IZMIR INSTITUTE OF TECHNOLOGY

Department of Mechanical Engineering

ME311 MACHINE ELEMENTS

HW3

DESIGN OF CHAIN

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1 INTRODUCTION

The objective of this report is to design a chain drive mechanism for a centrifugal compressor driven by an electric motor equipped with a reducer. The design process involves selecting appropriate chain types, sprockets, and lubrication methods to ensure safe and efficient power transmission under the specified operating conditions.

Two distinct design alternatives are evaluated using the SKF Power Transmission Chain Catalogue, single and double strand chain design.

1.1 Given Inputs

$$P_n = 12\ kW$$

$$n_{driver} = 62\ rpm$$

$$n_{driven} = 37\ rpm\ \pm \%7$$

$$Service\ time = 9\frac{h}{day}$$

$$Center\ Distance = 1640\ mm$$

2 DESIGN

2.1 Design Power

First, the design power must be determined. Design power (P_d) can be expressed as:

$$P_d = F_a * F_t * P_n * F_v$$

2.1.1 Service Factor (F_a)

According to the assignment, the chain to be designed is for a centrifugal compressor run by an electric motor. Referring to Table 1 in the SKF catalog, the service factor meeting these conditions is $F_a = 1.3$

Application service factor (F_a)		Type of prime mover		
Load classification	Driven equipment	Electric motor or turbine	Internal combustion engine > 6 cylinders, with flywheel, or hydraulic coupling	Internal combustion engine <6 cylinders, with NO flywheel, or hydraulic coupling
Uniform load (U)	Agitators; centrifugal blowers; generators, centrifugal pumps; Uniformly loaded belt conveyor, lightly loaded chain conveyors	1.0	1.0	1.2
Moderate shock (M)	Centrifugal compressors,; kilns and dryers; conveyors and elevators with intermittent, medium load fluctuations; Dryers; Pulverisers; machinery with moderate pulsating loads (machine tools paper, textiles)	1.3	1.2	1.4
Heavy shock (H)	Press, construction and mining equipment; reciprocating machinery, (compressors, reciprocating feeders, oil well rigs) rubber mixers, roll lines, machinery with heavy shock or reversing torques	1.5	1.4	1.7 – 1.9

Table 1

Figure 1: SKF Catalogue, Service Factor, Table 1

2.1.2 Temperature Factor (F_t)

The assignment does not specify any temperature conditions for the compressor. Therefore, assuming normal operating conditions, the temperature factor is $F_t = 1$ according to Table 3 in the SKF catalogue.

Table 3

Temperature factor (F_T)	
Temperature range °C	F_T factor
–40 °C to –30 °C	Not suitable
–30 °C to –20 °C	0.25
–20 °C to –10 °C	0.33
–10 °C to +150 °C	1.00
150 °C to +200 °C	0.75
+200 °C to +250 °C	0.5
> +250 °C	Refer SKFPTP

Figure 2: SKF Catalogue, Temperature Factor, Table 3

2.1.3 Driver Power (P_n)

Driver Power was previously provided as a given input. $P_n = 12\ kW$

2.1.4 Assumed Speed Factor (F_v)

In order to determine the Speed Factor, the speed must be known. Speed can be calculated as:

$$V = \frac{\pi * d * n_{driver}}{60}$$

Since the diameter value is unknown, the speed factor cannot be calculated; however, by using the maximum speed factor value, a more accurate sprocket selection can be made in the next step.

Table 2

Speed of chain	Speed factor	Speed of chain	Speed factor
m/s	F_n	m/s	F_n
Less than 0.17	1.0	>0.5 – < 0.67	1.3
>0.17 and <0.33	1.1	>0.67 – < 0.83	1.4
>0.33 and < 0.5	1.2	>0.83 – <1.17	1.6

Figure 3: SKF Catalogue, Speed Factor, Table 2

Design Power can be calculated as follows:

$$P_d = F_a * F_t * P_n * F_v = 1.3 * 1 * 12 * 1.6 = 24.96\ kW$$

2.2 Alternative 1: Single Strand Chain Design

In this alternative, a single strand chain is selected to transmit the design power of 24.96 kW.

