MODELLING OF A SUGAR CANE MILL

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ABSTRACT

A Sugar mill is an inherent part of most of the sugarcane juice extraction systems like milling tandem, diffuser or even low-pressure extraction system. Hence it is very imperative to have detailed analysis of forces acting in sugar cane mill head stock. In sugar machinery the most intrinsic equipment is sugar mill and particularly the mill head stock or cheek. The nature of forces acting during cane crushing is a very complex phenomenon and needs analysis of mechanical parameters like force, torque, power, speed and the eccentricity.

The purpose of this study is to present and analyze mechanical parameters to have exact idea about loading at various locations of mill head stock. Eccentricity in mills is a term, which is confused by mill engineers. This study expresses the importance of eccentricity to be provided in the mill. Each of these parameter is useful in designing of mechanical components and in achieving an optimistic design of the mill to deliver smooth functioning during operation. Optimum design means the maximum extraction of juice with least power consumption.

Russel and Murry presented experimental equations for estimating forces and torque in a pair of rolls as a function of the characteristics of sugarcane, dimension of rollers and mill settings. Hugot (1986) calculated mill power based on the assumption that the vertical load on the turn plate is 25% of the vertical load on the roller.

The force loading based on the principles and equations applied in this analysis have been used for design of 42" x 84" mill size head stocks and these are operating satisfactorily in India.

Keywords: Sugar mill head stock loading, mathematical modelling, eccentricity in mill, analysis of forces in sugar mill.

INTRODUCTION

A model is an idealization of a real-world situation that aids in the analysis of a problem. A model may be either descriptive or prescriptive. A descriptive model enables us to understand a real-world system or phenomenon like cutaway model of an aircraft gas turbine, pump etc. Such a model serves as a device for communicating ideas and information. However it does not help us to predict the behavior of the system. A prescriptive model is used primarily in engineering design because it helps us both understand and predict the performance of the system. Mathematical modelling is adopted many times to analyze a complex engineering system.

SYSTEM ENGINEERING

Engineers use models for thinking, communication, prediction, control for many engineering problems to deal with complex situations. Engineering systems frequently are very complex and needs breaking the system into simpler components and modeling each of them. In doing that allowance must be made for the interaction of the components with each other. Techniques for treating large and complex system by isolating the critical components and modeling them are at the heart of the growing discipline called System Engineering.
Once the chief components of the system have been identified the next step is to list the
important input and output parameters those describe and determine the behavior of the system.
The various parameters are related to each other by appropriate mathematical laws. The relations
transform the input parameters to output through algebraic or integral equations. The solution of
these equations is the last step in the modelling process.

METHODS

The construction of sugar cane mill is a complex assembly containing feed roller, top roller,
discharge roller, force feed roller, trash plate, crown pinions etc. All these components are then
housed in head stock assembly. Hence while carrying out the analysis of the whole system, it is
broken into an isolated or independent components as a free body. Interactions of parameters thus
are established to formulate the mathematical laws with the help of algebraic equations. These
equations with known inputs are then solved to get the final solution.

The main independent components of the system are:

A) Feed roller with its crown wheel.
B) Discharge roller with its crown wheel.
C) Bearing and trash plate reactions.
D) Extension to fourth roller application.

SYMBOLS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Power input to one mill</td>
<td>Watt</td>
</tr>
<tr>
<td>N</td>
<td>Mill speed</td>
<td>RPM</td>
</tr>
<tr>
<td>N₁</td>
<td>Under Feed Roller (UFR) Speed</td>
<td>RPM</td>
</tr>
<tr>
<td>A</td>
<td>Crown wheel pitch circle diameter</td>
<td>Meter</td>
</tr>
<tr>
<td>D</td>
<td>Top Roller journal diameter</td>
<td>Meter</td>
</tr>
<tr>
<td>α</td>
<td>Apex mill angle</td>
<td>Degree</td>
</tr>
<tr>
<td>γ</td>
<td>Trashplate contact angle with feed roller</td>
<td>Degree</td>
</tr>
<tr>
<td>ᵄ</td>
<td>Crown wheel pressure angle</td>
<td>Degrees</td>
</tr>
<tr>
<td>Rc</td>
<td>Normal force transmission ratio</td>
<td></td>
</tr>
<tr>
<td>Rp</td>
<td>Normal torque transmission ratio</td>
<td></td>
</tr>
<tr>
<td>Fₘ</td>
<td>Hydraulic load (FH₁ + FH₂)</td>
<td>Newton</td>
</tr>
<tr>
<td>e</td>
<td>Hydraulic load eccentricity</td>
<td>Meter</td>
</tr>
<tr>
<td>f</td>
<td>Friction dissipation factor</td>
<td></td>
</tr>
<tr>
<td>β</td>
<td>Trashplate inclination</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Length of roller between bearing centres</td>
<td>Meter</td>
</tr>
<tr>
<td>K</td>
<td>Crown wheel distance from bearing</td>
<td>Meter</td>
</tr>
<tr>
<td>C</td>
<td>Length of roller shell</td>
<td>Meter</td>
</tr>
<tr>
<td>b</td>
<td>Fraction of normal force taken up by trashplate</td>
<td></td>
</tr>
<tr>
<td>q</td>
<td>Sprocket distance from off-side bearing centre</td>
<td>Meter</td>
</tr>
<tr>
<td>δ</td>
<td>Fraction of driving torque transmitted to UFR</td>
<td></td>
</tr>
<tr>
<td>λ</td>
<td>Angle of action of normal force exerted by UFR on top roller</td>
<td>Degrees</td>
</tr>
</tbody>
</table>
Fig 3: Directions of torques acting at top roller and crown wheel

