Grinding Mill Computer Model

For preliminary designs

Table of Contents

1.Introduction

The workbook MILLCALC.XLS described in this report is useful for the preliminary design of mineral processing plants. This group cover the mill designs of A.M., R.M., B.M., and pebble mill designs. The programme is an EXCEL 5 workbook split into a number of spreadsheets which include the calculation sheets for printout and presentation, a graph showing the mill design relative to the minimum required and a data base of the mill regularly offered by the suppliers. Some of the larger size mills are not included because the suppliers design each one on a one off basis though these data bases will be extended.

The calculations used for each mill group are shown in the Appendix as are appropriate examples.

Each worksheet is completed by entering data in the areas shown in blue in the sheet - all other areas are locked to avoid inadvertent erasure of equations.

2. Metallurgical Power Requirements

These are the equations based on the work by Bond and Rowland with autogenous power requirement based on the work by Barratt. The equations work out the power required for the duty and are of an adequate form to provide to a mill supplier for final mill design.

The general form of the equation is the Bond equation with the various inefficiency factors for top size, dry/wet grinding, closed/open circuit etc. These factors and the equations to derive them are shown in Appendix 1.

A short section on the AG/SAG sheet lists the Advanced Media tests for testing whether a material may be suitable for a fully autogenous mill. An arbitrary criterion is used that 5 of the A.M tests are satisfied to suggest that a fully autogenous circuit can be used.

This section of the sheet is completed first

3. Mill Design

3.1 Autogenous Design

The general form of the equation is by Morgärdshammar that the power draw of a mill is derived from the power required to maintain mill revolutions with the mass of charge acting at the centroid of the mass. This is a form of equation used by many workers with the only variant being the "constant' factor in front of the equation. Morgärdshammar divide by 1200 but all equations are of the same form. The main calculation difficulty is finding the distance of the centroid from the centre of the mill. The geometric equations are not absolutely solvable from the % volume occupied and a numerical approach has been adopted off sheet. The resultant quaternary equation is listed on the sheet and compares well with data derived from tables in Morgärdshammar and Nördberg pamphlets.

In each case a calculation is also done based on a paper recently published in the IMM bulletin. This paper has a more fundamental derivation of the mass of centroid position and allows more carefully for the cone section in the mill and power losses in the drive chain. The fundamental aspect is then altered by a 1.26 factor to allow the predicted result to equal the real result!

The method of using the worksheet is to enter the number of mills required at H55 and the desired aspect ratio at G56. The sheet then returns two mill diameters and lengths as an approximate start point for the design based on the data base of mill manufacturers designs. The diameter and lengths are then adjusted on the main part of the sheet until the number of mills required is slightly less than the number of mills to be installed - the latter being the planned number. The sheet then allows for liner wear and gearbox inefficiencies to develop a recommended mill motor size.

A graph shows the mill design relative to its minimum design.

A data base allows standard mill sizes to be picked for each manufacturer and the motor size that the manufacturer would put on each mill size.

Initial indications are that the mill motor size recommended is higher than that supplied by the manufacturer though this probably reflects the less accurate estimate of the mill data base with only a limited number of variables considered.

3.2 Rod Mill Design

A different approach is taken with the rod mill design where equations by Bond and Rowling are used to calculate the mill power draw. The Morgärdshammar equation and the IMM equations are shown for comparison.

The method of use is similar to the AM section

3.3 Ball Mill Design

The ball mill designs also follow the Bond/Rowlings method with comparison with other methods. Again the method of use is the same

3.4 SAG/BM Combined design

This is the combined model of the SAG and BM models. The difference is that a provision in the BM model allows for the fact that finished product is in the BM feed. Based on information from Svedala if the finished product in BM feed is greater than 35% then they allow a credit for 75% of the finished product in terms of reduced power and tonnage - the programme calculates this and modifies the nominal feed sizing and tonnage.

3.5 Pebble Mill Design

This reverts to the Morgärdshammar method and is similar to the AM calculation

3.6 Tower Mill

The tower mill calculation is based on the ball mill design sheet, but is simplified in that the mill design section is omitted. A simple tower mill factor of 70% allows the mill power to be estimated.

4. Conclusion

The programme MILLCALC.XLS provides the basis of most mill designs. Variations reflect the "black art" of final mill sizing since even the rigorous IMM method gives significantly different answers to the manufacturers designs - claimed to be "14% low" in recent discussions with a well known designer. Ultimately the manufacturer has to warrant his mill and that has to be the final design.

