Design of Belt Conveyor System

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***Abstract*— Belt conveyor is today's very important mechanism used for raw material transportation in many industries. This paper discuss about study of detail design procedure of three roller type belt conveyor system for heavy duty application. Belt conveyor used for coal processing industry whose design capacity is 4400TPH and speed of the conveyor will be 4.65m/s. The paper study about design calculations of conveyor, stresses on pulley due to belt tensions at head side, tail/take up and snub side. Above belt conveyor designed according to Indian standards (IS-11592). It consists of tension calculations on pulley, stress analysis on pulley, on components of belt conveyor and its effect. 3D CAD model created into CAD software with exact dimensional data. Finite element analysis on ANSYS software with exact loading conditions, considering calculated tensions. Stress analysis carried out to find highly stressed components of belt conveyor which are prone to failure. Experimentation is carried out for verification of selected speed on various load conditions.**

***Index Terms*—Ansys, Belt conveyor, CAD, Finite Element Analysis**

I. Introduction

This paper includes study of design of three roller type belt conveyor system used for coal handling industry. Current civilization aims to produce innumerable items for utility and comfort of human being. The bulk material handling system consists of many equipment and auxiliary services to achieve required functional needs. Belt conveyor is most populous equipment in such system to achieve material flow from start to end point.

There are many types of conveyor systems according to their operating mechanism like roller, chain, spiral, screw, vibrating, pneumatic, etc. Selection of conveyor system is carried out according to functional requirements, size shape and weight of material, travelling distance, speed requirements, etc. The paper discuss about detail design procedure for three roller type belt conveyor system for coal handling industry and finite element analysis of pulley and its components.

II. Literature review

Conveyor systems can help you create warehouse efficiency and optimize operations, it can be achieved at different distances, different materials transportation. Conveyors are especially useful in applications involving the transportation of heavy or bulky materials most of the scientists are interested in research on optimization designing of belt conveyors and also more risk free mechanism.[1] Pulley is heart of the bulk mining material handling. The stability of cylindrical drum is very important S. P. Das and M.C. Pal considered the drum buckling under variable loading. They considered the buckling of drum under exponential load but not consider the variation along pulley face width. M. Ravikumar, Avijit Chattopadhyay considered the both variation that is exponential and along the face width. They analyse the pulley as integral that is pulley as whole. The studies using classical analytical approaches have considered the pulley in parts as well as a single structure.[2]

I observed and studied from research paper of author Konakalla Naga Sri Ananth importance of proper conveyor belt selection and effect of material characteristics on belt selection.[4] Also studied design calculations and considerations of belt conveyor system for biomass wood using 3 rolls idlers, in terms of power and tension, idler spacing, type of drive unit, maximum loading capacity in order ensure fast, continuous and efficient movement of crushed biomass wood while avoiding fatalities during loading and unloading.[5]

Following design carried out on taking all above literature study into consideration and design workflow considered as per Indian standard selection and design of belt conveyors-code of practise IS 11592: 2000.

III. Problem statement

Design belt conveyor of three roller type, having design capacity 4400TPH for coal processing industry. Speed of the conveyor will be 4.65m/s, with vertical lift of 31.45m. Study stress analysis on conveyor pulley and shaft.

Other specifications:

1. Length of the conveyor = 854.5m
2. Density of material =800kg/m3
3. Moisture contain =20%
4. Lump size = -100 mm
5. Troughing angle $=45^0$
6. Surcharge angle $=20^0$
7. Conveyor inclination $=8^0$