The Fig-1 shows the three-roller mill configuration containing top roller, feed roller and discharge roller. Rollers are placed in such a way that the angle between axial planes of feed and discharge roller is $\alpha$. The rollers are mounted in mill cheeks and are located at bearing centres of 'L'. The length 'C' is responsible to transmit torque to the cane crushing. The crown pinion mounted on top roller drive side transmits torque to the feed and discharge roller through mating gear and mounted at a distance 'K' from drive side bearing.

The fig-3 shows the directions of torques acting at top roller and crown wheel.

$\rightarrow$  
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$\rightarrow$  
$\rightarrow$  
$\rightarrow$  
$\rightarrow$  

$\rightarrow$  
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$\rightarrow$  
$\rightarrow$  
$\rightarrow$  
$\rightarrow$  

During cane crushing to satisfy the condition of uniform motion of roller without angular acceleration the vectorial sum should be zero.

\[
T_d + T_{fp} + T_{fc} + T_{dp} + T_{dc} + T_{tr} = 0
\]

\[
T_d = T_{fp} + T_{fc} + T_{dp} + T_{dc} + T_{tr}
\]

(1)
FEED ROLLER WITH ITS CROWN WHEEL.

The power is transmitted to the feed roller at a particular speed by developing specific torques. The position and direction of transmission of these torques is indicated in fig-4.

Fig. 4 and 5: Position and directions of torques

\[ T_{fp} = \text{Magnitude of driving torque exerted by top roller crown wheel due to power transmission.} \]

\[ T_{fc} = \text{Magnitude of opposing torque exerted at roller due to cane crushing.} \]

For smooth power transmission without angular motion the condition shall be

\[ T_{fp} - T_{fc} = 0 \]

\[ T_{fp} = T_{fc} \] (2)

DISCHARGE ROLLER WITH ITS CROWN WHEEL:

TRANSMISSION OF TORQUE

On the similar lines as in case of feed roller with its crown wheel, following expression is valid. (Refer Fig: 5)

\[ T_{dp} - T_{dc} = 0 \]

\[ T_{dp} = T_{dc} \] (3)

Where

\[ T_{dp} : \text{Magnitude of driving torque exerted by the top crown wheel due to power transmission} \]

\[ T_{dc} : \text{Magnitude of opposing torque exerted at roller due to cane crushing.} \]

Using equation (2) & (3), equation (1) becomes

\[ T_d = 2T_{fp} + 2T_{dp} + T_{tr} \]
Percentage of total torque developed is transmitted to the trashplate. Generally 10% torque is dissipated at trash plate. Hence it can be expressed as function of total torque as

\[ T_{tr} = f T_d \]

'f' being the friction dissipation factor and in most cases it is about 10%.

\[ T_{fp} + T_{dp} = \frac{1}{2} (T_d - T_{tr}) \]

Using

\[ T_{tr} = f T_d \]

\[ T_{fp} + T_{dp} = \frac{1}{2} T_d (1-f) \]

(4)

The torque transmission ratio is generally

\[ R_p = \frac{T_{dp}}{T_{fp}} \]

\[ T_{fp} (1 + R_p) = \frac{1}{2} T_d (1-f) \]

\[ T_{fp} = \frac{1}{2} \times \frac{T_d}{(1 + R_p) (1-f)} \]

(5)

**EVALUATION OF FORCES CAUSING THE TORQUE:**

The fig-3 shows the torque transmission diagram for the top roller and its crown wheel assembly.

Let the forces \( F_{fp}, F_{fc}, F_{dp}, F_{dc}, F_{tr} \) corresponds to the torques \( T_{fp}, T_{fc}, T_{dp}, T_{dc}, T_{tr} \) respectively.

