Principles of Mechanical Crushing

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- Manager Crushing Chamber and Materials Development
  - Product Development Center Crushing (R&D)
- Master of Science in Mechanics, specialized in mechatronics
- Ph.D 2007, Chalmers University
  - Partly funded by Sandvik
  - Modeling, simulation and optimization of crushing plants
  - Technical-Economic Optimization
- Sandvik employee since 2004
  - Manager Crushing and Screening Process Expertise
Crushing Chamber And Materials Development

- Crushing Chamber Geometry
- Crushing Chamber Materials
- Other Machine Parts Material

- Our Three Values
  - Safe!
  - Customer Values
  - Scientific Approach
Objective

Explain the interaction between rock material and crusher
Take home messages

The Take Home Messages will adress:

- Trouble Shooting
- Improve Yield
- Improve Performance
Agenda

- Cone Crusher Operating Principal
- Crusher and Rock Interaction
- Forces and Power Draw
- Capacity
- Operating the Crusher in a Process
- Optimization
- Conclusions

NCC, Borås, Sweden
Implementations

Scientific Approach

Problem / Research Question

Hypothesis / System behavior

Choice of method / proposal modeling
Study and/or prediction of system behavior

Verification

Prediction of performance

Utilize results for improvement

Customer Values

Knowledge
Cone Crusher

- Why Cone Crusher?
  - The **cone crusher** design concept is an effective and smart way of realizing compressive crushing

- Aggregate Production

- Mechanical Liberation of Valuable Minerals
Operating Principle

- Feed
- Product
- Heat
- Noise
- Power
- Lube Oil
- Hydraulic Oil
Operating Principle

All crushing starts with the chamber!
Operating Principle
Operating Principle

Feed

Concave

Mantle

CSS

Product

Eccentric speed

Throw

Product
Operating Principal

Opening Phase = Transport

Closing Phase = Crushing
Operating Principal

10 Indentations
Operating Principal

Single Particle Breakage

Inter Particle Breakage
Crusher Modeling

The compressive crushing process can be described with two functions.

Selection $S$ – which?

Breakage $B$ – how?
Crusher Modeling

Prediction of:
- Product Particle Size Distribution
- Capacity
- Crushing Force
- Hydraulic Pressure
- Power Draw

Design and Operation
- Computer Calculation Model of Cone Crushers
- Utilize the crusher as efficient as possible
- Energy efficient crushing
- Robust performance during the entire wear part life
- Maximize product yield
Crusher Modeling

Repeated size reduction steps

\[ p_i = \left\{ \left[ B_{i}^{\text{inter}} S_i + (1 - S_i) M_{i}^{\text{inter}} \right] + B_{i}^{\text{single}} M_{i}^{\text{single}} \right\} p_{i-1} \]

\( \left( \frac{s}{b} \right)_{u,i} = \text{Compression ratio} \)
Crusher Modeling

Laboratory investigation of breakage modes

Compressive crushing with hydraulic press.

Compression ratio

SPB

Compression ratio

IPB

Distribution width
Take home message:

It is easier to crush short fractions than long fractions.

Packing limit is reach earlier with long fractions.
Rock Breakage Behavior

**Breakage, B**

Take home message:

Interparticle crushing with high compression ratios crushing produces fines.

\[
B(x_k, s_k) = (1 - (\alpha_3 + \alpha_4 s_k))x_k^{\alpha_1} + \alpha_2 s_k + (\alpha_3 + \alpha_4 s_k)x_k
\]
Crushing Force and Power Draw

\[ F = f(s/b, \sigma) \]

- \( b \): Bed height
- \( s \): Compression
- \( s/b \): Compression ratio
- \( F \): Force
- \( \sigma \): Fraction length
Crushing Force and Power Draw

Take home message:

Interparticle breakage

Longer fractions results in higher crushing pressure and better particle shape.

\[ p\left(s_N, \sigma_N\right) = a_1 s_N^2 \sigma_N^2 + a_2 s_N^2 \sigma_N + a_3 s_N^2 + a_4 s_N \sigma_N^2 \]

\[ \sigma_N = \text{size distribution width} \]
Crushing Force and Power Draw

Single particle force response

Take home message:
Single particle breakage requires lower crushing force compared to interparticle.
Crushing Force and Power Draw
Crushing Force and Power Draw

\[
\tan \alpha_i = \frac{\int p(\alpha) \sin \alpha d\alpha}{\int p(\alpha) \cos \alpha d\alpha}
\]

\[
R_i = \frac{\int p(\alpha) r \sin \alpha d\alpha}{\sin \alpha_i}
\]
Crusher Capacity

• What is determining the crusher capacity?

• Machine parameters:
  • CSS
  • Throw
  • Chamber Design

• Environmental parameters
  • Moisture
  • Feed particle size distribution
  • and some others…
Crusher Capacity

Each ring volume represents the material that is crushed at each eccentric revolution.

CSS and Throw will affect the volume of all rings.
The capacity is volumetric.

**Crusher Capacity**

**Area function**

- **Nominal Cross-sectional Area**
- **Choke level**

[Graph showing the relationship between nominal cross-sectional area and Y-coordinate (m).]

- **Area** [m²]
  - Y-coordinate [m]
Crusher Capacity

Do you believe it?

