To identify best material for roller shafts using static structural analysis

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Abstract: **In tropical regions, Sugar is produced sugarcane. The sugar industry contains Milling section, Boiler section, Juice filtration section and Purification section etc. But to increase total crushing capacity per day (TCD), the milling section takes vital role in sugar industry. The aim of sugar industry is to extract maximum amount of juice from sugarcane. In milling section, the processed sugarcane is fed in between three roller shaft from different arrangement and each roller shaft assembly there are different loads applied on each part roller shafts. When load between all rollers varies then there is chance to bending, hence we need analysing the roller shaft condition. The different stress or forces applied to different sections of roller shaft with the help of finite element methods and we can calculate the maximum shear stress and total deformation on roller shaft using ANSYS WORKBENCH software. We were selecting titanium alloy materials for roller shaft to analyse the variation in results and we say the roller shafts is safe to use in sugar industry and titanium alloy is best material for this roller shafts.**

***Keywords*: Three Rollers, Static Analysis, Maximum shear stress, Total Deformation, ANSYS WORKBENCH.**

1. Introduction

In India, sugarcane is the basic raw material for the sugar production. Near about 5.2 million hectare of sugarcane cultivated in 2020 at India and sugar production is largely concentrated in the state of Uttar Pradesh, Maharashtra, Karnataka, Tamilnadu, and some other pockets. Sugar is produced from sugarcane juice and waste bagasse is used for power generation for boiler and remaining raw bagasse is mostly used for manufacturing of paper or cardboard generation of electricity ethanol and pellets. The extracted juice is refined and filtered to form sugar. But sometimes sugar produced from sliced of sugar beets, the juice sugar beet is purified through a series of milk of lime and different CO_2 processes. The filtered juice is evaporated and sugar is crystallized from it.

In the Sugar Industry, a cane transfer from one position to other with the help of cane carrier, which can transfer processed sugarcane to preparatory devices such as cutter, leveller, and shredder, the processed sugarcane is cut into small pieces and fed into the milling roller to extract the juice. The remaining waste product of this sugarcane is called bagasse and this bagasse is used as fuel for steam generation in the boilers. This steam is used to rotate the turbine and this turbine given power to rollers.

The main motive of sugar industry is to extract maximum amount of juice form sugarcane. Different Types of roller mills arrangement are used in different industries i.e. two high roller mill, three high roller mill, four high roller mill and Six high roller mill

Usually three roller mills setup is used nowadays to extract of juice form sugarcane in sugar industry. It consists of three rollers that are top, feed and discharge rollers. The processed Sugarcane is being fed in between top, feed and discharge rollers as well as the trash plate is placed between these rollers. The roller shaft is divided into eleven sections that is roller, two supports on both side of roller also there are four sections i.e. section 1 and section 2 of shaft on both side of roller and two key arrangements is shown in Fig. 3. The section1 and section2 is two main part of roller shafts where bearing and pinion placed around them. This roller arranged in isosceles triangle arrangement is shown in Fig. 2. A fourth press-roller i.e. toothed roller pressure feeder is used in industry, which will be used to fed sugarcane to top and feed rollers to facilitate extraction. The top roller had share about 50% of total hydraulic load, 15% hydraulic load is shared by feed roller and 35% is shared by discharge roller. These all rollers have high coefficient of friction and these rollers rotated with the help of steam turbine.

In three roller mill, three rollers are arranged in isosceles triangle arrangement which help to removing sucrose up to 96-97 % max. These three rollers are carried on heavy shafts running in their bearing and it is placed in casing, which is bolted on a bed plate. These heavy cast steel frame known as mill housing and bearings are supported in sugar mill head stocks in which rollers rotate at various speeds. Where hydraulic pressure is applied to these bearing on vertically downward to the top roller and it exerts constant pressure on it. The pressure developed during milling depends on the layer of bagasse which will be placed in between these rollers.

The rollers are arranged in an isosceles triangle with a top angle is 86^0. The feed and discharge rollers had at an angle of 44^0 & 50^0 respectively from the vertical below the top roller. The cane goes 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 direction of rotation of top and feed or discharge rollers is opposite. The A.C. power is given to the top roller for crushing of sugarcane. The top roller is important part in mill, the drive torque, hydraulic load and crushing load act on the top roller. These forces are give rise to shearing, bending, twisting and compressive stresses. The overall 50% of mill torque acted on top roller.

