 'Number of mechanisms starts per year'. The shaft is reversed bending and steady torque. Therefore, consider the worst case which is highlighted in the above figure.

Two single deep groove bearings are applied at both point A and point B, the rolling element bearings induce vibration into the shaft. Thus, stress raising factor caused by rolling element bearing needs to significantly consider.

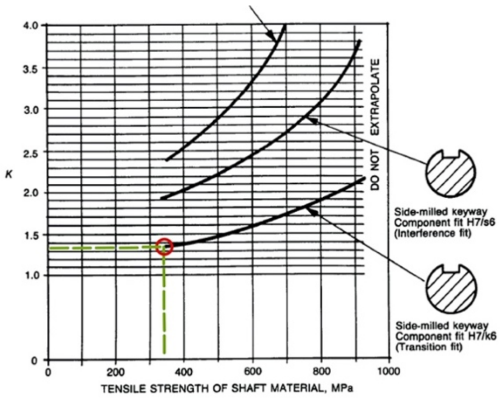
Fits for solid steel shafts (for thrust bearings)[1)]

Conditions	Shaft diameter [mm]	Tolerance class[2)]
Axial loads only		
Thrust ball bearings	–	h6
Combined radial and axial loads on spherical roller thrust bearings		
Stationary load on shaft washer	≤ 250	j6
	> 250	js6
Rotating load on shaft washer, or direction of load indeterminate	≤ 200	k6
	> 200 to 400	m6
	> 400	n6



According to SKF rolling bearings catalogue (SKF Group, 2016), for any shaft operating under rotating load condition with diameter less than 200mm, consider k6 tolerance class. Based on the AS1403 (Committee ME-005, 2004), the steel shaft has 325MPa tensile strength, the corresponding stress concentration factor is approximately 1.45. → $K_1 = 1.45$

The gear and hub are connected to the respective shaft by a plain square key. Thus, stress raising factor caused by key component has to consider as well.



Refers to AS1403 (Committee ME-005, 2004), select side-milled keyway with transition fit H7/k6, the steel shaft has 325MPa tensile strength, the corresponding stress concentration factor is approximately 1.35. → $K_2 = 1.35$

Those two stress-raising characteristics are coincident and separated by an axial distance (from A to G/ from B to G) greater than $0.24 * 14mm = 3.36mm$. Therefore, selection the greater value between K_1 and K_2. → the stress raising factor is $K = K_1 = 1.45$.

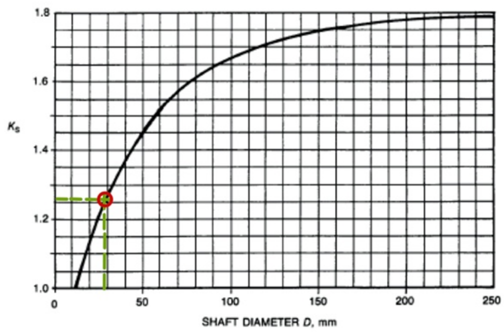
Maximum axial tensile force $P_q = 0$ in this case.

$$D^3 = \frac{10^4 \cdot F_s}{F_R} \cdot \sqrt{[K_S \cdot K \cdot (M_q + \frac{P_q \cdot D}{8000})]^2 + \frac{3}{16}[(1 + K_S \cdot K) \cdot T_q]^2}$$

$$D^3 = \frac{10^4 \cdot 10}{146.25} \cdot \sqrt{[1.05 \cdot 1.45 \cdot (5.1814)]^2 + \frac{3}{16}[(1 + 1.05 \cdot 1.45) \cdot 28]^2}$$

$$D = 27.85mm$$

$D = 27.8mm$ from AS1403 (Committee ME-005, 2004), to obtain a new value for the size factor $K_s = 1.26$.



$$D^3 = \frac{10^4 \cdot 10}{146.25} \cdot \sqrt{[1.26 \cdot 1.45 \cdot (5.1814)]^2 + \frac{3}{16}[(1 + 1.26 \cdot 1.45) \cdot 28]^2}$$

$$D = 28.97mm \approx 29mm$$

__Bearing selection:__

For selecting a proper deep groove bearing, consider angular deflection at each end of the shaft AB. Use the standard equation for support beam. The modulus of elasticity of hot rolled steel is 200GPa. The moment of inertia of shaft AB, and use unround up shaft diameter $D = 28.97mm$:

$$I = \frac{\pi D^4}{64} = \frac{\pi (0.02897)^4}{64} = 0.03457 \cdot 10^{-6} m^4$$

$$\theta_B = \frac{F_G \cdot b \cdot a \cdot (l + a)}{6 \cdot l \cdot E \cdot I} = \frac{201.3901 \cdot 0.05 \cdot 0.053 \cdot (0.103 + 0.053)}{6 \cdot 0.103 \cdot 200 \cdot 10^9 \cdot 0.03471 \cdot 10^{-6}} = 0.1948 \cdot 10^{-4}\, rads$$

