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ALTERNATE DESIGN AND OPTIMIZATION OF CONVEYOR PULLEY USING FINITE ELEMENT ANALYSIS

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Abstract

In this project, the main aim is to alter the design of conveyor pulley by changing the dimensions components with respect to the individual components of the design considered.

The main components of conveyor pulley are shaft, drum or shell, diaphragm plates, locking elements, hub, lagging and bearing assemblies. Designing units of this kind requires precise calculations of all belt tensions and loads in static conditions. The solid works analysis is performed on the total assembly of the conveyor pulley considered as a reference for the existing design and even for the altered design which is the main task of this project. The design and modeling is done in parametric software Pro/Engineer and finite element analysis is analyzed in solid works.

Key words: conveyor pulley, design, calculating diameter, altering the design, analysis.

1. Introduction

Pulley: Conveyor Pulley is used to transmit the motion power to belt and also Pulleys are necessary to change the direction of belt in any direction, and to form endless loop for continuous operation, and it is also used for the material handling system in various industries to transfer raw material from one place to another.

Components of Pulley:

1. Drum or shell
2. Diaphragm plates
3. Shaft
4. Locking elements
5. Hub
6. Lagging
7. Bearing assemblies

Drum or Shell: The drum is the portion of the pulley in direct contact with the belt. The shell is fabricated from either a rolled sheet of steel or from hollow steel tubing .shown in fig.1

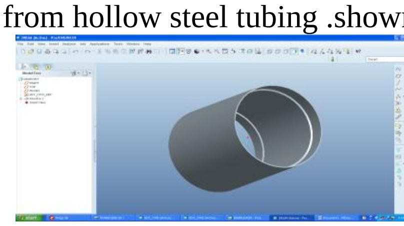

Fig No :1

Diaphragm Plates: The diaphragm or end disc of a pulley is circular discs which are fabricated from thick steel plate and which are welded into the shell at each end, to strengthen the drum. shown in fig.2

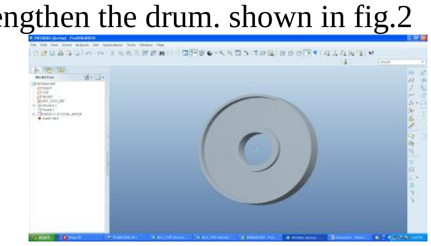

Fig No:2

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Shaft: The shaft is designed to accommodate all the applied forces from the belt and / or the drive unit, with minimum deflection. The shaft is located and locked to the hubs of the end discs by means of locking elements. The shaft is supported on both ends by bearings. Shown in fig.3

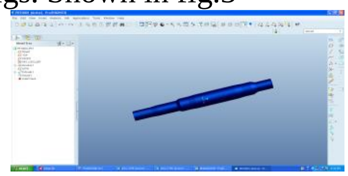


Fig No:3

Locking Elements: These are high-precision manufactured items which are fitted over the shaft and into the pulley hubs. The locking Elements attach the pulley firmly to the shaft via the end plates. Shown in fig.4

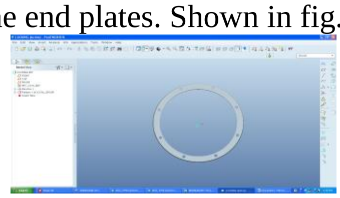


Fig No: 4

Hubs: The hubs are fabricated and machined housings which are welded into the end plates. The hubs are sized according to the size of the pulley. Shown in fig.5

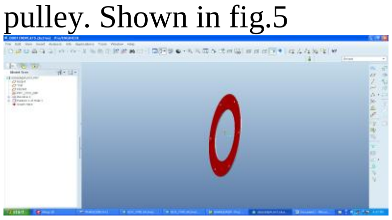


Fig No: 5

Lagging: It is sometimes necessary or desirable to improve the friction between the conveyor belt and the pulley in order to improve the torque that can be transmitted through a drive pulley. Shown in fig.6

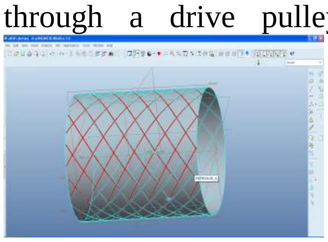


Fig No: 6

Bearing assemblies: Bearings support the rotating shaft and hence the pulley. Which enable the mass of the pulley assembly plus the belt tension forces to be transmitted for the supporting pulley structure. Shown in fig.7

