Design of industrial fan

By:

Saif-Aldain Aqel QTY3S6

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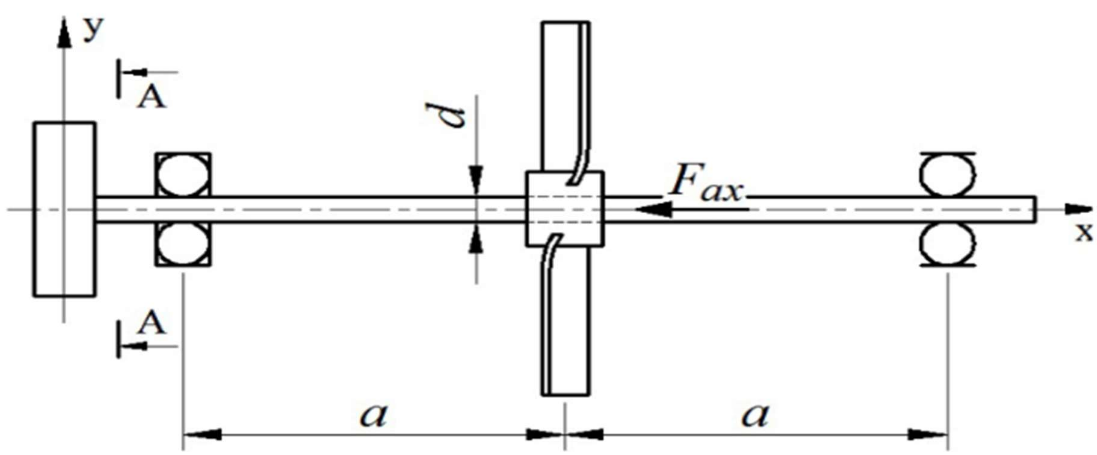
1. Description

The task is to design the shaft and bearing for an industrial fan system.

2. Calculations

2.1 Given data.

- Power: Pjk = 2.5 kW
- Operating Speed: njk = 940 rpm
- Thrust (axial) Load on the Rotor: Fax = 700 N
- Mass of the Rotor: mjk = 60 kg
- Distance of the Bearing from the Rotor: a = 355 mm
- Shaft Diameter under the Rotor: d = 60 mm
- Direction of the Belt pulling Force (H): α = 15°
- The required setup:

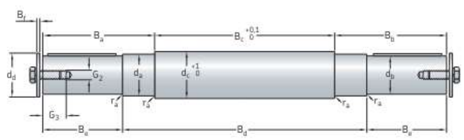


V1

2.2 Shaft selection.

We would need to use a solid shaft without any intricate geometrical shapes to reduce the procedure difficulty during the assembly process. The shaft selection is based on the geometrical data and the ease of assembly.
From the SKF Catalogue:

12.5 Shafts for two-bearing housings in the PDN 3 series
d_a **25 – 120** mm



Dimensions Shaft d_a	d_b	d_c	d_d	B_a	B_b	B_c	B_d	B_e	B_f	r_a	G_2	G_3
mm												
25	19	34	28	91	89,5	115,5	216	40	4	0,8	8	20
30	24	39	32	101,5	100	138,5	240	50	4	0,8	10	27
35	28	44	36	118,5	117	158,5	274	60	4	1,2	10	27
40	32	49	40	140	138,5	212,5	331	80	5	1,2	12	30
45	38	54	45	151,5	150	234,5	376	80	5	1,2	12	30
50	42	59	50	175	173,5	264,5	393	110	6	1,6	16	36
55	48	64	63	186,5	185	286,5	438	110	6	1,6	16	40
60	48	69	63	182,5	181	332,5	476	110	6	1,6	16	40
65	55	74	70	191	189,5	347,5	508	110	6	1,6	16	40
70	60	79	70	225	223,5	363,5	532	140	6	1,6	16	40
75	65	84	78	230,5	229	387,5	567	140	6	1,6	20	46
80	70	89	90	227	225,5	403,5	576	140	6	1,6	20	46
85	75	99	90	234,5	234,5	421	610	140	6	1,6	20	46
90	80	104	100	260	260	445	625	170	8	1,6	20	46
95	85	109	100	269,5	269,5	469	668	170	8	2,5	20	46
100	90	114	105	266,5	266,5	500	693	170	8	2,5	24	52
110	100	124	115	309,5	309,5	510	709	210	8	2,5	24	52
120	110	134	132	314	314	522	730	210	12	2,5	30	60

