Predicting Gyracone Crusher Performance

Using Dynamic Models

Gyratory and cone crushers (gyracyone crushers) are widely used in the mining and aggregates industry. With the increasing demands on the use of crushed material in recent years, the prediction of the performance of a crusher, in terms of properties such as mass flow, product size distribution and power draw/energy consumption as a function of material properties, machine specifications and operating conditions, is becoming much more important.

The following paper gives an overview of existing approaches and models used for the prediction of gyracone crusher performance.

PRINCIPLE OF OPERATION

The gyracone crusher’s main parts are a cone (mantle) and a concave. The cone is mounted on a main shaft and revolves eccentrically within the stationary concave. Particles are nipped, compressed and crushed in the chamber between the cone and concave as they fall through the crusher.

There is no significant difference between cone and gyratory crushers. The motion of the cone in cone crushers has a more or less substantial vertical component with a comparatively long throw, whereas in gyratory crushers the movement of the gyrating head is predominantly horizontal with a comparatively short throw.

The crushing process is very complex and the performance of the crusher is affected by many parameters including:

— machine parameters such as closed-side setting, open-side setting, stroke and speed
— machine and chamber geometry, such as the gap which rolls around the cone, and liner profiles.

To date, the search for an ideal model to predict crusher performance has been intense but has not met with great success. One key reason for this is the difficulty in characterizing rock materials because of flaws within the rock, ranging from geological faulting or jointing on the macro scale down to dislocations in crystal structure on the atomic scale.

EXISTING MODELS

Early investigations into the size-reduction process began in the 19th century. Since then many researchers have contributed to this field by applying ideas and solutions derived from the science of physics. The models developed can be summarized and categorized into four main groups:

Classical models

These are concerned with the relationship between the energy consumed by a particular crusher and the amount of size reduction that the consumption of this energy produces. Energy and breakage are related by Napier-Munn (Napier-Munn, T.J., 1996) as:

\[ dE = -K \cdot dx/x^a \]

Various researchers have given different interpretations of this relationship. In 1867 von Rittinger (von Rittinger, P.R., 1867) proposed that the new surface area produced is proportional to the energy consumed:

\[ E = K \cdot (1/x_2 - 1/x_1) \]

In 1885 Kick (Kick, F., 1882) suggested that the energy required for breakage is proportional to the reduction in the volume of particles concerned:

\[ E = K \cdot \ln (x_1/x_2) \]

A third relationship has been postulated by Bond (Bond, F.C., 1952):

\[ E = 2 \cdot K \cdot \left( \frac{1}{x_1} - \frac{1}{x_2} \right) \]

The proportionality constant in this equation was defined by Bond as the ‘Work Index’ and is now considered to be a function of the particle size. In all these equations, K is a constant and \( x_1 \) and \( x_2 \) are the feed and product size respectively (usually the 80% passing size).

These models are simple, easy and practical to use for the calculation of energy consumed by the material which is broken and can provide a useful gross description of total breakage. However, there is generally little confidence in the model results and it is also suspected that all these underlying ideas are incorrect and that the energy–size reduction relationship does not suitably define the process of size reduction (Napier-Munn, T.J., 1996) and (Lynch, A.J., 1977).

Black-box models

Black-box models consider a crusher as a transformation between feed and product size distribution. They predict the product size distribution from the feed size distribution, breakage characterization and machine operating conditions. The Whiten cone crusher model (Whiten, W.J., 1972) is the most widely used in cement, mining and aggregates industry.
used example in this class.
With his model, Whiten assumed that particles could either be broken or dropped through the crusher unbroken. The broken particles then have the same choice of dropping through the crusher or of being broken further. Thus the cone crusher can be simplified to a single breakage zone and a classification zone (fig. 1).

From the mass balances:

\[ f + B \cdot C \cdot x = x \]  \hspace{1cm} (1)
\[ x = C \cdot x + p \]  \hspace{1cm} (2)

Combining equations (1) and (2) gives:

\[ p = [I - C] \cdot [I - B \cdot C]^{-1} \cdot f \]

where \( x \) is the vector representing the amount in each size fraction and \( f \) and \( p \) are feed and product size distribution vectors respectively. \( C \) is the classification function (a diagonal matrix giving the proportion of particles in each size grouping which enter the breakage zone), \( B \) is a lower triangular matrix giving the relative distribution of the particles after the breakage and \( I \) is the unit matrix.

The Whiten crusher model has been used effectively in modelling and simulating the crushing process. Its strongest feature is its ability to reduce a complex operational process to a few numbers and parameters, which makes the real world easier to interpret.