A. Belt width selection

$$B.C. = 3.6 \times A \times \rho \times v \times k \quad (1)$$

A = 0.3532 m^2

Belt width selected =1800 mm

B. Actual cross section area

$$D = \frac{Belt\ Width}{No.of\ rollers} = 600 \quad (2)$$

From roller catalogue select roller face width w= 670 mm

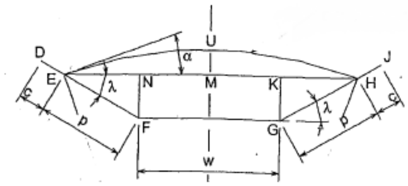

Fig. 1: Actual cross section area

Area A1= Area of triangle EFN + Area of triangle KGN + Area of rectangle NFGK

A1 = 314434.73 mm^2

Area A2 = $\left(\frac{\pi\alpha}{180} - \frac{\sin 2\alpha}{2}\right) R^2$ = 157180 mm^2

A3 = A1 + A2 = 471614 mm^2

A4 = Area of Rectangle FGSQ + Area of arc QSU

$= w \times [p \times \sin\lambda + R(\cos\beta - \cos\alpha)] + \left(\frac{\pi\beta}{180} - \frac{\sin 2\beta}{2}\right) R^2$ (3)

= 303037.21 mm^2

Percentage of area on central roller, $\frac{A4}{A3} \times 100$ = 64.25%

C. Driving Force Calculations:

Peripheral force on drive pulleys,

Te = R + Rs + Rsl + Rsp = 167874.9 N (4)

Where, R = Main Resistance, Rs = Secondary Resistance
Rsp = Special Resistance, Rsl = Slope Resistance

D. Power Calculations

1. Power required at drive pulley (P_{DP})

$P_{DP}= \left[\frac{Te \times V}{1000}\right] \times over\ loaded\ factor$ = 780.6 kW (5)

2. Power loss due to Drive pulley= $\frac{(Rw+Rb)\times V}{1000}$= 3.1kW

3. Absorbed power for gear box output shaft (Pa)

Pa = P_{DP} + Power loss due to drive pulley= 783.8kW

Required power at motor output shaft(Pm)

$Pm = \frac{Pa}{\eta}$ = 824.4kW (6)

Where η = drive efficiency = 0.823

Safety factor for motor selection = 1.1
Power with safety factor = 906.8kW
Motor selected is 1000 kW power

E. Belt Tension calculation

1. Max. Belt Tension on Carrying side

T1 = Te $\left[\frac{\xi}{e^{\mu\theta}-1} + 1\right]$= 232271N (7)

2. Min. Slack side Tension,
T2 = T1 – Te = 64396N

3. Minimum belt tension to limit belt sag,

$Tmin = \frac{Pc\times(Mb+Mg)\times g}{8\times s}$ = 18298 N (8)

4. Tail side tension:

$Tt = T2 + [f \times L \times g(Mb + Mr)] - (H \times g \times Mb)$ (9)
=61861N

5. Tail take up tension,

$Tt = T2 + [f \times L1 \times g(Mb + Mr)] - (H1 \times g \times Mb)$=62688N (10)

Type of take up shall be horizontal take up due to vertical space constrain.

F. Belt selection

Belt selected is 1600/5HD, on the basis of maximum working belt tension and tight side tension on belt.

G. Pulley selection

Selected belt carcass thickness is 8.4mm, and actual percent tensile force is 80.65 recommended and selected pulley diameters are as follows:

Table I

	Recommended Pulley Dia	Actual Pulley Dia	Bearing Dia Selected
Drive	800	800	260
Tail/Take Up	630	630	240
Snub/Bend	500	500	220

H. Convex curve calculations

1. Based on Belt width = 12x B = 21.6 m

2. Lack of Tension at Belt Centre =$\frac{E\times B\times\sin\lambda}{9\times\left[\frac{Tc\ overstress}{B}-4.5\right]}$=11.92m

3. Overstress of Belt Edges Rc3=$\frac{B\times sin\lambda\times E}{4.5\times\left[Tm-\frac{Tc\ edge}{B}\right]}$ = 38.12 m

Considering Rc1, Rc2 & Rc3, the maximum radius provided is 75 m.

