Redesigning & Optimization of Conveyor Pulley

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Abstract— Conveyor pulley is widely used in the area of material handling equipment field. Pulley is heart of the bulk mining material handling. The main components of conveyor pulley are shaft, drum or shell, end disk or diaphragm plates, locking elements, end disk, lagging and bearing assemblies. Since the stresses and deflections of its parts are depends on each other, an analysis of pulley assembly is mandatory for reliable pulley design. Designing pulley of this kind requires complex calculations of all belt tensions and loads in static conditions. This work will consider assumptions on load variations around its periphery & along the pulley face-width, axial load, self-weight, dead weight and angular velocity. This paper attempts to analyze steady state design characteristics for required capacity of conveyor pulley. The optimization of the design is done through number of iteration by designing problem parametrically.

Keywords— Shaft, Drum, End disk, Design Optimization, ANSYS.

I. INTRODUCTION

T

ne conveyor pulley is three component assembly of shaft, locking device and end disk welded with drum. It is a flat belt pulley which is majorly used for long distance transportation of bulk materials. The pulleys are widely used in mining sector, cement industry as well as sugar industry. Pulley and belt are main components of the whole bulk material handling system whose failure will cause substantial downtime as well as damage to other structure. 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 Chattopadhay 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. In this work, computation is easy, as a close form solution exists and it takes moderate execution time. But the solutions near the connection region between the parts cannot be accurate because of the approximation in treating the elastic coupling between them. Specially, their displacements are not coupled at their connections. This leads to significant errors in the stress and strain fields about the connectors. Also, these methods cannot be extended to complex shapes as those of pulleys having tapered webs or provided with taper-lock arrangements. On the contrary, the finite element method, though a little tedious and time consuming, offers a practical solution technique. Ma Xingguo Wang Yanling, Zhou Mingyu gives the optimal structure design for belt pulley but they don’t uses the load variation i.e. they considered linear belt load. As it is heart of the system, the efficiency of system working depends on how efficiently the pulley is working. So, the excessive strength and stiffness which corresponds to the excessive weight of the pulley is not necessary. Pulley with the excessive factor of safety is not required as it also increases the overall cost of the project. So, to decrease the weight and cost of project the pulley should be optimized keeping the deflection and stress in the component within the prescribed limit. A. Mallikarjuna Rao, G S S V Suresh, Priyadarshini Ddoes the theoretical calculation and optimization of conveyor pulley using FEA but considered the exponential variation only.

II. CONVEYOR PULLEY

A. Conveyor Pulley Cut Section

Fig.1 shows the cut section of the conveyor pulley. The pulley has the constant cross section as shown. So, we can analyse the pulley as axisymmetric model considering the ¼ model for the analysis. It minimizes the effort of creating the whole model and also saves the solution time. But actual forces acting on the pulley is much more severe than the uniform forces considered in axisymmetric analysis. But, axisymmetric analysis is possible only when model as well as the loads coming on it are uniform. In this work we are considering the load variation so analysis of the whole model is necessary in this case.

Fig.1. Pulley Cut Section
B. Modelling of Conveyor Pulley

Though the structure of the pulley looks simple the whole modelling of it is difficult. As the structures of pulley are huge the modelling is to be done keeping in mind that to minimize the number of nodes and element to be created. For it the meshing should be done by using quad element rather than tria element as they give the minimum no of nodes and element. As we are going to optimize the pulley which is an iterative process by varying different parameters, checking the strength and stability after changing the parameter is necessary. So, the parametric modelling of pulley becomes important. In the model various geometric parameters such as radius, length at different location for shaft, locking device, end disk, drum, length of bearing span, thickness of drum etc. are defined. The advantage of parametric modelling is that when we change any dimensional parameter, the whole model gets updated automatically. For modelling and FEA analysis ANSYS is used. For parametric modelling the code is written in notepad which can directly run in ANSYS APDL. Firstly the area model is created & meshed with dummy mesh by element mesh200 & kryopt(1)=7. Then the Solid model and brick mesh is created by using solid element and by rotating area model.

III. Finite Element Analysis

There are single or multiple loads acting on the pulley at a time. So, analysis for a single load as well as combined loads is necessary.

A. Load Cases Considered for Analysis

1) Pulley Deadweight: It is the load coming on the pulley due to its self-weight which acts at CG of the pulley.

2) Overhung Load: It is the load coming on the pulley due to gearing assembly.

