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THE IMPORTANCE OF PRIMARY CRUSHING IN MILL FEED SIZE OPTIMISATION

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ABSTRACT

As a part of its investigation into run-of-mine ore fragmentation, Highland Valley Copper discovered the role of primary crushing in the optimisation of mill feed size. Image analysis methods were used to quantify the effect of feed size on mill throughput and showed the in-pit crushers to be an integral step in the preparation of feed to the AG/SAG mills.

In the case of Highland Valley, optimal feed size for mill throughput requires a balance between blasting and run-of-mine crushing. While blasting produces the ultra-fine material beneficial to mill throughput, the crushers are used to control topsize and critical size material generated in the blast. Image analysis-based size measurements will be used to demonstrate the impact of blasting on crusher performance and crushing on mill performance.

An automatic crusher control system incorporating size data was developed to ensure a consistency in product quality not achievable before. Close control of the crusher operation will now allow Highland Valley to further exploit the possibilities of mine-to-mill interaction through "value-added" blasting.

BACKGROUND

Highland Valley Copper is located near Kamloops, in south central British Columbia, Canada. The mining operation moves over 250,000 metric tonnes per day (tpd) from two open pits using conventional truck and shovel equipment. Typical head grades vary from 0.2 to 0.5% copper with an ore:waste ratio of 1. With currently outlined ore reserves, the mine is expected to operate until the first quarter of 2009.

The concentrator treats approximately 135,000 tpd through five parallel grinding lines. These five grinding lines consist of two fully autogenous mills and three semi-autogenous mills each followed by ball mills and hydrocyclones for size classification. A bulk copper and molybdenum concentrate is produced using froth flotation. A separate molybdenum concentrate is then generated by flotation and leaching of the bulk concentrate. Highland Valley produces over 500 tonnes of copper per day contained in a 35 – 42% copper concentrate. This product is trucked and railed to Vancouver, where it is shipped to customers overseas.

Highland Valley has been investigating the effects of feed size on mill throughput since 1997. The initial work and findings are summarised in a previous paper (*Simkus 1998*). Very early in this study, it became clear that optimising mill feed size required careful control over blast fragmentation <u>and</u> primary crusher operation. The two size reduction steps could work with one another or against one another.

MEASUREMENT OF MILL FEED SIZE

Particle size measurements are made at key locations between the mine and the mill using the WipFrag© image analysis system from WipWare Inc. A description of the system and how it works is given elsewhere (*Maerz 1996*).

Installation

Cameras were installed on all five grinding line feed conveyors, as well as the feed and product of the two in-pit gyratory crushers. A typical installation of the camera housing and lighting is shown in Figure 1. Images are sent back to the central WipFrag computer via fibre optic cable or short lengths of coaxial cable.

Figure 1: WipFrag Camera Installation

An example image recorded by the cameras and sent to the system for processing is shown in Figure 2.

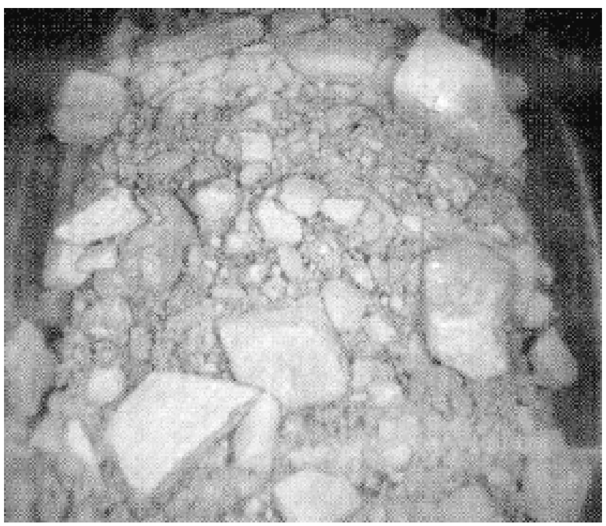

Figure 2: Example of Camera Image

The five mill feed cameras are handled by a single WipFrag computer with the four crusher cameras (two feeds and two products) handled by another computer due to their remote location. Image processing time is typically a few seconds and the system automatically cycles between cameras. All raw size measurements are sent to the Citect SCADA system which averages the data from the last 20 images for each camera and sorts the size distribution into three fractions: fine, medium and coarse.