I. Concave curve calculations

1. Empty Belt Condition, Rc1=$\frac{Tc\ empty\ belt}{9.81\times Mb}$ = 297 m

2. Fully Loaded Condition,
Rc1 = $\frac{Tc\ for\ loaded\ belt}{9.81\times(Mb+Mg)}$ = 35 m

3. Partially Loaded Condition, Rc1 = $\frac{Tc\ max}{9.81\times Mb}$ = 407 m

4. Overstress at centre of belt, Rc1 =$\frac{E\times B\times\sin\lambda}{9\times\left[Tm-\frac{Tc\ overstress}{B}\right]}$ =20 m

5. Lack of Tension at Belt edge Rc1=$\frac{B\times sin\lambda\times E}{4.5\times\left[\frac{Tc\ edge}{B}-4.5\right]}$ = 58 m

Finally selected radius 750 m.

J. Shaft calculations

1. Calculation for Drive Pulley

a. Based on Angular Deflection,

$H = (T1 \times \cos\emptyset) + \left(T2 \times \cos(210 - 180)\right)$ =345478 N

$V = (T1 \times \sin\emptyset) - \left(T2 \times sin(210 - 180)\right) + wp$=9090N

Shaft dia required at hub = $\frac{(Resultant\ \times a\times 64\times(I-2a))^{1/4}}{(\pi\times 4\times\varphi\times E)^{1/4}}$=0.261 m

Therefore, shaft dia at bearing = 260 mm

b. Based on equivalent torque

Shaft dia req at hub = $[\frac{Teq\times 16}{\pi\times Fs}]^{1/3} \times 1000$ = 261mm

Therefore, shaft dia at bearing = 260 mm *c*. Based on linear deflection

Shaft dia required = $\left[\frac{((64\times BM\times(3\times I)^2)-(4a^2))^{1/4}}{(24\times 3.14\times E\times d)^{1/4}}\right]$=0.265 m

Therefore, shaft dia at bearing = 260 mm
Final Diameter selected
Head Pulley Shaft dia at Hub = 280 mm
Head Pulley Shaft dia at Bearing = 260 mm
Head Pulley Shaft dia at Coupling = 240 mm

Similarly designed shaft for tail/take up and snub/bend pulley.
Tail/Take-up Pulley Shaft dia at Hub = 260mm
Tail/Take-up Pulley Shaft dia at Bearing = 240 mm

Snub/Bend Pulley Shaft dia at Hub = 240 mm
Snub/Bend Pulley Shaft dia at Bearing = 220 mm

IV. FINITE ELEMENT ANALYSIS OF CONVEYOR PULLEY

Analytical design is verified with the help of ANSYS software. Exactly similar forces and constraints simulated in ANSYS to get accurate results. Finite element analysis is carried out to find von mises stresses, total deflection on pulley and its components because of belt tensions.

For finite element analysis all standard material properties are assigned. Dead weight of the pulley is considered. Resultant tension is calculated and applied as a uniform radial pressure over the pulley surface in the region of angle of wrap, and throughout the belt width. Torques given for driven pulleys is applied at the drive end of the shaft. Initially 3D CAD model of pulley assembly created using NX CAD software.

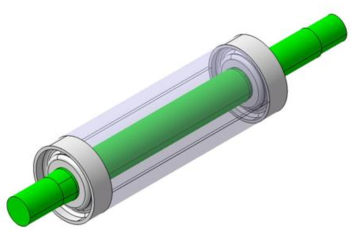

Fig 2: 3D CAD Model of Conveyor Pulley

Load and constraints applied to all three types of pulley. Maximum tight side tension is 232271N and maximum slack side tension is 64396N calculated by above analytical method. Horizontal and vertical forces are 345478N and 9090N respectively. Therefore resultant force calculated is 345598N. By considering equivalent weight of belt and rubber, contact length it gives total contact area. Using this area find out pressure acting on pulley is 0.1MPa. Boundary conditions applied on pulley are torque 90952Nm, pressure on belt 0.10Mpa, gravity force acting 9.806m/s^2.