Shaft diameter d_a	Appropriate parts Housing	Bearings	Shaft	Shaft keys to ISO 773	Mass Shaft only
mm	–				kg
25	PDN 305	2 x 6305	**VJ-PDNB 305**	6x6x32	1,4
30	PDN 306	2 x 6306	**VJ-PDNB 306**	8x7x40	2,2
35	PDN 307	2 x 6307	**VJ-PDNB 307**	8x7x40	3,35
40	PDN 308	2 x 6308	**VJ-PDNB 308**	10x8x63	5,25
45	PDN 309	2 x 6309	**VJ-PDNB 309**	10x8x63	7,3
50	PDN 310	2 x 6310	**VJ-PDNB 310**	12x8x80	9,85
55	PDN 311	2 x 6311	**VJ-PDNB 311**	14x9x80	13
60	PDN 312	2 x 6312	**VJ-PDNB 312**	14x9x80	15,5
65	PDN 313	2 x 6313	**VJ-PDNB 313**	16x10x80	19,5
70	PDN 314	2 x 6314	**VJ-PDNB 314**	18x11x100	25
75	PDN 315	2 x 6315	**VJ-PDNB 315**	18x11x100	30
80	PDN 316	2 x 6316	**VJ-PDNB 316**	20x12x100	34,5
85	PDN 317	2 x 6317	**VJ-PDNB 317**	20x12x100	43
90	PDN 318	2 x 6318	**VJ-PDNB 318**	22x14x140	51
95	PDN 319	2 x 6319	**VJ-PDNB 319**	22x14x140	59,5
100	PDN 320	2 x 6320	**VJ-PDNB 320**	25x14x140	67,5
110	PDN 322	2 x 6322	**VJ-PDNB 322**	28x16x180	87,5
120	PDN 324	2 x 6324	**VJ-PDNB 324**	28x16x180	106

Turning technologies will be used to reach the wanted dimensions keeping the lengths the same, for the shaft to be usable and fit with the wanted dimensions between the bearings (distance a=355 mm).

2.3 Motor selection.

we would need to have a motor with a higher rpm to reach a good ratio between the motor and the belt drive system.
From https://theissdrive.com/villanymotor/haromfazisu-villanymotor/.

Three-phase electric motor

230/400V D/Y up to IEC100 size

400/690V D/Y from IEC112 size

aluminum / cast iron housing

2, 4, 6, 8 poles

0.06kW – 315kW

IE1, IE2, IE3 efficiency classification

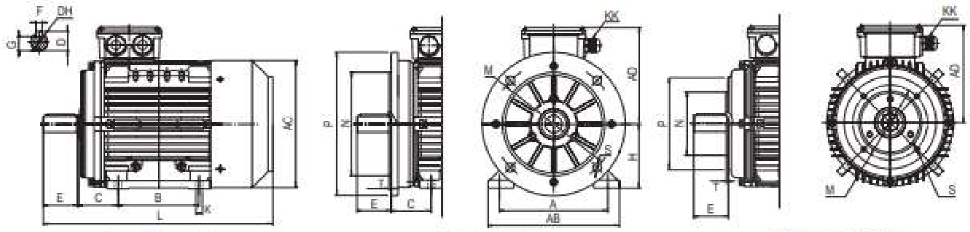
deep blue color

IE3 - 2 POLI - 3000rpm

kW	hp	model		rpm	η% 100%	η% 75%	η% 50%	cosφ	In (A) 400V 50 Hz	Is / In	Cn	Cs / Cn	Cmax / Cn	kg
0,75	1	T3A	80A2	2890	80,7	80,3	77,2	0,81	1,7	6,0	2,5	2,7	2,8	8,4
1,1	1,5	T3A	80B2	2890	82,7	82,5	79,9	0,82	2,4	6,7	3,7	2,7	2,9	10,2
1,5	2	T3A	90S2	2900	84,2	83,8	81,4	0,82	3,1	6,1	5,0	2,3	2,7	14,4
2,2	3	T3A	90L2	2910	85,9	86,1	84,7	0,84	4,4	7,0	7,4	2,6	2,7	16,2
3	4	T3A	100L2	2910	87,1	87,5	86,3	0,88	5,7	7,6	10,1	2,5	2,8	18,5
4	5,5	T3A	112M2	2920	88,1	88,2	87,0	0,90	7,3	7,8	13,1	2,5	2,7	30,2
5,5	7,5	T3A	132SA2	2930	89,2	89,4	88,2	0,89	10,0	7,8	18,1	2,4	2,9	44,1
7,5	10	T3A	132SB2	2930	90,1	90,2	89,1	0,90	13,4	7,9	24,6	2,7	2,8	52,0
11	15	7SM3	160MA2	2940	91,2	91,1	89,8	0,89	19,6	8,1	35,7	2,0	2,3	115
15	20	7SM3	160MB2	2940	91,9	91,8	90,7	0,89	26,5	8,1	48,7	2,0	2,3	125
18,5	25	7SM3	160L2	2940	92,4	92,3	90,4	0,89	32,5	8,2	60,1	2,0	2,3	147
22	30	7SM3	180M2	2955	92,7	92,6	91,6	0,89	38,5	8,2	71,1	2,0	2,3	195
30	40	7SM3	200LA2	2965	93,3	93,2	92,1	0,89	52,1	7,6	96,6	2,0	2,3	243
37	50	7SM3	200LB2	2965	93,7	93,5	92,3	0,89	64,0	7,6	119,2	2,0	2,3	258
45	60	7SM3	225M2	2970	94,0	93,6	92,4	0,90	76,8	7,7	144,7	2,0	2,3	324
55	75	7SM3	250M2	2975	94,3	94,1	93,0	0,90	93,5	7,7	176,6	2,0	2,3	432
75	100	7SM3	280S2	2975	94,7	94,3	93,0	0,90	127,0	7,1	240,8	1,8	2,3	560
90	125	7SM3	280M2	2975	95,0	94,6	94,3	0,90	151,9	7,1	288,9	1,8	2,3	603
110	150	7SM3	315S2	2980	95,2	94,8	93,6	0,90	185,3	7,1	352,5	1,8	2,3	880
132	180	7SM3	315M2	2980	95,4	95,0	93,9	0,90	221,9	7,1	423,0	1,8	2,3	960
160	220	7SM3	315LA2	2980	95,6	95,0	94,2	0,91	265,5	7,2	512,8	1,8	2,3	1030
200	270	7SM3	315LB2	2980	95,8	95,1	94,2	0,91	331,1	7,2	640,9	1,8	2,2	1358
250	340	7SM3	355MB2	2980	95,8	95,2	94,5	0,90	413,9	7,2	801,2	1,6	2,2	1802
315	430	7SM3	355LB2	2980	95.8	95.2	94.5	0.91	521.5	7.2	1009.5	1.6	2.2	2017