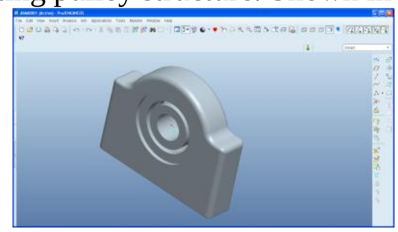


Fig No:7

PULLEY DESIGN:

Design Considerations for Pulleys:

The procedure for selecting pulleys for a conveyor for any given application involves the evaluation of a number of factors pertinent to the installation Consideration should be given to the following:-

a) Application / Environment

b) Conveyor design
   1. Angle of Wrap:
   2. Belt selection:
   3. Conveyor duty:
   4. Belt Tension:
   5. Belt width:

c) Standardisation

d) Specifications

e) Layout

f) Pulley design
   1. Dimensions
   2. Accessories
   3. Drive friction
   4. Materials

For the pulley design the main design of the pulley structure is dependent on the shaft design. Hence the shaft design is the initial consideration of the pulley design.

1) **Shaft design :**

In designing shafts on the basis of strength, the following cases may be considered:

- Shafts subjected to twisting moment or torque only.
- Shafts subjected to Bending moment only.
- Shafts subjected to Combined twisting and bending moments, and

- Shafts subjected to axial loads in addition to combined torsional and bending loads.

Material used for the shafts:

Generally at NMDC, according to the Indian Standards the shaft is designed and carbon steel of grade 40C8 is used.

For the design of the shafts the materials chosen for this thesis purpose are chosen according to the Indian standards are:

1. 37 Mn 2
2. 40 Cr 1 Mo 28
3. 40 Ni 2 Cr 1 Mo 28
4. 35 Ni 1Cr 60
5. 40 C 10 S 18
6. 40 C 15 S 12

Calculating the diameter of the shaft for 40Ni 2Cr1Mo28 material

Conveyor Input Values:

Horizontal length of conveyor belt = 69.919m
Lift = 5.5 m
Belt width = 1.2 m
Capacity = 2400 TPH
Bulk density of material = 2.4 tonnes/m^3
Belt speed = 2m/s
Carrier idler spacing = 1.2 m
Return idler spacing = 3m
Wt of one set of carrier idler = 27 kg
Wt of one set of return idler = 24 kg
Weight of belt per m =27 kg
Coefficient of friction, m or f = 0.023
Number of scrapers =3
Length correction factor =1.3
Weight of non drive pulley per m = 30.25 kg
Angle of wrap = 210^0
Coefficient of = 0.4
Weight of drive pulley = 1000 kg
Face width of pulley = 1.4 m
Length of skirt board = 1.5 m
Speed of motor = 1500rpm
Gear ratio = 1:25

Shaft material

Allowable bending stress = 1200 kg/cm^2
Allowable shear stress = 700 kg/cm^2
Service factor (Bending) = 2
Service factor (Torsion) =1.5

Diameter of pulley

Speed at pulley $= \frac{1500}{25}$ = 60 rpm

We know that, D = $\frac{60*v}{\pi*N} = \frac{60*2}{\pi*60}$ = 0.636 m

Therefore, Diameter of the pulley, D= 0.7 (or) 700 mm

Radius of pulley, R =0.35m

Power calculation:

To find out the power required to drive the pulley; $P=P_1+ P_2+ P_3+P_T$

Where, P is the total power required
P_1 is the power required to move empty belt
P_2 is the power required to move material horizontally
P_3 is the power required to lift the material
P_T is the power required for accessories

Step -1

Calculate the power required to move empty belt: $P_1 = \frac{c.f.l\left[\frac{M_C}{S_1}+\frac{M_R}{S_R}+2M_b+W_P\right]3.6v}{367}$ Where, C is the correction factor

f is the coefficient of friction
l is the horizontal length in m
M_C is approximate wt of one set of rotating part of carrying idler in kgf
M_R is approximate wt of one set of rotating part of return idler in kgf
S_1 is carrying idler spacing
S_2 is return idler spacing
M_b is approximate wt of belt per m in Kg/m
W_P is wt of non drive pulley per m in Kg/m
V is belt speed in m/s