Meshing of pulley is carried out with quad and tetra element type. Total slippage is considered between the shaft and the disc hub close to the drive side to simulate the worst possible loading condition. Limit stress in design is considered as the endurance stress for each materials are Diaphragm (IS:1030) is 100-104 MPa, Shell (IS: 2062-E250) is 93 MPa, Shaft (IS: 1570-EN8)is 93 MPa. Results from finite element analysis are as follows:

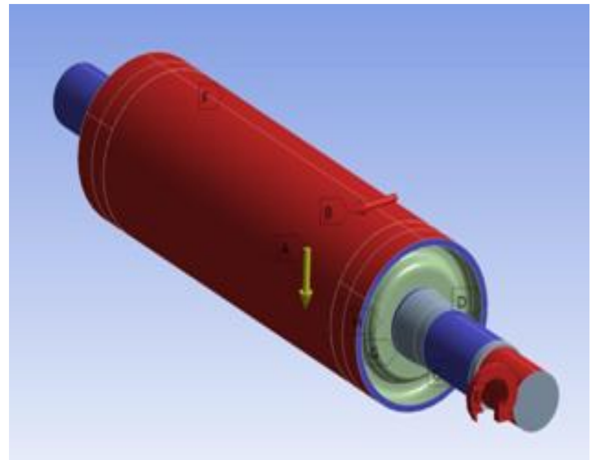

Fig 3: Load application on pulley

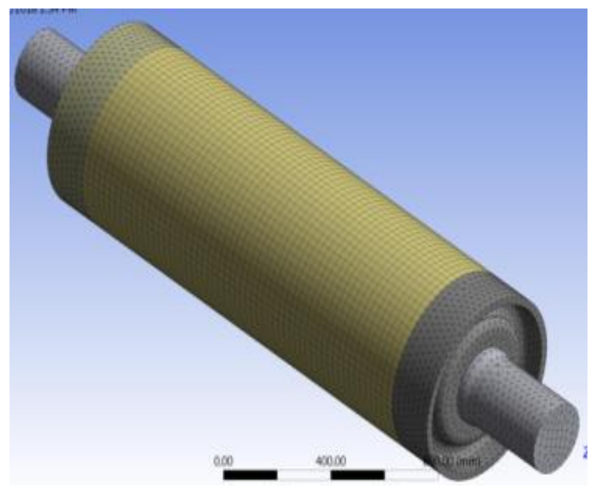

Fig 4: Mesh model of pulley

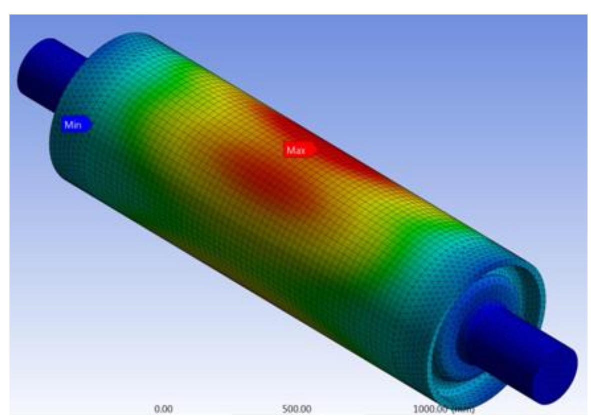

Fig.5: Maximum deflection 0.36029 mm

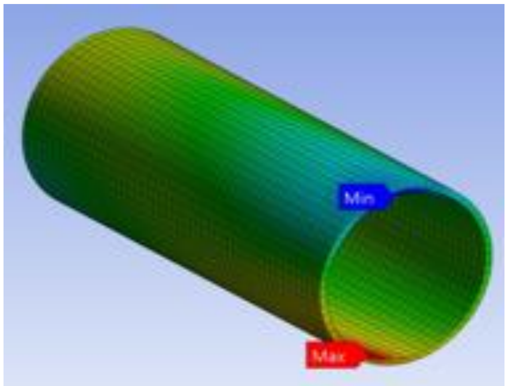

Fig6: Max Stress on shell 9.5768 MPa

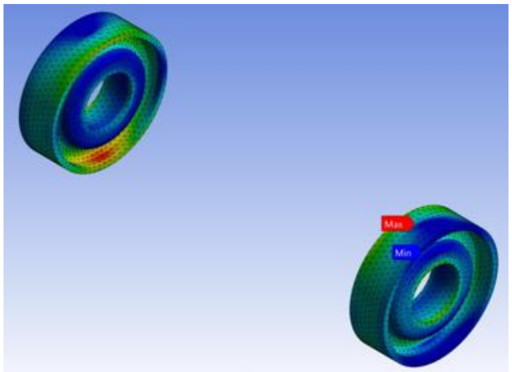

Fig7: Max Stress at Hubs 29.556 MPa

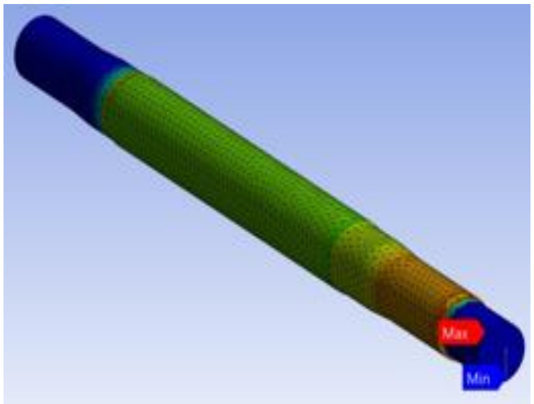

Fig8: Max stress on shaft 30.824 MPa

As the maximum stresses developed in worst possible conditions are clearly less than the allowable limits in all the cases, hence design is safe in all case of pulley mark. Similar analysis will be carried out for remaining two pulleys tail and snub.

IV. Experimental Results

After completing design and analysis of conveyor system it's also important to allow adequate time for testing prior to getting the new system up and running. There could be hidden mechanical issues that would delay production, or any number of other problems that may need to be adjusted so the conveyor system can perform at peak efficiency.

Basic initial testing step is visual safety inspection. Check all the guards in place, emergency pull-stops accessible at any point along the line. It's also important to ensure the mechanical and junction boxes are closed. Function testing is effective at identifying any major system flaws, but it's also important to fully load the system to see how it performs at full capacity. These load tests are also called simulated load tests. A simulated load test consisting of at least three consecutive test runs shall be conducted as soon as possible.

