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PILOT STUDY ON THE INFLUENCE OF THE ECCENTRIC SPEED ON CONE CRUSHER PRODUCTION AND OPERATION

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ABSTRACT

There are many different machine setup parameters and variables that affect the production of cone crushers in a mineral processing plant. One of these variables is the eccentric speed at which the cone gyrates. In June 2012, pilot tests were conducted on a 200 hp high speed cone crusher to determine the production and operating conditions over a wide spectrum of eccentric speed.

Every plant will have variations in the ore characteristics and feed rates throughout the life of the mine, and at times throughout a single shift of operation, which result in non-optimal use of the crushing energy and inconsistent process control. For high speed cone crushers, the crusher will exhibit a different capacity, power required, and discharge size distribution as the speed ranges over the design limits of the machine. This study documents the measured variation in production and energy efficiency both when the crusher was ran at full capacity as well as when the feed to the crusher was not sufficient to run at full capacity. Overall, the results match theory and the capacity and power fluctuated by 25% and 17%, respectively, over the speed range when operated full while there was an overall trend of slightly coarser discharge size distribution as the speed decreased. The results with the fixed feed rate were more telling, as the crushers had 4-14% higher production when making a theoretical minus 12.5 mm product when operating at the optimal speed as compared to the worst speed in the "typical" speed range for this application. Secondary analysis of the fixed tonnage testing also showed that the power draw was more consistent with lower magnitude spikes at the higher speeds (higher cavity level), as on average the standard deviation of the power draw increased from 7% to 18% and the peak power spikes from 20% to 48% over the speed range tested.

The findings lay groundwork for more efficient plant design. Varying the speed of the crusher can be used to tune the crusher speed during commissioning, adapt to changing ore conditions over long periods of time, or be used as a dynamic input into an advanced control system. Each action above would serve to make the crusher(s) more productive and more energy efficient, and would also have mechanical benefits for the machine.

Key Words: cone crusher, ore reduction, process control, crushing efficiency

INTRODUCTION

There are many parameters that affect the production and efficiency of a high speed cone crusher. One of these variables is the eccentric speed, or gyration frequency, of the moving crushing member (head). For the vast majority of installations today, the eccentric speed is a set parameter and is rarely changed after commissioning and even more rarely adjusted regularly. However, since each application would have a theoretical most advantageous speed for crusher production and efficiency, operating at a single speed over the life of the crusher does not allow for the optimal crusher arrangement.

At the start of operation, it is very possible that a crusher is not set up with the most optimal speed due to misapplication and/or inaccurate assumptions of ore properties, feed size, and reduction desired. Furthermore, the operation will see fluctuations in crusher loads that are both frequent (short periods of higher or lower loads) and long term

(varying ore hardness, blasting strategy, or a change in production requirements). An extensive pilot campaign with a 200 horsepower high speed cone crusher was executed in order to measure the different production that would be achieved with the cone crusher in both a full cavity condition as well as when the tonnage to the crusher was a fixed rate as is common during typical mine operation.

This paper briefly discusses crushing dynamics and the effect that gyration frequency has on capacity, reduction, and power utilization.

THEORY: EFFECT OF ECCENTRIC SPEED ON CRUSHER OPERATION

There are a number of parameters of the crusher set up that affect how material flows through the chamber, how much reduction is achieved, and how much power is needed to achieve this. A short list would include: eccentric speed, closed side setting, crushing throw, and chamber profile. This paper seeks to isolate the eccentric speed to measure the effect of this parameter only; in this regard, the throw and chamber profile during the testing were held constant and the closed side setting was adjusted only to track speed change effects in multiple applications. To understand the theory behind eccentric speed in crusher design, we must consider each of the factors above and determine the consequence of varying the speed.

The capacity, reduction, and power utilization of a cone crusher depend on how the particles flow through the chamber and what is the final opening that the particles need to pass in order to exit the chamber. The eccentric speed will be a significant factor in how far a particle can drop during one gyration cycle; this drop is referred to as one crushing zone. The speed at which the crusher would have the theoretical maximum capacity is known as the critical speed. High speed cone crushers are operated at super-critical speed, in the portion of the speed vs capacity curve where the capacity is dropping as the speed is increasing (see Figure 1). Note that the shape and magnitude of this curve will be slightly different for each crusher, setting, feed size, ore properties, etc.

