Redesigning & Optimization of Conveyor Pulley

Prasad C. Pol[1], S. M. Jadhav[2],

[1]*M.E. (Mechanical Design Engineer), Savitribai Phule Pune University, Pune, India,*

[2]*Assistant Professor, Department of Mechanical Engineering, NBN Sinhgad School of Engineering, Pune, India.*

***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

The 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 themain components of the whole bulk material handling system whosefailure 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 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. 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.

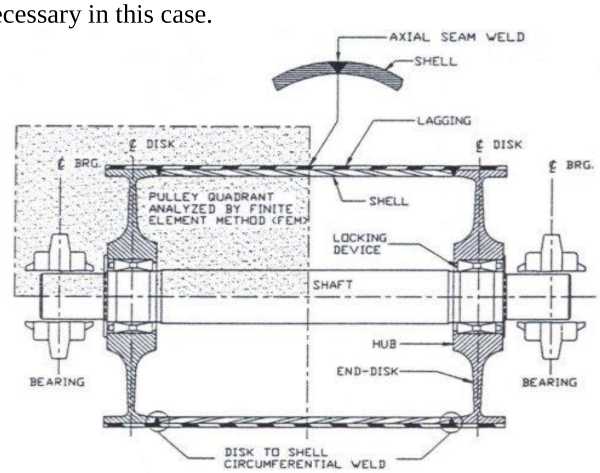

Fig.1. Pulley Cut Section

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 modelvarious 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 ANSYSis 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 &kyopt(1)=7. Thenthe Solid model and brick mesh is created by using solid element and by rotating area model.

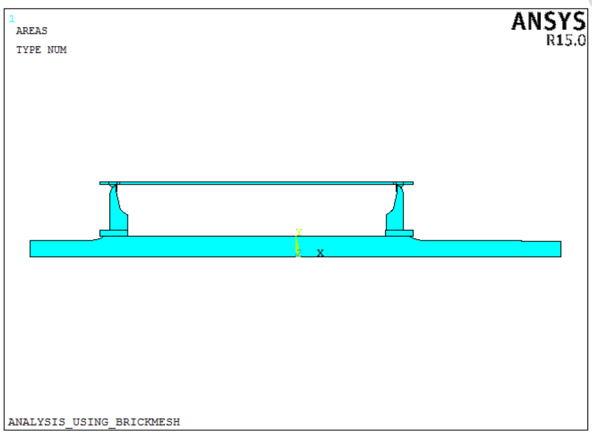

Fig.2. Area Model of Pulley

After rotating fig.2 the whole model with meshing is generated.Fig.3 shows the meshed model.

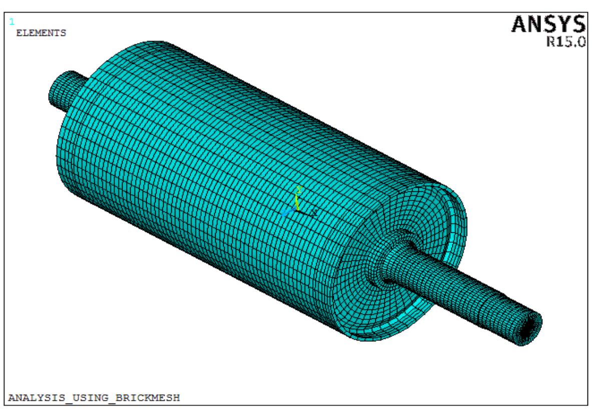

Fig.3. Brick Meshed Pulley Model

III. Finite Element Analysis

There aresingle 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 alldisplacement 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 glueit 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 I
Structural Parameter

parameter	**symbol**	**Value**
Belt width	lbelt	1400mm
Belt speed		1 m/s
Pulley face width	lpw	1600mm
Belt tension T1		234KN
Belt tension T2		65KN
Pulley wrap angle		210^o
Drum thickness	thdrum	16mm