The Sugar industry should simple structural arrangement with maximum production capability, which help to make profit to industry. With the help of finite element method we calculate maximum shear stress and total deformation with the help of different materials for roller shafts and to check which material is suitable for roller shaft to improve roller shafts conditions.

2. Methodology

The methodology to be worked out to achieve best design for roller shafts as follows:

2.1. Analytical Calculations:

Because of nature of continuous live loads acting on roller shafts, it makes roller as statically indeterminate structure. Hence need to calculate maximum shear stress and total deformation analytically to observe roller shafts conditions.

2.2. FEA Analysis:

Modelling will be continued with structural analysis software's. In this analysis pre-processing is done using the applying material property, load and boundary condition to rollers. Using ANSYS WORKBENCH software, we will get stress and displacement results.

2.3. Result Evaluation:

ANSYS WORKBENCH results for maximum shear stress and total deformation value is compared by using different material for roller shafts to find out which material is best for roller shafts.

3. Theoretical static structural analysis

3.1. *Theoretical analysis of Top roller*:

In milling section, Top roller rotates with the help of steam turbine at speed of 6 rpm. Near about 50% of milling torque applied on top roller. While analysing problem load is divided into two components that is horizontal load and vertical load and top roller is made up of forged steel material.

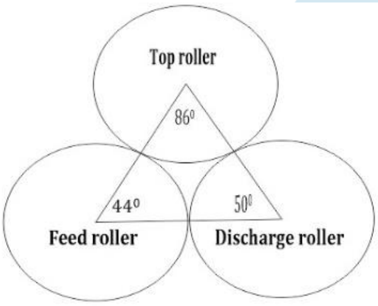

Fig. 2. Conventional 3 roller mill arrangement

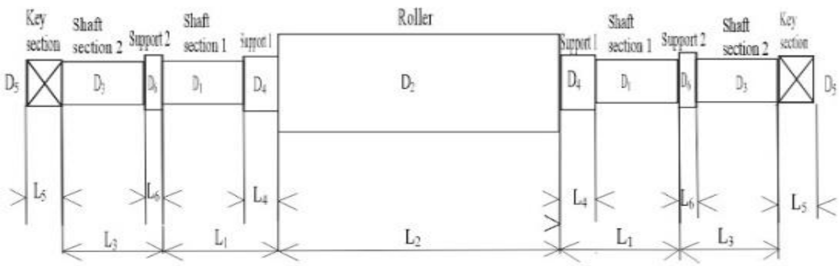

Fig. 3. Side view of roller mill shaft

Rollers Shaft inputs data are as follows:

D_1, D_2, D_3, D_4, D_5, D_6 is diameter of shaft section 1, roller, shaft section 2, support 1, key section and support 2.

L_1, L_2, L_3, L_4, L_5, L_6 is length of shaft section1, roller, shaft section 2, support 1, key section and support 2.

D_1= 305 mm, D_2 = 762mm, D_3 = 340 mm, D_4= 370.5mm, D_5=200mm, D_6= 370.5mm

L_1=550mm, L_2=1524mm, L_3 =400mm and L_4 =190mm, L_5=200mm, L_6=130mm

Pitch circle diameter of crown pinion= d =741 mm

$L=2L_1+L_2$=2624 mm,

The weight of top, feed and discharge roller shafts is 8 ton which is acting downwards.

Power (p) =450kw, Roller Speed (n) = 5.8 rpm,

Diameter of hydraulic Ram= d_h = 320 mm, Oil pressure= P_{oil} = 1.72 Kg/mm^2

Total hydraulic load acting on the top roller on each bearing= F_h= Area of piston* P_{oil} = 1383.3KN

4. Finite element analysis using ANSYS WORKBENCH

The Finite Element Analysis (FEA) is a numerical procedure for analysis of complicated shapes. In this method the geometrical model is divided into small area called as elements. Each element is connected by some nodes. Each node is having some degrees of freedom. Based on the number 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.

Finite Element Analysis or FEA is the simulation of a physical phenomenon using a numerical mathematical technique referred to as the Finite Element Method. This process is at the core of mechanical engineering, and a variety of other disciplines. It also is one of the key principles used in the development of simulation software. Engineers can use these FEM to reduce the number of physical prototypes and run virtual experiments to optimize their designs.