IE3 - 2 POLI - 3000rpm

The dimensions of the motor:



B3 (IM 1001) B35 (IM 2001) B14 (IM 3601)

SIZE	poles	A	AB	AC	AD	B	C	D	DH	E	F	G	H	K	KK	L	B5 M	B5 N	B5 P	B5 S	B5 T	B14 M	B14 N	B14 P	B14 S	B14 T
80	2-4	125	160	158	130	100	50	19	M6X16	40	6	15,5	80	10X13	M20 X 1,5	277	165	130	200	12	3,5	100	80	120	M6	3
90S	2-4-6	140	175	177	140	100	56	24	M8X19	50	8	20	90	10X13		312	165	130	200	12	3,5	115	95	140	M8	3
90L	2-4-6	140	175	177	140	125	56	24	M8X19	50	8	20	90	10X13		337	165	130	200	12	3,5	115	95	140	M8	3
100L	2-4-6	160	196	199	157	140	63	28	M10X22	60	8	24	100	12X16		375	215	180	250	15	4	130	110	160	M8	3,5
100LB	4	160	196	199	157	140	63	28	M10X22	60	8	24	100	12X16		375	215	180	250	15	4	130	110	160	M8	3,5
112M	2-4-6	190	220	220	168	140	70	28	M10X22	60	8	24	112	12X16	M25 X 1,5	397	215	180	250	15	4	130	110	160	M8	3,5
132S	2-4-6	216	252	261	187	140	89	38	M12X28	80	10	33	132	12X16		460	265	230	300	15	4	165	130	200	M10	3,5
132M	2-4-6	216	252	261	187	178	89	38	M12X28	80	10	33		12X16		498	265	230	300	15	4	165	130	200	M10	3,5
160M	2-4-6	254	320	330	261	210	108	42	M16X36	110	12	37	160	14X19	M32	665				18,5	5	215	180	250	M12	4
160L						254			M16X36	110		37		14X19		685				18,5	5	215	180	250	M12	4

2.4 Belt drive design.

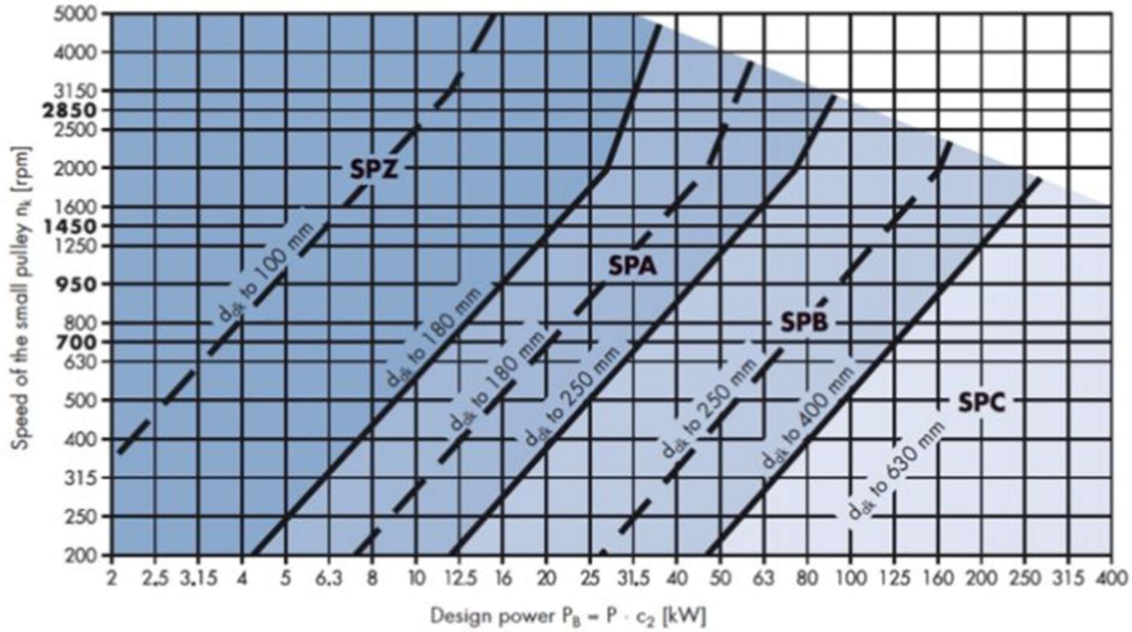
Examples for Work Machines	Examples for Drive Machines: AC motors and three-phase induction machines with a normal starting torque (up to 1.8 times nominal torque), e. g. synchronous motors and single-phase motors with a starting-aid phase, three-phase squirrel cage motors with direct start, star-delta connection or slip ring starters; direct-current shunt-wound motors, combustion engines and turbines n > 600 rpm — Load factor c_2 for daily operating time (hours): up to 10	over 10 to 16	over 16	AC motors and three-phase induction machines with high starting torque (over 1.8 times nominal torque), e. g. single-phase motors with high starting torque; direct-current series-wound motors with series connection and compound; combustion engines and turbines n < 600 rpm — Load factor c_2 for daily operating time (hours): up to 10	over 10 to 16	over 16
Light drives Centrifugal pumps and compressors, belt conveyors (light weight materials), fans and pumps up to 7.5 kW.	1.1	1.1	1.2	1.1	1.2	1.3
Medium drives Plate cutters, presses, chain and belt conveyors (heavy materials), vibrating screens, generators and exciters,						

