Static Structural Analysis of Conventional Sugar Mill Roller Shaft for Ø40”x 80” Milling Plant

Santosh Y. Salunkhe
Department of Sugar Engineering
Walchandnagar Industries Ltd, Walchandnagar, Maharashtra, India.

Abstract- Three roller sugar mill is the most vital part of sugar industry & sugar roller mill is used for to separate the sucrose-containing juice from the cane i.e. extraction of juice consist of three rollers namely Top, Feed and Discharge. The extraction of juice in a mill is achieved by squeezing prepared cane between two rolls. FEA 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. The 3D Geometrical model is created using modeling software Pro-E. The static structural analysis of roller shaft is carried out using analysis software ANSYS Workbench. The results for maximum shear stress on the Top, Feed, and Discharge roller are calculated analytically and compared with the results from software. Static structural analysis of all three rollers is done using forged steel materials for analyzing the results.

Keywords – Sugar mill rollers, Static analysis, Max. Stress, ANSYS Workbench.

I. INTRODUCTION

The main objective of milling is to separate the sucrose containing juice from the cane. The prepared cane comes under three roller mills between top roller and feed roller of these roller’s rotates the prepared cane is squeezed. Once by which juice is extracted and collected in a trough the bagasse obtained after squeezing the juice is guided by means of trash plate to the opening between top roller and discharge roller and bagasse is squeezed once again in set of three roller mills. In three roller mill, three rollers are arranged in triangular pattern for removing sucrose up to 96-97 % max. The arrangement of rollers in three roller mill is as follows.

Fig. No.1 Assembly of three Roller Conventional sugar mill.
Usually, three roller mills are used for extraction of juice which consists of top, feed and discharge rollers. Sugar cane is being fed into top and feed rollers which further passes through top and discharge roller along with trash plate. This trash plate is having a downside that 25% of total hydraulic load is shared by this trash plate in overcoming friction and remaining 75% only the useful one. i.e. 25% hydraulic load is shared by feed roller and 50% is shared by discharge roller. Crushing rolls are designed with high coefficient of friction and very low rotational speed up to 4 to 5 rpm.

The rollers are arranged in an isosceles triangle with a top angle of 73°. The feed and discharge rollers are placed at an angle of 36° & 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 A.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.

II. THEORETICAL APPROACH

In conventional sugar mill, hydraulic load distribution is as per the following & refers fig.no.2.

a) Hydraulic Load applied on Top Roller is 100% for juice extraction.
b) Trash-plate absorbs maximum 25% of hydraulic load applied on top roller.
c) For juice extraction purpose maximum 75% of hydraulic load is used.
   (i.e. 25% of hydraulic load on feed Roller & remaining 50% of hydraulic load on discharge roller)

![Fig. No.2 Conventional Roller mill hydraulic load details.](image)

The loads acting on the roller are due to crushing of sugar cane between top, feed, discharge roller & load due to the torque. 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. For safety and long life of top, feed & discharge roller shaft diameter is considered as Ø570 mm for Ø40”x80” conventional sugar mill. But due to heavy hydraulic load on shaft it is necessary to check and calculate the required size of roller shaft & bending stresses.
Fig. No. 3. Top, Feed & Discharge roller shaft.

The various terms relating to sugar mill roller used as per the following:-

a) Shaft- A round forged steel bar on which cast iron shell is fitted.
b) Roller journal – The polished surface at both ends of shell- seat on which bearing are fitted.
c) Pintle end- The shaft ends having a key-way for sprocket- fitting is known as Pintle end.
d) Square end- The shafts end on which pinion and coupling are fitted.
e) Shell – A hollow cast-iron round which is shrunk - fitted on the shaft.

A) Analytical calculation for stresses on the Top, Feed & Discharge Roller for Ø40”x 80” conventional sugar mill.

The roller shaft is an important item of sugar mill equipment and being subject to heavy loading it must be made to high standard of quality.

1) Shaft Material- 45C8 (C - 0.35-0.45 %, Mn - 0.60 to 0.90%), as per the standard IS: 1570-1979.
2) ρ - Density- 7850 Kg/m³.
3) E - Modulus of Elasticity = 210 GPa.
4) v - Poisson’s ratio = 0.31
5) Syt - yield strength in tension - 380 Mpa.
6) Sut - ultimate tensile strength - 710Mpa.
7) Se - Endurance limit = 23 Kg/mm²
8) Kf - Stress concentration factor =1.6
9) Maximum wt. of roller shaft with shell = 19.5 Ton.

