2D DEM verification: Load behaviour and forces on a lifter bar

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Synopsis

The Discrete Element Method (DEM) is a model that is used to simulate the motion of the media in a grinding mill. The sum of the energy that is lost in inter-media and media-wall collisions represents the power drawn by the mill. The fact that the DEM predicts the power drawn by grinding mills over a large range of diameters has been used to show the validity of the DEM. However, the power drawn by a mill is a function only of the *sum* of forces of the load on the shell liners. A more accurate and detailed validation of the DEM would be to measure these forces as a function of angular position as the liner moves under the load, and to compare these measurements with predictions generated using the DEM.

An experimental mill has been developed to reproduce exactly what the 2-dimensional DEM simulates. The 0,55 m diameter mill has a length of 0,023 m, which is fractionally larger than the diameter of the media used in the mill. One of the lifters in the mill has been instrumented so that the forces on the lifter can be measured as the mill rotates. The DEM simulation will be used to predict these forces. This will give experimental evidence of the validity of the DEM for modelling load behaviour in rotating grinding mills.

Introduction

The Discrete Element Method (DEM) has become a popular method of predicting the load behaviour of grinding mills. However, very little work has been done to scientifically verify the validity of the DEM simulations.

The DEM is a computational method using the basic laws of the physics of motion and collision[1]. In particular the collisions are modelled with the well-known spring-and-dashpot model to account for the energy lost in the deformation of the ball surface at the point of collision and subsequent rebounding of the balls. A pair of spring-and-dashpots is used in the normal and shear directions to account for oblique collisions. Thus the collision of each individual ball with others and with the mill wall is computed, from which the *en masse* motion of the charge is computed and displayed on the screen. The method has until recently been used to compute the behaviour of a thin two-dimensional section of the mill containing one layer of balls; this is termed a 'two dimensional DEM'. (Mintek have recently successfully developed a three-dimensional DEM.)

As part of ongoing work at the University, this paper outlines new work that aims to verify the DEM. The forces on a lifter bar in an experimental mill have been measured. These will be compared to forces predicted by the DEM. To provide additional measurements of the load behaviour in the mill, the position of the load will be measured at points within the mill, in addition to the measurement of forces exerted on the lifter bar.

This paper describes some of the preliminary work done in this project and some initial results. This work is presently ongoing.

Apparatus

'Two dimensional' mill

The experimental mill has been designed to reproduce that which the two-dimensional DEM actually simulates. The mill has an inner diameter of 0,55 m and a length of 0,023 m, which is fractionally larger than the media diameter. Thus only one layer of 0,0222 m diameter balls is present in the mill. The mill sides are constructed of glass so that the load behaviour can be observed and photographed. Twelve square lifter bars are equally spaced around the mill circumference.

The torque is measured using a load beam attached to the mill motor. The mill and motor are attached to the supporting frame only by means of bearings and the load beam as shown in Figure 1.

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Instrumented lifter

One of the lifter bars has been mounted on a specially designed load beam so that forces can be measured in the radial and tangential directions using strain gauges, as shown in Figure 2. A gap was cut into the shell. The strain gauges are mounted (on an aluminium beam with an H cross-section) in the appropriate fashion to make available measurements of the radial compression and the transverse shear suffered by the beam. The lifter is attached to the top of this beam, while the base of the beam is attached to the mill shell as shown.

The strain gauges were connected to PC68 strain gauge bridge amplifiers (supplied by Eagle Technology) mounted on the mill shell. The –5 to +5 Volt signals were removed from the mill via a slip ring assembly mounted on the front of the mill.

Load position measurement

Traditionally, load position has been measured at the shell of the mill. The force beam ensures that the toe and the shoulder of the load can be detected. Nothing else about the load shape is known except through analysis of photographs of load behaviour in mills with transparent sides.

In order to get a quantitative measurement of the load position, infra-red light sensors were mounted on the glass side panels. These give an indication of the load shape within the mill. The sensors, A and B, are positioned so that they are at the centre of the second and fourth rows of balls from the mill shell respectively. The signals were transmitted from the mill via the slip ring assembly.

