Design of a typical Autogenous Mill: Part-I
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**ABSTRACT**

An Autogenous Milling defined as used in this study, the term Autogenous milling means a process in which the size of the constituent pieces of a supply of rock is reduced in a tumbling mill purely by the interaction of the pieces, or by the interaction of the pieces with the mill shell, no other grinding medium being employed. The definition thus covers both 'run-of-mine' and 'pebble' milling, the only difference from the mathematical modeling viewpoint being that the feed to the first has a continuous, and the second a non-continuous, size distribution. This paper describes the detail design of a typical Autogenous mill.

Introduction

Over the past twenty or thirty years, mathematical modeling of ball and rod mills has been widely investigated, and reasonably satisfactory models are now available. The Autogenous mill has, however, received very little attention in this respect, and in view of the increasing importance of this type of mill, the Julius Kruttschnitt Mineral Research Centre in the Department of Mining and Metallurgical Engineering, University of Queensland, in 1970 commenced a programme of research into mathematical modeling of the Autogenous mill.

Special Characteristics of the Autogenous Mill

Autogenous milling differs fundamentally from non-Autogenous milling in two respects. (1) Size reduction occurs by two main modes, namely the detachment of material from the surface of larger particles (referred to as 'abrasion') on the one hand, and disintegration of smaller particles due to the propagation of crack networks through them (called 'crushing') on the other. Abrasion and crushing breakage overlap on the size scale. This contrasts with non-Autogenous milling, in which only crushing breakage, however caused, is regarded as significant. (2) The grinding parameters of the Autogenous mill load are not independent of the mill feed; the load is continually generated from the feed, and its parameters therefore depend directly on those of the feed. These two characteristics must be specifically included in the model of the Autogenous mill (George, 1947).

A special development is the Autogenous or semi-Autogenous mill. Autogenous mills operate without grinding bodies; instead, the coarser part of the ore simply grinds itself and the smaller fractions. To semi Autogenous mills (which have become widespread), 5 to 10 percent grinding bodies (usually metal spheres) are added. Autogenous and semi-Autogenous mills are designed for grinding or primary crushed ore, and are the most widely used in concentrators globally. Autogenous mills are so-called due to the self-grinding of the ore: a rotating drum throws larger rocks of ore in a cascading motion which causes impact breakage of larger rocks and compressive grinding of finer particles. It is similar in operation to a SAG mill as described below but does not use steel balls in the mill. Also known as ROM or "Run of Mine" grinding. Autogenous Mills operate, mechanically, similar to the ball mill. They differ in the media they use to break or grind the ore. Autogenous Mills use large particles of ore instead of steel or other balls for grinding media. Autogenous mills use large pieces of ore as grinding media. The grinding is facilitated in Autogenous mills by attrition with limited grinding by impact. For an ore to successfully grind autogenously, the ore must be competent, and it must break along grain boundaries at the desired product size. Another requirement is that the finer sizes should break easily and should be removed from the mill, otherwise, there will be a critical size buildup. Autogenous grinding has two advantages, (1) it reduces metal wear and (2) eliminates secondary and tertiary crushing stages. Thus it offers a savings in capital and operating costs. Autogenous mills are available for both wet and dry grinding. The diameter of Autogenous mills is normally two to three times the length. The ore charge is usually 25 to 35% of the mill volume. Autogenous mills have grate discharges to retain the coarse grinding media in the mill (Andrew et al., 2000).