Now substituting the values to find P_1

$$P_1 = \frac{1.3*0.023*69.919\left[\frac{27}{1.2}+\frac{24}{3}+2*27+30.25\right]3.6*2}{367}$$
$$= 4.7\text{KW}$$

Step- 2

Calculate the power required to move the material horizontally. $P_2 = \frac{c.f.l.Q}{367}$

Where, Q is the design capacity in TPH

Now, substituting the values to find P_2

$$P_2 = \frac{1.3*0.023*69.919*2400}{367} = 13.671\text{KW}$$

Step -3

Calculate the power required to lift the material. $P_3 = \frac{Q*H}{367}$ Where; H is lift in m

Now, substituting the values, to find P_3.

$P_3 = \frac{2400*5.5}{367} = 35.967$KW

Step- 4

Calculate power required for accessories.

$P_T = P_g + P_s$, Where,

$P_g = [LSK - (BW + v + 0.7)]\ v * 0.5$

$P_s = BW * v * 0.3 * NSP$

Where, LSK is length of skirt board in m

BW is the belt width

NSP is number of scrapers

Now, substituting the values to find P_s, P_g and finally P_T.

$P_s = 1.2 * 2 * 0.3 * 3 = 2.16$

$P_g = [15 + (1.2 + 2 + 0.7)]\ 2 * 0.05 = 1.41$

$P_T = P_{g + Ps} = 2.16 + 1.41 = 3.27$ KW

Total power required,

$P = P_1 + P_2 + P_3 + P_T$

$= 4.7 + 35.967 + 13.671 + 3.27$

$P = 57.6$ KW

Torque Calculations

Power, $P = \frac{2\pi N T_r}{367}$ Speed, $N = \frac{v*60}{\pi*d_p} = \frac{2*60}{\pi*0.7}$

$N = 54.55$ rpm.

Now, Power $P = \frac{2*\pi*54.55*T_r}{60}$

Torque $Tr = \frac{57.6*1000*60}{2\pi*54.55} = \frac{3456000}{342.74}$

$\underline{T_r = 10083.239 \text{ N-m}}$

To, find equivalent tension (Te),

$T_e * R = T_r$, $Te = \frac{10083.239}{0.35}$

$T_e = 28809.25$ N

We know that,

$T_1 + T_2 = 28809.25 \ldots\ldots. (1)$

Also, $2.3 \log\left({T_1}/{T_2}\right) = \mu\,\theta$

Where, μ is coefficient of friction = 0.4

θ is angle of wrap = $210^0 = {7\pi}/{6}$ rad.

$$2.3 \log\left({T_1}/{T_2}\right) = 0.4 * {7\pi}/{6}$$

$$\log\left({T_1}/{T_2}\right) = \frac{8.79}{13.8},\ {T_1}/{T_2} = 4.265 \ldots\ldots (2)$$

From (1) and (2), we get

$(4.265\ T_2) - T_2 = 28809.25$, $T_2 = \frac{28809.25}{4.265 - 1}$

$T_2 = 8823.66$ N

$T_1 = (8823.66)4.265$, $T_1 = 37832.91$ N.

Pulley Diagram:

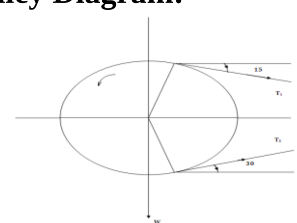


Fig No:8

Free Body Diagram:

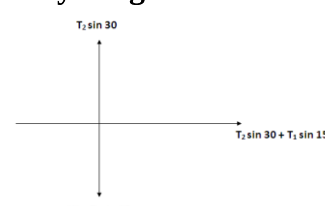


Fig No :9

Resolved Forces:

Bending moment:

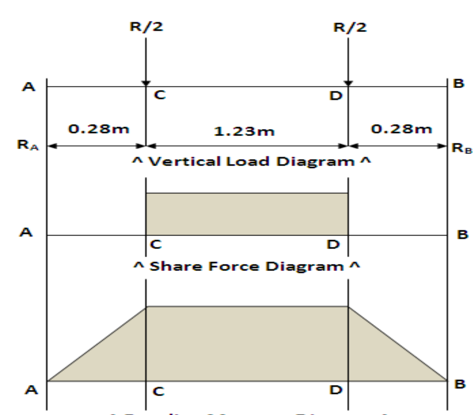


Fig No:9

Determining the Diameter of the Shaft:

Materials used for shaft is EN-9/BS: 970 (or) equivalent forged quality.

