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AUTOMATED CONDITION MONITORING OF MILL BALL SIZE DISTRIBUTION AND GRATE OPEN AREA

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ABSTRACT

Grinding media in coarse grinding tumbling mills constitute the biggest consumable cost to a comminution processing plant, therefore it is critically important to minimize associated wear. Secondly, efficient grinding is dependent on tight control of the desired ball size distribution, or else optimum impact breakage can not be assured. Despite the significance of monitoring ball size distribution for mill operation, no practically deployable systems are currently in industry use to measure it. This paper describes a new method for highly accurate, comprehensive, and rapid determination of ball size distribution.

Accurate SAG and AG mill product size control is dependent on appropriate Grate Open Area dimensions. Wear of the grate hole edges or in the plate thickness results in an increase of the open area due to the tapered hole cross section, which can result in oversize product exiting the mill. Conversely, some grate castings feature peening of the edges during mill operation, thereby decreasing open area, and therefore preventing the desired top size product from exiting the mill.

SAG mill throughput requires grate holes to remain open or else throughput is restricted. Many grates in operation are pegged by grinding media to varying degrees of severity. This paper introduces a comprehensive, accurate and rapid method to measure and track the size and pegging status of each and all grate holes in situ, and therefore provides tracking information on the Open Area of a SAG mill. This enables operators to control the primary mill product size and therefore the opportunity to stabilize downstream processes.

INTRODUCTION

Scanalyse Pty Ltd has been developing laser scanning based mill condition monitoring and optimisation techniques and associated software tools as presented at minerals processing conferences since 2006 [2, 3, 4, 5, 6]. The applied method of laser scanning and associated data capture relating to grinding mills produces a complete and highly detailed three-dimensional surface representation of the mill liners, and of the mill charge [4, 5, 6]. Once adequately pre-processed, such data forms the basis for a range of specific dimensioning and quantification output that is essential for precise operational control of a mill, and also for mill optimisation tools such as Discrete Element Modelling (DEM). To date, DEM had to rely on a number of input parameter estimations [1] due to the lack of precise and readily available measurement alternatives. This paper describes two new MillMapper™ output measurement parameters that can be utilized for the purpose, it introduces the latest functionality of ball size distribution and grate open area determination. Descriptions of these parameters are accompanied by associated results of rigorous accuracy checks.

Utilising such precise measurement data instead of estimated data will no doubt improve the validity of DEM. Whilst it is key to capture the physical phenomena of mill behavior in as much and as representative detail as possible, it is equally important to ensure that appropriately precise and representative input data is utilised. Else no matter how closely the model definitions represent actual mill behavior, the results will not represent a valid and therefore useful outcome. This applies to DEM in general, and to its aspect of breakage [7] in particular. Being able to precisely measure ball size distribution for use in DEM strengthens the validity of modelled breakage behavior. Similarly, being able to precisely measure open area strengthens the validity of mill product size and throughput modelling.

BALL SIZE DISTRIBUTION

The MillMapper™ ball size distribution algorithm analyses the scanned ball charge of a mill as shown in Figure 1 and outputs a set of extracted ball diameters within the software. This is achieved through a series of proprietary steps to segment the continuous point cloud coverage into subsets exclusively representing individual balls, without data omission weakening the subsequent sizing solution, or data commission introducing a sizing error. Following segmentation, each individual ball scan data subset is dimensioned through a least squares sphere fit as illustrated in Figure 3. Lastly, a series of automated proprietary filtering steps eliminates any inferior sizing output.

Algorithm extraction of ball size distributions as shown in Figure 4 achieves accurate results in an entirely automated fashion, with no manual operator interference required. It typically determines valid diameters of nominally between 1,000 and 2,000 balls for a SAG mill at all surface locations of the charge. Importantly, the position of each extracted sphere size within the mill is captured and visualized as shown in Figure 2. This allows for the detection of any potential location bias of particular ball sizes within the mill. The number of ball sizes determined far exceeds what can practically be achieved by manual physical ball measurements based on subjectively selected physical samples collected in the mill. Results are produced through post-processing, which does not affect the short mill downtime requirements of nominally 5 minutes to complete scan data collection. Overall, the MillMapper™ ball size distribution method is therefore supremely more representative.