Data Analysis

Highland Valley's method of interpreting the image analysis data is somewhat unique. Being very aware of the limitations of the technology and the differences in measuring size optically, no attempt is made to relate the results to a screen size distribution. Secondly, no estimation of the unmeasurable 'ultrafines' content is made by calibrating the results to physical samples. We are aware that the camera resolution prohibits measurements of fragments smaller than approximately 10 pixels (or 15 mm for the mill feed size).

The size measurements are used instead as control signals, with changes in the values inferring changes in the actual feed size. We are more confident in interpreting changes in measured sizes rather than analysing values that have been 'calibrated' or 'transformed' down to the ultrafine fractions.

As stated, the mill feed size distribution data are summarised into three fractions: the ***fine*** fraction is interpreted as minus mill discharge grate size material, the ***medium*** fraction as critical size and the ***coarse*** fraction as grinding media. Using these definitions, maximising the % fines, minimising the % medium while maintaining adequate % coarse is the objective of mill feed size optimisation.

Results

Monitoring the mill feed size WipFrag results showed a remarkable correlation between the % fines and mill tonnage for all grinding lines. The effect of feed size on one of our autogenous mills is shown in Figure 3 page I-193. Even short term changes in % fines (e.g. peak in middle of graph) results in swings in mill tonnage under power draw control.

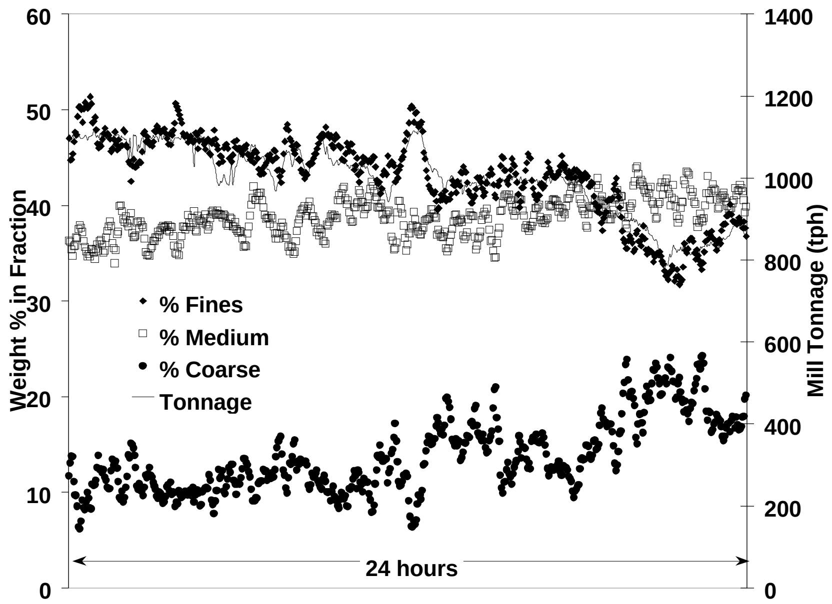

Figure 3: Effect of Feed Size on Autogenous Mill Tonnage

A similar graph for the variable-speed semi-autogenous mill is shown in Figure 4 below, where differences in mill tonnage from 1200 tph to over 2000 tph within a 24 hour period are accounted for by feed size changes.