Background

The Autogenous mill is designed for dry grinding of raw bath (cryolite) mixed with other materials as aluminium modules or sheets, iron scraps, papers, etc. The Raw bath, which is coming from the mill feed-belt conveyor, is provided with the mill spout feeder. The mill body is the driven unit of the driving pinion and ring gear. The raw bath is lifted during the rotation of the mill by the internal mill liners and it is then broken during free falling. As the size of the particle is reduced, the gas stream through the discharge trunion removes the ground product. It is then allowed to enter in process bag filter. The reduced size of bath is obtained by impact work and attrition work. A fan exhausts the air and it is fitted with motorised dampers. An air flow meter is located at stack inlet and it controls the position of this damper. It is required to maintain the air sweeping flow at a constant value corresponding to the size of bath particles to be exhausted from the mill.
The air drawn up by the fan then ensures 3 major functions such as 1) Reclaiming finished product from Autogenous mill, 2) Conveying ground bath up to the process bag filter 3) Making Autogenous Mill grinding process dust free, working under negative pressure. The Autogenous Mill is equipped with a lubrication unit consisting of a) One tank, b) One low-pressure motor pump unit and c) A set of accessories. The oil is pumped from the tank by a low-pressure motor pump unit and it feeds the mill bearings. The oil is filtered before reaching the bearing and cooled by an oil/air or oil/water exchanger. It is then distributed by flow regulating valves. The oil returns from the bearings to the lubrication unit by gravitational pressure. Based on the stated background and historical citation a typical Autogenous Mill has been designed and presented in this paper. Thus the objective of this research work was to design a Autogenous Mill for small and medium scale mill based on the available input parameters.

Materials and Methods:

The specifications for the design and developed Autogenous Mill are given below:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Autogenous Grinding Mill (Size: 3900x1450x50mm)</th>
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<tbody>
<tr>
<td>Type</td>
<td>Air Swept Discharge</td>
</tr>
<tr>
<td>Capacity</td>
<td>Rated- 20 TPH, Design- 30 TPH</td>
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<tr>
<td>Feed Material</td>
<td>Anode Bath for Aluminium Smelter</td>
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<tr>
<td>Bulk Density</td>
<td>1.8 – 2 T/Cu m</td>
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<tr>
<td>Desired Product Size</td>
<td>100% &lt; 5 mm, 95% &lt; 3 mm, 30% &lt; 74 microns</td>
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<tr>
<td>Gearing Ratio</td>
<td>9.16</td>
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<tr>
<td>Pinion speed</td>
<td>130 rpm</td>
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<tr>
<td>Material Characteristics</td>
<td>Very Abrasive</td>
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<tr>
<td>Auxiliary Systems</td>
<td>• Tramp Metal Butts Extractor with Feed Launder Movement Device and Dust collection Outlets • Access Doors • Main Driving Mechanism and Motor (150 kW-1500 rpm) • Inching Drive with Motor (3.7 kW- 1500 rpm) • Lubrication System</td>
</tr>
</tbody>
</table>
| Mill Shell | • 3900 mm dia inside liners  
| Mill length inside liners | 1250 mm |
| Mill Operating Speed | 16.37 rpm |
| Design Mill Charge | 45 % by volume maximum |

Fig.1 shows the complete Autogenous mill. The total Autogenous mill is consists of some of the critical major assemblies like Mill body assembly, Driving gear and pinion assembly, Spout Feeder Assembly, Outlet Duct Assembly, Babbit Bearing Assemblies, Metallic Butt Extractor Assembly, Drive Base Assembly.

Design Based Calculation of the typical Autogenous Mill (Malhotra, 1969)

Power calculation of AG mill

Mill inside liner diameter (3.9 m - 2 x 0.185 m), D = 3.53 m
Mill inside liner length (1.35 m - 2 x 0.13 m), L = 1.09 m
Bulk density, BD = 2MT/m³
Average % fraction of critical speed, Ci = 77%
Volumetric % fraction of mill charge Vf = 35%
Product size 80 % passing, P = 740 mm
Feed size 80 % passing (F) = 35000 mm
Short ton to metric tone conversion factor, k1 = 1.102
Kilo Watt to HP conversion factor, K2 = 1.341
Work index, WI = 13.50 STH
mill charge with 15% over loading, W = 7.47 MT

Power required based on material parameter and degree of size reduction

Optimum feed size, F0 = 3925 mm
Size reduction ratio, R = 473:1
Specific energy by Bond Equation E = 7.00

Total Mill Power with margin of 15% and 90% efficiency, HPAG = 189 HP or 141kW

Power required based on physical parameter like size, speed, loading etc.