\( F_{fp} = F_{fc} \) & \( F_{dp} = F_{dc} \), since the tangential forces are assumed to be acting at the same radial distance.

\[ F_{fp} = F_{fc} = \frac{T_{fp}}{A/2} \]

\[ F_{dp} = F_{dc} = \frac{T_{dp}}{A/2} \]

& \( F_{tr} = \frac{T_{tr}}{A/2} \)

(6)

Here it is assumed that the point of action of torque lies on PCD, which is not true for cane crushing but this assumption may be relaxed and exact forces are taken for a more accurate analysis.

The power is transmitted at a particular angular velocity \( \omega \).
Power Input \( P = T_d \omega \)

\[ T_d = \frac{P}{\omega} \]

\[ T_d = \frac{60P}{2\pi N} \]  \hspace{1cm} (7)

Using equations (5), (6) & (7), the tangential forces can be expressed as

\[ F_{fp} = F_{fc} = \frac{60P}{2\pi N} \times \frac{2}{A} (1 - f) \times \frac{1}{(1 + R_p)} \]  \hspace{1cm} (9)

\[ F_{dp} = F_{dc} = \frac{60P}{2\pi N} \times \frac{2}{A} R_p(1 - f) \times \frac{1}{(1 + R_p)} \]  \hspace{1cm} (10)

\[ F_{Tr} = \frac{60P}{2\pi N} \times f \times \frac{2}{A} \]  \hspace{1cm} (11)

**EVALUATION OF NORMAL FORCES:**

**Power transmission at discharge crown wheel:**

The resultant force acts in the direction of line of action, which is defined by the pressure angle of crown wheel \( \delta \).

Fig-6 shows, horizontal and vertical components of the resultant \( F_{rdp} \) on the discharge crown where as \( F_{rdp} \cos (\alpha/2 - \delta) \) and \( F_{rdp} \sin (\alpha/2 - \delta) \).

This resultant \( F_{rdp} \) can be expressed as a function of \( F_{dp} \) & pressure angle \( \delta \).

\[ \Rightarrow F_{dp} \]  \hspace{1cm} (12)

\[ \therefore F_{rdp} = \frac{F_{dp}}{\cos \delta} \]  \hspace{1cm} (13)
Fig. 6: Forces acting on crown wheel of rollers: discharge roller

\[
\vec{F}_{rdp} = \frac{\vec{F}_{dp}}{\cos \delta} \cos (\alpha/2 - \delta) \hat{i} + \frac{\vec{F}_{dp}}{\cos \delta} \sin (\alpha/2 - \delta) \hat{j}
\]

Similarly at feed roller crown wheel

\[
\vec{F}_{rfp} = \frac{\vec{F}_{fp}}{\cos \delta} \cos (\alpha/2 + \delta) \hat{i} + \frac{\vec{F}_{fp}}{\cos \delta} \sin (\alpha/2 + \delta) \hat{j}
\]

CANE CRUSHING

Fig. 7
The hydraulic load is applied through top cap and ram by maintaining a pressure of ‘P’

The hydraulic load \( F_n = F_{h1} + F_{h2} \)

Let ‘b’ be the fraction of hydraulic load taken up by the trash plate. Usually the value of ‘b’ is taken as 25% of the normal force.

\[
\therefore b F_n = F_{trc} \cos \beta 
\]

(11)

The normal force transmission ratio \( R_c \) be defined as

\[
R_c = \frac{F_{dc} \cdot \cos \alpha/2}{F_{fnc} \cdot \cos \alpha/2} = \frac{F_{dc}}{F_{fnc}} 
\]

(12)

FORCES ACTING OTHER THAN REACTION FORCES:

Top Roller
Side View

Fig – 8

Top View

Fig – 9
FREE BODY DIAGRAM FOR TOP ROLLER WITH ITS CROWN WHEEL: (FBD)

VCC- Vertical component of the resultant of normal & tangential forces caused by crushing.

VCP- Vertical component of the resultant of normal & tangential forces caused by power transmission.

HCC- Horizontal component of the resultant of normal & tangential forces caused by crushing

HCP- Horizontal component of the resultant of normal & tangential forces caused by power transmission

Taking $\Sigma F_y$ & $\Sigma F_x$ we can write

$$\Sigma F_y = + (F_{fp} + F_{fc}) \sin \alpha/2 + (F_{fnc} + F_{fnp}) \cos \alpha/2 + F_{trc} \cos \beta + F_{trc} \sin \beta$$

$$+ (F_{dc} + F_{dnc}) \cos \alpha/2 - (F_{dp} + F_{dcp}) \sin \alpha/2 + R_{1v} + R_{2v} = 0$$

$$\Sigma F_x = - (F_{fp} + F_{fc}) \cos \alpha/2 + (F_{fnc} + F_{fnp}) \sin \alpha/2 + F_{trc} \sin \beta - F_{tr} \sin \beta$$

$$- (F_{dc} + F_{dnc}) \sin \alpha/2 - (F_{dp} + F_{dcp}) \cos \alpha/2 + R_{1h} + R_{2h} = 0$$