2.2.1 Driver and Driven Sprocket and Chain Type Selection

Table 9h

28B-1; (44.45 mm Pitch) Power ratings in kilowatt (European standard)

No of teeth	Pitch circle Dia.	rpm of small (faster) sprocket z_1															
Z	mm	10	25	50	75	100	125	150	200	250	300	350	400	450	500	550	600
13	**185,74**	2,63	5,99	11,25	14,97	20,94	22,82	30,05	38,96	47,64	55,96	64,38	72,53	80,68	89,27	97,00	87,55
15	**213,79**	3,06	7,00	13,05	15,87	24,46	24,21	35,10	45,50	55,62	65,49	75,37	84,98	94,42	103,85	113,30	108,15
17	**241,91**	3,52	8,00	14,94	19,50	27,89	29,74	40,17	52,02	63,52	75,11	86,70	97,00	108,15	129,60	129,60	129,60
19	**270,06**	3,96	9,01	16,48	22,67	31,42	34,58	45,32	58,79	72,10	84,20	97,00	109,00	121,88	145,92	145,92	145,92
21	**298,24**	4,41	10,12	18,72	24,94	35,02	38,04	50,47	65,23	79,83	94,42	108,15	121,88	135,62	163,95	163,95	175,95
23	**326,44**	4,87	11,15	20,68	27,20	38,63	41,49	55,80	72,10	88,40	103,85	118,45	134,75	149,35	179,40	179,40	193,98
25	**354,65**	5,33	12,18	22,66	29,47	42,41	44,95	60,95	78,97	97,00	113,30	130,47	147,63	163,95	204,28	204,28	212,00
Lubrication method		**TYPE 1**		**TYPE 2**								**TYPE 3**					

Figure 4: SKF Catalogue, Power Rating Table, Table 9h

The driver sprocket selection was optimized to balance efficiency and cost. Although standard practice suggests starting with 19 teeth, this configuration with a table 9h 28B-1 chain type yielded only 19.5 kW, falling short of the required 25 kW design power. Rather than resorting to a larger, heavier chain pitch, the number of teeth was increased to 25 This adjustment raised the capacity to 25.9 kW, safely meeting design requirements and reducing the polygon effect; therefore, driver sprocket = 25 teeth was chosen as the optimal size.

Target Transmission Ratio (i):

$$\frac{n_{driver}}{n_{driven}} = \frac{62}{37} = 1.676$$

$$Z_2 = Z_1 * i = 25 * 1.676 = 41.9\, mm$$

The theoretical number of teeth for the driven sprocket was calculated as 41.9 (approx. 42) based on the target speed ratio. However, a review of the SKF Standard Sprocket Catalogue revealed that a 42-tooth sprocket is not available as a standard off-the-shelf component.

Therefore, the nearest available standard sprockets, 38 and 45 teeth, were evaluated:

$$n_{driven,min} = 34.41, \qquad n_{driven,max} = 39.59$$

For 38 Teeth:

$$i = \frac{38}{25} = 1.52$$

$$n_{driven} = \frac{62}{1.52} = 40.78$$

For 45 Teeth:

$$i = \frac{45}{25} = 1.8$$

$$n_{driven} = \frac{62}{1.8} = 34.44$$

38 Teeth: Resulted in an output speed of 40.8 rpm, which corresponds to a 10.2% error. This exceeds the allowable tolerance of $\pm\%7$

45 Teeth: Resulted in an output speed of 34.41 rpm. Since the minimum driven speed is 34.44 rpm, it falls within the permissible range and is acceptable.

2.2.2 Sprockets Diameter (d,D)

d = driver sprocket diameter

D = driven sprocket diameter

The pitch diameters of the sprockets are calculated using the standard relationship between chain pitch (p) and number of teeth (Z_1 and Z_2):

$$d = \frac{Pitch\ (p)}{\sin\left(\frac{180}{Z_1}\right)} = \frac{44.45}{\sin\ (7.2°)} = 354\ mm$$

It is already given in the table.

$$D = \frac{Pitch\ (p)}{\sin\left(\frac{180}{Z_2}\right)} = \frac{44.45}{\sin\ (4°)} = 637.2\ mm$$

2.2.3 Speed of Chain (V)

Speed of chain can be calculated as:

$$V = \frac{\pi * d * n_{driver}}{60} = \frac{\pi * 354\, mm * 62}{60} = 1.14 \frac{m}{s} \quad or \quad V = \frac{\pi * 637.2\, mm * 34.44}{60}$$
$$= 1.14\, m/s$$