Critical speed, Nd = 22.52 rpm
Mill speed, N = 16.37 rpm
Peripheral speed, Nph = 3.20 m/sec.
Specific energy, PPS = 11.31 kWh/MT

Mill Power with margin of 15% and 90% efficiency, HPAG = 108HP

Power Model based on speed & CG of charge = 77 kW
CG distance from mill center, Rg = 0.975 m
Energy constant factor, c = 1/1200 = 0.000833333
Mill Power with margin of 15% and 90% efficiency, HPAG = 134HP or 100 kW

Calculation of Load Capacity of Spur And Helical Gears (As per IS: 4460-95)

Input Data

Number Of teeth (Pinion), Z1 = 31
Number Of teeth (Gear), Z2 = 284
Normal Module, na = 16 mm
Normal Pressure Angle, α0 = 20 degree
Helix Angle, b = 0 degree
Pinion Speed, n1 = 150 rpm
Transmitted Power, P = 150000 W
Face Width, b = 150 mm
Life, L4h = 72000 h
Probablity Of Failure, Pi = 0.01
Accuracy Grade = 6
Material Hardness, HB1 = 250 BHN
Material Hardness, HB2 = 210 BHN
Modulus Of Elasticity, E1 = 206000 MPa
Poiisson’s Ratio, m = 0.3
Viscosity Grade Of Lubricant = ISO VG 32
Lubricant Viscosity, VG32, v40 = 32 mm²/s
Lubricant Viscosity, VG32, v50 = 20 mm²/s
Endurance Limit, $\sigma_{Hlim1}$ = 600 Mpa
Endurance Limit, $\sigma_{Hlim2}$ = 460 Mpa
Nominal Endurance Limit, $\sigma_{Hlim1}$ = 420 Mpa
Nominal Endurance Limit, $\sigma_{Hlim2}$ = 300 Mpa
Profile Correction Factor, $x_1$ = 0
Profile Correction Factor, $x_2$ = 0
Mean Roughness, $R_{z1}$ = 6.3 $\mu$m
Mean Roughness, $R_{z2}$ = 6.3 $\mu$m
Protuberance Angle $\alpha_{prot1}$ = 20°
Protuberance Angle $\alpha_{prot2}$ = 20°
Buckling Height, $h_{b2} (\alpha_{qprot})$ = 0 mm

**Supplementary Data**
- Ratio Of Gearing, $u$ = 9.16
- Gear Speed, $N_2$ = 16.37 rpm
- Pinion PCD, $d_1$ = 496 mm
- Gear PCD, $d_2$ = 4544 mm
- Outside diameter (Pinion), $d_{o1}$ = 528 mm
- Outside diameter (Gear), $d_{o2}$ = 528 mm
- Linear Speed, $v$ = 3.9 m/s
- Tangential Load, $F_1$ = 38505.23 N
- Transverse Module, $m_t$ = 16 mm
- Base Circle Dia.(Pinion), $db_1$ = 466.09 mm
- Transverse Pressure Angle $\alpha_t$ = 20°
- Trans. Working Pr. Angle, $\alpha_{w1}$ = 20°
- Base Helix Angle, $b_h$ = 0°
- Tip Pressure Angle, $\epsilon_{t1}$ = 28.03°
- Tip Pressure Angle, $\epsilon_{t2}$ = 21.07°
- Transverse Contact Ratio, $\epsilon_{c1}$ = 0.83
- Transverse Contact Ratio, $\epsilon_{c2}$ = 0.97
- Transverse Contact Ratio, $\epsilon_{a}$ = 1.8
- Normal Contact Ratio, $\epsilon_{n1}$ = 1.8
- Overlap Ratio, $\epsilon_o$ = 0
- Base Circle Dia. (Gear), $db_2$ = 4269.96 mm

**Factor of safety for contact stresses:**
- For Pinion SH1=1.50 and for Gear SH2=1.17
- For factor of safety for bending stresses: For Pinion SB1=3.56 and for Gear SB2=1.44