$$P_{planning} = c_2 P_{jk}$$

Using the above-mentioned formula and C2:

$$P_{planning} = C_2 P_{jk} = 1.8\ KW$$

Using this and the given diagram we can choose the belt's profile and the speed of the small pully.



As we have P_B=1.8≈2KW

So we have a SPZ profile and n_k=350 rpm.

$$I_{nominal} = \frac{n_{jk}}{n} = 0.3723$$

Since we have a SPZ profile the bigger pully will be placed on the shaft.

2.5 Pullies selection.

Choosing a small pulley of diameter 50 mm and a big pulley of diameter 80 mm.

Wedge belt profile DIN 7753 Part 1 and ISO 4184	–	–	–	SPZ	SPA	SPB	–	SPC	–	–	–	min.	max.	tolerance
	20.0											20.0	20.4	
	22.0											22.0	22.4	
	25.0											25.0	25.4	
	28.0	28.0										28.0	28.4	
	31.5	31.5										31.5	32.0	
	35.5	35.5										35.5	36.1	
	40.0	40.0	40	40								40.0	40.6	
	45.0	45.0	45	45								45.0	45.7	
	50.0	50.0	50	50								50.0	50.8	
	56.0	56.0	56	56								56.0	56.9	0.2
	63.0	63.0	63	63	63							63.0	64.0	
				67	67							67.0	68.0	
	71.0	71.0	71	71	71							71.0	72.1	
				75	75							75.0	76.1	
	80.0	80.0	80	80	80							80.0	81.3	
				85	85							85.0	86.3	
		90.0	90	90	90	90						90.0	91.4	
				95	95	95						95.0	96.4	
		100.0	100	100	100	100						100.0	101.6	
				106	106	106						106.0	107.6	
		112.0	112	112	112	112						112.0	113.8	
				118	118	118						118.0	119.9	
		125.0	125	125	125	125						125.0	127.0	

After the selection we check the center distance.

$$a > 0.7(d_1 + d_2)$$

$$a < 2\ (d_1 + d_2)$$

As both equations are satisfied the chosen pulley sizes are alright.

2.6 Belt selection.

We select the belt based on the required length, which can be determined by:

$$L = 2a + 1.57(d_1 + d_2) + \frac{(d_1 + d_2)^2}{4a} = 705\ mm$$

Selected length is L = 710 mm.

Based on the belt length we calculate a modified center distance.

$$a_{nom} = \frac{L - \frac{\pi}{2}(d_1 + d_2)}{4} + \sqrt{\left(\frac{L - \frac{\pi}{2}(d_1 + d_2)}{4}\right)^2 - \frac{(d_1 + d_2)^2}{8}} = 249.95\ mm \cong 250\ mm$$

Other quantities we need to calculate for the belt include:

- Belt speed.

$$v_{belt} = \frac{d_1 \pi n_1}{60} = 0.9163 \frac{m}{s}$$

Since the speed is less than 55 m/s, the belt is alright.

- Belt frequency.

$$f_{belt} = \frac{2 \cdot 1000 \cdot v_{belt}}{L_{belt}} = 2.58\ Hz$$

Since the frequency is less than 100 Hz , the belt is alright.

- Belt loops.

To complete the rest of the calculations we need to find a few factors depending on the contact angle.

$$\beta = 2arccosine\left(\frac{d_1 - d_2}{2a_{nom}}\right) = 174°$$

Using this we can obtain C_1 & C_3, since we already have C_2=1.2.

C_1=1

C_2=1.2

C_3=0.85

To find the number of the required belt loops we use:

$$z = \frac{PC_2}{P_N C_1 C_3} = 3$$

Where P_N=0.29 KW.

Therefore, we have 3 belt loops.