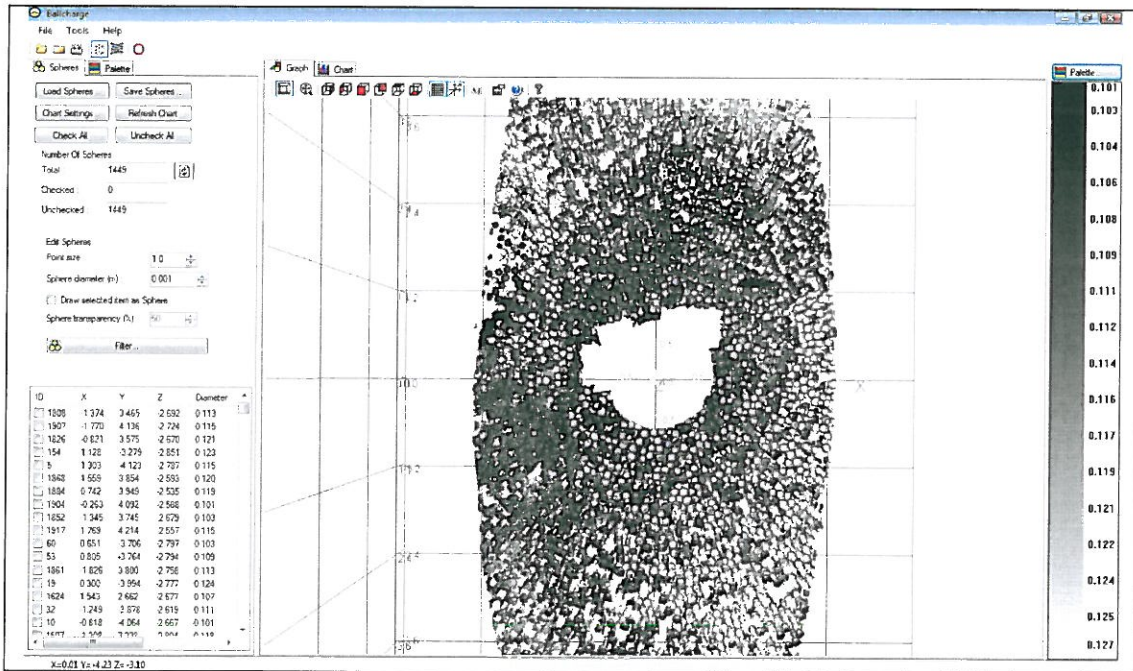


Figure 1: MillMapper™ ball size distribution software screenshot showing three-dimensional scan data coverage of a mill charge, tabulated extracted ball diameter sizes, and other output and functionality