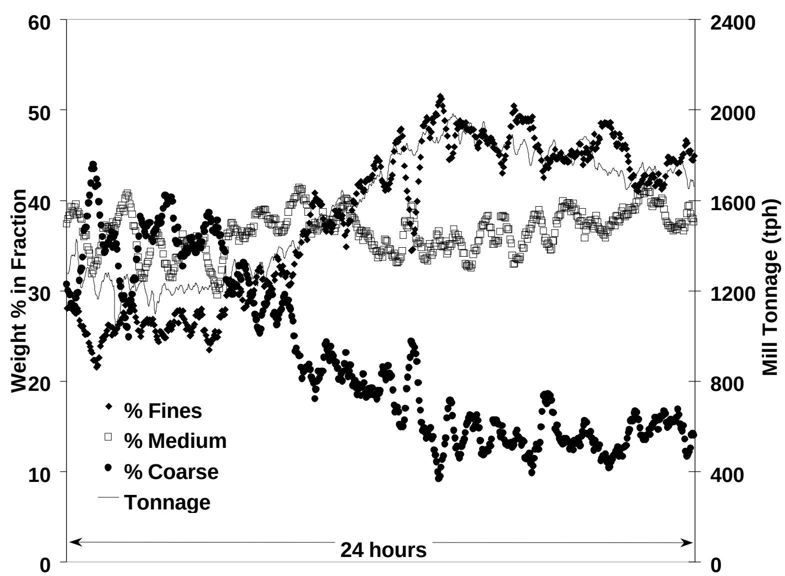

Figure 4: Effect of Feed Size on Semi-Autogenous Mill Tonnage

For all our five mills, feed size has shown to be an excellent and highly repeatable predictor of mill tonnage.

Based on these results, maximising throughput meant maximising the amount of "fines" (site-defined) in the mill feed. As these are generated largely in the blasting process and not in crushing, this is where our focus has been over the past four years.

ROLE OF PRIMARY CRUSHERS

Highland Valley operates three 60x89 Svedala Superior gyratory crushers: two are semi-mobile in the Valley pit and one is permanently located to process ore from the Lornex pit. As the Valley ore comprises the bulk of our feed and is generally much harder than the Lornex ore, the two semi-mobile crushers (Crusher 4 and Crusher 5) have been fitted with WipFrag cameras and will be the subject of the remainder of this paper.

Both Valley crushers are fed by a variable-speed apron feeder reclaiming material from the base of a truck dump hopper. The apron feeder discharges into the crusher pocket with crushed material falling onto a discharge belt which conveys the ore to one of three coarse ore stockpiles ahead of the mill. Both crushers have a hydraulic rock hammer to break oversize material in the crusher pocket.

For crusher operation, the apron feeder speed determines the throughput while the close-side-setting can be changed by raising or lowering the mantle hydraulically using the Hydroset mechanism.

So if most of the fines are generated in blasting, what is the role of the primary crushers in mill feed size optimisation? In terms of the three WipFrag fractions, crushing reduces the topsize (i.e. coarse) by generating medium and fine fraction material. Some of the medium material is also broken down. The pitfall to avoid is generating excessive critical size in the product or allowing medium-sized material to pass through uncrushed.

Feed Size Variability

The application of image analysis to measure the feed and product size on-line has provided detailed insights into crusher operating conditions. Figure 5, page I-195, shows the fluctuation in crusher feed size that can occur over a relatively short period. The similar % coarse values recorded by the WipFrag feed cameras at both crushers confirms the reproducibility of the measurements as well as the consistency of ore blending ahead of the crushers.

