Investigation and Model Validation of Media Motion in a Vertical Stirred Mill Using Positron Emission Particle Tracking

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Abstract *- One of the major growth areas within the minerals industry has been that of ultra-fine grinding. This Paper considers modelling the behaviour of a vertical stirred mill at a particulate level using distinct element analysis, with the first stage being the characterisation of the motion of the media within the mill. The analysis seeks to predict the motion of the grinding beads which determines the frequency and energy of the media collisions and so is crucial to the energy dissipation and breakage behaviour within the mill. Here we report on the use of positron emission particle tracking as a means of validation of the model. Initially two modes of motion were identified directly from the PEPT data and results are presented here showing the effect of impeller speed on the mode of motion. From the data directly a link between the media motion and the grinding action can be seen. The effect of different operating conditions including the media loading, slurry density and filling ratio will also be studied to allow validation of the model.*

Keywords: Modelling, Stirred Mill, Comminution, Positron Tracking

1. INTRODUCTION

Stirred Mills were first developed in the 1960’s for the size reduction of kaolin. They are simple in operation consisting of a grinding pot filled with spherical grinding media and slurry. A vertical impeller imparts motion to the charge causing size reduction. Plant scale mills are continuous in operation with a classification system integral to the design. Mills can be cascaded in series with different sized media to accept feed at 1-2mm and grind down to ~80% <2μm. Laboratory scale mills tend to be batch operated.

A considerable amount of research into stirred milling has been completed but mainly by the competing companies, consequently this information never entered the public domain due the grinding costs being a large proportion of the product value. Most of the work has been empirical, the fundamental aspects of the process are still unknown. This paper presents the early results of simulating the grinding process on a fundamental level by using the distinct element method of simulation. It is hoped that the energy dissipation and breakage within the mill can be quantified in order to improve the energy usage of the system.

With the model in it’s early stages it was identified that a method of model verification was needed to prove the motion in the simulation was correct. The breakage and energy dissipation can be verified by examining the particle size distribution and energy draw respectively. Positron Emission Particle Tracking, (PEPT). By following the path of one irradiated grinding bead the simulated motion could be verified. It is well suited to applications such as mixing vessels[4], fluidised beds[5], hopper discharge[3] and rotating drums[6].

1.1 Positron Emission Particle Tracking

[1] The technique of Positron Emission Particle Tracking (PEPT), has been developed at Birmingham for process applications. It enables a single radioactive tracer particle moving inside a piece of equipment to be tracked accurately at speeds up to 2m/s, as reported in detail elsewhere.[7,8]

2. EXPERIMENTAL CONFIGURATION

The mill used for the testwork was supplied by English China Clays International. As shown in figure 1, it is a laboratory scale mill with a grinding pot volume of 2 litres. A central pin type impeller with two sets of 90° offset pins driven by a single phase motor stirred the charge. Rotational speed of the impeller is controlled by a digital control system. No wear liner was needed as the pot was made from polyethylene rather than steel. This also had the benefit of attenuating the X-rays to a lesser degree. To estimate the energy input the mill is located on a frictionless platform which is free to rotate. The torque reaction from the mill is measured by a load sensor, this signal being converted to an energy reading by a separate integrator.

The charge to the mill consists of two main phases;

1. **Grinding Beads** – The spherical beads used were made of silicon/zirconium alloy. Approximately 1-2mm in diameter with a high hardness (740 Vickers) and density (4200 kg/m^3)
2. **Feed Slurry** – Pre-milled calcium carbonate powder (99% $CaCO_3$) with a 50% passing size of 18µm. Slurried at various pulp densities with water, some with dispersant added, (Dispex N-40)