- Tensile force

$$T = \frac{500(2.04 - C_1) \cdot P_B}{C_1 \cdot z \cdot v_{belt}} + kv_{belt}^2 = 340.56\ N$$

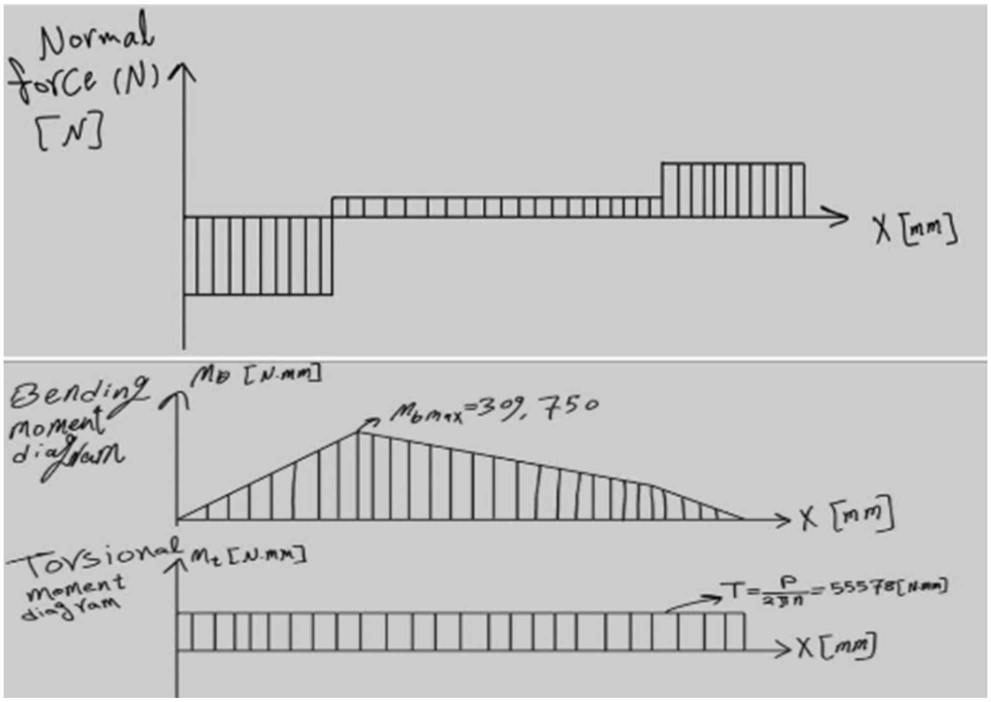
Where, k=0.07

- Pulling force

$$H \approx 2T \cdot \sin\left(\frac{\beta}{2}\right) \cdot z = 2040\ N$$

2.7 Checking shaft for bending.

Bending and moment diagram:



$$G = weight\ of\ rotor = 461\ N$$

$$m_g = weight\ of\ shaft = 588\ N$$

$$F_r = 730\ N$$

$$F_A = 255\ N$$

$$\sum F_x = A_x = F_x$$

$$A_x = 255\ N$$

$$\sum F_y = 0$$

$$A_y + B_y = G + F_r + m_g = 1779\ N$$

$$\sum M_{oz} = 0$$

$$xA_y - (x + a) \cdot (G + F_r + m_g) + (x + 2a) \cdot B_y = 0$$

$$A_y = B_y = 889.5\ N$$

$$H_z = 2040\ N$$

$$\sum F_z = 0$$

$$H_z + A_z + B_z = 0$$

$$\sum M_y = 0$$

$$(H_z \cdot x) - (B_z \cdot (2 \cdot a)) = 0$$

$$A_z = -2183.7\ N$$

$$B_z = 143.7\ N$$

$$A = 2357.9\ N$$

$$B = 901.0\ N$$

$$M_{hk} = H_z \cdot l + A_z(l - x) = 66.1\ Nm$$

Max M_{hk}=102 Nm when M_{hr}=0

Max M_{hr}=157.8 Nm when M_{hk}=66.1 Nm

$$M_h = \sqrt{M_{hk}^2 + M_{hr}^2} = 171.1\ Nm$$

$$Torque = \frac{P}{w} = 25.4\ Nm$$

Bending sectional modulus $K = \frac{d^2\pi}{32} = 173.2\ mm^2$

Polar sectional modulus $K_p = \frac{d^3\pi}{16} = 14547.1\ mm^3$

Bending stress $\sigma_{b,max} = \frac{M_h}{K} = 11.5\ MPa$

Shear stress $\tau_{max} = K_d \cdot T = 26.7\ MPa$

Equivalent stress $\sigma_{eq} = \sqrt{\sigma^2 + 3\tau^2} = 47.86\ MPa$

Shaft material is C55E with Re=400 MPa

Safety factor:

$$z = \frac{Re}{\sigma_{eq}} = 8.4$$

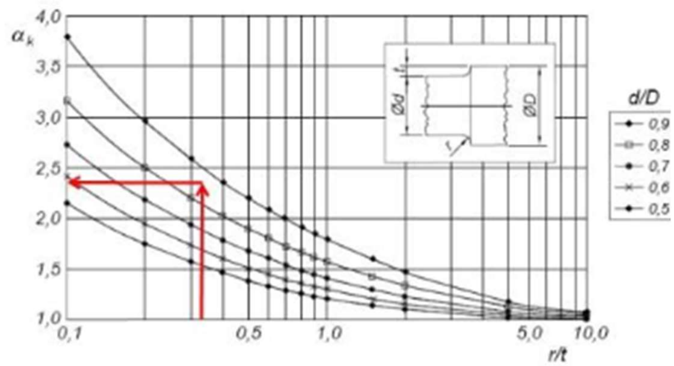
Safety factor is satisfactory.

