Static Structural Analysis of Crushing Rollers of Three Roller Sugar Mill

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***Abstract*— Sugarcane roller mill is the vital part of sugar industry. The main objective of milling is to separate the sucrose-containing juice from the cane. The extraction of juice in a mill is achieved by squeezing prepared cane between two rolls. Finite Element Method is a numerical technique used to carry out the stress analysis. In this method the solid model of the component is subdivided into smaller elements, constraints and loads are applied to the model. Geometrical model is created using 3D modeling software CATIA V5. The static analysis of each component is carried out using analysis software ANSYS WORKBENCH. The results for maximum shear stress on the top, feed, discharge roller are calculated analytically and compared with the results from software. Static analysis of all three rollers is done using different materials for analyzing the variation in results. From these results conclusions were drawn.**

Keywords*— Crushing roller, Static analysis, Max. Shear stresss theory, ANSYS Workbench.

I. INTRODUCTION

The main objective of milling is to separate the sucrose-containing juice from the cane. The extraction of juice in a mill is achieved by squeezing prepared cane between two rolls. In three roller mill three rollers are arranged in triangular pattern for removing sucrose 95-97%. These rollers are fed by two pressure feeder rollers which take prepared cane from a vertical chute and may be assisted by an under feed roller at the exit from the chute. The arrangement of rollers in three roller mill is as follows-

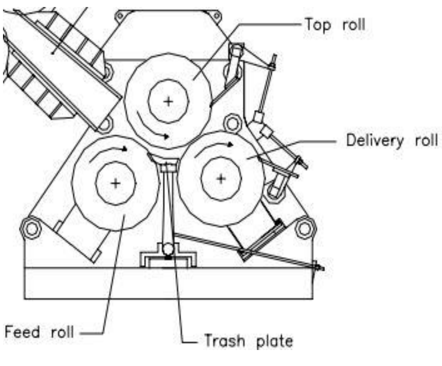

Fig. No. 1– Three roller sugar mill [7]

Three rollers are used named as top, feed & discharge roller. The rollers are arranged in an isosceles triangle with a top angle of 72^0. The feed and discharge rollers are placed at an angle of 35 & 37 respectively from the vertical below the top roller. The crushing of cane takes place first in top-feed roller and then in top-discharge roller. The shaft of roller is made up of forged steel and shell of the roller is made up of cast iron. The shell is shrink fitted on the shaft.

The power for crushing of sugarcane is given to the top roller which rotates feed and discharge roller with arrangement of pinion attached on one side of roller. The direction of rotation of top and feed – discharge rollers is opposite. The D.C. power is given to the top roller for crushing.

Top roller is critical component amongst all. As the drive torque, hydraulic load, crushing load is coming on the top roller. The forces acting on the mill rolls give rise to shearing, bending, torsion and compressive stresses. The top roller is most highly stressed, since it consumes about half of the mill torque. Out of total power 50% is taken by top roller, 35% is taken by discharge roller, 15% is taken by feed roller [7].

II. LITERATURE REVIEW

Work related to static and dynamic analysis of crushing rollers by using the analysis software is very less.

A. B. Kakade et al. [1] investigated the friction and wear behaviour of sugar mill roller shaft material EN8 under dry, lubricated, contaminated, and Lubricated with contaminated sliding conditions. As per their observations wear is always on the top roller shaft. Initiation of crack and wear on the surface of the shaft finally leads to crack propagation. The conditions taken for experiment are same as that of actual in industry. It is shown by result that friction and wear volume increases in contaminated condition. Also the very high weight of roller is only responsible for failure of bearing.

Walmiki S Rathod et al. [5] has presented work related to two roller sugar mill using FEA technique. They have calculated bending moment analytically and by software. Also have given results that taper gives less value of stress than the fillet.

ISSN: 2278-0181
Vol. 4 Issue 05, May-2015

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M. Prabaharan et al. [4] has presented work related to topology optimization. It is an optimization process which gives the optimum material layout according to the design space and loading condition. The topology optimization is applied to the 5 ton hydraulic press and scrap baling press using ANSYS WORKBENCH. The weight of both press is reduced by 24%. They claimed 26.26 percent cost reduction in scrap baling press. Also they have developed 5ton hydraulic press with cost reduction of 24.54 %.
P. Dumbre et al.[3] has performed the structural analysis of steering knuckle for weight reduction. The topology optimization is used for 11% weight reduction. HYPERMESH software is used for finite element modelling. The areas for redesign are located by optistruct software.