- All chambers have same capacity.
Chamber Design

Design drawings

Coarse

Fine
Chamber Design

Nominal Geometry, CSS=15

Nominal Cross-Sectional Area

Nominal Geometry, CSS=35

Nominal Cross-Sectional Area

CH440 F

CH440 EC
Chamber Design

Take home message:

Chamber design affects breakage modes.

Confined crushing zones
-interparticle breakage can occur

Less confinement
-mixed single and interparticle breakage
Results - Particle size distributions

Results from different CSS settings 8-16mm
Crusher Operation

- Relation between CSS and Shape
  - The size where the best shape can be found is at CSS
  - It is very difficult for cubical stones larger than CSS to pass the chamber
  - Breakage of stones creates flaky particles. Smaller flaky stones will more easily find their way through the chamber

![Graph showing the relation between Flakiness index and Particle size](image)
**Crusher Operation**

- **Relation between Feed size and Shape**
  - The greater reduction ratio the worse particle shape.
  - Inter particle breakage improves shape. When crushing a bed of material weaker particles will break first. Flaky or elongated particles are weaker than round.
  - Breaking round particles gives flaky material.

**Particle Shape:**

*The Particle Shape can be improved by moving the reduction to earlier stages in the plant*
Crusher Operation

Reduction:

Optimum CSS
Process Capacity

Design capacity: 200 tph
Crusher Capacity: 300 tph
Choke fed Crusher operation (300 tph):
Material in surge bin runs out at even intervals

Consequence:
Crusher is operated choke fed 66% of total operating time feeding the screen with 300 tph
Screen overload
Solution: Adjust throw in order to reach 200 tph capacity
Feeding, the key to successful operation

**Feeding:**

*Choke feeding yields more inter particular crushing*

*Choke feeding makes the liners wear evenly*

- Bed of rock gives smoother operation.
- The rocks are gradually crushed as they are transported through the crushing chamber.
- The entire chamber is utilized for crushing.

- The rocks fall/slides through the chamber until they are crushed directly between the concave and mantle.
- The rocks are crushed in one strike which yields big forces
- Most of the crushing in the lower part of the chamber
Feeding:

Feeding condition affects the forces in the crushers and thereby has a direct effect on maintenance cost.
Optimization of a Final Crushing Stage

- The crushers are the last size reduction stage in the value chain.
- Over crushing is common.
- The connection between crusher setting and yield is often unknown.
- The rock cannot be repaired.
- We need to control the crusher carefully.
Optimization of a Final Crushing Stage

- Optimization of one parameter (CSS) can be done by sampling and analysis
- The invested time and lost production will quickly be repaid by increased productivity
  - Combine product yield and economic aspects
  - This can be done by taking samples and making the analysis in MS Excel
Material from crusher is sampled

Measure the capacity at each crusher settings. CSS will effect the final product capacity, especially in a closed circuit.

Production of 4 valuable products
- 0.08-0.16” (2-4 mm)
- 0.16-0.32” (4-8 mm)
- 0.32-0.64” (8-16 mm)
- 0.64-0.87” (16-22 mm)

By-product with no value
- 0-0.08” (0-2 mm)
Optimization of a Final Crushing Stage

- Run the crusher at different settings
- Take at least one sample at each setting. (Multiple samples are often useful)

- Special Attention to Safety when taking samples!!
- Position of point were samples are taking.
- Ensure that the conveyor will not start by accident.
Optimization of a Final Crushing Stage

- Particle Size Distribution Plots
- If taking single samples on each CSS the risk of getting inconsistent results might make the graph look strange.

- Impossible to determine optimum setting by only using particle size distribution graphs
Optimization of a Final Crushing Stage

- If taking single samples on each CSS the risk of getting inconsistent results might make the graph look strange.

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Optimization of a Final Crushing Stage

- Combine the particle size distribution and capacity.
- Percentage of final product times the capacity gives the production capacity of each product.

- Example 0.08”-0.16” mm at CSS 0.79”:
  ✓ Percentage of crusher production
  ✓ 20% - 11% = 9%
  ✓ Crusher capacity
  ✓ 193 tph

  ✓ Total Production:
  ✓ 193 tph x 9% = 17 tph
Optimization of a Final Crushing Stage

- Entering all the values into MS Excel makes this easy to get production capacities.

- Still difficult to determine the optimal setting
Optimization of a Final Crushing Stage

- Use the price* per ton for all products:
  - 0-0.08": $ 0 (by-product)
  - 0.08-0.16": $ 12.30
  - 0.16-0.32": $ 13.85
  - 0.32-0.64": $ 16.90
  - 0.64-0.87": $ 10.80

- Make an income graph by combining prices with capacity

*All prices are estimates based on publicly available data
Optimization of a Final Crushing Stage

- What difference does it make?

- Running the crusher 0.08” off:
  - Decrease the profit by 58.5 $/h
  - Running the crusher at 1600 hours per year: 58.5*1600=$93600

Optimization:
The effort put in to optimization will repay itself quickly
Take home messages

- It is easier to crush short fractions than long fractions.
- Packing limit is reach earlier with long fractions.
- Longer fractions results in higher crushing pressure and better particle shape.
- Single particle breakage requires lower crushing force compared to inter particle breakage.
- Capacity is controlled by choke area.
- Chamber design determines breakage mode
- CSS and reduction ratio effects particle shape
- Crusher capacity and process capacity should match each other.
- Feeding conditions are important for efficient crusher operation
- Optimization of a crusher is easy and profitable.
LIGHTEN UP!

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