2.8 Checking shaft for fatigue.

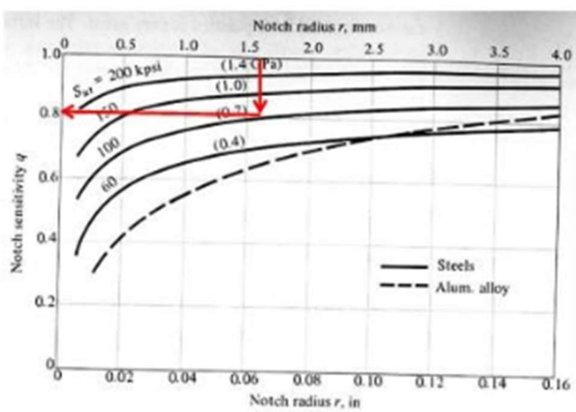
Investigation of the First shoulder (60 -70 mm):

& d/D = 0.86, t = (D-d)/2 = 5 [mm], ρ the fillet radius ρ = 1.6 [mm] then, ρ/t = 0.32 –

For bending: Stress concentration factor αk in case of bending from the diagram: αk = 2.4



Notch sensitivity (q) from the diagram: q = 0.81



Then, the Fatigue stress concentration factor βk :

βk = 1+q*(αk -1) = 2.134 bending moment applied on the shaft first shoulder:

M = Fr * l = 1500 * 140 = 210,000 [N.mm]

So, the normal stress for bending σa = M/K = 9.9 [MPa]

Then, to calculate the surface factor Ka = 0.575*Ka' + 0.425, where Ka' = 0.8 Ka = (0.575*0.8) + 0.425 = 0.885

And to calculate the size factor(Kb):

$$k_b = \begin{cases} 0.879d^{-0.107} & 0.11 \le d \le 2 \text{ in.} \\ 0.91d^{-0157} & 2 < \text{d} \le 10 \text{ in.} \\ 1.24d^{-0.107} & 2.79 \le \text{d} \le 51 \text{ mm.} \\ 1.51d^{-0.157} & 51 < \text{d} \le 254 \text{ mm.} \end{cases}$$

Kb = 1.51*d-0.157 = 0.79

Then, the endurance limit of the shaft shoulder:
σv’ = * Ka *Kb * σv , Where

σv = 350 [MPa]

σv’ = 114.668 [MPa]

Then the safety factor (n)

n = 11.58

For torsion:

T=55577.92 Nmm

so, torsional stress : τ = T/Kp = 1.31 [MPa]

Fatigue stress concentration factor: $\beta_k = 1+q*(\alpha_k -1) = 2.134$

The size factor(Kb): Kb = 1.51*d-0.157=0.79

The surface factor Ka = 0.6*Ka’ + 0.4 , where Ka’ = 0.8

Ka = (0.6*0.8) + 0.4 = 0.88

Then, the endurance limit for torsion: τv’ = 61.90 [MPa]

safety factor (n): n = τv’ / τ = 47.615 >> 2

Then, the first shoulder is well resistant to fatigue from bending or torsion

To investigate the second shoulder (70-79):

d/D = 0.886 , t = (D-d)/2 = 4.5 [mm], ρ the fillet radius ρ = 1.6 [mm] then, ρ/t = 0.356 –

For bending:
Stress concentration factor αk in case of bending from the diagram: αk = 2.3
Notch sensitivity (q) from the diagram: q = 0.81
Then, the Fatigue stress concentration factor βk : βk = 1+q*(αk -1) = 2.053 bending

moment applied on the shaft second shoulder:
$M = Fr * l = 1500 * 205 = 307,500$ [N.mm]

$\sigma a = M/K = 9.13$ [MPa]
$Ka = (0.575*0.8) + 0.425 = 0.885$ $Kb = 1.51*d^{-0.157} = 0.77$

$$\sigma_v' = \frac{1}{\beta k} * K_a * K_b * \sigma_v = 116.175 \text{ [MPa]}$$

n=12.72

- For torsion:

T = 55577.92 [N.mm]

Polar section modulus: $Kp = 67347.89$ [mm3] so,

torsional stress : $\tau = T/Kp = 0.825$ [MPa]
Fatigue stress concentration factor βk : $\beta k = 1+q*(\alpha k -1) = 2.053$
The size factor(Kb): $Kb = 1.51*d^{-0.157} = 0.77$
The surface factor $Ka = 0.6*Ka' + 0.4$, where $Ka' = 0.8$
$Ka = (0.6*0.8) + 0.4 = 0.88$

Then, the endurance limit for torsion: $\tau v' = 62.71$ [MPa]