5. References

- “Power Draw of wet tumbling mills” by S.Morrell reproduced in Trans IMM - 105, January - April 1996
- Design and Installation of Comminution Circuits by A.AL.Mular and G.V Jergensen
- Morgärdshammar handbook
- “Simple Empirical equations for Prediction of Mill Power Draw” – SRS Sastri and KK Rao – Trans IMM 106 – 1997
- “Selection of Rod Mills, Ball Mills, Pebble Mills, and Regrind Mills”, CARowland – AC Corporation – in Mular (Ibid)
- “Tools of Power Power” CA Rowland – 1976 SME –AIME Fall Meeting
- Grinding Ball Selection – FC Bond – Mining Engineering May 1958
- Comparison of Work Indices – CARowland Xth Int Min Proc Congress 1973
- Second SAG Milling Conference - Barratt

Metallurgical Energy Requirement - Autogenous Mill/SAG Mills

P_c - Power for crushing

$$10 * Wc * (\frac{1}{\sqrt{F_{r80}}} - \frac{1}{\sqrt{F_{80}}}) \quad ......(1)$$

F80/P80 - AG/SAG feed/product 80% passing size

Wc - Crushing work index kWh/t

Fr80 - 80% passing size for pseudo rod mill feed

Pr Power for rod milling

$$10 * Wr * (\frac{1}{\sqrt{F_{b80}}} - \frac{1}{\sqrt{Fr_{80}}}) \quad ....(2)$$

Wr - rod milling work index kWh/t

Fb80 - 80% passing size for pseudo ball mill feed

Pb - Power for ball milling

$$10 * W_b * (\frac{1}{\sqrt{110}} - \frac{1}{\sqrt{F_{b80}}}) \quad ......(3)$$

Wb - rod milling work index kWh/t. The 110 is replaced by the actual finished product grind if the AG/SAG is producing at less than 110µ

P_{comp}

$$10 * W_b * (\frac{1}{\sqrt{110}} - \frac{1}{\sqrt{P_{80}}}) \quad ....(4)$$

P_{mill} - AG/SAG power before circuit compensations

$$P_{sag} = 1.25*(Pc+Kr*Pr+Kb*Pb) - P_{comp} \quad ....(5)$$

E_4 - Oversized feed - if the feed is greater than 16,000µ for the rod mill and 4,000µ for the ball mill.

Rod Mill - Kr $Kr=E_4*E_5*E_6*E_7*E_8$	**Ball Mill Kb** $K_b=E_4*E_5*E_6*E_7*E_8$
$E_4 = \frac{R_r + (W_r - 7)*\left(\frac{F - F_o}{F_o}\right)}{R_r}$ $R_r = \left(\frac{F_r}{P_r}\right)$ Fo - Optimum Feed Size for rod mills $F_o = 16{,}000 * \sqrt{\frac{13}{W_r}}$	$E_4 = \frac{R_r + (W_b - 7)*\left(\frac{F - F_o}{F_o}\right)}{R_r}$ $R_r = \left(\frac{F_b}{P_b}\right)$ Fo - Optimum Feed Size for ball mills $F_o = 4{,}000 * \sqrt{\frac{13}{W_b}}$

E_5 - Fineness of grind - if the product is less than 75μ	$E_5=1.0$	$E_5 = \frac{P_{80}+10.3}{1.145 * P_{80}}$
E_6 - High or low ratio of Reduction - rod milling	$E_6 = 1 + \frac{(R_r - R_{ro})^2}{150}$ $R_{ro} = 8 + \frac{5*(L-0.5)}{D}$ L = mill length, D = mill diameter inside liners	$E_6=1.0$
E_7 - low ratio of reduction - Ball milling - if Rr <6.0	$E_7=1.0$	$E_7 = \frac{2*(R_r - 1.35)+0.26}{2*(R_r-1.35)}$
E_8 -Rod Milling Factor	$E_8=1.0$	$E_8=1.0$

Final Power Requirement	$P_{sag}=P_{mill} * E_1 * E_2$ .... (6)	E_1 - 1.3 for dry grinding 1.0 for wet grinding E2 - 1.2 for open circuit - 1.0 for closed circuit

Mill Power Capability - Autogenous Mill

General Equation:-

$$PowerDraw = \frac{MillVolume * Chargedensity * D * Rg * n}{1200}$$

Rg is a distance from the centre of gravity of the charge to the centre of the mill for a 1m diameter mill and n is the number of revs per minute of the mill - Morgardshammar/Marcy equation.