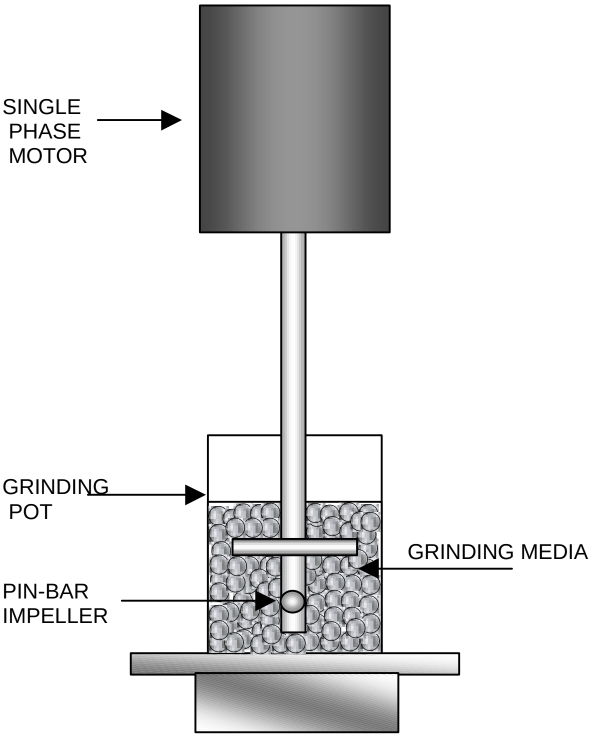

Figure 1: Schematic Diagram Of Stirred Mill

To enable the pot to be removed from the mill the bottom platform rotated out. This forced the mill to be positioned off centre between the two detector plates. To move the plates and realign the mill after each test run would have taken too much time to be feasible. For each test the required amount of beads, carbonate and water were measured and added to the mill. The irradiated bead was added and the mill started for 5s at minimum speed to homogenise the charge. With the detectors running the mill was started and run for the desired duration. After this, the pot was removed and washed out, the irradiated bead recovered and it's activity checked. Fresh charge would then be measured for the next test. This procedure would continue until the bead's activity dropped below the accuracy limit.

Initial testwork investigated a range of operating conditions within the mill in order to establish the limits of the controllable variables The first sets of tests were conducted as a two-phase mixture of grinding beads and water in differing proportions. The next set of tests varied the impeller speed, pulp density of the limestone feed slurry, total mill filling level and bead fraction. Finally the effect of dispersant was investigated by adding three concentrations of dispex to the calcium carbonate slurry prior to grinding.

To fix the position of the mill geometry in the camera several calibration runs had to be completed. This involved taking a radioactive point source and attaching it to various points on the pot and impeller.

3. INITIAL RESULTS

The trajectory of the irradiated bead is recorded as a set of co-ordinates at a particular time interval, together with an error value in millimetres derived by the positioning software. The time interval is not constant as it depends upon the number of events recorded by the detectors for one position. Typically the time interval was 10-15 ms.

Proprietary software from the University of Birmingham (*TRACK*) was be used to analyse the bead motion. There are four main ways to view the data, these are described below.

3.1 Displacement Graphs (Fig. 2)

The displacement of the particle in either cartesian or radial components can be viewed graphically.

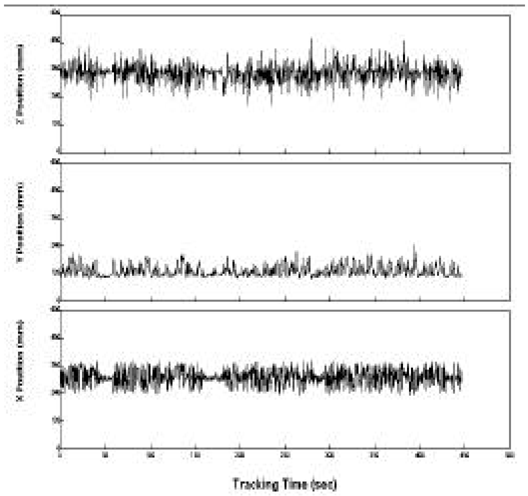

Figure 2: Displacement Graphs

3.2 Real Time Motion, (Fig. 3)

The motion of the irradiated bead can be viewed in real time on three sets of axes.

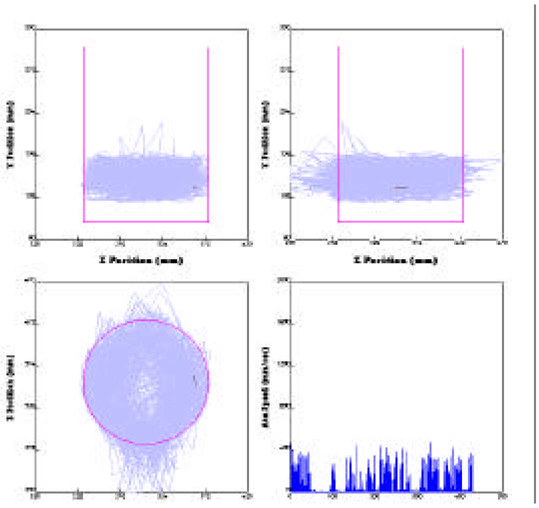

Figure 3: Real Time Motion

3.3 Occupancy Graph,(Fig 4)

The time spent by the particle in a location as a fraction of the run time is represented by a greyscale plot on the three axes.