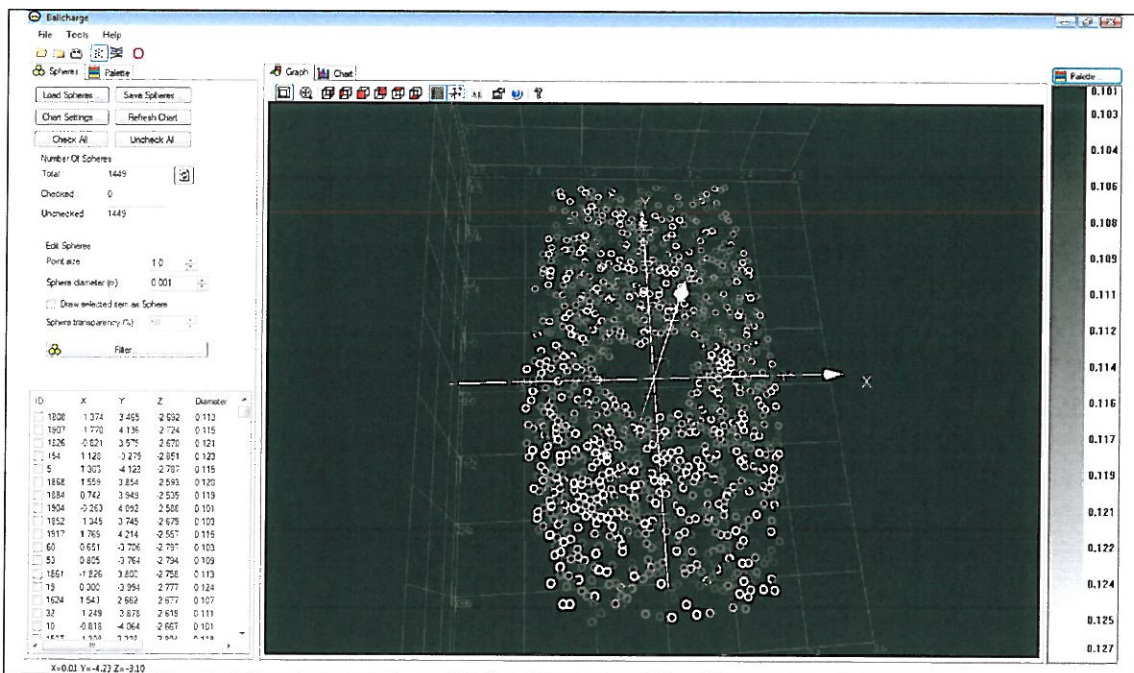


Figure 2: MillMapper™ ball size distribution software screenshot showing colour coded ball sizes at their actual location in the charge of a mill

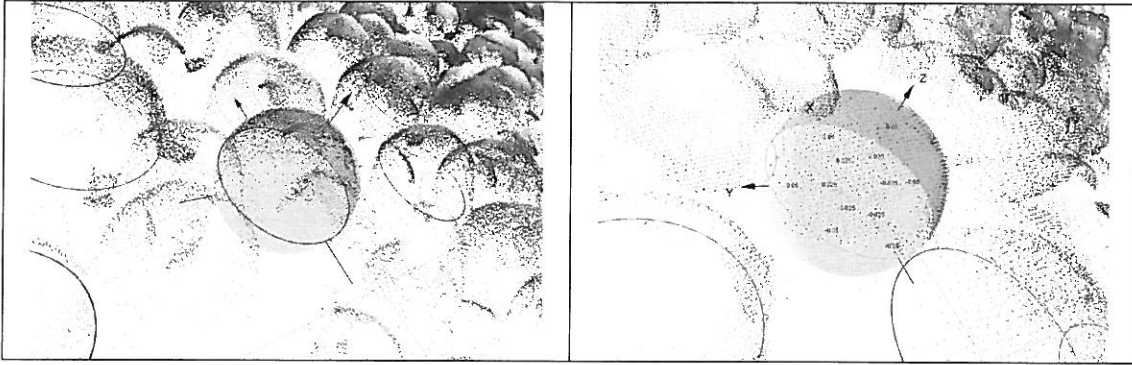


Figure 3: MillMapper™ ball size distribution software screenshots showing automatically generated and manually extracted spheres representing charge balls: scan point clouds used for extractions are visible in the background

Actual new or worn ball diameters along their respective three main axes may deviate from the perfect spherical shape due to the manufacturing process or wear characteristics. Nevertheless, sphere fitting does yield very accurate results as is demonstrated in Tables 1, 2 and 3.