Analyzing most of these phenomena can be done using partial differential equations, but in complex situations where multiple highly variable equations are needed, Finite Element Analysis is the leading mathematical technique and with the help of FEA stimulation software we find required results.

4.1. *Finite element 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.

5.1.1. Mesh Generation of top roller:

Meshing is performed in the ANSYS WORKBENCH software. Meshing is the process of converting the model into number of discrete parts called as element. It is higher order 3-D, 10-node tetrahedral structural solid as shown in figure.

The element has quadratic displacement behaviour and is well suited to modelling irregular meshes. The element is defined by 10 nodes having three degree of freedom at each node translations in the nodal X, Y, and Z direction. Fine meshing size is 10 mm and near about 334760 elements and 497480 nodes are obtained after meshing.

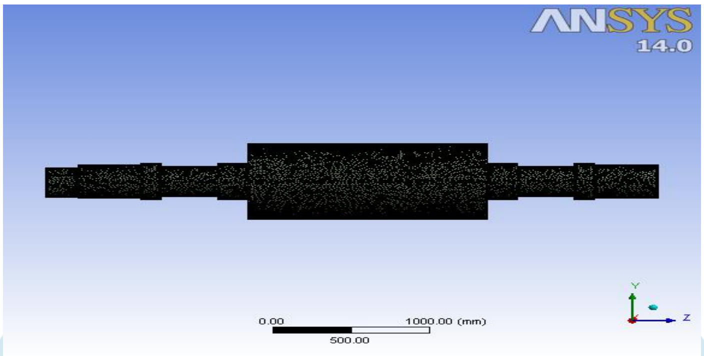

Fig. 10. Meshing of Model of roller for top roller

5.1.2. Loading and Boundary conditions:

For Top roller, Drive torque = $\frac{p*9.55}{n}$= 740.9 KNm

Out of the total torque 50% of torque is taken by top roller=Torque on the top roller= τ_{top} =370.4KNm

Force acting on horizontal component= F_{ph} = $\frac{Drive\ torque\ on\ top\ roller}{d/2}$ = 1000 KN

Force acting on vertical component= F_{pv} = $\tau_{top}\cos\Theta$ = 266.155 KN

The roller shaft is simply supported so all degrees of freedom of roller are fixed at the bearing position and 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= 1360.32 KN (up), Total horizontal load= 661.7 KN (left)

The Horizontal and vertical components of load due to power transmission are applied at pinion end of roller,

Tangential Component = 1000 KN, Radial Component = 266.155 KN

Hydraulic load is applied at the each bearing position is 1383.3KN and Standard earth gravity is applied.

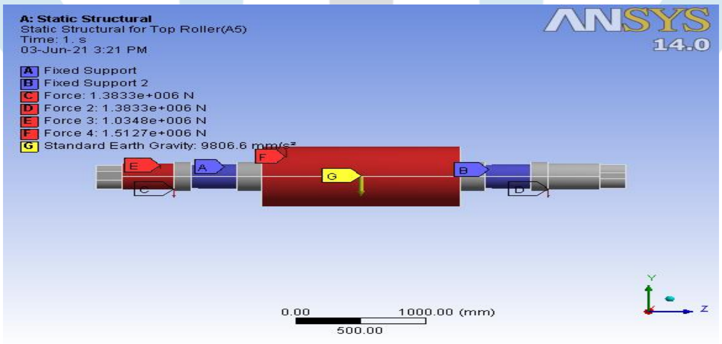

Fig. 11. Loading and boundary condition details

5.1.3. Top Rollers static analysis:

Maximum shear stress and total deformation for top roller using ANSYS WORKBENCH are Shown in below figures