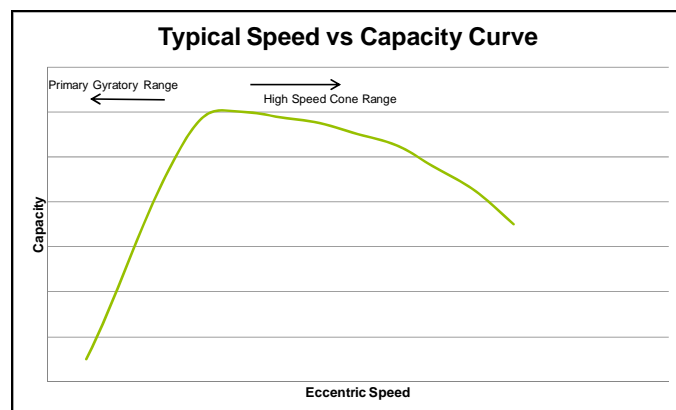


Figure 1. Typical Speed vs Capacity Curve for a Cone Crusher.

As can be seen by the curve in Figure 1, for a high speed cone crusher the volumetric capacity of the machine should decrease as the eccentric speed is increased (all other things considered equal). If this were the only important output, it could be deduced that operating at

the lowest speed possible would yield the best outcome. However, the speed also affects the number of crushing zones and how the particles drop through the crushing zones; so for a given closed side setting, varying the speed will change the reduction (discharge size distribution), power utilized, and particle shape of the discharge. A higher eccentric speed can result in an increase in the number of crushing zones and more impact in the parallel zone (lower portion of chamber). Lowered speed and the increase in capacity also results in an increase in work being done, which is seen in the power utilized to operate the crusher. Finally, increasing the quantity of crushing zones down a chamber in effect decreases the reduction in each zone, which is beneficial to particle shape and can reduce the resultant crushing force.

There will be limits on what can be done with the crushers. The first limit is the volumetric limit of the machine, which means the feed rate has met or exceeded the physical limit of how much material can pass through the chamber. This is considered to be the ideal situation for the crusher. The second limit is the power limit. Each crusher is designed with a certain amount of power transmission in the design, and exceeding this limit will put stress on the drive components. The third limit is the force limit; most crushers have a system to relieve the crushing forces to protect the frame and internal components. Exceeding the force limit can put stress on the machine and cause fluctuation in discharge size. The fourth limit is the mechanical design limit for a particular crusher. The lubrication, bearing surfaces, and drive equipment is designed based off of a specific speed range, and operating outside this range may cause fatigue stress or failure of crusher components. These four limits will need to be monitored and adhered to during operation.

One final factor towards cone crusher production is the level of material that is filling the chamber, or what is referred to as cavity level. As the cavity level increases in the crushing chamber, the bed of particles above the chamber help to push the ore through the chamber and increase interparticle comminution in the chamber due to elevated particle density (Jacobson, 2010). In many mining operations, due to fluctuating size distribution of the run-of-mine, changing ore characteristics, plant design, and production requirements from the crushing section there is simply not enough feed to effectively and consistently keep the crusher choke fed. This leads to a decrease in overall productivity and efficiency of the cone crushing station. This situation was specifically simulated in this study to measure the benefits that can be seen in these conditions.

Using eccentric speed to manipulate production as part of a monitoring and control system has been documented, with a study on the use of dynamic control of the eccentric speed to increase production and liner life for a 300 horsepower cone (Hulthen, 2011). There are also many instances where a simple change to a different speed has increased production over the originally installed speed, as well as adjusting speed based on production demands.

PILOT TEST PROCEDURE

The research was performed in Tampere, Finland at the Metso Minerals Research Center using an HP200 cone crusher. This study can be separated into three groups of testing: base tests, fixed tonnage tests, and feed size distribution effect tests. The base tests were used to measure the crusher's maximum performance for a given eccentric speed. The fixed tonnage tests simulated operating conditions where the feed rate to the crusher is limited below the maximum capacity based on the base eccentric speed and CSS. A third set of tests utilized a different feed size in order to verify results as well as reducing the effect of top size particles possibly being inhibited to enter the crushing cavity.