Case 1: Considering only Torque

$$K_t * T_r = \frac{\pi}{16} * \tau * d^3$$

$$1.5 * 10083.239 = \frac{\pi}{16} * 700 * 9.81 * 10^4 * d^3$$

$$d = 0.112 \text{ m (or) } 112.6 \text{ mm}$$

Case 2: Considering only bending moment

$$K_m * M = \frac{\pi}{32} * \sigma_b * d^3$$

$$2 * 6540.82 = \frac{\pi}{32} * 1200 * 9.81 * 10^4 * d^3$$

d= 0.114m (or) 114.7mm

Case 3: Considering both torque and bending moment: *(i)* Equivalent Torque, τ_{re}

$$\sqrt{(K_t * T_e)^2 + (K_m * M)^2} =$$

$$\sqrt{(1.5 * 10083.29)^2 + (2 * 6540.82)^2}$$

T_{re} = 22426.57 N-m, Now,

$$T_{re} = \frac{\pi}{16} * \tau * d^3$$

$$22426.57 = \frac{\pi}{16} * 550 * 9.81 * 10^4 * d^3$$

$$d = 0.95 \text{ m (or) } 95\text{mm}$$

(*ii*) Equivalent Bending moment,

$$M_e = {}^1/_2 \, [(K_m * M) + T_{re}]$$

$$= {}^1/_2 \, [(2 * 5440.82) + 22426.58]$$

$$M_e = 16118.9 \text{ N-m}$$

Now, $M_e = \frac{\pi}{32} * \sigma_b * d^3$

$$d = \sqrt[3]{\frac{16118.9 * 32}{\pi * 1200 * 9.8 * 10^4}},$$

$$d = 0.134 \text{ m (or) } 134 \text{ mm}$$

At equivalent torque, diameter is maximum. Hence, diameter of shaft is d = 124 mm. Therefore, d = 140 mm. (with reference to preferred numbers.

Case 4: Deflection based diameter

Angular deflection:

Given angular deflection = 6 minutes at hub.

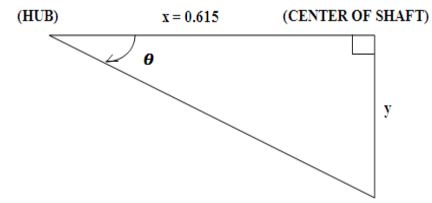


Fig No: 10

$$\tan\theta = \frac{y}{x}, \quad \tan\left(\frac{1}{10}\right) = \frac{y}{0.615}$$

y = 0.615 tan (0.1) = 1.07 mm.

$$y_{max} \text{ (or) } y_{act} = \frac{Pa}{24EI}[3L^2 - 4a^2]$$

Where, P is force acting on shaft = 23360 N
a is distance btwn bearing and hub =0.28 m
L is the length of the shaft between two bearings= 1.79 m
E is young's modulus = $2.05 * 10^{11}$ N/m^2
I is area moment of inertia of the shaft = $\pi \frac{d^4}{64}$ = $1.88 * 10^{-5}$ m^4

$$y_{act} = \frac{23360 * 0.28}{22 * 2.05 * 1.88 * 10^{-5} * 10^{11}}[(3 * 1.79^2) - (4 * 0.28^2)]$$

= $7.07 * 10^{-5}$ (9.2987), = 0.8296 mm

Deflection of the designed shaft is less than the maximum limit. Hence, the design is safe.

Tensional Deflection:

Given torsional deflection = 0.26 deg/m

Torsional deflection = 0.26 *L
= 0.26 * 1.79 = 0.465 deg.