S. Manokruang et al. [2] has presented Methodology of Bus-Body structural redesign for lightweight productivity improvement. Because of high bus structure there were problem of high fuel consumption, high cost, low efficiency problem. The performance is increased by redesigning the structure of bus based on experts knowledge. First the CAD model is generated by using CATIA & analysis is done by finite element method. The weight is reduced by taking out unnecessary elements.

III. THEORETICAL APPROACH

A. Analytical calculation for stresses on the top roller:-[6]

The top roller is most highly stressed, since it consumes about half of the mill torque. The forces on the top roller are because of power transmission, crushing, and hydraulic load. The loads on the roller are divided into horizontal and vertical component of loading.

Power(p)= 900 kw
Roller Speed (n)= 5 rpm
Roller dia.= 1200 mm
Shaft dia. at roller=710mm
Shaft dia. at bearing support=610mm
Shaft dia. at pinion=630mm
Pitch circle dia. of crown pinion= 1136 mm

$$\text{Drive torque} = \frac{Power * 9.55}{Speed\ (rpm)} \quad (1)$$
$$= 1718.87 \text{ KNm}$$

Out of the total torque 50% of torque is taken by top roller, so-

Torque on the top roller= 859.435 KNm

Tangential component (Horizontal) of force due to torque

$$(Fph) = \frac{Torque}{(P.C.D)/2} \quad (2)$$

∴ Fph =1513.0914 KN

Radial component (Vertical) of force due to torque (Fpv)= 705.566 KN
The load of crushing from discharge roller is acting at an angle of 53^0 from right side=590 tons=5900 KN

The vertical component of load= 4711.94 KN
The horizontal component of load=3550.7 KN(left)

The load of crushing from feed roller is acting at an angle of 55^0 from left side=275 ton=2750 KN
The vertical component of load=2252.668 KN
The horizontal component of load=1577.3352 KN (right)

The weight of top roller is 32 ton which is acting downwards.

The total vertical load acting on the roller = 6645KN
The total horizontal load acting on the roller = 1973 KN

The load of crushing is acting on the surface of roller so, it will be shown as uniformly distributed load on the loading diagram-

Intensity of U.D.L. in vertical loading diagram

$$(Wv) = \frac{Total\ vertical\ load\ due\ to\ crushing}{Length\ of\ shell\ of\ roller} \quad (3)$$
$$= 2.889 \text{ KN/mm}$$

Intensity of U.D.L. in horizontal loading diagram (Wh)= 0.8578 KN/mm

Diameter of hydraulic Ram=460mm
Oil pressure= 2.35 Kg/mm^2

Total hydraulic load acting on the top roller

$$=2 * \text{Areaof piston} * \text{oil pressure} \quad (4)$$
$$= 2 * \frac{\pi}{4} (460)^2 * 2.35$$
$$= 7800 \text{KN}$$

Hydraulic load on each bearing=3900KN

1) Vertical loading diagram:-

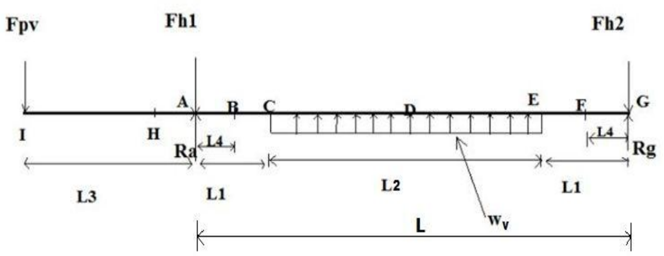

Fig. No.2 Vertical loading diagram

Here,
L_1= 650mm
L=2300mm
L_3=950mm
L_4=375mm
Fh_1 and Fh_2 are hydraulic forces =3900KN

Fp_v=Vertical component of force due to torque=705.566 KN

W= Intensity of U.D.L= 2.889 KN/mm

R_a and R_g are reaction forces from bearing.