**Empirical models**

Empirical models have been developed on the basis of a large number of industrial and laboratory results that have been obtained by using regression techniques to try to establish the relationships between machine variables and crusher performance. Karra’s work (Karra, V.J., 1982) is a good example of this kind of model. He constructed equations relating machine variables and throughput and power consumption after performing repeated tests.

### Fundamental models

The aim of the recently developed fundamental models is to generate a relationship between detailed physical conditions within a crusher and its process outcome, thus moving towards more general models of the crushing process. Briggs has (Briggs, C.A., 1997) developed one such model of a cone crusher. In his work he developed a flow model to predict the throughput:

\[ \text{material flow} = P_i \cdot V_i \cdot dA_i \]

where \( P_i \) is local bulk density, \( V_i \) is average velocity of material, and \( dA_i \) is local cross-sectional area.

The model also calculates the final product size distribution by evolving the feed size distribution as the material moves down through the crusher. The power used to break the size distribution in the crusher is predicted by:

\[ \text{power} = \text{TSE} \times \text{mass flow} \]

where:

\[ \text{TSE} = \text{total specific energy} = \sum E_i \times M_i \]
\[ E_i = \text{specific energy} \]
\[ M_i = \text{mass fraction being broken} \]

This fundamental model incorporates crushing geometry with material breakage characteristics by considering how material progresses through the crusher. It differs from traditional approaches and opens a new perspective on modelling the crushing process. However, the proposed method for predicting power is of limited general use in relation to the issue of how crusher parameters and rock material changes affect the power required to break the material. More research is required to accurately calculate the power required by a crusher.

**PREDICTION OF CRUSHER POWER**

Power consumption is recognized as one of the most significant factors affecting the optimization of plant design, due primarily to its influence on project economics. As indicated by other studies, 1.3% of the total electrical energy generated in the US is consumed in comminution processes (Pitt, C.H & Wadsworth, M.E., 1980).

Realistic improvements in the energy efficiency of comminution could result in annual energy savings in the US alone of more than 20 billion kWh per annum (Flavel, M.D., 1977), or about 15% of Australia’s entire annual consumption of electrical energy in 1993/94 (Lynch, A.J., 1977).

The power costs associated with size reduction can account for more than half of the operating costs of a mineral processing plant. Even small improvements in the energy efficiency of a crusher can have a significant effect on the economic performance of an entire plant. As the emphasis on cost reduction and production efficiency increases in the mining and quarrying industries, efficient use of power/energy is becoming increasingly important. The application of a general model to accurately predict the energy/power consumption of new crusher designs and to optimize existing crushers should therefore be very important to these industries.
Because of the simplicity of the relationship between the cost of crushing and the size reduction, three of the classical models mentioned previously are still being successfully used today in predicting the crusher power draw.

Recently Anderson (Andersen, J.S & Napier-Munn, T.J., 1988) predicted crusher power draw using a single regression equation relating the power actually drawn by the industrial machine in producing a particular product size distribution, to the calculated power required to achieve the same size reduction in a laboratory test:

$$P_c = A \times P_p + P_n$$

where:
- $P_c$ = power drawn by the crusher under load (kW)
- $P_p$ = calculated pendulum power (kW)
- $P_p = \sum E_{ci} J_{10i} \cdot C_i \cdot x_i$
- $P_n$ = power drawn by the crusher under no load
- $A$ = a dimensionless constant for a particular crusher, obtained by regression

This power model provides a means of comparing the power efficiency of different patterns and types of crusher, in terms of efficiency constant $A$, and has been found to provide satisfactory predictions for several crusher types. However, as the regression coefficients are not valid for all crushers, the tests must be repeated for some crusher types.

In practice, manufacturers also have their own formulae to calculate the required power.

**SUMMARY**

All of the above methods have often proven to be unreliable and are only valid for a limited range of variables. They do not consider the physical mechanisms occurring inside the crushing chamber, nor how and why the operating variables have a particular effect on the crusher power consumption. They are therefore inadequate for the precise prediction of the energy consumed by a crusher.

New models that integrate the processing and mechanistic considerations are required for a more precise description and prediction of crusher performance. The existing models are deficient when it comes to establishing a more direct link between the load, energy and design parameters of the crusher. Such links are essential if the models are to be used for optimal crusher design.

A new model that integrates both processing and mechanistic considerations is currently being developed by Dr Aleksandar Subic and his research group. This model focuses on the transmission of loads and energy throughout the crusher, from the crushing zone to the motor drive, and evaluates not only the energy required to crush the rock, but also the energy lost in the mechanical system and the energy required to drive the crusher.

It is anticipated that this type of model will allow a reduction in crusher size and weight while meeting the same performance requirements, which is a basis for optimization of the crushers of the future.

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