Similarly taking $\Sigma M_y$ & $\Sigma M_x$,

$$\Sigma M_x = + F_{fc} \sin \alpha/2. L/2 + F_{fp} \sin \alpha/2 (L+K) + F_{fnc} \cos \alpha/2. L/2 + F_{fnp} \cos \alpha/2 (L+K)$$

$$+ F_{trc} \cos \beta. L/2 + F_{trc} \sin \beta. L/2 + F_{dnc} \cos \alpha/2. L/2 + F_{dnp} \cos \alpha/2 (L+K)$$

$$- F_{dc} \sin \alpha/2. L/2 - F_{dp} \sin \alpha/2. (L+K) + R_{2v}. L = 0$$

$$\Sigma M_y = - F_{fp} \cos \alpha/2 (L+K) - F_{fc} \cos \alpha/2. L/2 + F_{fnc} \sin \alpha/2 L/2 + F_{fnp} \sin \alpha/2 (L+K)$$

$$+ F_{trc} \sin \beta. L/2 - F_{trc} \cos \beta. L/2 - F_{dnc} \sin \alpha/2. L/2 - F_{dnp} \sin \alpha/2 (L+K)$$

$$- F_{dp} \cos \alpha/2 (L+K) - F_{dc} \cos \alpha/2. L/2 + R_{1h}. L = 0$$

211
\( (L+K) \left[ -Ffp \cos \alpha/2 + Ffnp \sin \alpha/2 - Fdp \cos \alpha/2 \right] + L/2 \left[ -Ffc \cos \alpha/2 + Ffnc \sin \alpha/2 + Ftr \sin \beta - Ftr \cos \beta - Fdnc \sin \alpha/2 - Fdc \cos \alpha/2 \right] + R_{h}L = 0 \)

\[ R_{h} = \frac{1}{L} \left\{ (L+K) \left[ (Ffp + Fdp) \cos \alpha/2 - (Ffnp + Fdnp) \sin \alpha/2 \right] - L/2 \left[ (Fdc - Ffc) \cos \alpha/2 + (Ffnc - Fdnc) \sin \alpha/2 + Ftr \sin \beta - Ftr \cos \beta \right] \right\} \]  \( \cdots \) (13)

From equation of \( \Sigma M_x = 0 \), We can write

\( (L + K) \left[ Ffp \sin \alpha/2 + Ffnp \cos \alpha/2 + Fdnp \cos \alpha/2 - Fdp \sin \alpha/2 \right] + \frac{L/2}{i} \left[ Ffc \sin \alpha/2 + Ffnc \cos \alpha/2 + Ftr \cos \beta + Ftr \sin \beta + Fdnc \cos \alpha/2 - Fdc \sin \alpha/2 \right] \)

\[ + R_{2v} \frac{L}{i} - F_{tt2L} = 0 \]

\[ R_{2v} = \frac{1}{i} \left\{ (L+K) \left[ (Fdp - Ffp) \sin \alpha/2 - (Ffnp + Fdnp) \cos \alpha/2 \right] - \frac{L/2}{i} \left[ (Ffc - Fdc) \sin \alpha/2 + (Ffnc + Fdnc) \cos \alpha/2 + Ftr \cos \beta + Ftr \sin \beta \right] \right\} \]  \( \cdots \) (14)

Similarly

\[ R_{1v} = + \left[ Fdp + Fdc - Ffp - Ffc \right] \sin \alpha/2 - \left[ Ffnc + Ffnp + Fdnc + Fdnp \right] \cos \alpha/2 - Ftr \cos \beta - Ftr \sin \beta - R_{2v} \]  \( \cdots \) (15)

\[ R_{1h} = (Ffp + Ffc + Fdp + Fdc) \cos \alpha/2 + (Fdnc + Fdnp - Ffnc - Ffnp) \sin \alpha/2 - Ftr \sin \beta + Ftr \cos \beta - R_{h} \]  \( \cdots \) (16)

Using above equations the reactions at the bearings can be evaluated

Actually the bearing reactions \( R_{1v} \) & \( R_{2v} \) are known as they are the hydraulic loading values the unknowns are only \( Ffnc \) & \( Fdnc \) which are in the ratio of \( 1:Rc \)

**Figures 11 to 13**: Free body diagram for feed roller with crown wheel

**Feed Roller**

**Side View**

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*FEn-3* 212
Top View

\[ \Sigma F_y = -(F_{fnp} + F_{fnc}) \cos \alpha/2 + R_{f,v} + R_{f,w} = 0 \]

\[ \Sigma F_x = -(F_{fnp} + F_{fnc}) \sin \alpha/2 + R_{f,h} + R_{f,w} = 0 \]