After solving for vertical loading diagram-

R_a = 1469.257 KN

R_g = 391.308 KN

Maximum bending moment is at point D = -4405.294 * 10^3 KN mm

2) *Horizontal loading diagram:-*

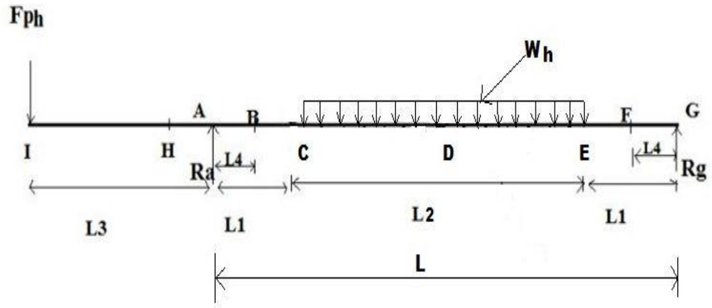

Fig. No.3 Horizontal loading diagram

Here,
Fp_h=Horizontal component of force due to torque= 1513.0914 KN

W= Intensity of U.D.L= 0.8578 KN/mm

R_a and R_g are reaction forces from bearing.

After solving for vertical loading diagram-

R_a = 2898.879 KN

R_g = 587.2119 KN

Maximum bending moment is at point A = -1437.436 * 10^3 KN mm

3) *Resultant of horizontal and vertical loading:-*

Resultant reaction at 'a' =3249.956 KN

Resultant reaction at 'b' = 705.648 KN

Resultant bending moment at 'D' = 4432.435 * 10^3 KN mm

4) *Maximum shear stress:-*

According to maximum shear stress theory-[6]

$$\tau_{max} = \frac{16}{\pi d^3}\sqrt{(M)^2+(T)^2}$$

(5)

τ_{max} = 101.306 N/mm^2

The material used for the roller is forged steel-

for forged steel S_{yt}=380 N/mm^2

Therefore S_{sy}=0.5*380=190 N/mm^2 > τ_{max}

Therefore shaft is safe according to maximum shear stress theory.

B. Analytical calculation for stresses on the Discharge roller

Geometry and material of discharge roller is same as top roller. The loads acting on the roller are due to crushing of sugarcane between top and discharge roller and load due to torque. Out of the total torque 35 % torque is taken by discharge roller. The same procedure of horizontal and vertical loading diagram is used for finding the value of maximum shear stress.[7]
Resultant reaction at 'a' =6865.909 KN
Resultant reaction at 'b' = 2815.822 KN
Resultant bending moment at 'D' = 3301.950 * 10^3 KN mm
Max. Shear stress = 75.3082 MPa
Therefore shaft is safe according to shear stress theory.[6]

C. Analytical calculation for stresses on the Feed roller:-

Same Geometry and material of top roller is used for feed roller. The loads acting on the roller are due to crushing of sugarcane between top and Feed roller and load due to torque. Out of the total torque 15 % torque is taken by Feed roller. The same procedure of top roller is used for finding the value of maximum shear stress.[7]
Resultant reaction at 'a' =1568.6581 KN
Resultant reaction at 'b' = 1529.4969 KN
Resultant bending moment at 'D' = 1890.239 * 10^3 KN mm
Max. Shear stress = 42.8055 MPa
Therefore feed roller shaft is safe according to shear stress theory.[6]

IV. Three Dimensional CAD Model

A three dimensional model of crushing roller is made by using modeling software CATIA V5. CATIA is the most powerful and widely used CAD software of its kind in the world.

All three rollers i.e. top, feed and discharge roller having same dimension and geometry.

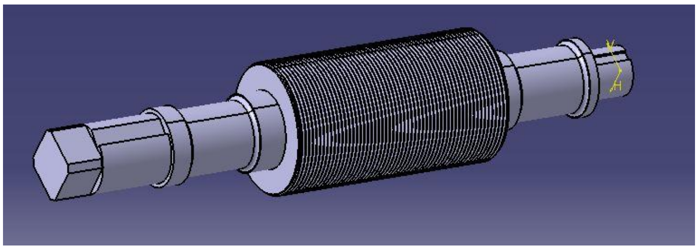

Fig.No.4 3-D model of mill roller

V. Finite Element Approach

The Finite Element Analysis (FEA) is a numerical procedure for analysis of complicated shapes. In this method the geometrical model is divided into small areas called as elements. Each element is connected by some nodes. Each node is having some degrees of freedom. Based on the no. Of nodes, degrees of freedom, material properties element stiffness matrix is generated for each element. Stiffness matrixes of all elements are assembled for finding the stiffness matrix of component. Selection of type of element affects directly on the accuracy of results. Accuracy of result is increased either by increasing number of element or by selecting higher order element.