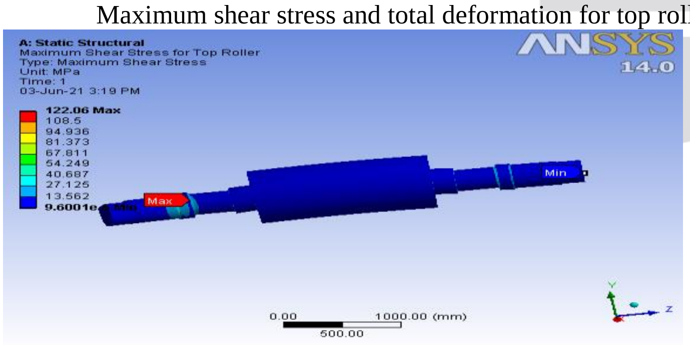

Fig. 12. Maximum Shear Stress in top roller for forged steel

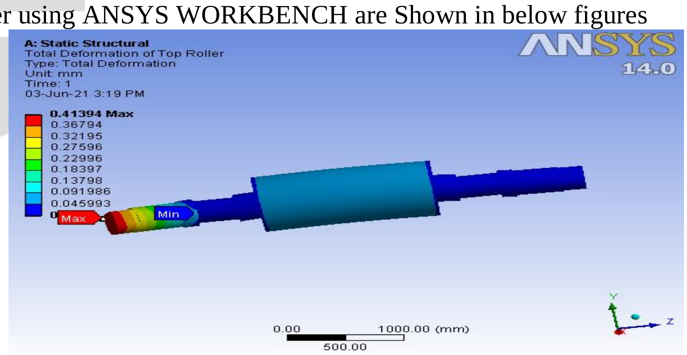

Fig. 13. Total deformation of top roller for forged steel

Maximum shear stress is 122.08 MPa which is at bearing position of top roller. Maximum value of shear stress is within limit, so shaft is safe to use. The minimum value of shear stress is 9.60e-5 MPa at bearing, shell and pinion on other end and Maximum value of total deformation is 0.4139 mm at the pinion end of top roller and Minimum value of deformation is 0 mm which is at bearing position.

4.2. *Finite element analysis of Feed Roller*:

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

5.2.1. Mesh Generation of feed roller: Mesh generating pattern is similar like top roller.

5.2.2. Material used of feed roller:

Forged steel material used for feed roller and materials property is similar like top roller.

5.2.3. Loading and Boundary conditions:

Boundary condition:

Geometry similar like top roller and discharge roller is made up of forged steel. The loads acting on the roller are due to sugarcane lies in between top and discharge roller.

Out of the total torque, 35% of torque is taken by Discharge roller= $\tau_{discharge}$= 260KNm

Force acting on horizontal component= F_{ph}= 700KN

Force acting on vertical component=F_{pv}=199.17KN

The total vertical load acting on the roller=1505.5 KN

The total horizontal load acting on the roller= 1465.09 KN

Standard earth gravity (self-weight is applied)

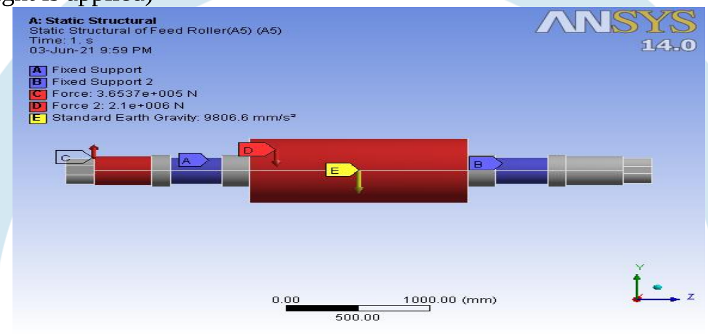

Fig. 14. Loading and boundary condition details for Feed Roller

5.2.4. Results of static analysis for Feed roller:

Maximum shear stress and Total deformation for feed roller using ANSYS WORKBENCH and results shown in below