Let us consider the bending moment about the bearing - 1

\[ \therefore \Sigma M_x = -F_{fnp} \cos \alpha/2 (L + K) - F_{fnc} \cos \alpha/2. L/2 - F_{fp} \sin \alpha/2 (L + K) \]

\[ \text{about bearing } -1 \] + F_{fc} \sin \alpha/2. L/2 + R_{f,2V}. L = 0

\[ \therefore R_{f,v} = 1/L \{(L+K) [F_{fnp} \cos \alpha/2 + F_{fp} \sin \mu/2] + L/2 [F_{fnc} \cos \alpha/2 - F_{fc} \sin \alpha/2]\} \] ---- (17)

Similarly taking

\[ \Sigma M_y = -F_{fnp} \sin \alpha/2 (L+K) - F_{fnc} \sin \alpha/2. L/2 + F_{fp} \cos \alpha/2 (L+K) \]

\[ \text{about bearing } -1 \] - F_{fc} \cos \alpha/2. L/2 + R_{f,h}. L = 0

\[ \therefore R_{f,h} = 1/L \{(L+K) (F_{fnp} \sin \alpha/2 - F_{fp} \cos \alpha/2) + L/2 (F_{fnc} \sin \alpha/2 + F_{fc} \cos \alpha/2)\} \] ---- (18)
\[ R_{f,V} = (F_{np} + F_{nc}) \cos \alpha/2 - R_{f,V} \]  
\[ R_{f,h} = (F_{np} + F_{nc}) \sin \alpha/2 - R_{f,h} \]  

**DISCHARGE ROLLER**

**SIDE VIEW**

**TOP VIEW**

**FBD**

**Fig - 14**

**Fig - 15**

**Fig - 16**
Figures 14 to 16: Free body diagram for discharge roller with crown wheel

Taking $\Sigma F_y$ & $\Sigma F_x$ as

$\Sigma F_y = - (F_{dp} + F_{dc}) \cos \alpha/2 + R_{dv} + R_{dV} = 0$

$\Sigma F_x = (F_{dp} + F_{dc}) \sin \alpha/2 + R_{dh} + R_{dh} = 0$

Taking bending moment $\Sigma M_x$ & $\Sigma M_y$ about bearing - 1

$\Sigma M_x = - F_{dp} \cos \alpha/2 (L+K) - F_{dc} \cos \alpha/2. L/2 + F_{dp} \sin \alpha/2 (L + K)$

(about bearing -1) $- F_{dc} \sin \alpha/2. L/2 + R_{dv} \times L = 0$

$\therefore R_{dv} = \frac{1}{L} \{(L+K) \left[ F_{dp} \cos \alpha/2 - F_{dc} \sin \alpha/2 \right] + \frac{L}{2} \left[ F_{dc} \cos \alpha/2 + F_{dp} \sin \alpha/2 \right] \}$ ---- (21)

Similarly,

$\Sigma M_y = + F_{dp} \sin \alpha/2 (L+K) + F_{dc} \sin \alpha/2. L/2 + F_{dp} \cos \alpha/2 (L + K)$

(about bearing -1) $- F_{dc} \cos \alpha/2. L/2 + R_{dh} \times L = 0$

$\therefore R_{dh} = \frac{1}{L} \{(L+K) \left[ -F_{dp} \sin \alpha/2 - F_{dp} \cos \alpha/2 \right] - \frac{L}{2} \left[ F_{dc} \sin \alpha/2 - F_{dc} \cos \alpha/2 \right] \}$ ---- (22)

Also on similar lines $R_{dV}$ & $R_{dh}$ can be evaluated.

$R_{dv} = (F_{dp} + F_{dc}) \cos \alpha/2 - R_{dv}$ ---- (23)

$R_{dh} = -(F_{dp} + F_{dc}) \sin \alpha/2 - R_{dh}$ ---- (24)

**BEARING AND TRASH PLATE REACTIONS:**

**Top Bearing**

![F.B.D](image-url)

Fig.17: Free Body Diagram of the Top Bearing
Reaction force from head stock \( = R_h \)

The forces \( F_h \) & \( R_V \) separated at a distance of \( C \). These forces being equal in magnitude & acting parallel in opposite direction will form a couple, which has to be balanced by \( R_c \) from the head stock operating at a distance ‘\( m \)’.

\[ \tan \theta = \frac{R_h}{R_V} \]

\[ \therefore \text{ Couple produced by } R_c = \text{ Couple produced by } F_h \text{ & } R_V \]

\[ \therefore R_c x m = F_h (D/2 \sin \theta - e) \text{ clockwise} \]

\[ R_c = \frac{F_h (D/2 \sin \theta - e)}{m} \] \hspace{1cm} (25)

Similarly for Bearing 2

\[ R_c = \frac{F_h (D/2 \sin \theta - e)}{m} \] \hspace{1cm} (26)

**BOTTOM ROLLER BEARINGS**

**Feed Roller Bearing – 1**

The force \( F_r_h \) is transferred to the left side cap and \( F_r_v \) to the head stock.