A. Static Analysis of Top Roller:-

Static analysis of top roller is done for observing maximum stresses and deformation of roller when different forces such as crushing, hydraulic, torque due to power transmission etc. Are applied on it. Static structural analysis is done using ANSYS WORKBENCH.

1) Mesh Generation:-

The CAD model in IGES format is imported in ANSYS Workbench. Meshing is performed in the same software. Meshing is the process of converting the model into number of discrete parts called as element. SOLID187 element is used for meshing. It is higher order 3-D, 10-node tetrahedral structural solid as shown in fig-no-5 [8]

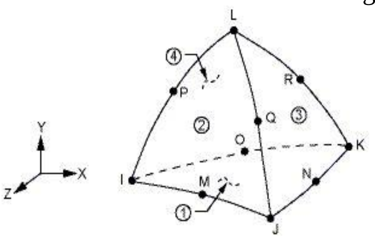

Fig No.5 SOLID187 element[8]

The element has quadratic displacement behaviour and is well suited to modelling irregular meshes(such as those produced from various CAD/CAM systems). The element is defined by 10 nodes having three degree of freedom at each node translations in the nodal X,Y,Z direction. Fine meshing is done at the portion where stress is maximum. 10 mm mesh size is used for fine meshing and 30 mm for the area where stress is negligible. At the mesh size 10 & 30 mm stress values are nearly same so selected for meshing. Total 1253187 elements and 1738482 nodes are obtained after meshing.

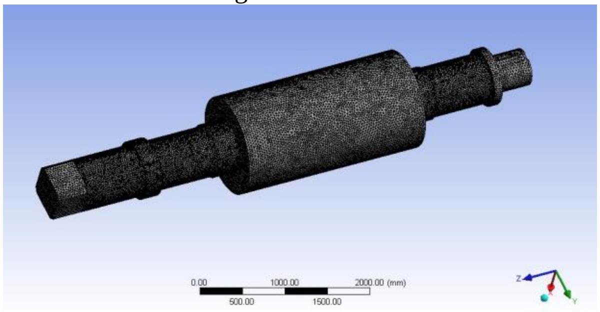

Fig No.6 Meshing of Model

2) Loading And Boundary conditions:-

Boundary condition: - As roller is simply supported so all degrees of freedom of roller are fixed at the bearing position.

Loading Details:-

The horizontal and vertical component of loads due to crushing are applied on roller shell as Uniformly Distributed Load (U.D.L).

Total vertical load= 6964.617 KN (up)

Total horizontal load= 1973 KN (left)

The Tangential (horizontal) and Radial (vertical) components of load due to power transmission are applied at pinion end of roller.

Tangential Component = 1513.0914 KN

Radial Component = 705.566 KN

Hydraulic load is applied at the bearing position. Which is 3900KN

Standard earth gravity is applied). And is shown in fig.no-7

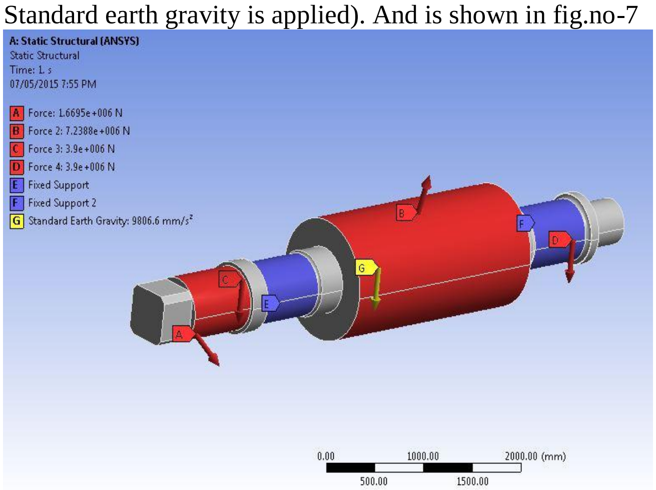

Fig No7.- Loading and boundary condition details

3) Material Properties:-

Material for Crushing roller shaft is forged steel.