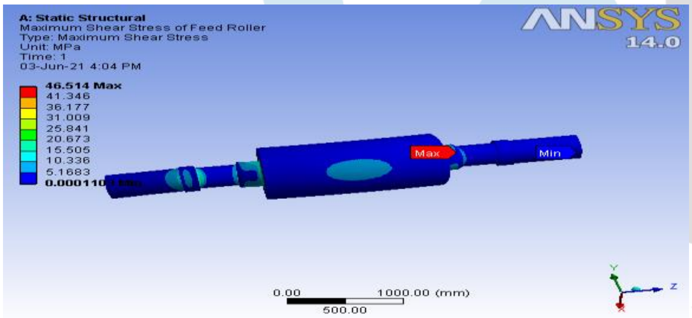

Fig. 15. Maximum Shear Stress in feed roller for forged steel

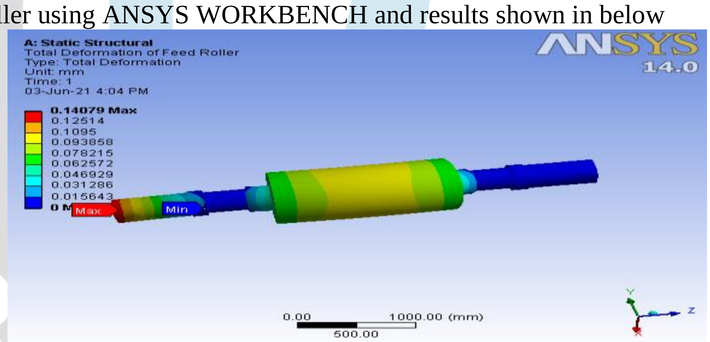

Fig. 16. Total deformation of Feed roller for forged steel

Maximum value of shear stress is 46.51 MPa which is at bearing position of feed roller. Maximum value of shear stress is within limit so shaft is safe. The minimum value of shear stress is 0.0001103 MPa at bearing, shell and pinion end and Maximum value of total deformation is 0.14079 m at the pinion end of feed roller and minimum value of deformation is 0 mm which is at bearing position.

4.3. *Finite element Analysis of Discharge Roller*:

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

5.3.1. Mesh Generation: Mesh generating pattern is similar like top roller.

5.3.2. Material used of Discharge roller: Forged steel material used for feed roller and materials property is same as top roller.

5.3.3. Loading and Boundary conditions:

Geometry similar like top roller and discharge roller is made up of forged steel. The loads acting on the roller are due to sugarcane lies in between top and discharge roller.

Out of the total torque, 35% of torque is taken by Discharge roller= $\tau_{discharge}$= 260KNm

Force acting on horizontal component= F_{ph}= 700KN

Force acting on vertical component=F_{pv}=199.17KN

The total vertical load acting on the roller=1505.5 KN

The total horizontal load acting on the roller= 1465.09 KN

Standard earth gravity (self-weight is applied)

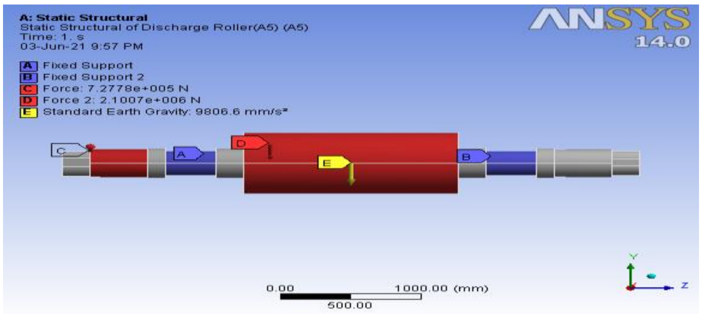

Fig. 17. Loading and boundary condition details for Discharge Roller

5.3.4. Results of static analysis for Discharge roller:

Maximum shear stress and Total deformation for discharge roller using ANSYS WORKBENCH and results shown in below