A. Load Test

Conveyor load test carried out on basis of three load conditions. First is no load, second is actual load and full load condition. Testing speed is variable of conveyor on the basis of load variation.

We measured linear speed of conveyor belt by using contact tachometer with wheel attachment. We held the wheel against the conveyor and get calculated linear speed on the display based on the rotational rate and fixed diameter of the wheel.

We also measured voltage and current required for each load with the help of multi meter and calculated motor power consumption. At full load motor is using 921KW power which is less than motor capacity. This test helps to verify design safety under extreme load conditions. Following table shows the results under various load conditions.

Table II

Load	Capacity (TPH)	Speed (m/s)	Motor Power(KW)
No load	0	4.7	405
Actual capacity	1500	4.65	633
Designed capacity	4400	4.623	921

V. Conclusion

Above finite element analysis results gave Maximum stresses developed at extreme high load conditions on conveyor pulleys are less than the allowable limits, hence design of conveyor system is safe.

Design of belt conveyor for given design capacity is found safe as stress and deflection calculations from finite element analysis on critical parts of conveyor pulley are less than allowable limits. Approximately constant conveyor speed achieved at various material loading conditions therefore conveyor are safe and efficient to use for heavy duty applications with time circumstances. Maximum power required at full load condition whereas in case of actual load condition power is comparatively lower. This ensures design and motor safety under extreme heavy load conditions.

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