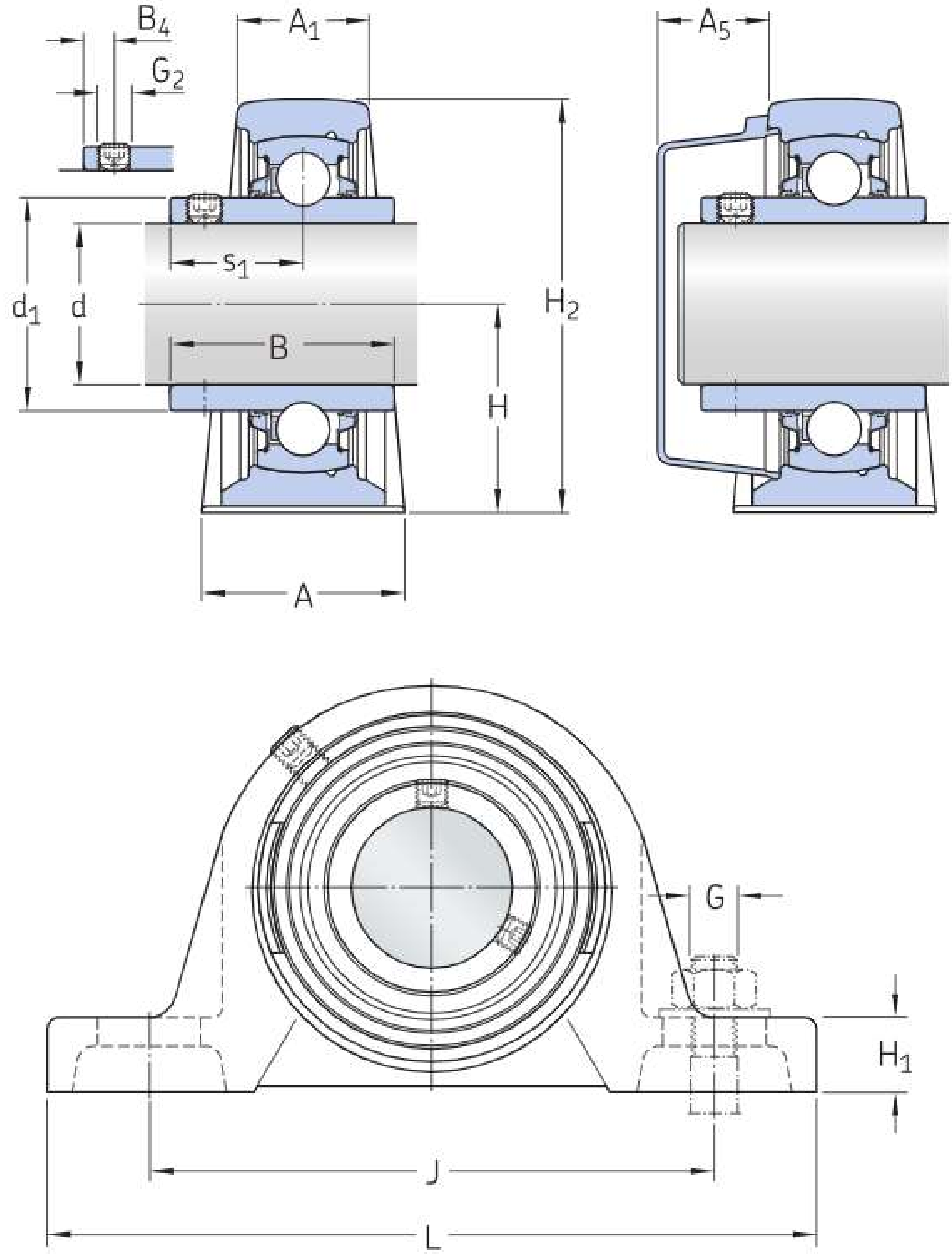
safety factor (n): $n = \tau v' / \tau = 76 >> 2$

Then, the second shoulder is well resistant to fatigue from bending or torsion

2.9 Bearing selection.

Dbearing= 35mm

The selected bearing:



B4
G2
A1
A5
d1
d
s1
B
H
H2
A
G
H1
J
L

Dimensions

d	35 mm	Bore diameter
d_1	≈ 46.1 mm	Shoulder diameter of inner ring
A	45 mm	Base width
A_1	27 mm	Top width
A_5	24.5 mm	Standout of end cover
B	42.9 mm	Width of inner ring
B_4	6 mm	Distance from locking device side face to thread centre
H	47.6 mm	Height of spherical seat centre
H_1	19 mm	Foot height
H_2	93 mm	Overall height
J	126 mm	Distance between attachment bolts
J	max. 133 mm	Distance between attachment bolts
J	min. 119 mm	Distance between attachment bolts
L	160 mm	Overall length
N	14 mm	Diameter of attachment bolt hole
N_1	21 mm	Length of attachment bolt hole
s_1	25.4 mm	Distance from locking device side face to raceway centre