Mill diameter inside liners - D	D = D_{shell} -0.15	Allowance for liners

Approximate mill diameter is derived from:	$Power = 5.6115 * D^{2.46} * L$ $L = a * D$ where *a* is the aspect ratio *L/D* For SAG mills the equation becomes $Power = (5.6115 + \%balls * 0.1438) * D^{2.46} * L$	derived from a regression equation on 25 manufacturers' mill size and power relationships

Mill Critical speed *Crit*	$Crit = \frac{42.3}{\sqrt{D}}$	
n - revs per min	$n = Cs * Crit$	Cs is the fraction of the critical speed

Slurry S.G ρ_p	$\rho_p = \frac{100 * \rho s}{(100 - \%S) * \rho s + \%S}$	ρs=SG of solids %S is % solids by wt
Charge density - ρ_c	$\rho_c = \left(\frac{\%balls}{\%pulpload} * 7.8 + \frac{(\%pulpload - \%balls)}{\%pulpload} * \rho_s \right) * 0.6 + \rho_p * 0.4$	

Charge Volume -Vol	$Vol = L * D^2 * \frac{\pi}{4} * \frac{\%pulpload}{100}$	In main cylinder

Volume in cone end	Iterative value from Calc sheet based on segment height and segment area. $SegmentArea = \frac{D^2}{4} * (\theta - \sin(\theta))$ $SegmentHeight = \frac{D}{2} * \left(1 - \cos\left(\frac{\theta}{2}\right)\right)$ θ radians is the angle subtended at the mill centre by the pulp level Total volume= Charge vol + Vol cone	Formula assumes that a proportion of one end contributes to mill power draw

Rg factor	$Rg = 0.1957x^4 - 0.1817x^3 + 0.1467x^2 - 0.6629x + 0.501$ *x = % pulpload*	Derived from geometry and similar to the Morgarsdhammar pamplet with values listed in cells G60:H71

From discussions with Svedala a low pulp density can reduce the power draw by upto 25% due to slippage. This is allowed for by reducing the power draw on a pro rata basis from 65% solids down to 50% by 1.3% per 1% reduction in pulp % solids.

The final power requirement is derived by adding three factors:

The power calculated above

An allowance for increased liner wear based on the pro rata increase in internal mill diameter

The rest of the cone volume not included in the cone effect.

An allowance for 98% gearbox inefficiency is then added to derive the motor size.

An alternative power formula based on a paper by S.Morrell in the IMM bulletin is listed on sheet IMM with the result calculated for reference. This result will generally give a low result.

Metallurgical Energy Requirement - Rod Milling

Pr - Power for rod milling - before correction	$10*Wr*(\frac{1}{\sqrt{P_{80}}}-\frac{1}{\sqrt{F_{80}}})$ ....(1)	*Wr* - rod milling work index kWh/t *F_{80}* - 80% passing size for rod mill feed *P_{80}* - 80% passing size for rod mill product

	Efficiency Factors	
E_1 - Wet/Dry grinding	1.0 - wet grinding 1.3 - dry grinding	
E_2 - Closed/Open circuit	1.0 - Closed circuit 1.2 - in open circuit	D = mill diameter inside liners
E_3 - Diameter efficiency	$E_3=\left(\frac{2.44}{D}\right)^{0.2}$	if D>3.81m then E_3=0.914
E_4 - Oversized feed - if the feed is greater than 16,000µ for the rod mill	$E_4=\frac{R_r+(W_r-7)*\left(\frac{F_{80}-F_o}{F_o}\right)}{R_r}$	$R_r=\left(\frac{F_{80}}{P_{80}}\right)$ Optimum Feed Size for rod mills $F_o=16{,}000*\sqrt{\frac{13}{W_r}}$
E_5 - Fineness of grind - if the product is less than 75µ	E_5=1.0	
E_6 - High or low ratio of Reduction - rod milling	$E_6=1+\frac{(R_r-R_{ro})^2}{150}$	$R_{ro}=8+\frac{5*(L-0.5)}{D}$ - L = mill length,
E_7 - low ratio of reduction - Ball milling - if Rr <6.0	E_7=1.0	

E_8 -Rod Milling Factor	<u>Rod mill circuit only</u> 1.4 - open circuit crushing 1.2 - closed circuit crushing <u>Rod Mill/Ball Mill circuit</u> 1.2 - open circuit crushing 1.0 - closed circuit crushing
Final Power Requirement	P_{rod} = Pr * by the product of all above factors - ....(2)