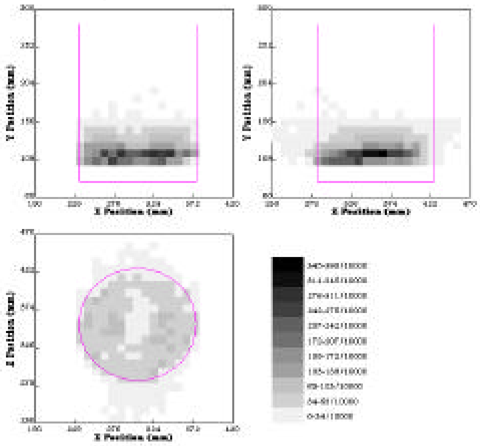

Figure 4: Occupancy Chart

3.4 Velocity Profile, (fig 5)

The component velocities and average speed profiles can be viewed.

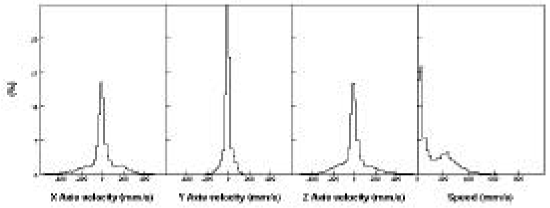

Figure 5: Average Velocity Profiles

3.5 Data Screening

By viewing the real time motion of the trajectories for all of the tests it could be seen that the resolution of the data in the Z direction was poor. The Z direction being with the detector plates facing each other. The irradiated bead moved out of the boundary of the mill shell and the centre of motion was shifted from the centre of the mill. Overall the Z-component of the trajectory seemed ‘stretched‘, the effect increasing with impeller speed. This was due to the positioning of the mill, the highest resolution of the camera is at a central point between the plates. Also the speed of the bead was close to the maximum limit of detection, the reconstruction algorithm tended to ‘shift’ the position of the bead towards the centre in the Z-plane.

To overcome this problem in the data a data manipulation program was written inhouse. By transforming the motion into vertical slices each slice can be corrected in the Z- direction by comparing the data with the X- direction co-ordinate and the reference of the mill and impeller geometry. Figure 6 shows the manipulated data.

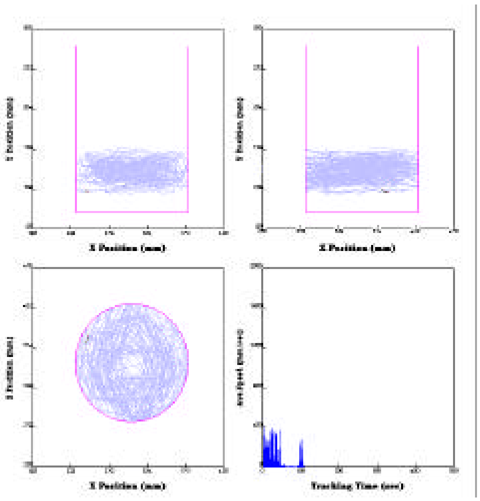

Figure 6: Manipulated Motion Data

Two generalised forms of motion could be seen at this stage;

Wall Mode – The bead moves slowly in a circle around the base of the pot following the impeller

Impeller Mode – The bead travels quickly in a helical path up into the top of the bed.

These two types of motion can be seen most clearly comparing the X and Y displacement graphs, figure 7

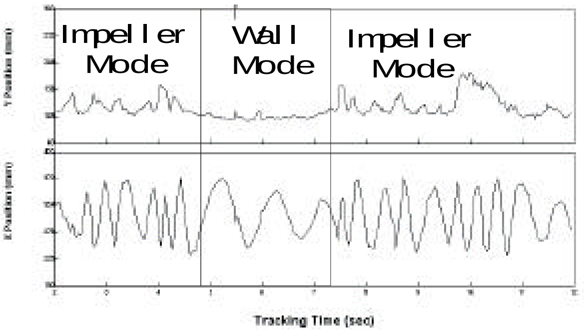

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Figure 7: XY Displacement Graphs

By comparing the X and Y data the motion can be classified. Figure 8 shows the percentage no of events recorded in impeller mode as a function of impeller speed. As can be seen from the graph with increasing impeller speed the amount of time spent in impeller mode increases.