Testing of the MillMapper™ ball size distribution algorithm accuracy was performed in two steps and is further detailed in subsequent paragraphs :

- 1) Comparison of automated algorithm ball sizes and calliper measured ball samples
- 2) Comparison of automated algorithm ball sizes and spheres manually extracted from scan data

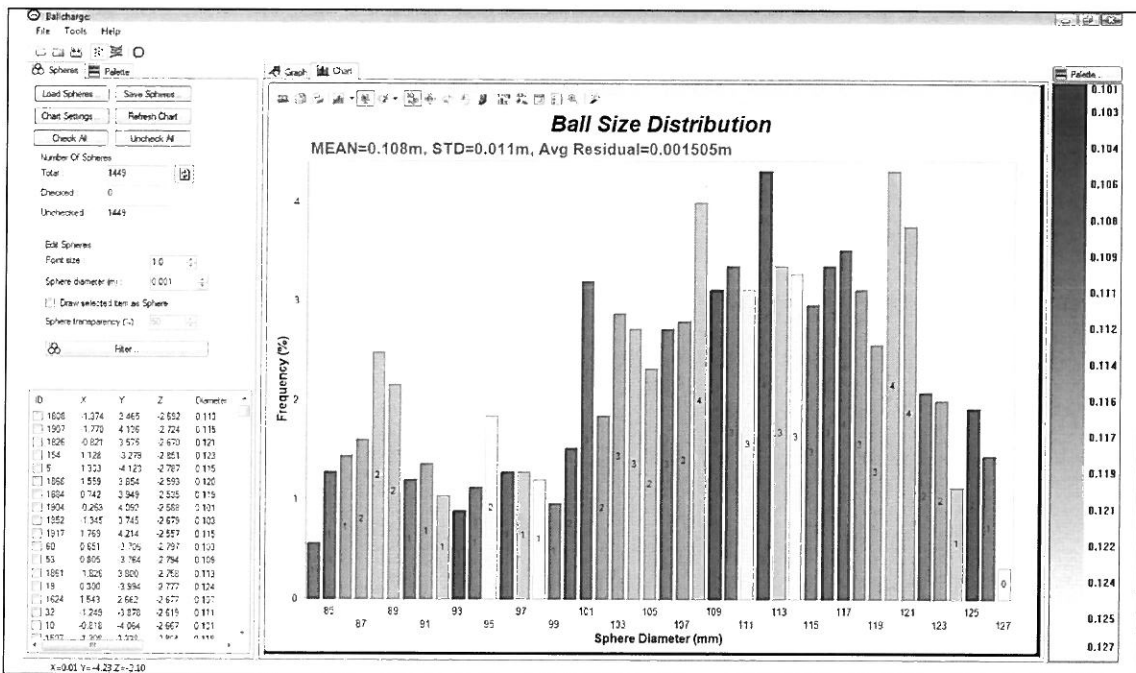


Figure 4: Sample MillMapper™ ball size distribution software screenshot showing extracted ball sizes for a total of 1449 balls

Algorithm to Calliper Ball Size Comparison

In order to validate algorithm ball size output, the diameters of a number of randomly selected balls were manually measured with engineering grade callipers along their respective X, Y, and Z dimensions during four regular MillMapper™ mill surveys. The same balls were identified in the scan data, and their diameters as extracted by the algorithm were compared to the matching calliper dimension, which is shown in Table 1. Note that the quantity of balls that can be calliper measured during a shut down is always restricted for obvious economic reasons by short available time frames.

Table 1: MillMapper™ algorithm to calliper measured ball size comparison

SAG Mill	Number Of balls assessed	Mean XYZ calliper diameter [mm]	Mean MillMapper diameter [mm]	Diameter difference [mm]	Standard deviation [mm]	Diameter difference [%]
KCGM Fimiston	5	107.73	107.20	-0.53	5.74	0.57
OZ Century	20	80.16	85.15	4.99	15.49	4.25
ADITYA BIRLA Nifty Copper	4	104.83	103.00	-1.83	0.96	1.89
OZ Prominent Hill	9	94.81	94.44	2.63	11.70	2.42

Table 2: MillMapper™ algorithm maximum ball size to calliper measured new ball size comparison

SAG Mill	Number of new balls calliper measured	Mean calliper diameter [mm]	Ball supplier stated new ball diameter [mm]	Largest algorithm diameter [mm]
KCGM Fimiston	10	126	125	125
OZ Century	35	95	105	101
OZ Prominent Hill	20	123	125	116

In order to determine the validity of top ball size determination by the algorithm, an additional check on a series of new balls was performed. The new balls were calliper measured in storage bins before comparing their recorded diameters to the extracted in situ maximum ball sizes for the applicable mill. The requirement was for maximum in situ ball sizes not to exceed associated calliper measured new ball sizes. The results for these comparisons are presented in Table 2. They

illustrate that from a total of over 1,000 algorithm extracted balls per examined mill, none exceeded the diameter size of a new ball.