Shaft radius	r	112mm
End disk radius	re	145mm
Shaft length	ls	2702mm
Shaft radius at bearing mount	rb	90mm
Bearing span	bspan	204mm
Shaft radius at locking device	rh	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

Component	**Deflection mm**	**Stress Kg/mm^2**
Shaft	0.0102	4.96
Locking Device	0.00323	3.376
Hub	0.006865	5.653
Drum	0.0263	10.911

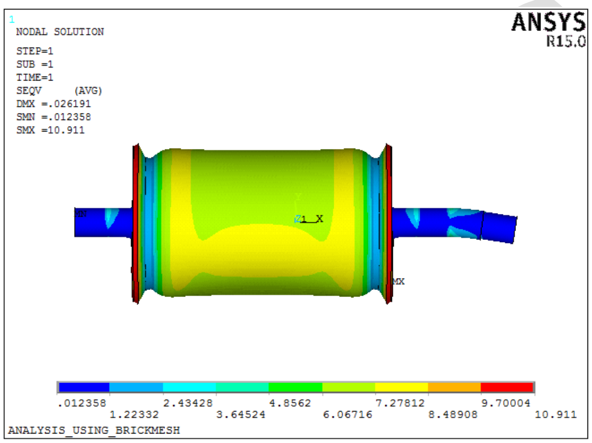

Fig.4. von mises Stress in Pulley

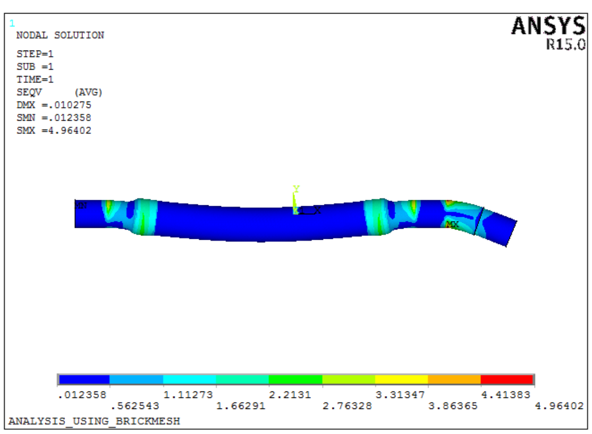

Fig.5. von mises Stress in shaft

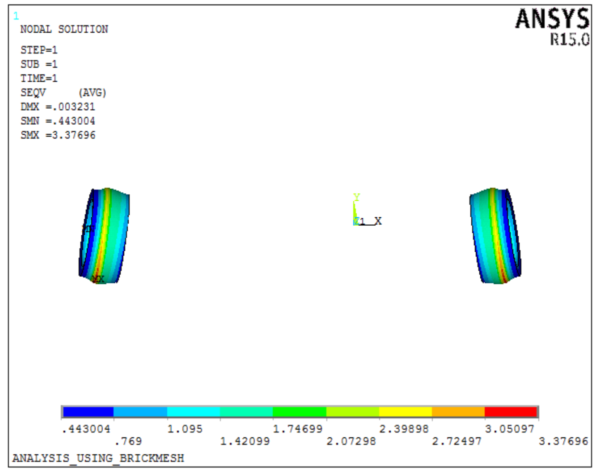

Fig.6. von mises Stress in locking device

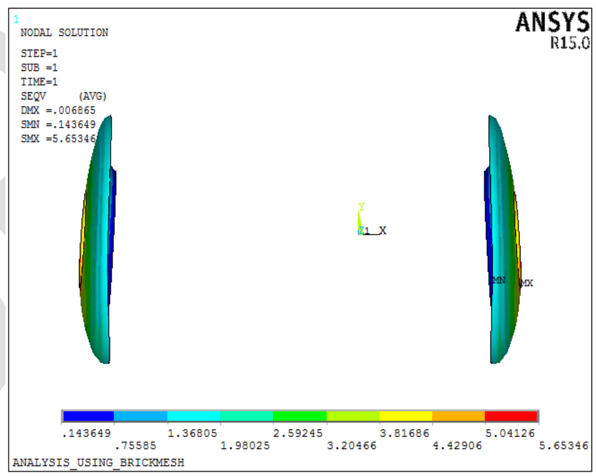

Fig.7. von mises Stress in end disc

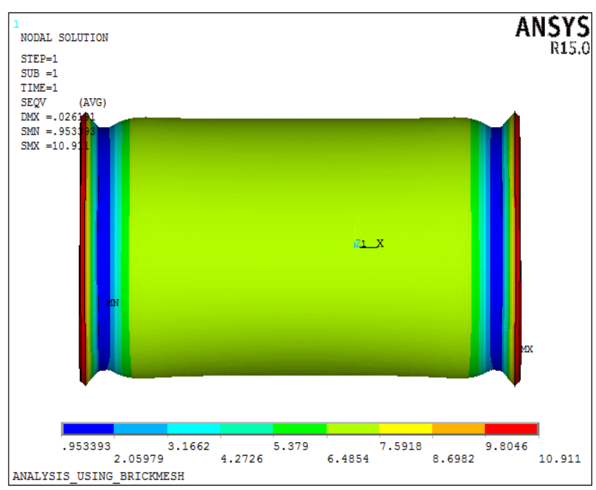