2.10 Lifetime calculation.

For estimating the expected bearing life, If we consider only the load and speed, you can use the basic rating life, L10. The basic rating life of a bearing in accordance with ISO 281 is

$$\boxed{L = \left(\frac{C}{P}\right)^p}$$

P =X Frad + Y Fax , X & Y are radial and axial load factor for the bearing respectively which can be drawn from this table

$$F_e = X_i V F_r + Y_i F_a \qquad (11\text{–}9)$$

Table 11–1

		$F_a/(VF_r) \le e$		$F_a/(VF_r) > e$	
F_a/C_0	e	X_1	Y_1	X_2	Y_2
0.014*	0.19	1.00	0	0.56	2.30
0.021	0.21	1.00	0	0.56	2.15
0.028	0.22	1.00	0	0.56	1.99
0.042	0.24	1.00	0	0.56	1.85

Since $\frac{Fax}{C_o} = 650/45000 = 0.014, \frac{F\,ax}{F\,rad} = 0.43 > \mathrm{e} = 0.19$

Then, X = 0.56 & Y = 2.30 from the table

So, P = (0.56 * 1500)+ (2.30 * 650) = 2335 [N] Then,L10h = 358,057.48 Service Hours.

Then this bearing is acceptable for 40,000 service hours.

2.11 Critical speed calculation.

Model applied for the calculations:

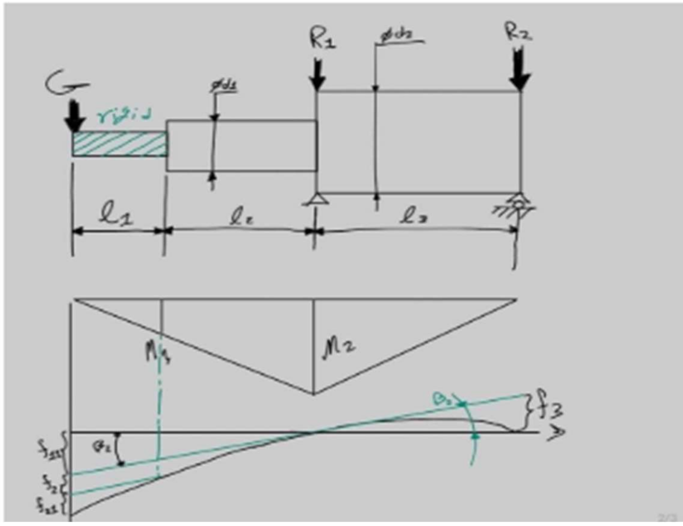
-The weight of the shaft is neglected

-The impeller is considered a rigid body and its weight is acting on single point (its center of gravity)

-The bearings allow rotation, but rigid radially.

The shaft and impeller are a 1 degree of freedom oscillating system and its frequency is identical to the critical rotational speed.

First, the reaction forces are determined by applying the impeller's weight (G)



Static Equilibrium equations:

$G+R_1+R_2 = \text{zero}$

ΣM_{R1} :- $G^*(l_1 + l_2) = R_2{}^* l_3$. Then, $R_2 = 344.75$ [N] & $R_1 = 933.35$ [N] Deformation:

$2*l3^3{}_3 = \overline{\qquad}$ $Rd\pi$ ^{4}] E = $2^4*{}_2 = \frac{}{64}$ $2.1*10^5$ [N/mm^2]

f= 0.0184 [mm], I= 1911957.63 [mm

$2*I2*E$

$\beta_2 = f_3/l_3 = 0.0184/350 = 5.259*10^{-5}$

$f_{11} = \beta_2 * (l_1+l_2) = 0.0108$ [mm]

And to calculate f_2 we need to get M_1 first, where $M_1 = G*l_1 = 82992.6$ [N.mm]

So, f $= \overline{\quad} + \overline{\quad}$, where I= 1178588.12 $1 = \frac{}{64}2$ $3*l1*E$ $2*l1*$ $G\,l3^3$ $M1*l1^2$ $d1^4*\pi$ ^{4}] [mm

E

$f_2 = 0.0047$ [mm]

$\beta_1 = \frac{G*l2^2}{3*l1*} + \frac{M1*l1}{1*} = 0.00015$ [mm] E I E

So, $f_{21} = \beta_1 * l_1 = 9.6*10^{-3}$ **[mm]**

so, total deflection due to impeller's weight $f_1 = f_{11} + f_2 + f_{21} = 0.0251$ [mm]

Then, the spring characteristics: $C = f_1/G = 4.26 * 10^{-5}$ [mm/N] Frequency:

$\alpha = \sqrt{\frac{g}{G*C}} = 625.169$ [rad]

Then, the critical speed: $n_{cr} = (60^* \alpha)/(2\,\pi) = 5969.927$ [rpm]

$\left(\frac{ncr\ \ n}{n} * \mathbf{100\%}\right) = 531.738\%$

Then, the shaft is suitable for this rotation speed(n) since $n_{cr} >> n$.

3. References

1)SKF Catalogues for shafts

https://www.skf.com/binaries/pub12/Images/Shafts%20for%20two-bearing%20housings%20in%20the%20PDN%202%20serie_tcm_12-231227.pdf

2) Bearing Catalogues from SKF

https://www.skf.com/binaries/pub12/Images/Two-bearing%20housings%20in%20the%20PDN%20series_tcm_12-231223.pdf

3)design aid

4)theissdrive

https://theissdrive.com/villanymotor/haromfazisu-villanymotor/