3) Axial load: It is taken some percentage (nearly 10 to 15 \%) of the maximum load acting on the pulley where belt is in contact with the drum.

4) Belt Tension: It is the most distorting force acting on a pulley. This force varies exponentially along the circumference of pulley and sinusoidal along pulley face width. The belt tension acts on drum where belt is in contact with drum.

5) Centrifugal Force: It is the inertia force acting on pulley due to the rotational speed of the pulley. It acts at CG of pulley.

B. Constraint

To obtain ANSYS results from the model there should not be any rigid body motion i.e. the model should be sufficiently constrained. As the pulley is supported on two bearings the different constraints are applied at bearing surfaces. Bearing at non drive end are given displacement constraints in y and z direction and at drive side bearing all displacement constraints are applied.

C. Contact Consideration

For the model to perform as realistic as possible, contacts are defined after model creation. As contacts are used in the model the analysis of model becomes nonlinear. Four Contact pairs are defined i.e. two pairs between shaft and locking device and two pairs between locking device and end disc.

As locking device is not welded to shaft as well as end disk it should not be glued directly in ANSYS. If we glue it together it will perform as welded connection and we are unable to calculate the contact stress between shaft & locking device pair and locking device & end disk pair. It is very important to calculate contact stress between contact pair, as it is frictional contact between them which transfers the torque & power applied by driving motor.

Some Parameters used for modelling and analysis are given in table I

<table>
<thead>
<tr>
<th>Structural Parameter</th>
<th>symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belt width</td>
<td>lbelt</td>
<td>1400mm</td>
</tr>
<tr>
<td>Belt speed</td>
<td>lms</td>
<td>1 m/s</td>
</tr>
<tr>
<td>Pulley face width</td>
<td>lpw</td>
<td>1600mm</td>
</tr>
<tr>
<td>Belt tension T1</td>
<td>T1</td>
<td>234KN</td>
</tr>
<tr>
<td>Belt tension T2</td>
<td>T2</td>
<td>65KN</td>
</tr>
<tr>
<td>Pulley wrap angle</td>
<td>therdrum</td>
<td>210°</td>
</tr>
<tr>
<td>Drum thickness</td>
<td>thdrum</td>
<td>16mm</td>
</tr>
</tbody>
</table>
Shaft radius  $r$  112mm  
End disk radius  $r_e$  145mm  
Shaft length  $l_s$  2702mm  
Shaft radius at bearing mount  $r_b$  90mm  
Bearing span  $b_{span}$  204mm  
Shaft radius at locking device  $r_h$  110mm  

As per considered loads, boundary condition analysis is done in ANSYS. The maximum stress is coming on drum which shown in fig.4 & fig.8 which is 10.911 kg/mm$^2$ near outskirt of the drum. The fig.5 gives the maximum stress for shaft which is 4.96 kg/mm$^2$ occurs at bearing constraint. The maximum stress in end disk is 5.65 kg/mm$^2$ which occurs near weld as shown in fig.7. The maximum stress & deflection values are summarized in Table II.

**TABLE II**
The deflection & stress of each component

<table>
<thead>
<tr>
<th>Component</th>
<th>Deflection (mm)</th>
<th>Stress (kg/mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft</td>
<td>0.0102</td>
<td>4.96</td>
</tr>
<tr>
<td>Locking Device</td>
<td>0.00323</td>
<td>3.376</td>
</tr>
<tr>
<td>Hub</td>
<td>0.006865</td>
<td>5.653</td>
</tr>
<tr>
<td>Drum</td>
<td>0.0263</td>
<td>10.911</td>
</tr>
</tbody>
</table>

Fig.4. von mises Stress in Pulley

Fig.5. von mises Stress in shaft

Fig.6. von mises Stress in locking device

Fig.7. von mises Stress in end disc

Fig.8. von mises Stress in drum
IV. OPTIMIZATION CONSIDERATION

Optimum means to meet all specified requirement at minimum expense. Optimization means to reduce the weight, volume, surface area, path to follow or increase the efficiency of engine, transmission etc. In optimization model basically there are three variables which are design variable, state variable & objective function.

A. Design Variable(DV)

These are independent quantities which are varied to achieve the optimum design. Theoretically all the geometric parameters such as length, radius etc. can be treated be as DV, but in practice parameter which causes the sufficient change in objective function is selected as DV. In the problem we are considering the shaft radius(r) & drum thickness (thdrum) as DV.