Fig.8. von mises Stress in drum

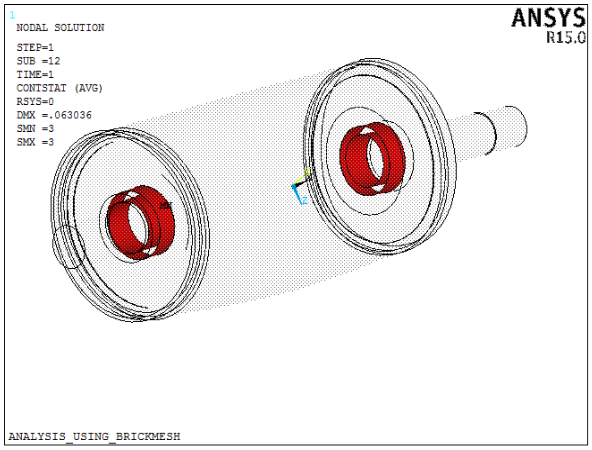

Fig.9 Contact Status between four contact pair

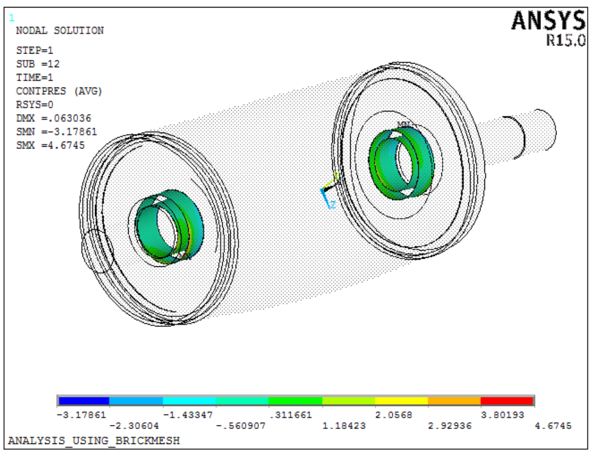

Fig.10.Contact pressure between contact pairs

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 III
Optimization Result

Set no.	**Region**	**Shaft radius mm**	**Drum thickness mm**	**Stress Kg/mm^2**	**Disp. sum mm**
1	Feasible	112	16	10.911	0.02619
2	Feasible	112	15.236	10.887	0.02702
3	Feasible	100	14.813	10.871	0.02749
4	Feasible	100	14.502	10.862	0.02790
5*	Feasible	100	14.429	10.859	0.02801
6	Feasible	100	14.517	10.862	0.2788
7	Feasible	100	14.441	10.860	0.02799
8	Infeasible	100	14.000	10.896	0.02865
9	Infeasible	100	14.0000	10.846	0.02865