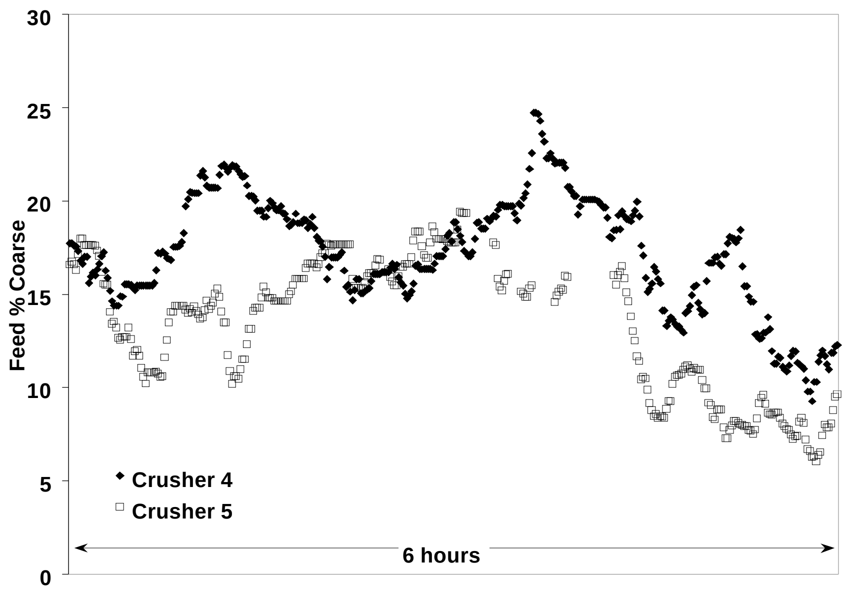

Figure 5: Variation in Crusher Feed % Coarse

The effect of crusher feed size on product sizing is shown in Figure 6 page I-196. For a constant setting or gap, the product % coarse is directly related to the feed % coarse. In other words, the shape of the feed size distribution is reflected in the product distribution. Other measurements have shown that the medium size material is largely unaffected during primary crushing. Therefore, as high energy blasting reduces the topsize of the crusher feed (particularly in difficult to blast zones), there is a greater chance of the medium or critical size material passing straight through the crusher and reporting to the mill. This critical size material has relatively slow grinding rates and lowers mill throughput.

Feed Source/Hardness Variability

The variation in crusher feed size can also be due to ore source changes or shovel movements within a blast pattern. Figure 7 page I-196 shows the effect of shovel movements or shovel blending changes on crusher feed size. In the data shown, the shovels did not change blast patterns, instead a greater amount of the 'softer' shovel was fed to both Crusher 4

and 5 resulting in significantly less coarse material measured by the WipFrag cameras.

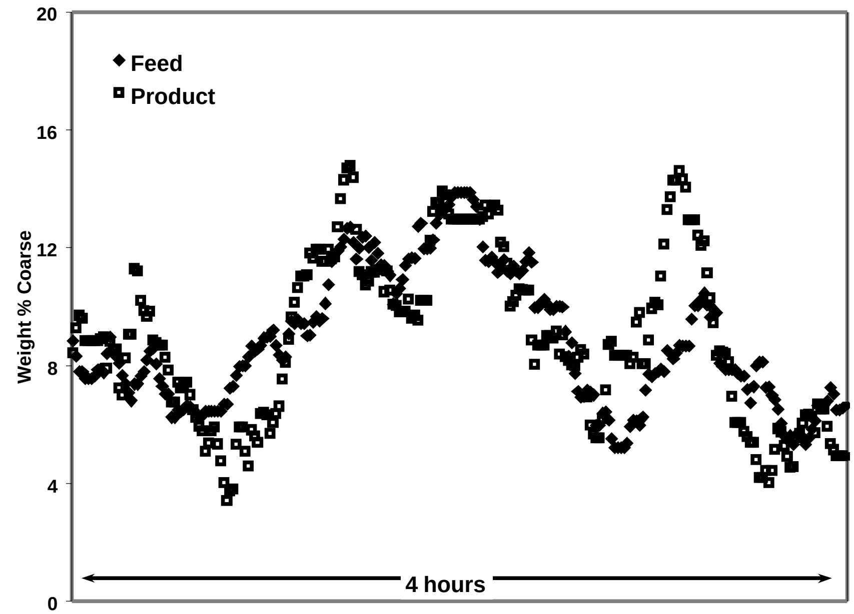

Figure 6: Crusher Feed & Product % Coarse (constant setting)