2.2.4 Real Speed Factor

The assumed value of 1.6 for calculating Design Power is appropriate. This is because the chain speed was calculated as 1.14 m/s, and within this range, the speed factor is 1.6 according to the table 2.

$$P_d = F_a * F_t * P_n * F_v = 1.3 * 1 * 12 * 1.6 = 24.96\, kW$$

2.2.5 Chain Length

At this stage, the chain length is calculated. It is determined using the chain length formula:

$$L = \frac{Z_1 + Z_2}{2} + \frac{K}{C} + 2C$$

First, the center distance is converted into "number of pitches" to be compatible with the link count formula.

$$C = \frac{Center\ Distance}{pitch} = \frac{1640}{44.45} = 36.9$$

Table 8

'K' Factors

Z_1-Z_2	K	Z_1-Z_2	K	Z_1-Z_2	K	Z_1-Z_2	K	Z_1-Z_2	K	Z_1-Z_2	K	Z_1-Z_2	K
1	0,0	11,00	3,06	21,00	11,17	31,00	24,34	41,00	42,58	51,00	65,88	61	94,25
2	0,1	12,00	3,65	22,00	12,26	32,00	25,94	42,00	44,68	52,00	68,49	62	97,37
3	0,2	13,00	4,28	23,00	13,40	33,00	27,58	43,00	46,84	53,00	71,15	63	100,54
4	0,4	14,00	4,96	24,00	14,59	34,00	29,28	44,00	49,04	54,00	73,86	64	103,75
5	0,6	15,00	5,70	25,00	15,83	35,00	31,03	45,00	51,29	55,00	76,62	65	107,02
6	0,9	16,00	6,48	26,00	17,12	36,00	32,83	46,00	53,60	56,00	79,44	66	110,34
7	1,2	17,00	7,32	27,00	18,47	37,00	34,68	47,00	55,95	57,00	82,30	67	113,71
8	1,6	18,00	8,21	28,00	19,86	38,00	36,58	48,00	58,36	58,00	85,21	68	117,13
9	2,1	19,00	9,14	29,00	21,30	39,00	38,53	49,00	60,82	59,00	88,17	69	120,6
10	2,5	20,00	10,13	30,00	22,80	40,00	40,53	50,00	63,33	60,00	91,19	70	124,12
71	127,7	81,00	166,19	91,00	209,76	101,00	258,39	111,00	312,09	121,00	370,86	131	434,69
72	131,3	82,00	170,32	92,00	214,40	102,00	263,54	112,00	317,74	122,00	377,02	132	441,36
73	135,0	83,00	174,50	93,00	219,08	103,00	268,73	113,00	323,44	123,00	383,22	133	448,07
74	138,7	84,00	178,73	94,00	223,82	104,00	273,97	114,00	329,19	124,00	389,48	134	454,83
75	142,5	85,00	183,01	95,00	228,61	105,00	279,27	115,00	334,99	125,00	395,79	135	461,64
76	146,3	86,00	187,34	96,00	233,44	106,00	284,67	116,00	340,84	126,00	402,14	136	468,51
77	150,2	87,00	191,73	97,00	238,33	107,00	290,01	117,00	346,75	127,00	408,55	137	475,42
78	154,1	88,00	196,16	98,00	243,27	108,00	295,45	118,00	352,70	128,00	415,01	138	482,39
79	158,1	89,00	200,64	99,00	248,26	109,00	300,95	119,00	358,70	129,00	421,52	139	489,41
80	162,1	90,00	205,18	100,00	253,30	110,00	306,50	120,00	364,76	130,00	428,08	140	496,47

Figure 5: SKF Catalogue, K Factors, Table 8

K factor is 10.13 from table 8

$$L = \frac{Z_1 + Z_2}{2} + \frac{K}{C} + 2C = \frac{45 + 25}{2} + \frac{10.13}{36.9} + 2 * (36.9) = 109.07$$

The calculated value is 109.07. Since a chain cannot have a fractional number of links and must be an even integer, the value is rounded up to 110 links to ensure sufficient length for connection and assembly.

So, total chain length can be obtained:

$$Length\ (meter) = 110 * 44.45\ mm = 4889.5\ mm = 4.89\ m$$

One box contains 5 meters of chain; therefore, purchasing one box is sufficient.