The tests in each group used the same, homogenous feed of known characteristics, with a feed sample being taken approximately every fourth test for verification. All product belt cut samples were taken using accepted sampling standards, with product samples being collected for every test. Crusher adjustment ring vibration and countershaft speeds were measured and recorded, along with crusher power draw, both average and instantaneous peaks and valleys. The

throughput of each test was taken from two calibrated belt scales and from belt sample weight. Pictures and videos were taken during each test to visually record cavity levels and flow through the chamber.

An open circuit configuration was used in every test to ensure consistent feed properties. A local volcanite of known properties (medium-hard hardness, medium density) and specific size fractions was used for all tests. The crusher was set up with a smooth liner configuration; a stepped liner profile is common for secondary crushers, but these profiles can result in a situation where particles can have difficulty passing a step if the speed is at a critical point. The tests were completed over a four day period. At every step, care was taken to ensure homogenous feed conditions and fixed testing parameters (outside of the eccentric speed).

For the base tests, a coarse feed of an approximate size of 90 x 20mm was used for testing. The base tests were run at two different CSS; one near the minimum setting, 19mm, and another near a typical operating setting of 32mm. Eight tests were run at the CSS of 32mm, with each test operating at a different countershaft speed. A consistent cavity level of 300mm over the feed plate was used over the course of the eight tests. This procedure was repeated with a 19 mm CSS at five speeds determined from results of the first set of testing, as well as a 25 mm CSS to be used for comparison with fixed tonnage tests.

The fixed tonnage tests used the same feed as the base tests. For these tests, the fixed tonnage (fixed feeder speed) was chosen based off of results from the base tests; the goal then was to achieve a full cavity at the highest eccentric speed. The theory would be that as the eccentric speed decreased and the volumetric capacity increased, the cavity level would decrease inside the crusher. The fixed tonnage tests were carried out at 19 mm and 25 mm CSS, at a minimum of 4 different speeds that covered the majority of the design speed range for the crusher.

The feed size distribution tests were conducted using a finer feed fraction (56 x 13 mm). The purpose of the test was to verify the previous tests and check for irregularities due to a particle feed size and crushing chamber combination. Also, with a finer feed and a relatively coarse cavity, these tests would theoretically eliminate the inhibited flow that can be seen when a coarse particle has difficulty entering a chamber. These tests were conducted at four speeds over the crusher design range.

PILOT TEST RESULTS

The results of the pilot testing will be discussed in this section. To show indicative values, all results are given in a relative percentage from a referenced test result. The referenced test result in the case of base testing will be the countershaft speed that would most often be chosen for a generic greenfield crusher installation, and for the fixed tonnage testing the reference speed will be the highest speed tested. In most cases, the comparative values showed clear trends and gave results that match theory. Since many of the measured results are related, a brief explanation of each performance indicator will be given followed by a more in-depth study of the test results.

Before examining the test results, comments on the test procedure and sample accuracy should be made. Most of the data showed clear trends in capacity, power, and discharge size distribution as the eccentric speed was varied. There is a presence of outlier points that do not fit a liner trend, and these are an indication of small fluctuations in feed size, flow through the chamber, or sampling error. Verification samples were randomly collected, and belt scale readings were analyzed to check for system stability and consistency of crusher discharge; crusher discharge will inherently contain small fluctuations in instantaneous discharge but overall the sampling error was found to be minimal and within industry pilot testing (controlled environment) standards. Small fluctuations in feed size to the crusher were observed, however the calculated standard deviation of 2.9 mm for an average Feed Equivalent of 47.1 mm indicates relatively homogenous feed throughout. The final source for deviation of overall trends is changes of crushing zones and flow through the crushing cavity; this has been observed in field applications and in simulation results.

These small irregularities need to be accounted for when determining optimal eccentric speed to operate with.

Base Testing Results

For the base testing where each test was operated at the optimal cavity level to develop a baseline for maximum production, the results matched theory. As the eccentric speed was increased the capacity decreased in a nearly linear (but not proportional) manner. On average, the total capacity tph fluctuated by 22.5% over a design speed range of 34%. Concerning the reduction through the machine, the trend shows a slightly finer discharge as the speed increased, with several exceptions at transition points that may indicate a shift in crushing zones through the chamber. The increase in capacity but decrease in reduction as the speed is lowered results in relatively low changes to power draw. These basic results are shown in Figure 2.