Mill Power Capability - Rod Mill

General Equation:-

$$PowerDraw = 1.752 * D^{0.34} * (6.3 - 5.4 * FractRods) * Cs$$ *Mass of charge

FractRods is the rod charge level and *Cs* is the speed as a fraction of the critical speed. This equation is from page 402 'Design, Installation of Comminution Circuits'

A second equation by Morgardshammar is also shown off the print out sheet for comparison based on a 45% rod charge.

$$PowerDraw = \frac{1000 * Massofcharge * 0.235 * D * n}{1800}$$

Massofcharge is in tonnes and *n* is the RPM of the mill

Mill diameter inside liners - D	D = D_{shell} - 0.15	Allowance for liners
Approximate mill diameter is derived from:	$Power = 6.776 * D^{2.469} * L$ $L = a * D$ where *a* is the aspect ratio *L/D*	derived from a regression equation on 15 manufacturers' mill size and power relationships

Mill Critical speed *Crit*	$Crit = \frac{42.3}{\sqrt{D}}$	
n - revs per min	$n = Cs * Crit$	Cs is the fraction of the critical speed

Slurry S.G ρp	$\frac{100 * \rho s}{(100 - \%S) * \rho s + \%S}$	ρs=SG of solids %S is % solids by wt
Charge density - rod charge only	Based on a lookup chart list on page 400 of 'Design, Installation of Comminution Circuits'.	

Charge Volume -Vol	$Vol = L * D^2 * \frac{\pi}{4} * \frac{\%Rods}{100}$	In main cylinder
Mass of charge -	M= Charge density * Charge Vol	

The final power requirement is derived by adding two factors:

The power calculated above

An allowance for increased liner wear based on the pro rata increase in internal mill diameter

An allowance for 98% gearbox inefficiency is then added to derive the motor size.

An alternative power formula based on a paper by S.Morrell in the IMM bulletin is listed on sheet IMM with the result calculated for reference. This result will generally give a low result.

Rod Size, rod wear and liner wear

These formulae have been derived from equations listed on pages 435-7 of 'Design,Installation of Comminution Circuits'

$$RodSize = 0.16 * F_{80}^{0.75} \left(\frac{Wr * \rho s}{100 * Cs * (3.281 * D)^{0.5}} \right)^{0.5}$$ mm

$$RodWear = 0.159 * (Abrasion - 0.020)^{0.2}$$ kg/kWh

$$Linerwear = 0.0159 * (Abrasion - 0.015)^{0.3}$$ kg/kWh

Metallurgical Energy Requirement - Ball / Pebble Milling

Pb - Power for ball milling - before correction

$$10 * W_b * \left(\frac{1}{\sqrt{P_{80}}} - \frac{1}{\sqrt{F_{80}}}\right) \quad \text{...... (1)}$$

W_b - rod milling work index kWh/t

F_{80} - 80% passing size for ball mill feed

P_{80} - 80% passing size for ball mill product

	Efficiency Factors	
E_1 - Wet/Dry grinding	1.0 - wet grinding 1.3 - dry grinding	
E_2 - Closed/Open circuit	1.0 - Closed circuit 1.2 - in open circuit	D = mill diameter inside liners
E_3 - Diameter efficiency	$E_3 = \left(\frac{2.44}{D}\right)^{0.2}$	if D>3.81m then E_3=0.914
E_4 - Oversized feed - if the feed is greater than 4,000μ for the ball mill	$E_4 = \frac{R_r + (W_b - 7) * \left(\frac{F_{80} - F_o}{F_o}\right)}{R_r}$	$Rr = \left(\frac{F_{80}}{P_{80}}\right)$ $F_o = 4{,}000 * \sqrt{\frac{13}{W_b}}$
E_5 - Fineness of grind - if the product is less than 75μ	$E_5 = \frac{P_{80} + 10.3}{1.145 * P_{80}}$	
E_6 - High or low ratio of Reduction - rod milling	E_6=1.0	
E_7 - low ratio of reduction - Ball milling - if Rr <6.0	$E_7 = \frac{2 * (R_r - 1.35) + 0.26}{2 * (R_r - 1.35)}$	
E_8 -Rod Milling Factor	1.0	

Final Power Requirement	P_{ball} = Pb * by the product of all above factors - (2)