We know that, $\frac{T_r}{J} = \frac{C\theta}{L}$

Where, T_r is the torque = 10083.29 N-m
L = 1.79 m
C is rigidity modulus = $0.84 * 10^{11}$ N/m^2
J is moment of inertia = $\pi \frac{d^4}{32}$ = $3.7 * 10^{-5}$ m^4

$$\theta = \frac{T_r * L}{C * J} = \frac{10083.29 * 1.79}{{}^{\pi}/_{32} * 0.140^4 * 0.84 * 10^{11}}$$

$$= 5.8 * 10^{-3} \text{ rad} = 0.33 \text{ deg}$$

Deflection of the designed shaft is less than the maximum limit. Hence, the design is safe.

Determining the diameter of hub:

Material used for hub is St.41 W, IS: 2062-1992

We know that, Hub diameter (D_H) is equal to 1.6 times of shaft diameter.

$D_H = 1.6 * d = 1.6 = 0.224$ m

To check the design of hub:

Consider hub is made as a hallow material as that of shaft.

Lets us consider hub as a hallow shaft .we know that,

Maximum torque, $T_r = \frac{\pi}{16}\ \tau \left[\frac{D_H^4 - d^4}{D_H}\right]$

$$10083.23 = \frac{\pi}{16}\ \tau \left[\frac{0.224^4 - 0.14^4}{0.224}\right]$$

$\tau = 5.391 * 10^6$ N/m^2.

Allowable shear stress of the material = 500 kg/cm^2 = 4.9 * 10^6 N/m^2.

Shear stress of the designed hub is less than the allowable shear stress of the material. Hence, the design is safe.

Determining the Thick Ness of End Disc (or) Diaphragm:

Consider diaphragm as a column of length, I and square cross section on which resultant force is acting. Material used for diaphragm is MS as per IS: 226

The procedure to calculate the thickness of the shell is very complicated. Research is being carried out to find out an easier and accurate way to calculating the thickness. The thickness found out from mathematical calculation is very less, which cannot be fabricated. Hence, the thickness is assumed based on the practical application (12 mm in our case).Material used for the shell is St .42, IS: 2062-1992

Mass of the shell:

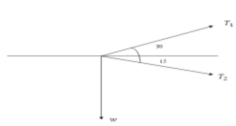
Density of the shell = 0.078 *10^6 N/m^3

Area of shell = 2* π *R *face width.

Volume = area = thickness = 0.073 m^3

Mass = density * volume = 0.078 * 10^6 * 0.073 =581.03 kg

Forces Acting on Diaphragm:



To find resultant acting on diaphragm:

T_1 =37832.91 N,

T_2 = 8823.66 N

W= mg =581.02 * 9.8 = 5694 N

$$R = \sqrt{(T_2 cos30 + T_1 cos15)^2 + (W + T_1 \sin 15 - T_2 sin30)^2}$$

R = 45550.95 N

Now, $B.S = \frac{\beta P(B-L) * L * \alpha * t}{2D(L+1)}$

Where, B.S = bending stress = 300 MN/m^2

b is disc constant = 1.22

P is resultant load = R/2 = 22775.47 N

= 2324.02 kg

B is distance between two bearings = 179 cm

L is distance between two discs =123 cm

A is disc constant = 4.9

t is thickness of disc

D is outer diameter of the disc =67.6 cm

On substituting,

$$t = \frac{3000*2*67.6*124}{1.22*2324.02*179*4.9*56} = 0.36 \text{ cm} = 3.6 \text{ mm}$$

Hence, thickness of end disc plate is 4mm.

Similarly the diameter of the shafts for:

1. 37 Mn 2
2. 40 Cr 1 Mo 28
3. 35 Ni 1Cr 60
4. 40 C 10 S 18
5. 40 C 15 S 12 determined as 150, 140,150,160,160 respectively.

Analysis values of the conveyor pulley stress,strain and displacement values: :

Diameter of the Shaft	**Material considered for the shaft**	**Stress (N/mm2) or(MPa)**		**Strain**		**Displacement (mm)**	
		Min	**Max**	**Min**	**Max**	**Min**	**Max**
140 Diameter	40Ni2Cr 1Mo28 40 Cr 1 Mo 28	0 N/m m2 (MPa)	352.807 N/m m2 (MPa)	0	0.0009 24929	0 mm	1.24316 e+008 mm
150 Diameter	35 Ni 1Cr 60 37 Mn 2	0 N/m m2 (MP	455.759 N/m m2 (MP	0	0.0011 5619	0 mm	1.32087 e+008 mm

		a)	a)				
160 Diameter	40 C 10 S 18 40 C 15 S 12	0 N/mm2 (MPa)	459.38 N/mm2 (MPa)	0	0.00121743	0 mm	1.28931e+008 mm