**Load factor for surface durability:**
- Application factor (U/M) $K_A$ = 1.25

**Load distribution factors (For contact stress):**
- Longitudinal $K_{HB}$ = 1.19
- Transverse $K_{HB}$ = 1.0

**Dynamic load factor $K_V$ (For contact stress):**
- Auxiliary value $K_V = \left( \frac{Z_z \cdot v}{100} \right) \left( \frac{u^2}{1 + u^2} \right)$
- Factor $K_{V0}$ = 1
- Factor $K_{V1}$ = 1
- Factor $K_V = K_V \cdot C_Z \cdot K_{V0} - K_{V1} = 1$

**Zone factor $Z_H$:**
- $Z_H = \left( \frac{2 \cos \beta \cdot \cos \sigma_{slr}}{\cos \alpha_1 \cdot \sin \sigma_{slr}} \right)$
- Factor $K_{V0}$ = 1
- Factor $K_{V1}$ = 1
- Factor $K_V = K_V \cdot C_Z \cdot K_{V0} - K_{V1} = 1$

**Elasticity factor $Z_k$ (For contact stress):**
- $Z_k = \sqrt{\frac{1 - u^2 + 1 - u^2}{E_1}} = 189.81$

**Permissible contact stress $\sigma_{HP}$**
- $\sigma_{HP} = \frac{F_1(1 + u)}{bd_u}$

**Factor of safety $S_H$:**
- $S_H = \frac{\sigma_{HP}}{\sigma_{HO}}$

For pinion $S_{H1} = 1.79$, for gear $S_{H2} = 1.58$
Load Factor for Bending Strength

Table 2 describes the supplementary data for the gear while Fig. 2 shows the shear force and bending moment diagram.

Table 2 Supplementary Data

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic Rack Addendum, h&lt;sub&gt;ax1&lt;/sub&gt;</td>
<td>31.25 mm</td>
</tr>
<tr>
<td>2</td>
<td>Basic Rack Addendum, h&lt;sub&gt;ax2&lt;/sub&gt;</td>
<td>31.25 mm</td>
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<tr>
<td>3</td>
<td>Tip Radius of Basic Rack, θ&lt;sub&gt;a1&lt;/sub&gt;</td>
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<td>13</td>
<td>Tip Nor. Pr. Angle, θ&lt;sub&gt;d2&lt;/sub&gt;</td>
<td>22.04°</td>
</tr>
</tbody>
</table>

Application factor (U/M) K<sub>α</sub> = 1.25

Load distribution factors (For contact stress)

Longitudinal K<sub>β</sub> = 1.21
Transverse K<sub>δ</sub> = 1

Dynamic load factor K<sub>V</sub> (For contact stress)

Auxiliary value K<sub>V</sub> = \( \left( Z_1 \frac{v}{10^2} \right)^2 = \frac{u^2}{1 + u^2} = 0.86 \)

Factor K<sub>V0</sub> = 1
Factor K<sub>V</sub> = K<sub>V0</sub> - C<sub>δ</sub> ((K<sub>V</sub> - K<sub>ββ</sub>) = 1

Life factor, Y<sub>N</sub>

For bending strength
Life cycle = 6E+8 cycles
Life cycle L<sub>n2</sub> = 7E + 8 cycles
Y<sub>N1</sub> = 1, Y<sub>N2</sub> = 1

Stress concentration factor

Notch parameter q<sub>sl1</sub> = 3.04
Notch parameter q<sub>sl2</sub> = 3.34
Auxiliary value L<sub>s1</sub> = 0.78
Auxiliary value L<sub>s2</sub> = 0.95
Y<sub>K1</sub> = (1.2 + 13a<sub>1</sub>)<sup>4</sup>q<sub>sl1</sub>(1 + 1.21 + 2.3/L<sub>s1</sub>) = 1.81
Y<sub>K2</sub> = (1.2 + 13a<sub>2</sub>)<sup>4</sup>q<sub>sl2</sub>(1 + 1.21 + 2.3/L<sub>s2</sub>) = 1.75