**Feed Roller Bearing – 2**

The force \( F_r_h \) is transferred to the left side cap and \( F_r_v \) to the head stock.

**Discharge Roller bearing – 1**

\( R_d_h \) is taken up by the right side cap and \( R_d_v \) by the head stock

**Discharge Roller bearing – 2**

\( R_d_h \) is taken up by the right side cap and \( R_d_v \) by the head stock
TRASH - PLATE

Refer figure 20 where vertical component of force resulting from $F_{tr}$ & $F_{trc}$, $(F_{trc} \cos \beta + F_{tr} \sin \beta)$ is acting down-wards. This reaction has to be balanced by reaction from the headstock. The horizontal component $(F_{trc} \sin \beta - F_{tr} \cos \beta)$ is acting leftward and has to be balanced by reaction from the headstock.

EXTENTION OF FOURTH (UFR) ROLLER APPLICATION:

TORQUE TRANSMISSION

Refer figure 21 where $UFR$ & $F$, $(UFR \cos \gamma + F \sin \gamma)$ is acting down-wards. This reaction has to be balanced by reaction from the headstock. The horizontal component $(UFR \sin \gamma - F \cos \gamma)$ is acting leftward and has to be balanced by reaction from the headstock.
To

Fig. 23 & Fig. 24: Torque Transmission

\[ T_d = T_{ac} + T_{ap} + T_{fp} + T_{fc} + T_{tr} + T_{dp} + T_{dc} \]

Where \( S = \) fraction of driving torque transmitted to the fourth roller crown wheel.

\[ T_d = 29.T_d + 2(1 + R_p) T_{fp} + fT_d \]

\[ T_{fp} = \frac{T_d (1 - 29 - f)}{2 (1 + R_p)} \]

EVALUATION OF FORCES CAUSING THE TORQUE:

The forces \( F_{fpn}, F_{fcn}, F_{dp}, F_{dc}, F_{tr} \), corresponding to the respective torques, can be evaluated as before using the equation (6)
\[
\begin{align*}
\therefore F_{fp} &= F_{f} = \frac{60 \times P}{2 \pi \, N_1} \times \frac{(1 - 2 \theta - f)}{2 \,(1 + R_p)} A
\\
F_{dp} &= F_{dc} = \frac{60 \, P}{2 \pi \, N_1} \times \frac{R_p \,(1 - 2\theta - f)}{2 \,(1 + R_p)} A
\\
F_{tr} &= \frac{60 \, P}{2 \pi \, N_1} \times f \times A
\\
F_{ap} &= F_{ac} = \frac{60 \, P}{2 \pi \, N_1} \times \theta \times A
\end{align*}
\]

EVALUATION OF NORMAL FORCES

Fig. 25

Fig. 26

\[F_{dnp} \& F_{np}\] will remain same as before

\[
\begin{align*}
\therefore F_{dnp} &= F_{dp} \tan \delta \\
F_{fnp} &= F_{fp} \tan \delta \\
F_{anp} &= F_{ap} \tan \delta
\end{align*}
\]  \hspace{1cm} (31)
FORCES ON TOP ROLLER AND ITS CROWN WHEEL:

SIDE VIEW

![Side View Diagram]

Fig-27

TOP VIEW

![Top View Diagram]

Fig - 28

FBD

![Free Body Diagram]

Fig - 27 to 29: Forces on Fourth Roller

Taking $\Sigma F_x$, $\Sigma F_y$, $\Sigma M_x$ & $\Sigma M_y$ we can write

$$\Sigma F_y = (F_{ap} + F_{ac}) \cos \lambda + (F_{an} + F_{anp}) \sin \lambda + (F_{fp} + F_{fc}) \sin \alpha/2$$

$$+ (F_{fnc} + F_{fnp}) \cos \alpha/2 + F_{trc} \cos \beta + F_{tr} \sin \beta + (F_{dn} + F_{dnp}) \cos \alpha/2$$

$$- (F_{dp} + F_{de}) \sin \alpha/2 - F_{H_2} = 0$$
The forces analysis for feed roller with its crown wheel and discharge roller with its crown wheel remains exactly as before.