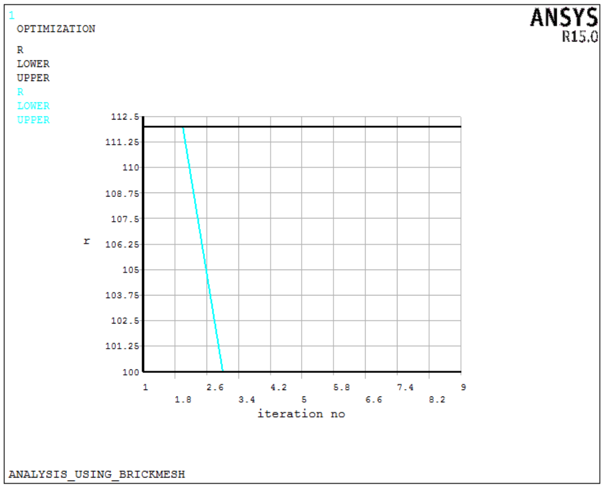

Fig.11Variation of shaft radius vs iteration no.

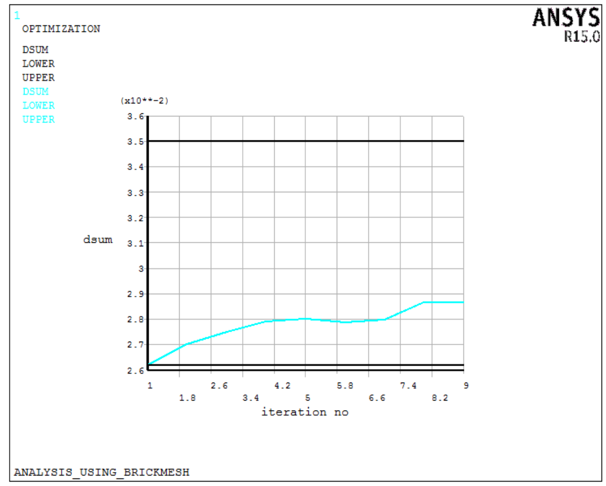

Fig.14 Variation of displacement sum vs iteration no.

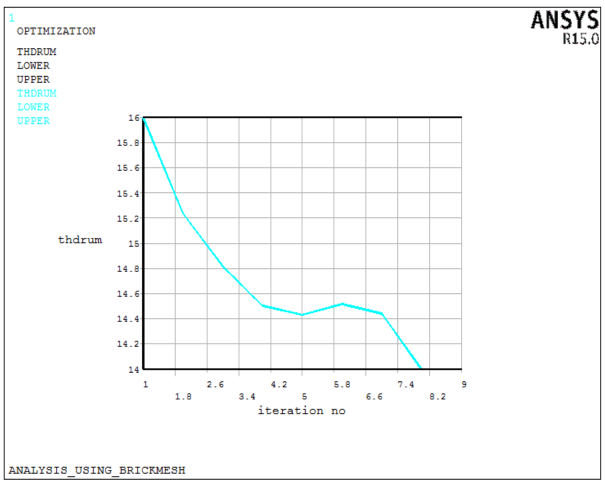

Fig.12Variation of drum thickness vs iteration no.

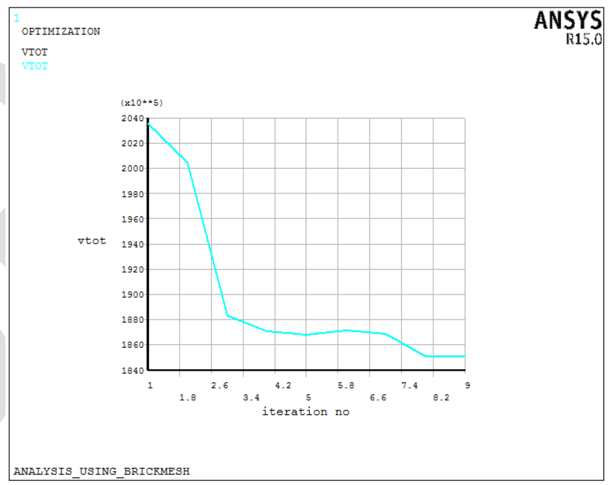

Fig.15 Variation of total volume vs iteration no.