B. State Variable(SV)

State variables are the variables that constraint the design problem. In general stress, deflection in component, temperature, flow rate, frequency etc. are the state variables. In the problem we are considering the deflection & stress in the pulley acts as a SV.

C. Objective Function

It is a dependent variable which is to be optimized. Our problem is to minimize the weight. If we use the same material for each component then the weight and volume can be interrelated. So, our problem of minimizing weight becomes problem of minimizing volume of conveyor pulley.

V. OPTIMIZATION RESULTS OF ANALYSIS

The ANSYS program offers two optimization methods to accommodate a wide range of optimization problems. The sub problem approximation method is an advanced zero-order method that can be efficiently applied to most engineering problems. The first order method is based on design sensitivities and is more suitable for problems that require high accuracy. For both the sub problem approximation and first order methods, the program performs a series of analysis-evaluation-modification cycles. That is, an analysis of the initial design is performed, the results are evaluated against specified design criteria, and the design is modified as necessary. This process is repeated until all specified criteria are met. The optimization loop is run in ANSYS with the relevant commands for defining state variable, design variable, objective function and their range between which that variable is going to varied during optimization loop. The maximum number of iteration defined in loop are ten.

<table>
<thead>
<tr>
<th>Set no.</th>
<th>Region</th>
<th>Shaft radius mm</th>
<th>Drum thickness mm</th>
<th>Stress Kg/mm^2</th>
<th>Disp. sum mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Feasible</td>
<td>112</td>
<td>16</td>
<td>10.911</td>
<td>0.02619</td>
</tr>
<tr>
<td>2</td>
<td>Feasible</td>
<td>112</td>
<td>15.236</td>
<td>10.887</td>
<td>0.02702</td>
</tr>
<tr>
<td>3</td>
<td>Feasible</td>
<td>100</td>
<td>14.813</td>
<td>10.871</td>
<td>0.02749</td>
</tr>
<tr>
<td>4</td>
<td>Feasible</td>
<td>100</td>
<td>14.502</td>
<td>10.862</td>
<td>0.02790</td>
</tr>
<tr>
<td>5*</td>
<td>Feasible</td>
<td>100</td>
<td>14.429</td>
<td>10.859</td>
<td>0.02801</td>
</tr>
<tr>
<td>6</td>
<td>Feasible</td>
<td>100</td>
<td>14.517</td>
<td>10.862</td>
<td>0.2788</td>
</tr>
<tr>
<td>7</td>
<td>Feasible</td>
<td>100</td>
<td>14.441</td>
<td>10.860</td>
<td>0.02799</td>
</tr>
<tr>
<td>8</td>
<td>Infeasible</td>
<td>100</td>
<td>14.000</td>
<td>10.896</td>
<td>0.02865</td>
</tr>
<tr>
<td>9</td>
<td>Infeasible</td>
<td>100</td>
<td>14.0000</td>
<td>10.846</td>
<td>0.02865</td>
</tr>
</tbody>
</table>
Fig. 11 Variation of shaft radius vs iteration no.

Fig. 12 Variation of drum thickness vs iteration no.

Fig. 13 Variation of equivalent stress vs iteration no.

Fig. 14 Variation of displacement sum vs iteration no.

Fig. 15 Variation of total volume vs iteration no.

The optimization result value of shaft diameter, drum thickness, stress and deflection at each iteration is summarized in Table III. Fig 11 to Fig 15 gives the variation of design variable, state variable and objective function with respect to iteration number.

The plot shown fig. 11 gives the idea how the shaft radius varies with each iteration. The fig. 12 shows the variation of drum thickness with each iteration as well as the lower and upper limit of range. The fig. 13 explains the behavior of equivalent stress with respect to iteration number.

The graph shown fig. 14 gives the idea how the displacement sum increases with iteration. The fig. 15 shows how the objective function i.e. total volume reduces with each iteration.
VI. CONCLUSIONS

The above ANSYS results shows that the total volume of pulley is reduced by 9.3% which ultimately reduce the weight of the pulley. Change in equivalent stress in optimized & pre optimized pulley is very less whereas the displacement sum is increased by 9%.

After optimization optimal value of shaft diameter is 100mm, drum thickness is 14.29mm approximated to 14.5mm. The weight of optimized pulley comes out to be 1439 kg.

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