Mill Power Capability - Ball Mill

General Equation:-

$$\text{PowerDraw} = 4.879 * D^{0.3} * (3.2 - 3.0 * Fractballs) * Cs * \left(1 - \frac{0.1}{2^{(9-10*Cs)}}\right) + Ss$$

* Mass of charge

Fractballs is the fractional ball charge level and *Cs* is the speed as a fraction of the critical speed. *Ss* is a term called the ball size factor. This equation is from page 402 'Design, Installation of Comminution Circuits'

A second equation by Morgardshammar is also shown off the print out sheet for comparison based on a 45% rod charge.

$$PowerDraw = \frac{1000 * Massofch\arg e * 0.235 * D * n}{1470}$$

Massofcharge is in tonnes and *n* is the RPM of the mill

Mill diameter inside liners - D	$D = D_{shell} - 0.15$	Allowance for liners
Approximate mill diameter is derived from:	$Power = 10.552 * D^{2.2014} * L$ $L = a * D$ where *a* is the aspect ratio *L/D* Grate mill powers are derived by increasing the above by 16%	derived from a regression equation on 120 manufacturers' mill size and power relationships

Mill Critical speed *Crit*	$Crit = \frac{42.3}{\sqrt{D}}$	
n - revs per min	$n = Cs * Crit$	Cs is the fraction of the critical speed
Ball size factor	$Ss = 1.102 * \left(\frac{B - 12.5 * D}{50.8}\right)$	*B* is the ball size in mm *Ss* - kWh/t
Ball size - B	$B = 25.4 * \left(\frac{F_{80}}{K}\right)^{0.5} * \left(\frac{\rho s * Wb}{100 * Cs * (3.281 * D)^{0.5}}\right)^{0.34}$	The value of K is: Wet overflow 350 Wet Grate 330 Dry Grate 335

Slurry S.G ρp	$\frac{100*\rho s}{(100-\%S)*\rho s+\%S}$	ρs=SG of solids %S is % solids by wt
Charge density - ball charge only	4.6	

Charge Volume -Vol	$Vol = L*D^2*\frac{\pi}{4}*\frac{\%Balls}{100}$	In main cylinder
Mass of charge -	M= Charge density * Charge vol	

For a grate discharge mill the power draw is increased by 16%

The final power requirement is derived by adding two factors:

The power calculated above

An allowance for increased liner wear based on the pro rata increase in internal mill diameter

An allowance for 98% gearbox inefficiency is then added to derive the motor size.

An alternative power formula based on a paper by S.Morrell in the IMM bulletin is listed on sheet IMM with the result calculated for reference. This result will generally give a low result.

Ball wear and liner wear

These formulae have been derived from equations listed on pages 435-7 of 'Design,Installation of Comminution Circuits'

$BallWear = 0.159*(Abrasion-0.015)^{0.34}$ kg/kWh

$Linerwear = 0.0118*(Abrasion-0.015)^{0.3}$ kg/kWh

Mill Power Capability - Pebble Mill

General Equation:-

$$PowerDraw = \frac{1000 * Massofcharge * 0.235 * D * n}{1200}$$

Massofcharge is in tonnes and *n* is the RPM of the mill

The equation is by Morgardshammar based on a 45% pebble charge.

Mill diameter inside liners - D	D = D_{shell} -0.15	Allowance for liners

Approximate mill diameter is derived from:	$Power = 3.55 * D^{2.7031} * L$ $L = a * D$ where *a* is the aspect ratio *L/D*	derived from a regression equation on 10 manufacturers' mill size and power relationships

Mill Critical speed *Crit*	$Crit = \frac{42.3}{\sqrt{D}}$	
n - revs per min	$n = Cs * Crit$	Cs is the fraction of the critical speed

Slurry S.G ρ_p	$\frac{100 * \rho s}{(100 - \%S) * \rho s + \%S}$	ρs=SG of solids %S is % solids by wt
Charge density	ρs*0.7	

Charge Volume -Vol	$Vol = L * D^2 * \frac{\pi}{4} * \frac{\% pulp}{100}$	In main cylinder
Mass of charge -	Charge Density * Charge Vol	

The final power draw is derived by adding two factors:

The power calculated above

An allowance for increased liner wear based on the pro rata increase in internal mill diameter

An allowance for 98% gearbox inefficiency is then added to derive the motor size.

An approximate liner wear has been used based on the ball mill model

$$Linerwear = 0.0118 * (Abrasion - 0.015)^{0.3}$$