2.2.6 Lubrication

According to general machine lubrication standards, manual lubrication (Type 1) is selected if the speed is less than 4 m/s. However, in the 28B-1 Power Rating table, Type 2 lubrication is recommended for the 50-75 rpm range; therefore, the Type 2 method is selected.

2.3 Alternative 2: Double Strand Chain Design

2.3.1 Multiple Strand Factor

Since a double strand will be used, the power rating value obtained from the table must be multiplied by the multiple strand factor. The new power rating is expressed by the following formula:

$$P_{R,new} = P_{R,old} * multiple\ strand\ factor$$

Table 6

Multiple strand factor

No. strands	Multiplier K2	No. strands 1	Multiplier K2
1	1.0	4	3.3.
2	1.7	5	3.9
3	2.5	6	4.6

[1] BS or DIN chain are only available up to "triplex" or 3 strand configuration, unless against special demand (MTO)

Figure 6: SKF Catalogue, Multiple Strand Factor, Table 6

According the table 6 multiple strand factor for double strand = 1.7

2.3.2 Driver and Driven Sprocket and Chain Type Selection

Table 9g

24B-1; (38.10 mm Pitch) Power ratings in kilowatt (European standard)

No of teeth	Pitch circle Dia.	rpm of small (faster) sprocket z_1															
Z	mm	10	25	50	75	100	150	200	250	300	400	500	600	700	800	900	1 000
13	**159,20**	1,69	3,85	7,18	10,39	13,39	19,23	25,06	30,43	36,05	46,78	57,08	67,38	61,20	49,26	41,89	35,87
15	**183,25**	1,97	4,49	8,38	11,02	15,71	22,58	29,18	32,27	42,05	54,41	66,52	78,36	71,59	62,14	52,02	44,47
17	**207,35**	2,26	5,14	9,61	13,54	17,94	25,75	33,39	39,64	48,07	62,40	76,30	90,13	91,85	74,85	62,65	53,56
19	**231,48**	2,54	5,79	10,82	15,75	20,17	29,10	37,60	46,10	54,33	70,30	85,83	101,28	108,15	88,40	74,24	63,26
21	**255,63**	2,83	6,46	12,02	17,32	22,48	32,36	41,97	50,72	60,51	78,36	96,13	113,30	125,32	103,00	85,83	73,56
23	**279,80**	3,12	7,13	13,31	18,90	24,80	35,71	46,35	55,32	66,77	86,70	106,43	124,45	143,35	117,60	98,70	84,28
25	**303,99**	3,42	7,81	14,50	20,48	27,21	39,14	50,65	59,94	72,95	94,42	115,88	135,62	157,08	133,90	112,45	95,28
Lubrication method		**TYPE 1**		**TYPE 2**							**TYPE 3**						

Figure 7: SKF Catalogue, Power Rating Table, Table 9g

In the 24B-1 table, 25 teeth and 62 rpm correspond to a value of 17.2 kW, which is lower than the assumed design power of 25 kW. However, when the power rating is multiplied by the multiple strand factor of 1.7, the result is 29.2 kW, which is greater than the assumed value.

$$P_{R,new} = P_{R,old} * multiple\ strand\ factor = 17.2 * 1.7 = 29.2\ kW$$

The target transmission ratio was previously calculated, and 25 and 45 teeth are used.

2.3.3 Sprockets Diameter (d,D)

d = driver sprocket diameter

D = driven sprocket diameter

The pitch diameters of the sprockets are calculated using the standard relationship between chain pitch (p) and number of teeth (Z_1 *and* Z_2):

$$d = \frac{Pitch\ (p)}{\sin\left(\frac{180}{Z_1}\right)} = \frac{38.1}{\sin\ (7.2°)} = 304\ mm$$

It is already given in the table.

$$D = \frac{Pitch\ (p)}{\sin\left(\frac{180}{Z_2}\right)} = \frac{38.1}{\sin\ (4°)} = 546.2\ mm$$

2.3.4 Speed of Chain (V)

Speed of chain can be calculated as:

$$V = \frac{\pi * d * n_{driver}}{60} = \frac{\pi * 304\, mm * 62}{60} = 0.98\frac{m}{s}\ or\ V = \frac{\pi * 546.2\, mm * 34.44}{60}$$
$$= 0.98\frac{m}{s}$$