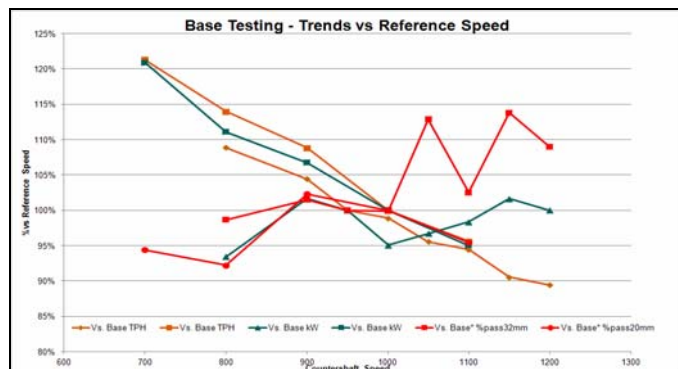


Figure 2. Base Testing – Trends vs Reference Speed.

In order to obtain a more complete value to compare crusher set ups, the production of theoretical products and specific energy to produce these size fractions is analyzed. For the base testing with a full cavity throughout, it was seen that there were slight benefits in both tph of product produced and specific energy to crush down to those product sizes when the crusher was operating near the minimum design eccentric speed. In essence, the higher capacity outweighed the slight loss in reduction through the machine, and the machine was more mechanically efficient at the lower speeds, though there were again data points that did not match the overall trend. In general, if there was not a limit on tonnage to the crusher it was best to operate near the low end of the speed range. These are shown in Figures 3 and 4.

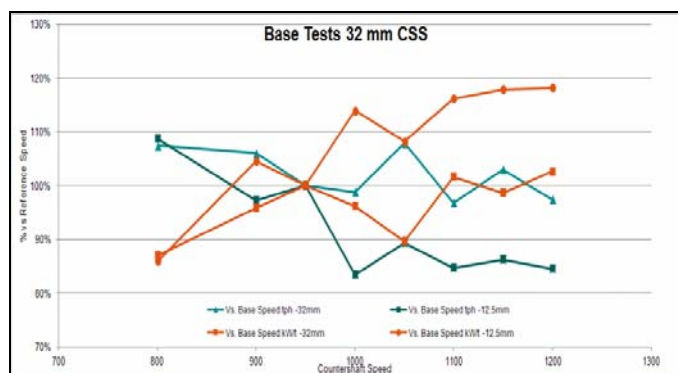


Figure 3. Production and Specific Energy of Theoretical Products – Base Tests 32 mm CSS.

Fixed Tonnage Test Results

The tests operated at a fixed tonnage were conducted to simulate a crushing application where the crusher is not the limiting equipment; therefore, the tonnage to the crusher is fixed by other plant limitations and the crusher cannot normally achieve a full choke fed condition. In the base testing, the only variable was the eccentric speed; in the fixed tonnage testing, the eccentric speed will be the only variant in crusher setup but the operating conditions will fluctuate as the cavity level of the crushing chamber raises and lowers.

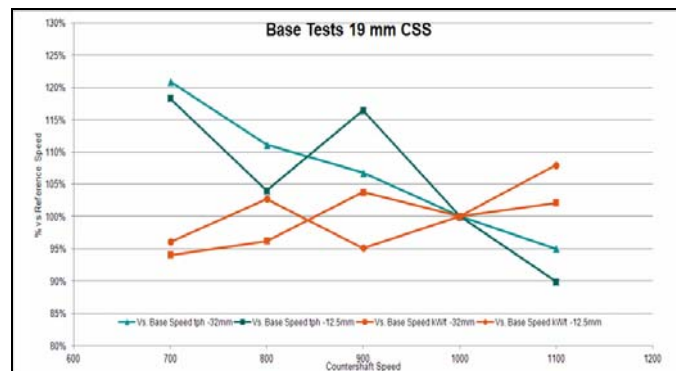


Figure 4. Production and Specific Energy of Theoretical Products – Base Tests 19 mm CSS.