Material: - 40C8 steel

Density: - 7850 Kg/m^3

Modulus of Elasticity:- 200GPa

Poisson's ratio: - 0.3

Tensile yield strength: - 380 MPa

Tensile ultimate strength: - 680 Mpa

4) Results of static analysis for top roller:-

Maximum shear stress, Total deformation are calculated as static analysis results. Shown in below figures-

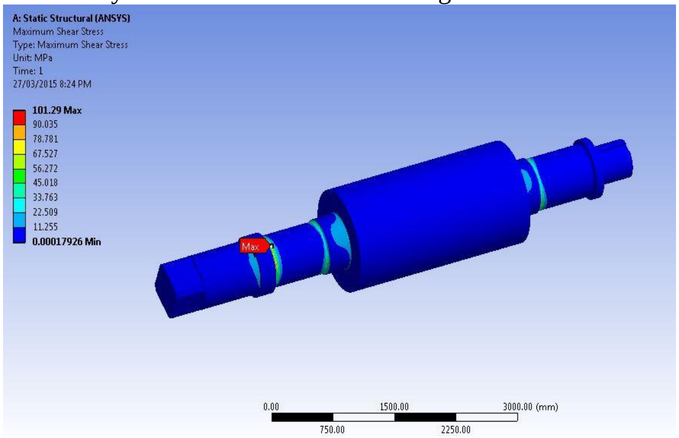

Fig.No8.- Maximum Shear Stress in top roller

Maximum value of shear stress is 101.29 MPa which is at bearing position of top roller. Maximum value of shear stress is within limit so shaft is safe. Minimum value of shear stress is 1.7926e-4 MPa at bearing, shell and pinion end .

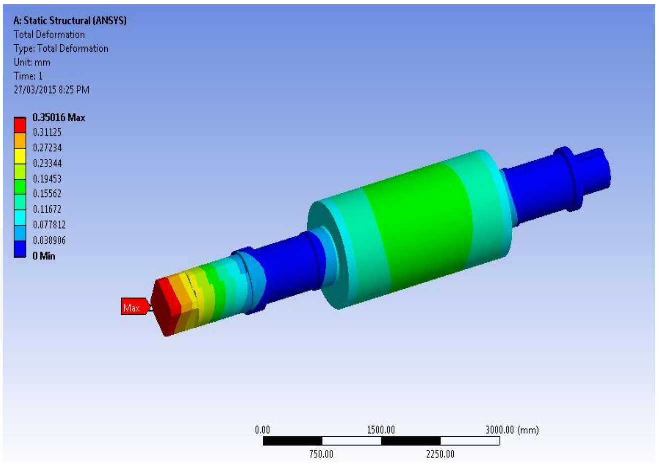

Fig.No9- Total deformation of top roller

Maximum value of total deformation is 0.35016 mm at the pinion end of top roller, which is within limit. Minimum value of deformation is 0 mm which is at bearing position.

B. Static Analysis of Discharge Roller:-

CAD model, meshing, material, boundary conditions are same as that of top roller.

The horizontal and vertical component of loads due to crushing are applied on roller shell as Uniformly Distributed Load (U.D.L).

Total vertical load= 4711.949 KN (down)

Total horizontal load= 3550.708 KN (right)

The Tangential (horizontal) and Radial (vertical) components of load due to torque are applied at pinion end of roller.

Tangential Component = 1059.1619 KN

Radial Component = 493.895 KN

Standard earth gravity (self weight is applied).