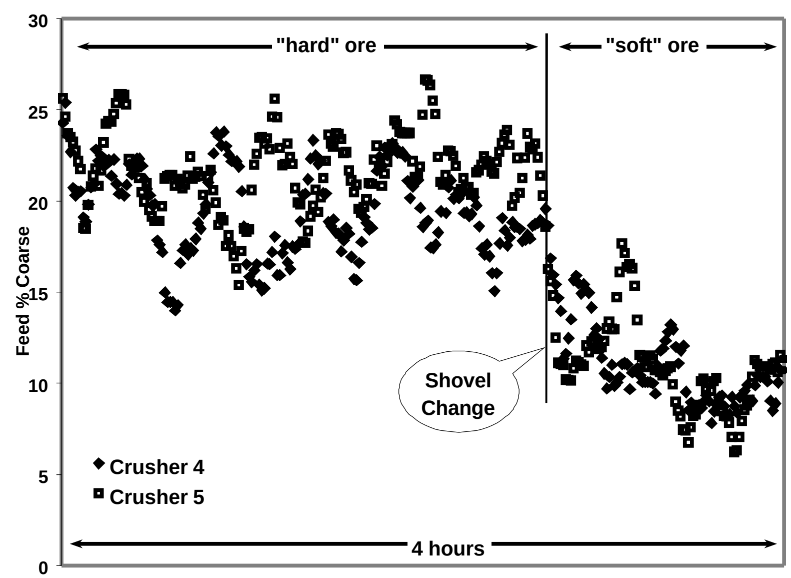

Figure 7: Ore Hardness Effects on Crusher Feed

At this time, Highland Valley does not blend its ore sources based on fragmentation size (although it is possible). Therefore, the other blending constraints (grade, hardness, etc.) dictate the crusher feed blend which can mean large variations in fragment size between each truck load.

Product Size Effects

To quantify the influence of the medium fraction in the crusher product, the material was tracked through the stockpile network and monitored as it entered the mill (approximately 24 hour delay). Figure 8 shows how the crusher product % medium values match up with the mill feed 24 hours later. Understandably, as the amount of critical size fed to the mill rose, the tonnage of one of the semi-autogenous mills fell from 2000 tph to 1800 tph.

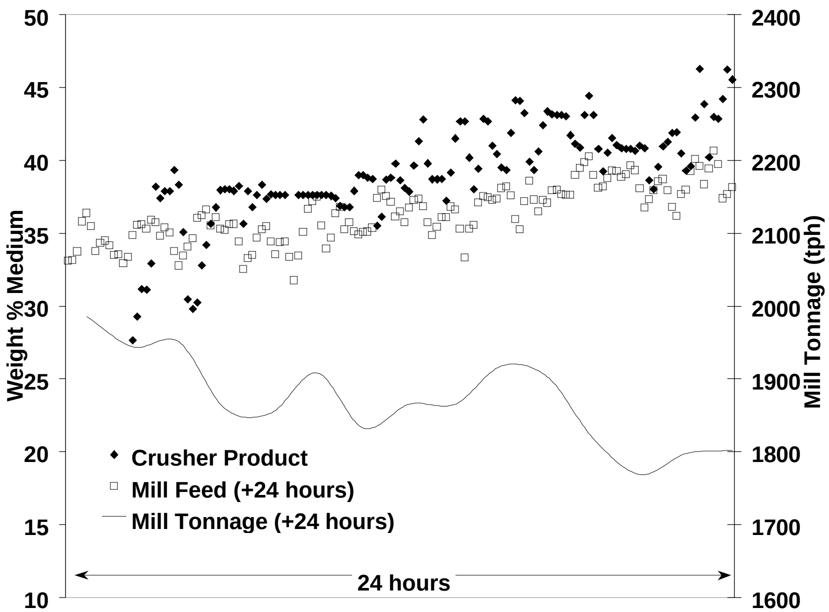

Figure 8: Crusher Product Effect on Mill Feed

CRUSHER OPERATION

Using image analysis size measurements, the previous section showed that large variations in feed size were common at Highland Valley's primary crushers. These variations were due to local ground conditions within the blast (rock hardness, in-situ block size, drill hole water infiltration problems, etc.) or as shovels moved between blast patterns.

More importantly, these feed size changes were reflected in the product size. Finally, the crusher product size – in particular the medium fraction – was shown to have a significant impact on mill production.

So how can the primary crushers be operated to reduce the impact of feed size changes on mill throughput? What can be done to stabilise the crusher product and even improve it in terms of mill feed size optimisation? HVC achieves this by attempting to choke feed the primary crushers <u>at all times</u>, using a combination of feedrate and set.

Highland Valley is blessed with the ability to regulate tonnage to each in-pit crusher through the apron feeder speed. Many other operations do not have this capability and are severely hampered in their prospects for primary crusher control.