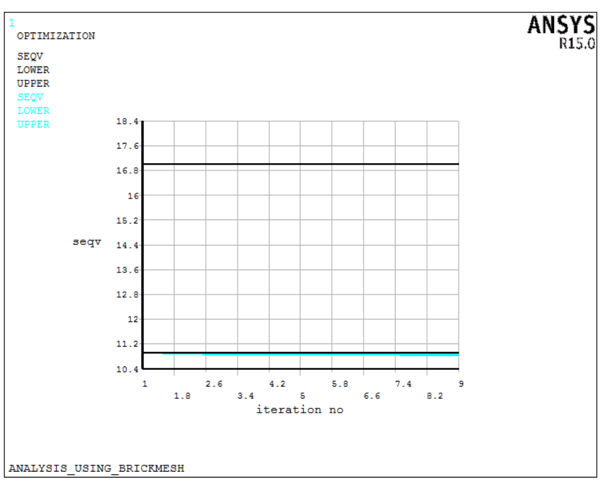

Fig.13 Variation of equivalent stress vs iteration no.

The optimization result value of shaft diameter, drum thickness, stress and defection at each iteration is summarized in Table III. Fig11 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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REFERENCES

[1]. J.A. Martins, I. Kovesdy, I. Ferreira, "Fracture Analysis of Collapsed Heavy-Duty Pulley in A Long-Distance Continuous Conveyors Application", Science Direct Engineering Failure Analysis, 16 (2009).
[2]. Ch. Affolter, G. Piskoty, R. Koller, M. Zgraggen, T.F. Rutti, "Fatigue Failure Analysis In The Shell Of A Conveyor Drum", Science Direct Engineering 14 (2007).
[3]. Mallikarjuna Rao, G S S V Suresh, Priyadarshini D, "Alternate Design and Optimization Of Conveyor Pulley Using Finite Element Analysis", International Journal of Engineering Research & Technology (IJERT), Vol. 1 Issue 7, September – 2012.
[4]. M. Ravikumar, Avijit Chattopadhyay, "Integral Analysis Of Conveyor Pulley Using Finite Element Method", Computers and Structures 71, (1999).
[5]. N. Siva Prasad and RadhaSarma, "A Finite Element Analysis For The Design Of A Conveyor Pulley Shell", Computers & Structures Vol. 35, No. 3, 1990.
[6]. S. P. Das and M. C. Pal," Stresses and Deformations of A Conveyor Power Pulley Shell under Exponential Belt Tensions", Computers & Structures Vol. 35, No. 3, 1990.
[7]. Lu Hong-Sheng," Shell Strength of Conveyor Belt Pulleys: Theory and Design" Lu Hong-Int. J. Mech. Sci. Vol. 30, No. 5, 1988.
[8]. Ma Xingguo Wang Yanling, Zhou Mingyu, "An Optimal Structure Designing Of Belt Pulley", Third International Conference on Intelligent Networks and Intelligent Systems, 2010.
[9]. Vinod M. Bansode, Abhay A. Utpat, “Fatigue Life Prediction Of A Butt Weld Joint In A Drum Pulley Assembly Using Non-Linear Static Structural Analysis”,International Journal of Mechanical and Production Engineering (IJMPE) ISSN 2315-4489, Vol-1, Iss-1, 2012.
[10]. Terry J King, “The Function and Mechanism of Conveyor Pulley Drums”, International Material Handling Conference BELTCON 3.
[11]. Allan Lill, “Conveyor Pulley Design”, International Material Handling Conference.
[12]. Tim Well, “Effect of Drive Assembly Overhung loads on Belt conveyor and pulley Design.”
[13]. ANSYS Mechanical APDL Basic Analysis Guide
[14]. ANSYS Mechanical APDL Command Reference.