Algorithm to Manually Extracted Ball Size Comparison

In order to strengthen the validity of accuracy testing of the comparison between algorithm and calliper ball diameters, a further test series based on the scan data was conducted. The procedure involved arbitrarily selecting a number of algorithm identified spheres for each mill. Sizes for these spheres were then manually extracted by using custom sphere editor functionality to achieve a visibly best fit to the scan data as shown in Figure 3. The operators performing manual sphere fitting had no knowledge of corresponding automated algorithm extracted ball sizes. Differences between the size of spheres as generated by the algorithm and by the manual editing procedure are shown in Table 3.

Table 3: MillMapper™ algorithm to manually extracted ball size comparison

SAG Mill	Number Of balls assessed	Mean MillMapper diameter [mm]	Mean diameter manual spheres [mm]	Diameter difference [mm]	Standard deviation [mm]	Diameter difference [%]
KCGM Fimiston	55	114.1	115.8	1.7	3.2	1.97
OZ Century	22	93.1	98.9	5.8	5.6	5.73
ADITYA BIRLA Nifty Copper	55	105.4	107.1	1.7	3.2	1.82
OZ Prominent Hill	44	99.3	101.2	1.9	1.7	1.92

OPEN AREA

The MillMapper™ Open Area algorithm analyses the size and the condition of each individual visible grate hole at the discharge end of SAG or AG mills and records the results visually as shown in Figure 5, and numerically as shown in Figure 6. Like all other MillMapper™ functionality this process is based on laser scan data input and is completed in an automated fashion. The steps involved are the identification of hole candidate locations, estimation of initial candidate dimensions and alignments, elimination of scanner noise data prevalent near hole edges and inside holes through proprietary filtering routines, iterative determination of final hole dimensions, automated identification of pegged holes, and output of all relevant statistics.

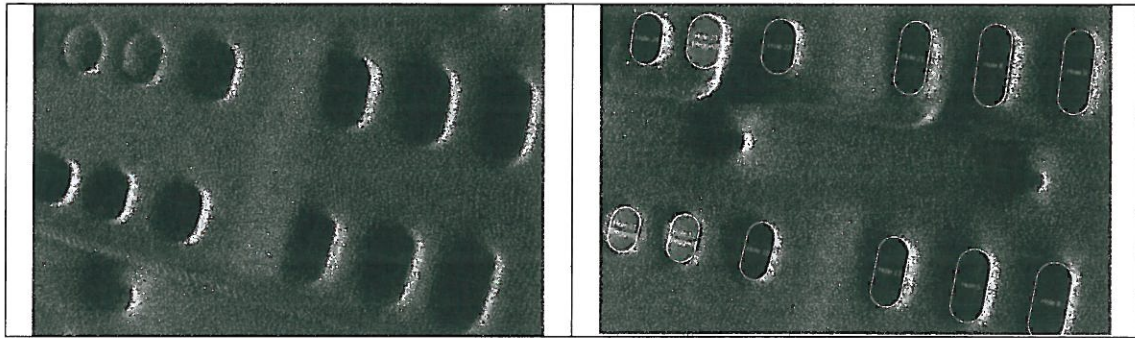


Figure 5: MillMapper™ open area software screenshots showing detail of a raw grate scan including two pegged holes (left) and extracted hole sizes and conditions (right) for a worn grate