$$\theta_B = 0°0'4.02''$$

$$\theta_A = \frac{F_G \cdot b \cdot a \cdot (l + b)}{6 \cdot l \cdot E \cdot I} = \frac{201.3901 \cdot 0.05 \cdot 0.053 \cdot (0.103 + 0.05)}{6 \cdot 0.103 \cdot 200 \cdot 10^9 \cdot 0.03471 \cdot 10^{-6}} = 0.1911 \cdot 10^{-4}\, rads$$

$$\theta_A = 0°0'3.94''$$

Bearing data

	Single row deep groove ball bearings
Dimension standards	Boundary dimensions: ISO 15 Snap rings and grooves: ISO 464
Tolerances	Normal P6 or P5 on request **SKF Explorer and SKF E2 bearings** Dimensional tolerance to P6 and reduced width tolerance: D ≤ 110 mm → 0/−60 µm D > 110 mm → 0/−100 µm Geometrical tolerance D ≤ 52 mm → P5 52 mm < D ≤ 110 mm → P6 D > 110 mm → Normal tolerances
For additional information (→ **page 132**)	Values: ISO 492, (→ **tables 3** to **5**, **pages 137** to **139**)
Internal clearance	Normal Check availability of C2, C3, C4, C5, reduced ranges of standard clearance classes or partitions of adjacent classes **SKF E2 bearings** C3 Check availability of other clearance classes
For additional information (→ **page 149**)	Values: ISO 5753-1 (→ **table 6**, **page 314**), except for stainless steel ...
Misalignment	≈ 2 to 10 minutes of arc
	The permissible angular misalignment between the inner and outer rings depends on the size and internal design of the bearing, the radial internal clearance in operation and the forces and moments acting on the ...
Friction, starting torque, power loss	Frictional moment, starting torque, and power loss can be calculated as specified under *Friction* (→ **page 97**), or using the tools ...
Defect frequencies	Defect frequencies can be calculated using the tools ...

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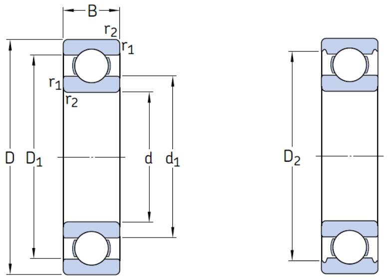
As the figure shown above (SKF Group, 2016), the permissible angular misalignment of deep groove single row ball bearing is 2~10 minutes of arc. Thus, it is safe to use deep groove bearings.

Select a suitable single row deep groove ball bearing from SKF catalogue, choose a size up from 29mm. However, to ensure all rolling elements are rolling inside the race, best to choose a bearing that can withstand the reaction forces at A and B. Also, the thickness of bearing cannot exceed the thickness of gearbox which is 30mm based on the given information.

1.1 Single row deep groove ball bearings
d **25 – 35** mm



Principal dimensions			Basic load ratings dynamic	static	Fatigue load limit	Speed ratings Reference speed	Limiting speed	Mass	Designation
d	D	B	C	C_0	P_u				
mm			kN		kN	r/min		kg	–
25	37	7	4,36	2,6	0,125	38 000	24 000	0,022	**61805**
	42	9	7,02	4,3	0,193	36 000	22 000	0,045	**61905**
	47	8	8,06	4,75	0,212	32 000	20 000	0,06	* **16005**
	47	12	11,9	6,55	0,275	32 000	20 000	0,078	* **6005**
	52	15	14,8	7,8	0,335	28 000	18 000	0,13	* **6205**
	52	15	17,8	9,8	0,4	28 000	18 000	0,12	**6205 ETN9**
	62	17	23,4	11,6	0,49	24 000	16 000	0,23	* **6305**
	62	17	26	13,4	0,57	24 000	16 000	0,22	**6305 ETN9**
	80	21	35,8	19,3	0,815	20 000	13 000	0,54	**6405**
28	58	16	16,8	9,5	0,405	26 000	16 000	0,17	**62/28**
	68	18	25,1	13,7	0,585	22 000	14 000	0,3	**63/28**
30	42	7	4,49	2,9	0,146	32 000	20 000	0,025	**61806**
	47	9	7,28	4,55	0,212	30 000	19 000	0,049	**61906**
	55	9	11,9	7,35	0,31	28 000	17 000	0,089	* **16006**
	55	13	13,8	8,3	0,355	28 000	17 000	0,12	* **6006**
	62	16	20,3	11,2	0,475	24 000	15 000	0,2	* **6206**
	62	16	23,4	12,9	0,54	24 000	15 000	0,18	**6206 ETN9**
	72	19	29,6	16	0,67	20 000	13 000	0,35	* **6306**
	72	19	32,5	17,3	0,735	22 000	14 000	0,33	**6306 ETN9**
	90	23	43,6	23,6	1	18 000	11 000	0,75	**6406**

There are several options for 30mm diameter bearing. Select 61806 as it is the smallest of nine choices above (SKF Group, 2016).