1) Results of static analysis for discharge roller:-

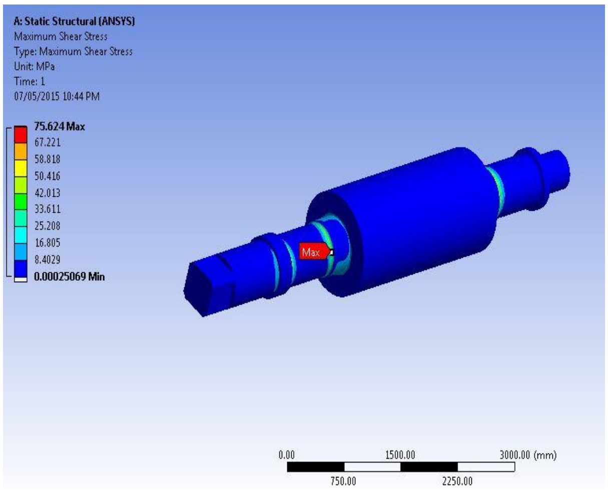

Fig. No. 10 Maximum Shear Stress in discharge roller

Maximum value of shear stress is 75.624 MPa which is at bearing position of discharge roller. Maximum value of shear stress is within limit so shaft is safe. Minimum value of shear stress is 2.5069e-4 MPa at bearing, shell and pinion end.

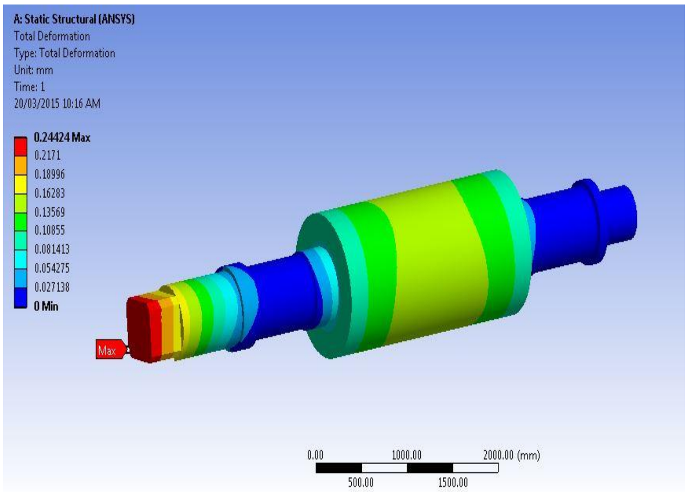

Fig.No.11- Total deformation of Discharge roller

Maximum value of total deformation is 0.24424 mm at pinion end of discharge roller.

C. Static Analysis of Feed Roller:-

CAD model, meshing, material, boundary conditions are same as that of top roller.

The horizontal and vertical component of loads due to crushing are applied on roller shell as Uniformly Distributed Load (U.D.L).

Total vertical load= 2252.668 KN (down)

Total horizontal load= 1577.335 KN (left)

The Tangential (horizontal) and Radial (vertical) components of load due to torque are applied at pinion end of roller

Tangential Component = 453.9269 KN

Radial Component = 211.6695 KN

Standard earth gravity (self weight is applied).

ISSN: 2278-0181
Vol. 4 Issue 05, May-2015

1) Results of static analysis for Feed roller:-

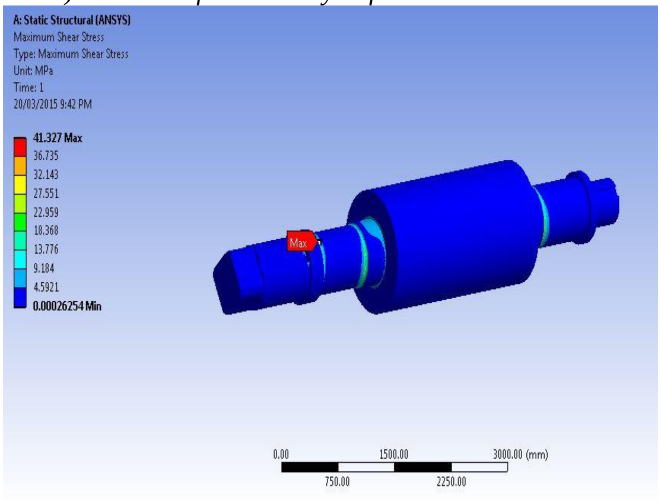

Fig. No.12 Maximum Shear Stress in Feed roller

Maximum value of shear stress is 41.327 MPa which is at bearing position of feed roller. Maximum value of shear stress is within limit so shaft is safe. Minimum value of shear stress is 2.6254e-4 MPa at bearing, shell and pinion end.