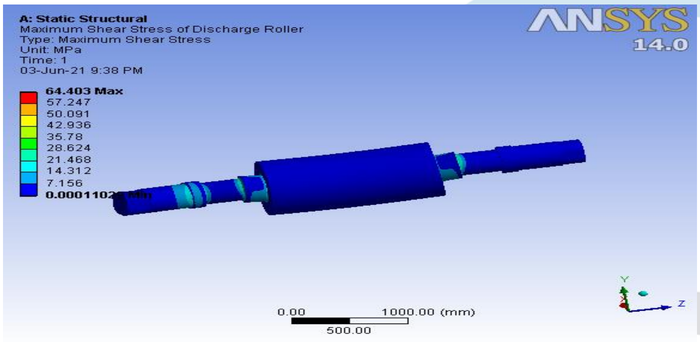

Fig. 18. Maximum Shear Stress in discharge roller for forged steel

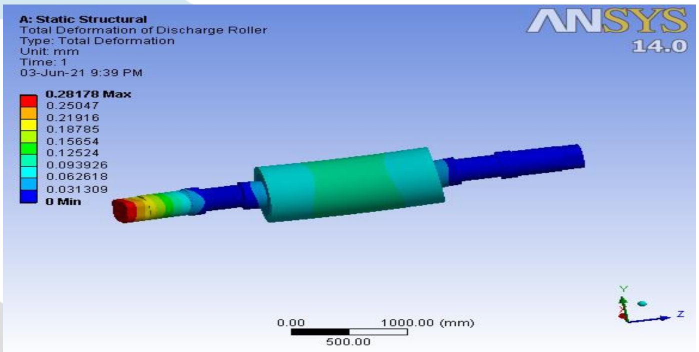

Fig. 19. Total deformation of Discharge roller for forged steel

Maximum value of shear stress is 64.403 MPa which is at bearing position of feed roller. Maximum value of shear stress is within limit so shaft is safe. The minimum value of shear stress is 0.00011 MPa at bearing, shell and pinion end and Maximum value of total deformation is 0.028178 m at the pinion end of feed roller and minimum value of deformation is 0 mm which is at bearing position.

5. Using different material for roller shafts to identify variation in results

The rollers are actually made of forged steel but to analysing its effect, we will use different materials for roller shaft to get best results. In sugar industry, load acted in between three rollers are dynamical and this load varies due to load of crushing sugarcane. If roller condition is safe for static analysis but it is not same for dynamical analysis. Hence we need to get best results for roller shafts to avoid this effect on roller shafts. Hence we need to check maximum shear stress and total deformation using different material for roller shafts and this is done using ANSYS WORKBENCH is shown below:

Table 2. Maximum shear stress and deformation for top roller shaft.

Top Roller Shaft						
Material	*Aluminum alloy*	*Grey cast iron*	*Copper alloy*	*Magnesium alloy*	*Titanium alloy*	*Stainless steel*
Maximum Shear Stress, MPa	119.69	123.73	119.18	118.35	117.8	121.28
Total Deformation, mm	1.1591	0.75415	0.7477	1.8209	0.85218	0.42835

Table 3. Maximum shear stress and deformation for feed roller shaft.

Feed Roller Shaft						
Material	*Aluminum alloy*	*Grey cast iron*	*Copper alloy*	*Magnesium alloy*	*Titanium alloy*	*Stainless steel*
Maximum Shear Stress, MPa	44.927	47.472	45.042	44.169	44.134	46.083
Total Deformation, mm	0.39715	0.25677	0.25414	0.6248	0.2911	0.14571

Table 4. Maximum shear stress and deformation for discharge roller shaft.

Discharge Roller Shaft						
Material	*Aluminum alloy*	*Grey cast iron*	*Copper alloy*	*Magnesium alloy*	*Titanium alloy*	*Stainless steel*
Maximum Shear Stress, MPa	64.306	64.67	64.209	64.104	63.987	64.474
Total Deformation, mm	0.79187	0.5147	0.51012	1.2443	0.5819	0.29228

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. While analyzing, the best material to be used for roller shaft is Titanium alloy.

6. Result and discussion

The main motive of sugar industry is to extract maximum amount of juice from sugarcane, When load between all rollers varies then there is chance to bend the roller shaft assembly, to avoid this bending we will analyze the roller shaft condition. To avoid this failure, we will analyze roller shaft conditions. When different stress or forces applied to different sections of roller shaft with the help of Finite element methods and we can find maximum shear stress and total deformation on roller shaft using ANSYS WORKBENCH software.

While analyzing, the maximum shear stress for calculated and software (Using ANSYS WORKBENCH) values for roller shaft using forged steel material are nearly equal.

Table 6. Result of static analysis or roller shaft using forged steel material.

Roller	**Maximum Shear Stress, MPa**		**Total Deformation, mm**
	Calculated	*Software Based*	*Software Based*
Top Roller	121.941	122.06	0.41394
Feed Roller	45.814	46.514	0.14079
Discharge Roller	63.386	64.403	0.28178

Static analysis of all three rollers is done using different materials for analyzing the variation the maximum shear stress and total deformation.

Table 7. Maximum shear stress for different material.