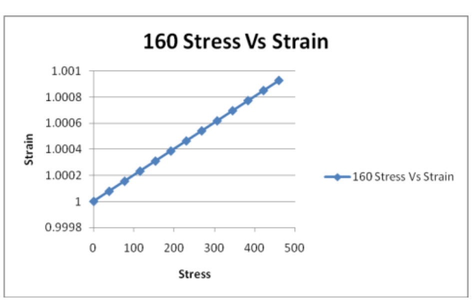
Table No:1

Failures analysis of the conveyor puleey with different diameters :

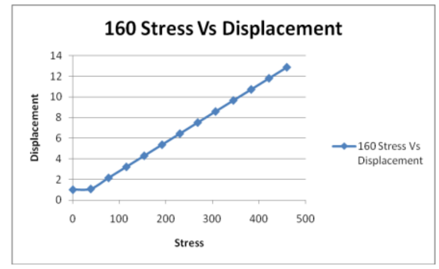
Diameter	Damage percentage		Load factor		Life cycle(cycles)	
	Min	Max	Min	Max	Min	Max
140	0.1	0.1	4.44262	8.40989 e+028	1e+006	1e+006
150	0.1	0.348904	3.45074	8.83039 e+0.28	286612	1e+006
160	0.1	0.376359	3.41691	8.83039 e+028	265704	1e+006

Table No:2

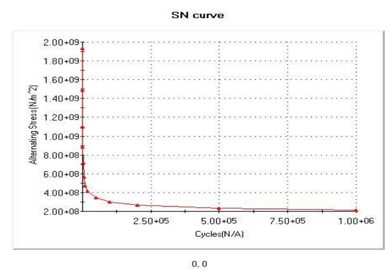
160 diameter stress vs strain graphs :



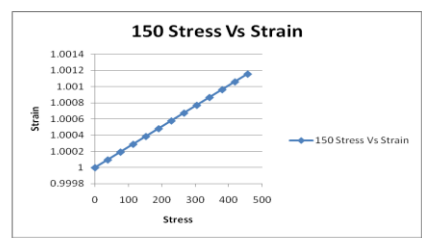
160 Diameter Stress Vs Displacement graphs :



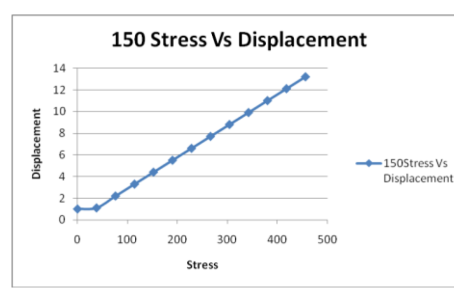
160 failure analysis



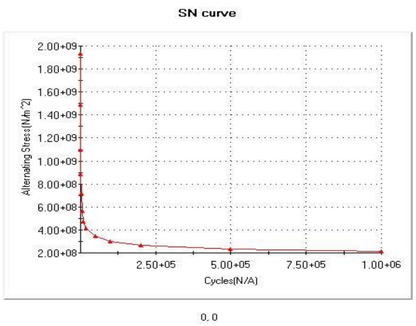
150 diameter Stress Vs Strain Graphs



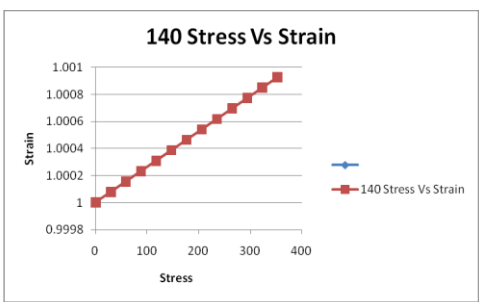
150 diameter Stress Vs Displacement graphs