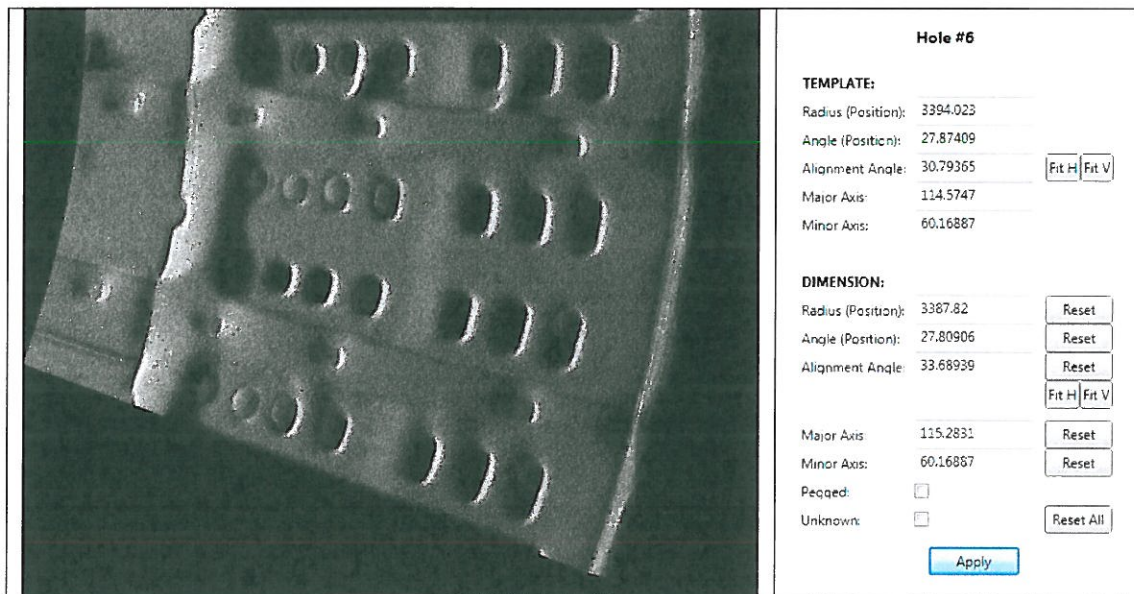


Figure 6: MillMapper™ open area software screenshots showing data for a full single grate (left) and extracted dimensioning information for one specific hole example (right)

As is evident in the example grates shown in Figures 5 and 6, grate holes are often pegged by grinding media. In severe cases this can significantly reduce mill throughput. The combined use of MillMapper™ open area and ball size distribution tracking functionality over time caters for the identification of particularly detrimental grate hole size and ball size combinations. Any localised spatial dominance of specific ball sizes near the grates may be of particular relevance in this context. In other words, if there are times during the life of the grates when pegging is more severe than during other times due to applicable hole size changes that cause an increase in pegging likelihood by a dominant ball size, it may be possible to temporarily vary the size of new ball additions as a countermeasure.

CONCLUSIONS

Two new MillMapper™ condition monitoring methods for the determination and tracking of ball size distribution and of open area have been presented. They are suitable as accurate mill operational management tools, or as input data for DEM, resulting in an increase in validity of such modeling work.

Presented algorithm to calliper measurement comparisons for four test mill data sets yield an overall ball diameter accuracy of 2.5 mm, which equates to an error of 2.28%. Comparisons between algorithm and manually extracted spheres yield a ball diameter accuracy of 2.8 mm, which equates to an error of 2.86%.

Ball size distribution output can be applied to establish the optimum ball addition rate for a mill, or to establish which supplier can provide superior grinding media wear behavior during media trials. In combination with open area output, it can be used to eliminate or minimize the severity of pegging.

Open area output and tracking can be utilized to strengthen the validity of mill modeling work undertaken in JKSIMMET or similar software. It may also be used to establish a suitable refine time for grate liners in time before SAG or AG product sizes deviate in excess of a set limit. This enables mill operators to avoid negative impact on downstream processing, or to avoid excessive regrind requirements.

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