The foregoing analysis based on mathematical modelling express the importance of eccentricity, pressure angle of crown pinion and the mill apex angle. All these parameters are basically in the
hands of mill designer. The eccentricity is necessary and must be at an optimum value so as to just counter balance the effect of couple acting at the top roller bearing. If eccentricity provided is not accurate, it may call unnecessary couple acting on side liners of top roller bearings and may restrict smooth movements and free lifting of top roller. Also this will adversely effect the lubrication in top roller bearing sides and mill liners to operate under zone of restricted lubricant supply condition. Also it yields very important loading data of forces acting on headstock to design head-stock, side-cap, top cap and base of the headstock.

**HEAD - STOCK LOADING CALCULATIONS**

Consider the mill size of 42" x 84" having ram diameter of 420mm.

\[ \therefore \text{Hydraulic load} = \frac{\pi}{4} (D)^2 \times P(\text{hyd}) \]

\[ FH_1 = FH_2 = 3802.4 \text{ kN} \]

\[ \text{Power} = P = 900 \text{ HP} = 671400 \text{ W} \]

\[ f = 0.1 \quad Rp = 2.0 \]

\[ A = 1.080 \text{ m} \quad N = 3.64 \text{ rpm} \]

Using equations (6) & (8)

\[ \therefore \text{Ff}_p = \frac{60 \times P}{2nN} \times \frac{1}{2} \times (1 - f) \times \frac{x}{(1 + Rp) \times A} \]

Also

\[ \text{Ff}_p = 489.3 \text{ kN} \]

\[ \text{Fdp} = \text{Rp} \times \text{Ff}_p = 978.6 \text{ kN} \]

\[ \text{Ff}_np = \text{Ff}_p \tan \delta = 108.5 \text{ kN} \]

\[ \text{Fdp} = \text{Fdp} \tan \delta = 216.9 \text{ kN} \]

\[ \text{Fdc} = \text{Fdp} = 978.6 \text{ kN} \]

\[ \text{Ffc} = \text{Ff}_p = 489.3 \text{ kN} \]

\[ \frac{\text{Ffnc}}{\text{Fdnc}} = \frac{\text{Re}}{\text{A}} = 2 \]

\[ R_{v} = \frac{\text{FH}_1}{0.25 \times 3802.4} = \frac{\text{FH}_2}{965.3 \text{ kN}} \text{ using equation} \]

\[ \text{Ftrc} = \frac{b}{11} \times \frac{\text{FH}_1}{\cos \beta \times \cos 10^\circ} = 965.3 \text{ kN} \]

\[ \text{Ftr} = \frac{60 \times P}{2 \pi N} \times f \times \frac{2}{\Lambda} = \frac{60 \times 671400}{2 \pi \times 3.64} \times \frac{2}{0.1 \times 1.080} = 326.2 \text{ KN} \]
Substituting in equation (15), we get

\[ 3802.4 = [978.6 + 978.6 - 489.3 - 489.3] \sin (37.5^\circ) - [2 Fdnc + 108.5 + Fdnc + 216.9] \cos (37.5^\circ) - 965.3 \cos (10^\circ) - 326.2 \sin (10^\circ) - 3802.4 \]

\[ \therefore (3 Fdnc + 325.4) \cos (37.5^\circ) = -8016.44 \text{ kN} \]

\[ \therefore Fdnc = 3259.7 \text{ kN} \]
\[ Ffnc = 6519.4 \text{ kN} \]

Substituting these values in equation (13)

\[ R_{zh} = 1193.48 \text{ kN} \]

For 
\[ \text{Rc use equation (26)} \]

\[ R_{c} = \frac{F_{h}}{m} \frac{1}{D/2 \sin \theta_{z} - e} \]
\[ F_{h} = 3892.4 \text{ kN} \]
\[ m = 566 \text{ mm} = 0.566 \text{ m} \]
\[ D = 560 \text{ mm} = 0.56 \text{ m} \]
\[ \theta = \tan^{-1}\left(\frac{R_{zh}}{R_{zh}}\right) = \tan^{-1}\left(\frac{1193.48}{3802.4}\right) = 17.42^\circ \]
\[ e = \text{eccentricity} = 30 \text{ mm} = 0.03 \text{ m} \]

Using equation (26)

\[ R_{c} = 361.60 \text{ kN} \]

For \[ R_{fzh}, \text{ use equation (18)} \]

\[ R_{fzh} = 1568.0 \text{ kN} \]

For \[ R_{fzv}, \text{ use equation (17)} \]

\[ R_{fzv} = 2913.73 \text{ kN} \]

For \[ R_{dzh}, \text{ use equation (22)} \]

\[ R_{dzh} = 2032.57 \text{ kN} \]

For \[ R_{dzv}, \text{ use equation (21)} \]

\[ \therefore R_{dzv} = 1064.7 \text{ kN} \]

The reaction \[ Frc \cos \beta + Ftr \sin \beta \]

\[ = 965.3 \cos 10 + 326.2 \sin 10 \]

\[ = 1007.3 \text{ kN} \]
The results obtained are plotted separately (Refer fig 30).