The force diagram is shown in following figures.

Input data:-

L3=650 mm
L2=1275 mm
L1=1925 mm
D- Roller Dia. OD. = Ø1080 mm
d- Shaft dia. at centre. = Ø570 mm
HP- Mill power for drive = 670HP.
N-rpm of roller shaft = 4.0 rpm
Wh- Total hydraulic load = 760 Ton.

1) Calculation of Top, Feed & Discharge Roller shaft diameter (d):-

B.M. on shaft = [(760x 1000) x 385] / 8
= 36575000 Kg-cm

Torque transmitted = HP x 4500
2 x Π x N
Therefore, the diameter of shaft can be calculated as per the formula given below
\[
\frac{(\pi d^3)}{32} = \frac{1}{7600} \times \left\{ \left(\frac{7600}{3850} \times 1.6 \times 36575000\right)^2 + \left[11996300\right]^2 \right\}^{1/2}
\]
\[
= 1.315 \times 10^4 \times \left\{ \left(1.334 \times 10^{16} + 1.4391 \times 10^{10}\right) \right\}^{1/2}
\]
\[
d^3 = \frac{(15269.81 \times 32)}{\pi}
\]
\[
d = 537.78 \text{ mm} \quad \approx \quad 538 \text{ mm}
\]
As per the theoretical calculation of Top, Feed & Discharge roller actual shaft size is required Ø538mm, for Ø40”x 80” conventional sugar mill. Therefore for safety & long life of shaft, the considered shaft size diameter Ø570 mm is corrected.

2) Calculate the Maximum stresses on centre of shaft & Bearing support Journal.

a) Bending moment on roller shaft (B.M.):-

B.M. on roller shaft = \( (380 \times 10^3) \times 1925 - (380 \times 10^3) \times (1275 / 2) \)
\[
= 489250000 \text{ Kgf.mm.}
\]

Moment of Inertia (MI) \[
= \frac{\pi \times (1080)^4}{64}
\]
\[
= 6.678 \times 10^{10} \text{ mm}^4.
\]

Therefore, maximum Bending stress (\( \sigma \) stress) on roller shaft:-
\[
\sigma \text{ stress} = \frac{489250000 \times 1080}{6.678 \times 10^{10} \times 2}
\]
\[
= 3.956 \text{ kgf.} / \text{mm}^2
\]

b) Bending moment on Bearing supported journal (B.M.):-

B.M. @ bearing supported shaft = \( (380 \times 10^3) \times 650 \)
\[
= 247000000 \text{ Kgf.mm.}
\]

Moment of Inertia (MI) \[
= \frac{\pi \times (570)^4}{64}
\]
\[
= 5181664874 \text{ mm}^4.
\]

Therefore, maximum Bending stress (\( \sigma \) stress) at Bearing support journal
\[
\sigma \text{ stress} = \frac{247000000 \times 285}{5181664874}
\]
\[
= 13.58 \text{ Kgf.} / \text{mm}^2
\]
Hence, the shaft is safe but to check the stress concentration effect ($K_t$) at bending on bearing support journal.

*The Stress concentration effects ($K_t$):*

Mathematical analysis and experimental measurement show that in a bearing loaded member changes in the section, distributions of stress occur in which the peak stress reaches much larger magnitudes than does the average stress over the section. This increase in peak stress near sharp corners other changes in section is called *stress concentration.*

The stress concentration effect at bending (refer page- 280, Table 6-1, 7b).

$$K_t = C_1 + C_2 (2h/D) + C_3 (2h/D)^2 + C_4 (2h/D)^3$$

Where,

\[ C_1 = 0.594 + 2.958 \sqrt{2h} - 0.520 \times 2h \]
\[ C_2 = 0.422 - 10.545 \sqrt{2h} + 2.692 \times 2h \]
\[ C_3 = 0.501 + 14.375 \sqrt{2h} - 4.486 \times 2h \]
\[ C_4 = - 0.613 - 6.573 \sqrt{2h} + 2.177 \times 2h \]