Choke Feeding

The operating practice of choke feeding ensures that the crushing chamber is always full of rock. This generates the finest possible crush (given the feed size and tonnage conditions) by maximising retention time and inter-particle crushing. The higher power draw reflects the greater amount of crushing action, with many researchers now extolling the virtues of 'micro-fractures' to aid grinding rates (for example *Nielsen 1998*).

Testing at Highland Valley has shown choke feeding to produce more fine fraction material and less coarse, with the medium fraction largely unaffected (*Simkus 1998*). The fine material is desirable as mill feed.

Crusher Setting Changes

The data presented in Figure 6 showed that under constant close-side-setting conditions, the amount of coarse material in the primary crusher feed was reflected in the product as well. The effect of increasing the setting from 152 mm to 165 mm is shown below in Figure 9 page I-199. While the feed size % coarse dropped from 15% to 8%, the larger setting allowed more to pass through uncrushed and the product % coarse values actually increased over time.

Automatic Control

In 1999, Highland Valley initiated the development of an automatic control system for the two Valley in-pit crushers. This control system

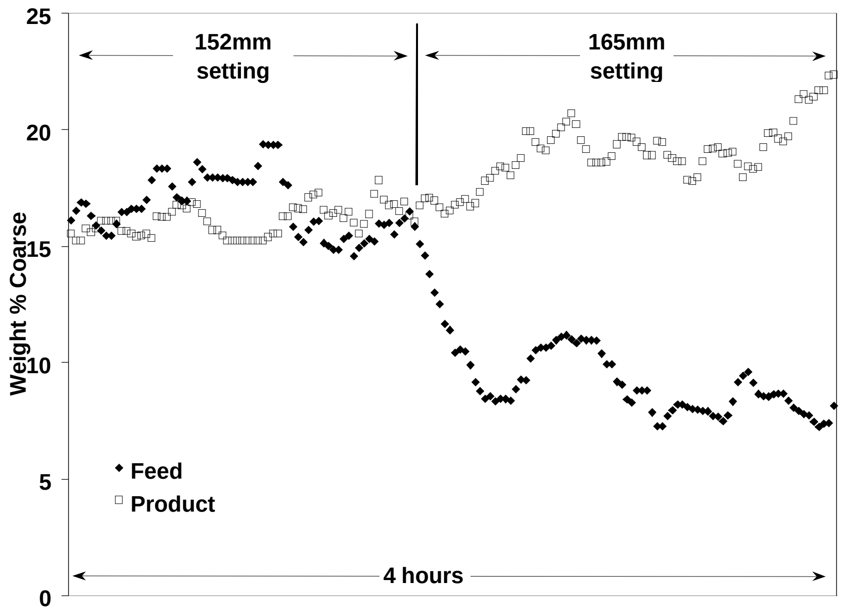

Figure 9: Crusher Setting Effect on Product Size

would maintain choke feed conditions and monitor the product size to ensure that it was of acceptable ‘quality’.

The situation at the primary crushers is a dynamic one – constantly changing feed size (often load-by-load) along with variable truck arrival frequency. Maintaining a constant crushing condition and product size is quite a challenging task. Essentially, the control system identifies opportunities when the trucks are arriving less often – and hence, the tonnage is lower. Under these conditions, the system tightens the setting by raising the mantle so that the crusher remains choked. If the trucks start arriving more frequently, then the mantle is lowered automatically and the setting is widened.

The primary crushers are well-instrumented, however, novel laser sensors had to be installed to measure the dump hopper and crusher pocket levels. This was a challenge in itself due to the severe dust conditions that were often present. Figure 10 page I-200 shows the crusher operator control graphic including the associated measurements.