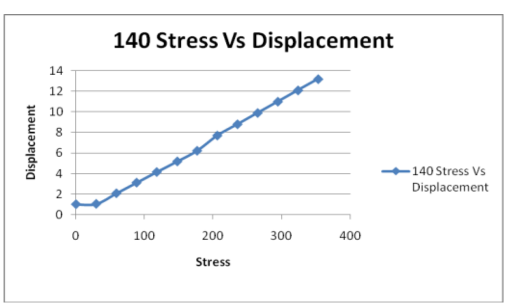
150 failure analysis



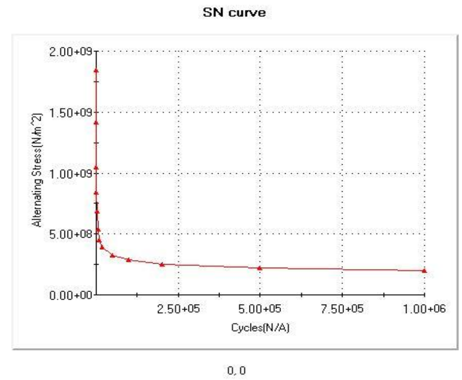
140 diameter Stress Vs Strain Graphs



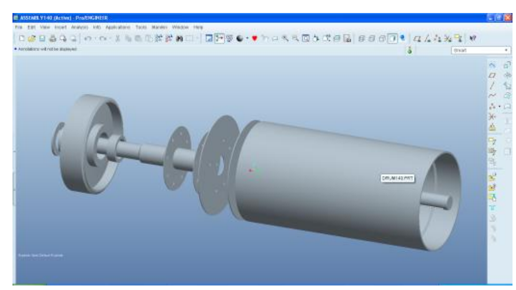
140 Stress Vs Displacement Graphs



140 failure analysis

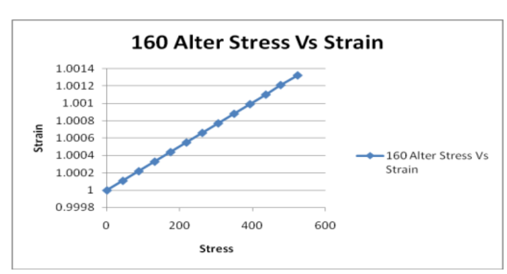


Analysing the analysis of the conveyor pulleys with different diameter a new alter design of the conveyor pulley of 160 diameter is designed for the better improvement in the design standards and techniques:

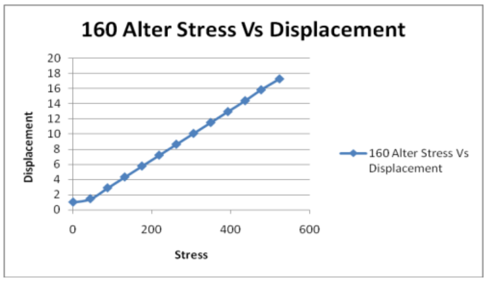


The altered design results for the 160 diameter is the maximum stress that are in 160 diameter is 523.151 N/mm2 or (MPa) and the strain obtained in the conveyor pulley is 0.00132252 and displacement that can be obtained in the total assembly is 1.7271e+008 mm.

160 diameters Stress Vs Strain

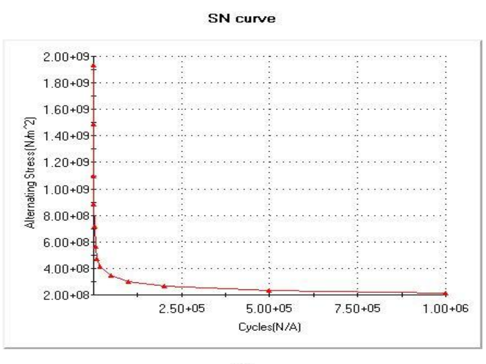


160 diamter Stress Vs dispalcement



And in the failure analysis for the altered design of the conveyor pulley the damage percentage is max 0.689413 and the load factor that can be applied for the pulley is max of 8.83039e+028 and the life cycle of the pulley is 1e+006 cycles.

Failure analysis for alter design :



Conclusion:

According to the Indian Standards the materials chosen for design of conveyor pulley followed by the total assembly of the conveyor pulley is safe and can be used for the general conveyor purposes. The alter design of the conveyor pulley without shaft is also proved as a safe design and can be used for the conveyor purpose. Hence, chosen materials are safe for the design and working purposes.

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