Material	**Maximum shear stress, MPa**		
	Top roller shaft	*Feed roller shaft*	*Discharge roller shaft*
Aluminium alloy	119.6	44.927	64.306
Grey Cast iron	123.7	47.472	64.67
Copper Alloy	119.1	45.042	64.209
Magnesium Alloy	118.3	44.169	64.104
Titanium Alloy	117.8	44.134	63.987
Stainless Steel	121.2	46.083	64.474

Table 8. Total Deformation for different material.

Material	**Total Deformation, mm**		
	Top roller shaft	*Feed roller shaft*	*Discharge roller shaft*
Aluminium alloy	1.1591	0.39715	0.79187
Grey Cast iron	0.7541	0.25677	0.5147
Copper Alloy	0.7477	0.2541	0.51012
Magnesium Alloy	1.8209	0.6248	1.2443
Titanium Alloy	0.8521	0.2911	0.5819
Stainless Steel	0.4283	0.1457	0.29228

While analyzing we says, The maximum shear stress and total deformation result for all three roller shaft for titanium alloy is lesser as compare to other material and it is useful for sugar industry to improve lifespan and performance of roller shafts. Hence titanium alloy is the best material to be used for roller shaft

7. Conclusion

Using static structural analysis, Maximum shear stress for top, feed and discharge roller is less than yield strength and analytical calculations and software based results are nearly equal, so results are validated for forged steel material so roller shafts is safe to used. Based on the maximum shear stress, total deformation and cost of raw materials, titanium alloy material is the best among given materials, and using this material we optimize structure of roller shaft

References

[1] Sheetal, Kumar R. Rethinking on growth mechanism of Indian sugar industry. Journal of Asia Business Studies 2019;13:412–432

[2] Sawhney DM. The Indian sugar industry. Zuckerindustrie.Sugar.Industry 2002;127:186–194.

[3] Solomon S. Sugarcane production and development of sugar industry in India. Sugar Tech 2016;18:588–602.

[4] Randhawa G, Gupta A. Present status and challenges of sugar industry in Punjab. Prajnan 2014;42:375–391.

[5] Varshney D, Mandade P, Shastri Y. Multi-objective optimization of sugarcane bagasse utilization in an Indian sugar mill. Sustainable Production and Consumption 2019;18:96-114.

[6] Uygan D, Cetin O, Alveroglu V, Sofuoglu A. Improvement of water saving and economic productivity based on quotation with sugar content of sugar beet using linear move sprinklet irrigation. Agricultural Water Management 2021;255:106989.

[7] Mubarak MU, Zahir M, Ahmad S, Wakeel A. Sugar beet yield and industrial sugar contents improved by potassium fertilization under scarce and adequate moisture conditions. Journal of Integrative Agriculture 2016;15:2620-2626.
[8] Prada M, Godinho CA, Garrido MV, Rodrigues DL, Coelho I, Lopes D. A qualitative study about college students attitudes, knowledge and perceptions regarding sugar intake. Appetite 2021;159:105059.
[12] Kakade A, Sudeep Ingole S, Bhatt DV, Menghani J. Tribological behavior of sugar mill roller shaft in laboratory simulated condition. Wear 2013;302:1568–1572.
[13] Pater Z., Tomczak J, Bulzak T. Problems of forming stepped axles and shafts in a 3-roller skew rolling mill. Journal of Materials Research and Technology 2020;9:10434-10446.
[14] Hou Y, Wang X. Measurement of load distribution in a cylindrical roller bearing with an instrumented housing: Finite element validation and experimental study. Tribology International 2021;155:106785.
[15] kakade A, Ingole S, Bhatt DV, Menghani JV. Tribochemistry of Sugar Mill Roller Shaft Materials, Material todays: proceedings 2017;4:434-441.
[16] Dalvi SD, Chandrababu HD, Satav S, Vijoykumar. Failure analysis of a carbon steel roller shaft of continuous pad steam machine. Engineering failure analysis 2017;9:118-128.
[17] E.E.T. ELSawy, M.R. EL-Hebeary, I.S.E. El Mahallawi. Effect of manganese, silicon and chromium additions on microstructure and wear characteristics of grey cast iron for sugar industries applications. Wear 2017;390–391:113–124.
[18] V.B. Bhandari, "Design of machine element, Tata McGraw Hill publications".
[19] E.Hugot, "Handbook of cane sugar engineering third edition", Elsevier science publishers, 1986.
[20] ANSYS workbench help.