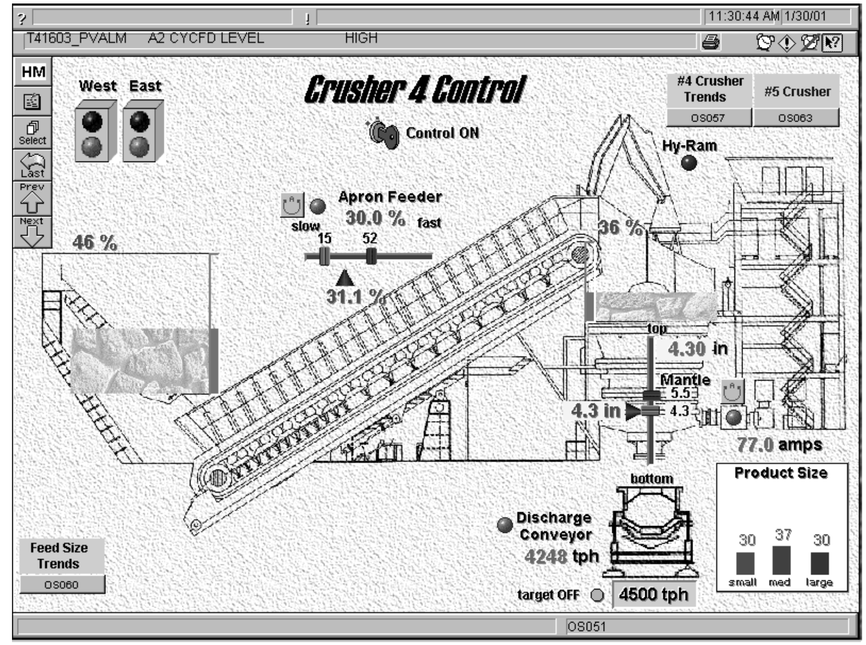

Figure 10: Automatic Crusher Control Graphic

The control system utilises a fuzzy logic-based algorithm that determines the apron feeder speed and mantle height (i.e. setting) every 30 seconds based on the crusher conditions. The dump hopper level, crusher pocket level, crusher motor power, product size and tonnage are all considered in the strategy. There is even provision to set a target tonnage that will override the product size constraints should the crusher not be achieving acceptable throughput.

This control system was commissioned in late 1999 and is currently operating full time on both crushers. An added benefit of the control system and choke feeding are longer life for concave liners and more even wear of the mantle liners.

In order to get the maximum benefit out of the primary crushers, Highland Valley needed some measurement of product quality. Through the use of image analysis, we were able to quantify the effect of feed size on mill performance. The second important item was the ability to regulate crusher product size through a combination of feedrate and setting control. The design and layout of our semi-mobile crusher installations made this possible.

These factors should be considered when designing new primary crusher installations where mill feed size optimisation is an issue.

IMPORTANCE OF PRIMARY CRUSHING

As a part of the investigation into mill feed size, Highland Valley realised the importance of the primary crushers in adding value to the mill feed. As the amount of fines was directly related to tonnage, whatever blasting and crushing could do to improve mill feed size would be rewarded by higher throughput. The down side was that, unless the crushers were always choke fed, finer blast fragmentation could actually make matters worse through more critical size passing through to the mill uncrushed.

Historical Perspective

To gain perspective, it is interesting to look back over the years at efforts in the mining industry to improve mill production through feed size. For operations where rod and ball mills were the primary grinding devices, crushing plants were necessary in order to carefully prepare a suitable feed size – these types of mills would not accept anything less. In order to eliminate the costly crushing plants that were difficult to keep running, autogenous and semi-autogenous milling was developed. These devices were capable of handling almost any size of feed and still keep running. Unfortunately, these mills would do so at different grinding rates – which led to variable tonnage. To improve this rate, balls were added in ever increasing amounts and recycle crushers were installed to treat problem material that never should have been fed to them in the first place.

So where are we now? Efforts are being put into improving blast fragmentation (a far more efficient process than grinding) to reduce or eliminate the problem material before it enters the mill. Very recently, reports are being made of the successful application of pre-crushing and screening ahead of autogenous-type mills. Sound familiar? Whatever the primary grinding device, careful preparation of the feed size to suit the type of equipment will produce higher and more stable tonnage. And because of the relative cost and energy efficiency of blasting and crushing compared with grinding, the economics can usually justify spending dollars upstream of the mill.

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