Pick the reaction force at point G as the dynamic bearing load to calculate the basic rating life

$$L_{10} = \left(\frac{C}{P}\right)^p = \left(\frac{4490}{201.3901}\right)^3 = 11082.17\ million\ revolution$$
$$L_{10h} = \frac{10^6}{60 \cdot n} \cdot L_{10} = \frac{10^6}{60 \cdot 2880} \cdot 11082.17 = 64132.9\ operating\ hours$$

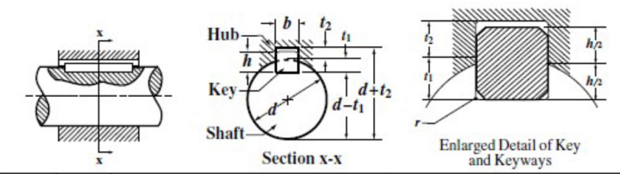
Where index $p = 3$ for ball bearings.

Key design:

Yield strength of material of shaft, $\sigma_{AB} = 180MPa$
Yield strength of material of gear, $\sigma_G = 180MPa$
Factor of safety 1 for key.
Rounded up shaft diameter $D = 29mm$

A plain square key is designed to resist crushing and shear forces due to the hub and the shaft. The yield strength of key material normally is the half of the shaft material. Based on the research (SubsTech, 2012), consider using cast aluminum alloy 514 due to its yield strength is 80MPa. The related data about cast aluminum alloy 514 is indicated in the table below. Yield strength of material of key, $\sigma_K = 80MPa$.

Cast aluminum alloy 514.0				
Chemical composition: Mg=4.0%, Al balance, sand casting				
Property	**Value in metric unit**		**Value in US unit**	
Density	2.65 $*10^3$	kg/m³	165	lb/ft³
Modulus of elasticity	71	GPa	10300	ksi
Thermal expansion (20 ºC)	24.1 $*10^{-6}$	ºC⁻¹	13.4 $*10^{-6}$	in/(in* ºF)
Specific heat capacity	963	J/(kg*K)	0.230	BTU/(lb*ºF)
Thermal conductivity	138	W/(m*K)	957	BTU*in/(hr*ft²*ºF)
Electric resistivity	4.9 $*10^{-8}$	Ohm*m	4.9 $*10^{-6}$	Ohm*cm
Heat of fusion	3.89 $*10^5$	J/kg	167	BTU/lb
Liquidus temperature	641	ºC	1185	ºF
Solidus temperature	599	ºC	1110	ºF
Tensile strength (F)	170	MPa	24660	psi
Yield strength (F)	80	MPa	11600	psi
Elongation (F)	5	%	5	%
Shear strength (F)	140	MPa	20300	psi
Fatigue strength (F)	50	MPa	7250	psi
Hardness (F), range	35-65	HB	35-65	HB



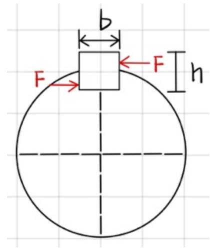
Shaft		Key	Keyway											
Nominal Diameter d			Width, b						Depth				Radius r	
				Free Fit		Normal Fit		Close Fit	Shaft t_1		Hub t_2			
Over	Up to and Incl	Size, b × h	Nominal	Shaft (H9)	Hub (D10)	Shaft (N9)	Hub (J_S9)[a]	Shaft and Hub (P9)	Nominal	Tolerance	Nominal	Tolerance	Max.	Min.
				Tolerances										
Keyways for Square Parallel Keys														
6	8	2 × 2	2	+0.025 / 0	+0.060 / +0.020	−0.004 / −0.029	+0.012 / −0.012	−0.006 / −0.031	1.2	+0.1 / 0	1	+0.1 / 0	0.16	0.08
8	10	3 × 3	3						1.8		1.4		0.16	0.08
10	12	4 × 4	4	+0.030 / 0	+0.078 / +0.030	0 / −0.030	+0.015 / −0.015	−0.012 / −0.042	2.5		1.8		0.16	0.08
12	17	5 × 5	5						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	+0.098 / +0.040	0 / −0.036	+0.018 / −0.018	−0.015 / −0.051	4	+0.2 / 0	3.3	+0.2 / 0	0.25	0.16
30	38	10 × 8	10						5		3.3		0.40	0.25
38	44	12 × 8	12	+0.043	+0.120 / +0.050	0 / −0.043	+0.021 / −0.021	−0.018 / −0.061	5		3.3		0.40	0.25
44	50	14 × 9	14						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		4.4		0.40	0.25
65	75	20 × 12	20	+0.052	+0.149 / +0.065	0 / −0.052	+0.026 / −0.026	−0.022 / −0.074	7.5		4.9		0.60	0.40
75	85	22 × 14	22						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	+0.062	+0.180 / −0.080	0 / −0.062	+0.031 / −0.031	−0.026 / −0.088	11		7.4		0.60	0.40
130	150	36 × 20	36						12	+0.3 / 0	8.4	+0.3 / 0	1.00	0.70
150	170	40 × 22	40						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	+0.074	+0.220 / +0.100	0 / −0.074	+0.037 / −0.037	−0.032 / −0.106	20		12.4		1.60	1.20
260	290	63 × 32	63						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	+0.260 / +0.120	0 / −0.087	+0.043 / −0.043	−0.037 / −0.124	28		17.4		2.50	2.00
440	500	100 × 50	100						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.