For the fixed tonnage tests, there is no need to evaluate pure crusher throughput other than as a measure of how consistent the tonnage was for each corresponding test. The power draw of the crusher dropped heavily as the speed decreased, resulting in a lower kW/t specific energy through the machine. However, there was a major shift in reduction through the machine so the production and specific energy of theoretical products should be used for evaluation. When looking at the production of minus 32 mm product, there was very little difference. This product size is difficult to evaluate in this block of tests due to the relatively tighter CSS compared to 32 mm particles size; however, it does give an indication that the effective top size of the discharge did not fluctuate greatly throughout the fixed tonnage testing. The focus then is put on the 12.5 mm product. The tph of minus 12.5 mm produced fell slightly as the eccentric speed reduced from reference speed by approximately 20%, after which there was a trend for a large drop off in production at the lowest speed (see Figure 5). The latter phenomenon occurred at a point where the cavity level in the crusher could not fill up half of the crushing chamber and the discharge became much coarser. The investigation of the specific energy for the 12.5 mm product was not as conclusive and even showed a slightly lower specific energy as the slower speeds. While operating with a higher cavity level was more efficient, the crusher was also more mechanically efficient at the slower speeds. It should be noted, however, that the power drawn during operation was much more stable at the higher speed (higher cavity), which will be discussed in the next section.

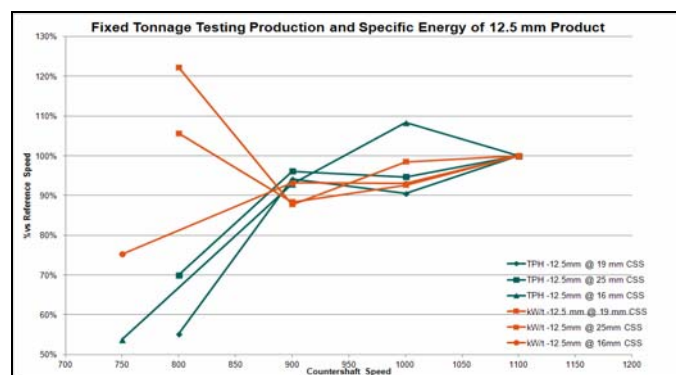


Figure 5. Production and Specific Energy of Theoretical Product – Fixed Tonnage Tests.

Going to a finer product (minus 6.3 mm) shows similar trends as above, but with slightly more irregularity. It should be noted that the results of the fixed tonnage tests did not give a linear relationship and in many cases there were data points that did not follow the overall trend; these occurred even outside of possible statistical error, which is another indication that the flow and crushing zones through a cone crusher cavity have an effect on production and speed changes will not always act as expected if using overall linear trends.

Another operating condition that was studied in this test work was the fluctuation of the power draw of the crusher. Power spikes are

detrimental to the efficiency of the crusher and can make control logic more difficult; therefore, a steady and controlled power draw is preferred. For the sake of this paper, we will look at the standard deviation of the power draw and the magnitude of the highest power spike during normal crushing (shown as %max kW in relation to average kW). For the base testing (full choked chamber on all tests), the higher speeds had a slightly lower standard deviation and %max kW than the lower speeds but the difference was only slight as the full chamber allowed for steady flow through the cavity. For the fixed tonnage tests, however, there was a marked improvement in the variation of power draw as the speed and cavity level increased.

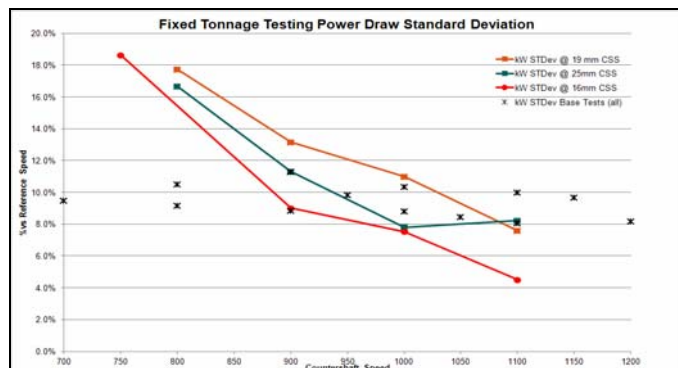


Figure 6. Fixed Tonnage Testing Power Standard Deviation (Base Tests shown for reference).