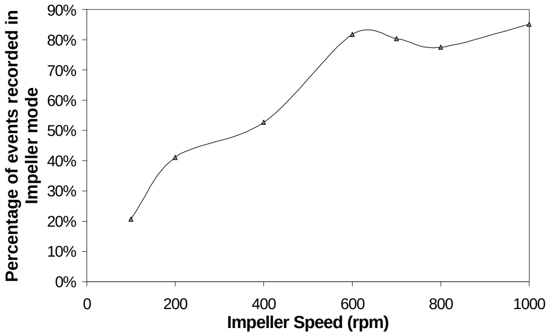

Figure 8 : Impeller Mode Trend.

The graph peaks at 600rpm and then is relatively constant. From practical testwork it has been found that most efficient grinding takes place after ~600rpm, this thought to be due to sufficient grinding action caused by relative motion between the beads. This suggests that the majority of grinding action occurs when the beads are in impeller mode. More analysis needs to be completed to see the influence of other variables on the mode of motion, but this is a direct correlation from the PEPT motion data and the physical system.

4. THE DISTINCT ELEMENT METHOD

To model the motion of the grinding beads a computer model utilising the distinct element method is used.
The distinct element method is a special class of numerical scheme pioneered by Cundall and Strack [1] for simulating the behaviour of large discrete, interacting bodies. The numerical algorithm is very simple. Every sphere in the assembly is identified separately by its radius, mass, moment of inertia and contact properties. For each sphere a list of spheres in close contact is maintained. Therefore in order to find out which other spheres are in contact with it only that spheres list has to be checked. When there is contact between spheres then the normal and shear forces at the contact are determined from the magnitude and rate of overlap. The forces are resolved to determine the energy of impact and the net resultant force acting on the particle. From this force, the acceleration, velocity and displacement of the sphere is calculated. This procedure is carried out for all the spheres in contact. This methodology has been used extensively to predict behaviour of Fluidised beds[9], jigging[10], conveyors[11], agglomerate fracture[12] and other particulate processes

The contact force model consists of a pair of damped harmonic oscillators: one perpendicular and one tangential to the contact plane. A slider is present to model the friction between the two spheres, as shown in Fig 9.

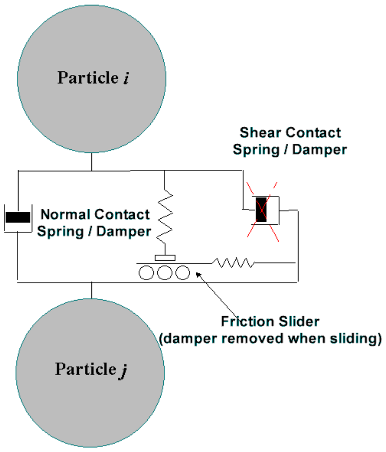

Figure 9: DEM Configuration

5. MODEL VALIDATION

The aim is to use the PEPT data to validate the DEM model, we hope to achieve this by using the following procedure.

By modifying the DEM simulation, the coordinates of one bead in the system are recorded. The bead chosen being approximately the same position as it's counterpart in the PEPT run. As the simulation progresses the co-ordinates of the simulated bead are recorded in the same format as the datafile used for the PEPT software interface. Hence a direct comparison using the same software can be made between the 'real' and simulated data. If the model does not prove to be accurate enough certain coefficients can be changed in order to 'tune' the model. These coefficients being the spring and damper coefficients of integration, the time step for interaction or the hydrodynamic properties of the system.

It is of paramount importance in all forms of modelling to validate the model. Otherwise the model has no application to a real system. In this case several methods of validation were considered such as Electrical Capacitance Tomography, Electrical Resistance Tomography, Optical tracking etc. but none could offer the advantages of PEPT. With PEPT the motion could be tracked using the same mill configuration as is used in real life, i.e. same media, carbonate slurry etc, rather than using artificial substitutes. Also PEPT is a non- invasive tracking system so the measurement of the system does not affect the motion of the beads.

In summary the technique of PEPT has provided a variety of data which can be used to validate the DEM model, as well as gaining an insight into the process itself.

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