Then,

$$2h = D - d$$
$$D=1080 \text{mm}$$
$$d = 570 \text{ mm}$$
$$2h = 510 \text{ mm}$$

\[ C_1 = 3.36 \]
\[ C_2 = - 8.28 \]
\[ C_3 = 11.22 \]
\[ C_4 = - 5.34 \]

$$K_t = 3.36 - 8.28 (2h / D) + 11.22 (2h / D)^2 - 5.34 (2h / D)^3$$

$$= 3.36 - 8.28 (510 /1080) + 11.22 (510 /1080)^2 - 5.342 (510 /1080)^3$$

$$= 1.38 \text{ mm}.$$  

Therefore, Maximum shear stress = $K_t \times 13.58$

$$= 1.38 \times 13.54$$

$$= 18.740 \text{ Kgf/mm}^2 = 187.40 \text{ Mpa}$$

### III. THREE DIMENSIONAL MODEL

A three dimensional model of crushing roller is made by using modeling software Pro-E. Pro-E is the most powerful and widely used software of its kind in the world. All three rollers i.e. top feed and discharge roller having same dimensions and geometry.
IV. FINITE ELEMENT TECHNIQUE

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 number of nodes, degrees of freedom, material properties element stiffness matrix is generated for each element. Stiffness matrices 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 Rollers:-

Static analysis of top, feed & discharge roller is done for observing maximum stresses, deformation and von-Mises stresses 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 software of ANSYS, workbench.

1) Meshing of roller shaft:-

The Pro-E model in converted in .stp format and imported in ANSYS workbench. Meshing is performed in the same software. Meshing is the process of converting the model in to number of discrete parts called as element. The element has quadratic displacement behavior and is well suited to modeling 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 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 89039 elements and 132367 nodes are obtained after meshing.
2) **Boundary & Loading conditions:-**

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

Loading detail: - The vertical component of loads due to crushing are applied on roller shell as uniformly distributed load. Total hydraulic load of shell is 760 ton. The Hydraulic load is applied at the bearing position which is 380 ton each side.
3) Results of static analysis for top, feed & discharge roller:

a) Maximum shear stress is calculated as static analysis results shown in below figures-

![Image of maximum shear stress](image1.png)

Fig. No.7. Maximum shear stress in top, feed & discharge roller.

Maximum value of shear stress is 188.66 MPa which is at bearing position of roller journal. Maximum value of Stress is within limit so shaft is safe. Minimum value of shear stress is 1.0896e-4 MPa at bearing and pinion end.

b) Total deformation is calculated as static analysis results shown in below figures-

![Image of total deformation](image2.png)
Maximum value of total deformation is 0.21291 mm at the shell of roller shaft, which is within limit and minimum value of deformation is 0 mm which is at bearing position.

c) von-Mises stress is calculated as static analysis results shown in below figures-

Maximum value of von-Mises equivalent stress is 287.83 Mpa. on roller shaft, which is within limit and minimum value of von-Mises stress is 2.2274e-4 Mpa.

V. RESULTS OF STATIC ANALYSIS OF CONVENTIONAL SUGAR MILL ROLLER SHAFT

Top, Feed & Discharge mill roller shaft are analyzed theoretically as well as with the help of ANSYS, workbench software for its safe working by checking various parameters within limit. Theoretical & Numerical values also compared for validation of results, please refer table no.1

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Rollers</th>
<th>Material</th>
<th>Max. Shear stress (by Analytical)</th>
<th>Max. Shear stress (by ANSYS Software)</th>
<th>Total mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Top, Feed &amp; Discharge</td>
<td>Forged steel-45C8</td>
<td>187.40 Mpa</td>
<td>188.66 Mpa</td>
<td>19479 Kgs.</td>
</tr>
</tbody>
</table>

Therefore, the maximum shear stress values by analytical calculations and by ANSYS software are nearly same.

VI. CONCLUSION
The static structural analysis & 3D model is done for conventional sugar mill top, feed & discharge roller both analytically and by ANSYS software.

Due to the above results it is concluded that:-

- Maximum shear stress value of top, feed & discharge rollers is less than yield strength, therefore all three roller are safe.
- The maximum shear stress values by analytical calculations and by software are nearly same, therefore above all results are validated.

REFERENCES