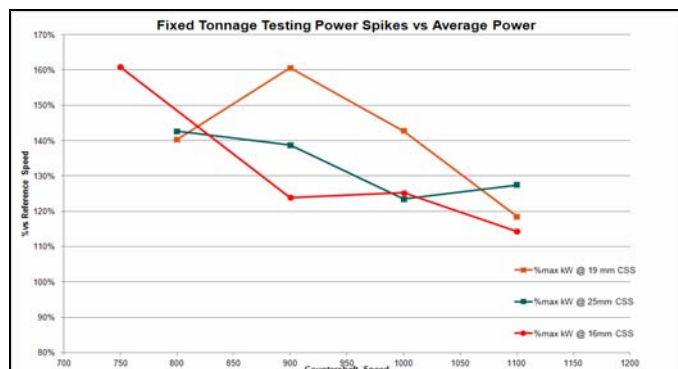


Figure 7. Fixed Tonnage Tests – Power Spikes vs Average Power.

PRACTICAL APPLICATION

There are a number of uses for these principles in a crushing plant. The main three points of discussion will be changing speed to find a more optimal operating setup than strictly as supplied from the factory, manipulating the speed based on current static plant conditions, and dynamic control of eccentric speed in a control system.

The vast majority of cone crushers are supplied with a specific motor speed and sheave combination to operate at a fixed speed. The speed initially chosen is based on simulations, liner selection, experience, and very often by using assumed values for feed size, hardness, and other operating conditions. Unfortunately, many crushers operate at non-optimal speed either from the beginning, or after feed conditions from the mine or production requirements change. In this study, we looked at the production and efficiency of the crusher while operating at a reference speed (as in the speed that the crusher would supplied with based on assumed operating conditions) against the rest of the speed range. Interestingly, one set of tests from the base testing showed that the reference speed would have been the correct speed (highest production with similar power draw to the other speeds). The other set saw marked improvement by going to a slightly slower speed than the reference speed; in this case, a similar discharge size distribution was achieved at the slightly lower speed while increasing throughput 9% and increasing production of minus 12.5 mm by 16%, at the expense of 11% higher power draw. In field cases where the speed was adjusted after initial installation the final

speed typically showed marked improvement over the initial speed, as most instances where the speed was changed had installed speeds which were mis-applied to begin with.

As long as the plant exhibited these feed conditions consistently, this increase in production and efficiency could be realized over long term operation. However, as a mine progresses and ore properties, blasting techniques, and crushing requirements vary over time, there is room to increase crushing production by occasionally auditing the plant and determining optimal operating speed for the cone crusher(s). These simple changes are often not investigated, as testing typically would require changing sheaves and belts on the drive system which can take hours away from production. However, the possibility to optimize eccentric speed may be of benefit as feed conditions and plant requirements change.

The third application, using a variable frequency drive to dynamically manipulate the eccentric speed of a cone crusher, has not been widely tested in large scale metallic mining applications. This approach was documented in the Hulthen paper for an aggregate plant where speed and CSS were adjusted for liner wear, among others. By observing the results of the speed testing in this study, it can be shown that operating at varying speed can have benefits to production rates and energy efficiency. For example, when the throughput requirements of the crusher are high it could be operated most efficiently in the lower speed range; if the throughput requirements drop for a short period of time, it would then be more productive and efficient to increase the speed of the crusher and operate with a fuller chamber. For cone crushers with non-dynamic CSS adjustment, the speed can be varied to account for a certain degree of liner wear. An underlying benefit for greater control of the crusher operation is maintaining a choke fed condition, which has benefits to production, operating cost, and the mechanical health of the crusher. The control logic would appear to be straightforward: monitor the power draw, cavity level, and tonnage rate and adjust the speed accordingly. However, there needs to be consideration that the measurements read for power, capacity, and cavity level may not follow exact trends and certainly will not be perfectly linear.

CONCLUSIONS

The focus of the study was to determine the effect of manipulating eccentric speed for a specific cone crusher on the production and other operation results. The paper highlighted relevant results and how they can be used to increase production, energy efficiency, and improve mechanical operation of production cone crushers. The main benefits would be to apply the optimal speed for long term operation of the crusher, to adjust the speed periodically to account for changing ore/feed conditions, or to use the speed as a dynamic input parameter into a control system to continually react to changing feed characteristics due to plant fluctuations. While manipulating speed had a great benefit on allowing for a more consistent power draw with fewer spikes, any control logic must still consider that the relationship between eccentric speed versus capacity, power draw, and cavity level will not always be consistent or linear due to changing flow patterns through the crushing cavity.

ACKNOWLEDGEMENTS

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