Contact ratio factor

Y<sub>β</sub> = 2.5 + .75/C<sub>α</sub> = 0.72
Helix angle factor
Y<sub>β</sub> = 1 - C<sub>β</sub>/R<sub>0</sub> = 1

Notch sensitivity factor
Y<sub>N1</sub> = 1, Y<sub>N2</sub> = 1

Roughness factor
Y<sub>R1</sub> = 1.03, Y<sub>R2</sub> = 1.03

Size factor
Y<sub>s1</sub> = 1.05-1.03*m<sub>b</sub> = 0.88
Y<sub>s2</sub> = 1.05-1.03*m<sub>b</sub> = 0.88

Reliability factors

Reliability factor K<sub>φ</sub><sub>α</sub>

For bending strength
K<sub>φ</sub> = 0.79 – 0.105 log<sub>10</sub>(P<sub>0</sub>) = 1

Maximum nominal stress
σ<sub>φ01</sub> = (F<sub>φ0</sub>/b<sub>α</sub>) + Y<sub>φA</sub>Y<sub>φK</sub>Y<sub>φC</sub>Y<sub>φY</sub> = 29.71 MPA
σ<sub>φ02</sub> = (F<sub>φ0</sub>/b<sub>α</sub>) + Y<sub>φA</sub>Y<sub>φK</sub>Y<sub>φC</sub>Y<sub>φY</sub> = 40.68 MPA

Maximum permissible stress
σ<sub>φF1</sub> = (σ<sub>φF/K<sub>φ</sub></sub>)Y<sub>φN</sub>Y<sub>φE</sub>Y<sub>φY</sub>Y<sub>φT</sub> = 381.14 MPA
σ<sub>φF2</sub> = (σ<sub>φF/K<sub>φ</sub></sub>)Y<sub>φN</sub>Y<sub>φE</sub>Y<sub>φY</sub>Y<sub>φT</sub> = 344 MPA

Factor of safety

For pinion = 8.50, For gear = 5.60

Weight of the gear

Face width b = 200 mm, Ring thickness t = 92.3 mm, Inner diameter, d = 4329 mm
Weight of the gear W = 2.03

Calculation of Pinion Shaft and Bearing:

Number Of teeth (Pinion), z<sub>1</sub> = 31
Normal Module, m = 16 mm
Pinion PCD, d<sub>1</sub> = 496 mm
Pinion Speed, n<sub>1</sub> = 150 rpm
Linear Speed, v = 3.9 m/s
Transmitted Power, P<sub>max</sub> = 150000 W

Bearing reaction, R<sub>1</sub> = 19253 N
Bearing reaction, R<sub>2</sub> = 19253 N
Maximum bending moment, M<sub>max</sub> = 5776 N m
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\[ G = \frac{1}{3} h [f_0 + 4f_1 + 2f_2 + 4f_3 + \ldots + 2f_{10} + 4f_{11} + f_{12}] \]

For Lade Base Bearing Material, Bearing Load, \( F_{\text{max}} = r \cdot S_{\text{max}} \cdot G \)

| Bearing radius, r | = 1000 mm |
| Allowable bearing pressure, \( S_{\text{max}} \) | = 7.5 MPa or N/mm², For Lead Bas |
| Bearing length, L | = 170 mm |
| Bearing reaction load, \( R_w \approx 42/2 \) | = 21 MT |

Bearing angle, \( y_1, y_2 \) = + 60° to -60°

Allowable reaction load, \( R_a \) = \( (F_{\text{max}} l)/2 \) = 70 MT

Factor of safety (for \( l = 160 \) mm) = \( R_a/R_w = 3.3 \)

**Conclusions**

An Autogenous Milling has been designed based on the customer need and presented in this paper. During the design process the two main character of an Autogenous Mill e.g. size reduction and the grinding parameters has been specifically included in design of the Autogenous mill. Design process was carried out following Simpson’s 1/3rd rule and satisfactorily results were obtained.

**References:**