Select the key from the above figure (Briozzo, 2020), that the dimension of 10mm in width * 8mm in height.

Tangential force on key F,



$$F = \frac{\tau}{r} = \frac{28}{0.029/2} = 1931.0345N$$

Area resisting crushing $A_C = L \cdot \frac{h}{2} = 0.5(8)L = 4L\ mm^2$

The Maximum crushing stress,

$$\frac{\sigma_K}{F.S.} = \frac{F}{A_C} \quad \frac{80}{1} = \frac{1931.0345}{4L} \quad L = 6.0345\ mm$$

Area resisting shear $A_S = L \cdot b = 10L\ m^2$.

By the distortion-energy theory, the shear stress,

$$\frac{0.577 \cdot \sigma_K}{F.S.} = \frac{F}{A_S} \quad \frac{0.577 \cdot 80}{1} = \frac{1931.0345}{10L} \quad L = 4.1834\ mm$$

Based on the calculation above, the minimum key length that can withstand the compressive stress is 6.0345mm, and shear strengths is 4.1834mm. Therefore, consider the key length is the same as the hub length of the pinion.

$L = 25mm$

Area resisting crushing $A_C = L \cdot \frac{h}{2} = 0.5(8)(25) = 100\ mm^2$

The Maximum crushing stress,

$$\sigma_C = F.S.(\frac{F}{A_C}) = 1 \cdot (\frac{1931.0345}{100}) = 19.31MPa < 80MPa$$

Area resisting shear $A_S = L \cdot b = 10(25) = 250\ m^2$.

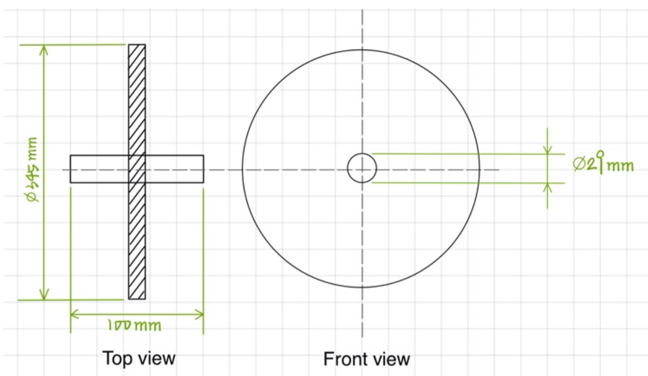
By the distortion-energy theory, the shear stress,

$$\sigma_S = F.S.(\frac{F}{A_S}) = 1 \cdot (\frac{1931.0345}{250}) = 7.724MPa < 80MPa * 0.577 = 46.16MPa$$

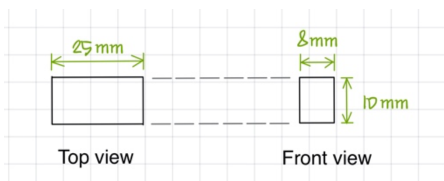
Therefore, it is safe to apply that the key dimension is 10mm in width * 8mm in height * 25mm in length.

The table below lists all the components that have been calculated in this document.

Components	Dimensions
Shaft	Minimum diameter: 28.97mm Minimum diameter (rounded up): 29mm
Single row deep groove ball bearings	Inner diameter: 30mm
Key	Width: 10mm Height: 8mm Length: 25mm



FBD (Shaft and pinion)



FBD (Key)

Reference:

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SKF Group (2016). MECH2400 *SKF Rolling Bearings Catalogue* [tutorial materials]. Retrieved from https://www.skf.com/binaries/pub12/Images/0901d196802809de-Rolling-bearings---17000_1-EN_tcm_12-121486.pdf

SubsTech (2012). *Cast Aluminum Alloy 514*. Retrieved from https://www.substech.com/dokuwiki/doku.php?id=cast_aluminum_alloy_514.0

Briozzo, P. (2020). MECH2400 *Keyway Metric Sizes Table* [tutorial materials]