Fig. 30 : Sugar Mill Head — Stock Loading Through Mathematical Modelling

CONCLUSION

Applied and fundamental analysis of torque, speed, point reactions due to power transmission gives clear idea of forces exerted on mill housing at side caps, hydraulic caps, foundation bolts, couple acting on liners. It also specifies the importance of provision of appropriate eccentricity. This approach leads to optimistic design of housing and accessories in sugar mills.

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MOEDLO DE UN INGENIO DE CAÑA DE AZÚCAR

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RESUMEN

El molino es una parte inherente de la mayoría de los sistemas de extracción de jugo de azúcar de caña, como por ejemplo un tren de molienda, un difusor o hasta un sistema de extracción a baja presión. De aquí que sea imperativo tener análisis detallado de las fuerzas que actúan en la vigen del molino. En maquinaria de azúcar, el equipo más intrínseco es el molino y particularmente la virgen del molino. La naturaleza de las fuerzas que actúan durante la trituración de la caña es un fenómeno muy complejo y necesita análisis de parámetros mecánicos como fuerza, torsión, potencia, velocidad y excentricidad.

El propósito de este estudio es presentar y analizar parámetros mecánicos para tener una idea exacta acerca de la carga en varias partes de la virgen del molino. Excentricidad en molinos es un término el cual es confundido por ingenieros de molienda. Este estudio expresa la importancia de excentricidad dada en un molino. Cada uno de estos parámetros es útil en diseño de componentes mecánicos y en el logro del diseño óptimo de molino para conseguir el funcionamiento fácil durante la operación. Diseño óptimo significa la máxima extracción de jugo con el menor consumo de energía.

Russi y Murry presentaron ecuaciones para estimar fuerzas y torques en un par de rodillos como una función de las características de la caña de azúcar, dimensión de rodillos y posición del molino. Hugot (1986) calculó, la potencia del molino basándose en la suposición que la carga vertical sobre el plato rotatorio es un 25% de la carga vertical sobre el rodillo.

La carga basada en los principios y ecuaciones aplicados en este análisis han sido utilizados para el diseño de virgen de molienda de 42” x 84” que está operando muy satisfactoriamente en India.

Palabras Claves : Virgen del molino, modelar matemáticamente, excentricidad en molino, análisis de fuerzas en el molino.
MODÉLAGE D’UN MOULIN DE LA CANNE À SUCRE

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RÉSUMÉ

Un moulin de sucre est une partie inhérente de la plupart des systèmes de l’extraction du jus de la canne à sucre comme tandem de métier de meunier, diffuseur ou même système de l’extraction de la pression bas alors que c’est très impératif d’avoir l’analyse détaillé de pouvoir qui agissent dans le réserve de la tête du moulin de la canne à sucre. Dans la machinerie du sucre le matériel le plus intrinsèque est moulin du sucre et en particulier la réserve de la tête du moulin ou joue. La nature de pouvoir qui agissent pendant que la canne écrase est un phénomène plus complexe comme analyse des besoins de paramètres mécaniques comme la pouvoir, moment de rotation, faire fonctionner, vitesse et l’excentricité.

Le but de cette étude est de présenter et analyser des paramètres mécaniques pour avoir l’idée exacte au sujet de chargement à plusieurs emplacements de réserve de la tête du moulin. L’excentricité dans les moulin est un terme qui est confondu par les ingénieurs du moulin. Cet étude donne l’importnace d’excentricité fourni dans le moulin. Le paramètre est utile dans dessin de composants mécaniques et dans accomplir le dessin optimiste du moulin pour délivrer le fonctionner lisse pendant l’opération. Les moyens du dessin optimums d’extraction maximale de jus avec consommation du pouvoir la plus bas.

Russel et Murry ont présenté des équations expérimentales pour estimer le pouvoir et momnet de rotation dans une paire de pouleaux comme une fonction du caractéristics de canne à sucre, dimension de rouleaux et cadres du moulin. Hugot (1986) le pouvoir du mou;in calculé est basé sur la supposition que la charge verticale sur la plaque du tour est 25% de la charge verticale sur le rouleau.

Le force charger basé sur les principes et équations appliquées dans cette analyse a été utilisé pour dessin de 42” x 84” réserves de la tête de la dimension du moulin et ceux-ci opèrent en Inde d’une manière satisfaisante.

Mot-clés: Sucre moulin tête réserve charger, Modelage mathématique, Excentricité