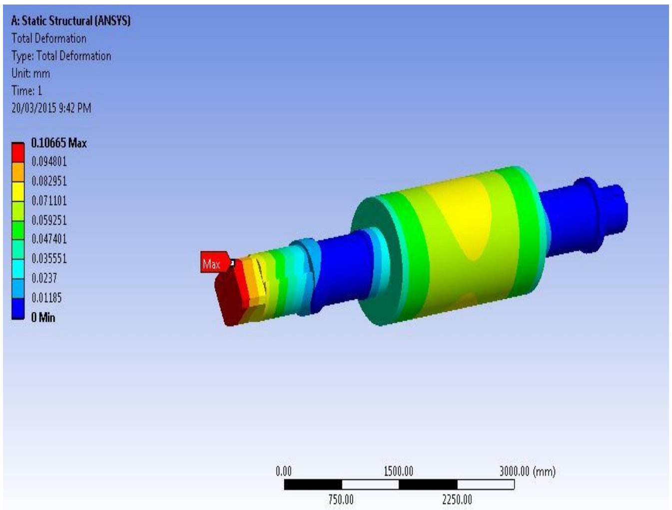

Fig.No.13- Total deformation of Feed roller

Maximum value of total deformation is 0.10665 mm at pinion end of Feed roller.

VI. COMPARISON OF RESULTS

Maximum shear stress value by theoretical and numerical are compared for validation of results.

Table No.-1 Comparison of results

Roller	Max. Shear stress (By Analytical) MPa	Max. Shear stress (By Software) MPa
Top Roller	101.306	101.29
Discharge Roller	75.3082	75.624
Feed Roller	42.8055	41.327

Maximum shear stress values by analytical calculations and by software are nearly same, so results are validated.

VII. RESULTS OF STATIC ANALYSIS OF ROLLERS WITH DIEFFERENT MATERIALS

Static analysis of all three rollers is done using different materials for analyzing the variation in maximum shear stress, total deformation and mass of the rollers. Results are shown in below tables-

Table No.- 2 Results of static analysis for top roller

Material	Max.shear stress (MPa)	Total defomation (mm)	Mass(Kg)
Forged Steel	101.29	0.35016	29283
Aluminium alloy	99.809	0.97192	10333
Copper alloy	99.249	0.62969	30962
Magnesium alloy	98.66	1.5218	6714.6
Titanium alloy	98.025	0.71331	17234

Table No.- 3 Results of static analysis for discharge roller

Material	Max.shear stress (MPa)	Total defomation (mm)	Mass(Kg)
Forged Steel	75.624	0.24424	29283
Aluminium alloy	72.246	0.67589	10333
Copper alloy	72.416	0.43918	30962
Magnesium alloy	70.296	1.0575	6714.6
Titanium alloy	69.859	0.4964	17234

Table No.- 4 Results of static analysis for Feed roller

Material	Max.shear stress (MPa)	Total defomation (mm)	Mass(Kg)
Forged Steel	41.327	0.10665	29283
Aluminium alloy	39.636	0.29133	10333
Copper alloy	39.799	0.19196	30926
Magnesium alloy	38.678	0.45471	6714.6
Titanium alloy	38.503	0.2149	17234

VIII. CONCLUSIONS

3-D modeling and analysis is done for top, feed and discharge roller both analytically and by software. Also static analysis is done for different materials. From the results it is concluded that-

1) Maximum shear stress value for top, feed and discharge roller is less than yield strength in shear of material so, all three shafts are safe.
2) As the value of max. Shear stress is very less than yield strength in shear of material, so there is scope for weight optimization.
3) Maximum shear stress values by analytical calculations and by software are nearly same, so results are validated.
4) Based on the total deformation and cost of raw materials, forged steel is the best among given materials.
5) As material is a changed value of max. Shear stress is nearly same.

ACKNOWLEDGMENT

I would like to express my deep sense of gratitude towards my co-guide Mr.Ankush Kadam (Vice President Design & Engg. SAISIDHA Sugar Equipment & Engg.) For his continuous encouragement and support and the valuable feedback he provided throughout the project.

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