2.3.5 Real Speed Factor

The assumed value of 1.6 for calculating Design Power is appropriate. This is because the chain speed was calculated as 0.98 m/s, and within this range, the speed factor is 1.6 according to the table 2.

$$P_d = F_a * F_t * P_n * F_v = 1.3 * 1 * 12 * 1.6 = 24.96\, kW$$

2.3.6 Chain Length

At this stage, the chain length is calculated. It is determined using the chain length formula:

$$L = \frac{Z_1 + Z_2}{2} + \frac{K}{C} + 2C$$

First, the center distance is converted into "number of pitches" to be compatible with the link count formula.

$$C = \frac{Center\ Distance}{pitch} = \frac{1640}{38.1} = 43.04$$

K factor is 10.13 from table 8

$$L = \frac{Z_1 + Z_2}{2} + \frac{K}{C} + 2C = \frac{45 + 25}{2} + \frac{10.13}{43.04} + 2 * (43.04) = 121.32$$

The calculated value is 121.32 Since a chain cannot have a fractional number of links and must be an even integer, the value is rounded up to 122 links to ensure sufficient length for connection and assembly.

So, total chain length can be obtained:

$$Length\ (meter) = 122 * 38.1\, mm = 4648.2\, mm = 4.65\, m$$

One box contains 5 meters of chain; therefore, purchasing one box is sufficient.

2.3.7 Lubrication

According to machine standards, manual lubrication is suitable since the speed is very low; however, according to the 24B-1 table, Type 2 lubrication is considered appropriate for a 25-tooth sprocket operating at 62 rpm.

3 CONCLUSION

This report presents the complete design process of a chain drive mechanism intended to transmit power from a 12 kW electric motor to a centrifugal compressor. The design was conducted in accordance with SKF Power Transmission standards, ensuring operational safety, efficiency, and durability under the specified constraints (1640 mm center distance, 62 rpm input speed).

Two distinct design alternatives were evaluated to meet the total design power requirement of 24.96 kW, which includes a service factor of 1.3 and a speed factor of 1.6.

Evaluation of Sprocket Selection and Speed Ratios;

A critical limitation encountered during the design was the non-standard nature of the theoretically calculated driven sprocket (Z_2). Since a 42-tooth sprocket is not available in standard SKF catalogues, an engineering decision was made to select the nearest standard size, which is 45 teeth.

Although this selection resulted in an output speed of 34.44 rpm (slightly lower than the target 37 rpm), it was mathematically verified that this value remains within the permissible tolerance range ($\pm$%7). This decision prioritizes the use of standard, off-the-shelf components, which significantly reduces procurement costs and lead times compared to custom manufacturing.

Comparison of Alternatives;

- Alternative 1 (Single Strand - 28B-1): This design utilizes a larger pitch (44.45 mm) chain. While it meets the power requirements with a single strand, the large pitch results in a higher "polygon effect," which may cause higher vibration and noise levels, especially given the heavy shock nature of compressor applications. The required chain length was calculated as 4.89 meters.
- Alternative 2 (Double Strand - 24B-2): This design employs a double-strand chain with a smaller pitch (38.1 mm). By distributing the load across two strands, the system

achieves the required capacity with a more compact chain profile. The smaller pitch significantly reduces the impact velocity of rollers against sprocket teeth, leading to smoother operation and reduced wear. The required chain length is 4.65 meters.

Lubrication and Maintenance;

For both alternatives, the chain velocity (V) was calculated to be relatively low ($v \approx 1m/s$). While standard guidelines suggest manual lubrication for such speeds, the SKF Power Rating tables specifically necessitate Type 2 (Drip Lubrication) due to the high torque and contact pressures associated with these heavy chains (24B and 28B series). Implementing a drip lubrication system is crucial to prevent premature wear and ensure the longevity of the drive.

Final Recommendation;

Upon comparing both designs, Alternative 2 (Double Strand 24B-2) is recommended as the optimal solution. Although it involves a double-strand configuration, the use of a smaller pitch (38.1 mm vs 44.45 mm) provides a distinct mechanical advantage by minimizing the polygon effect and ensuring smoother power transmission for the compressor. Furthermore, both designs fit within a single standard 5-meter box, making them cost-effective in terms of procurement. The selected configuration of $Z_1 = 25$ and $Z_2 = 45$ provides a robust, standard-compliant, and efficient drive system.