Experimental program

Calibration

To enable the comparison of the forces measured on the lifter to those simulated by the DEM, the instrumented lifter had to be calibrated.

The instrumented lifter has two sets of strain gauges. These measure shear and compressive forces on the h-bar respectively. Radial and tangential forces on the lifter produce responses from both sets of strain gauges. The relationship between the respective forces and the voltages produced by each set of strain gauges is as follows:

$$V_i = a_i + (b_{y,i}\, y_i + c_{tan,i})F_{tan} + (b_{x,i}\, x_i + c_{rad,i})F_{rad}$$

Where i:	shear or compressive
a_i, $b_{y,i}$, $b_{x,i}$, $c_{tan,i}$, $c_{rad,i}$:	constants
F_{tan}, F_{rad}:	Tangential and Radial Forces respectively [N]
x_i, y_i:	position of application of force [m]

The calibration was done by applying tangential and radial forces of varying magnitudes on various positions (A–F) on the lifter (see Figure 2). The resulting voltages were noted. By fitting the above model to the data, the constants for the model were found. Figure 3 shows the fit of the model to the data for the strain gauge bridge most sensitive to radial (compressive) forces. A similar fit of the model to the data for the tangential force measurements was found.

Experiments

The aim of the project is to gather data over a wide range of

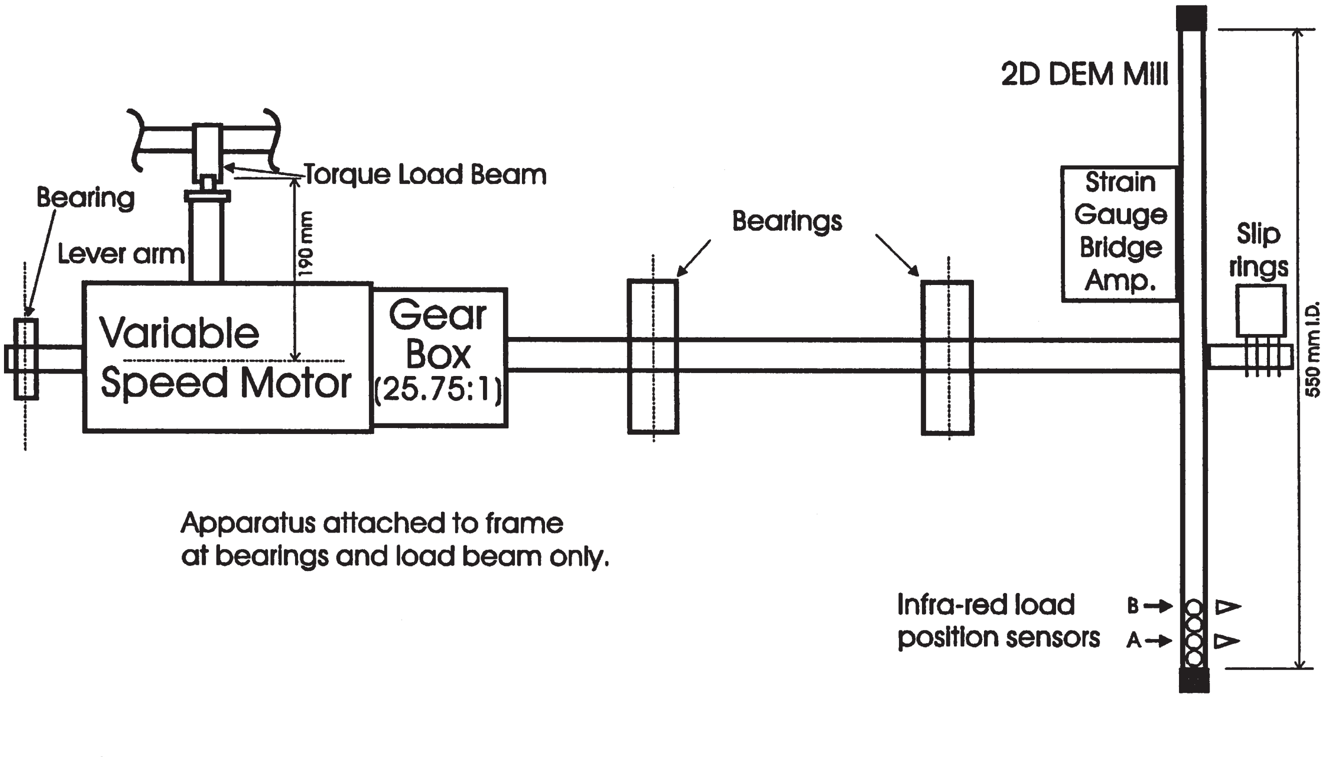

Figure 1—Schematic of the experimental apparatus

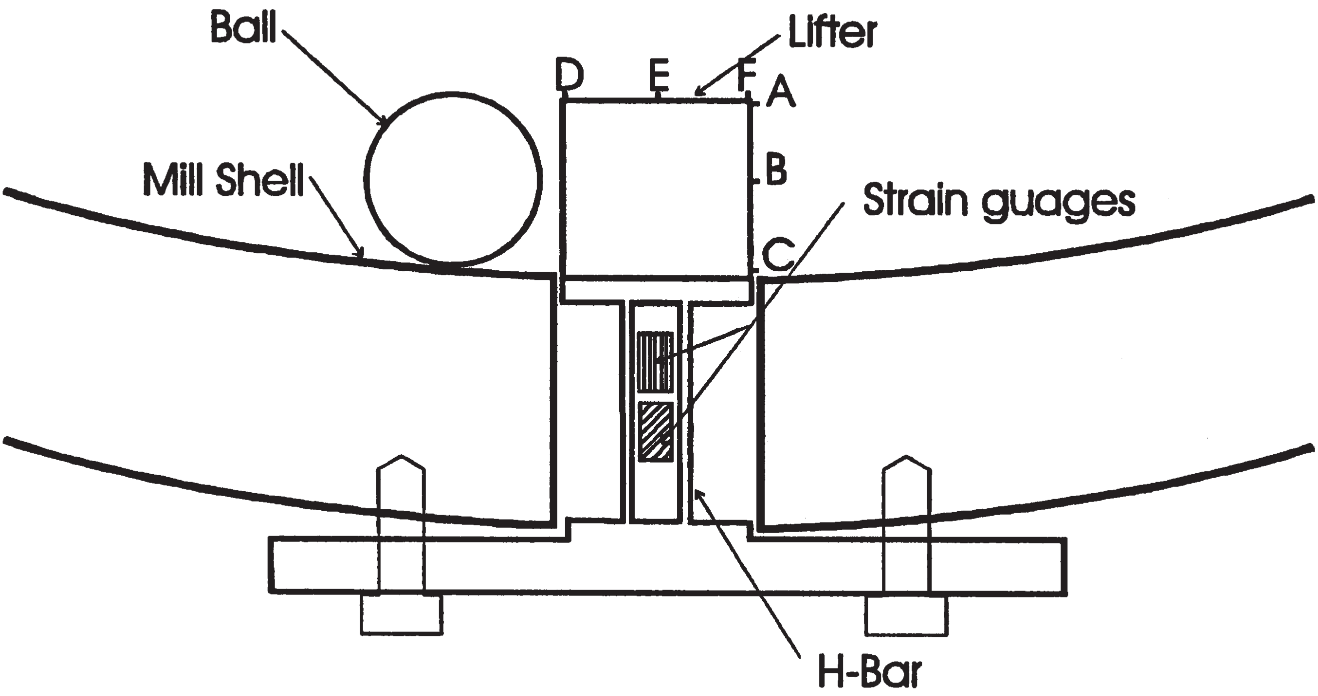

Figure 2—The instrumented lifter bar. Strain gauge bridges were mounted in such a way that compressive and shear forces could be measured. A–F indicate points of application of forces used to calibrate the strain gauge bridges

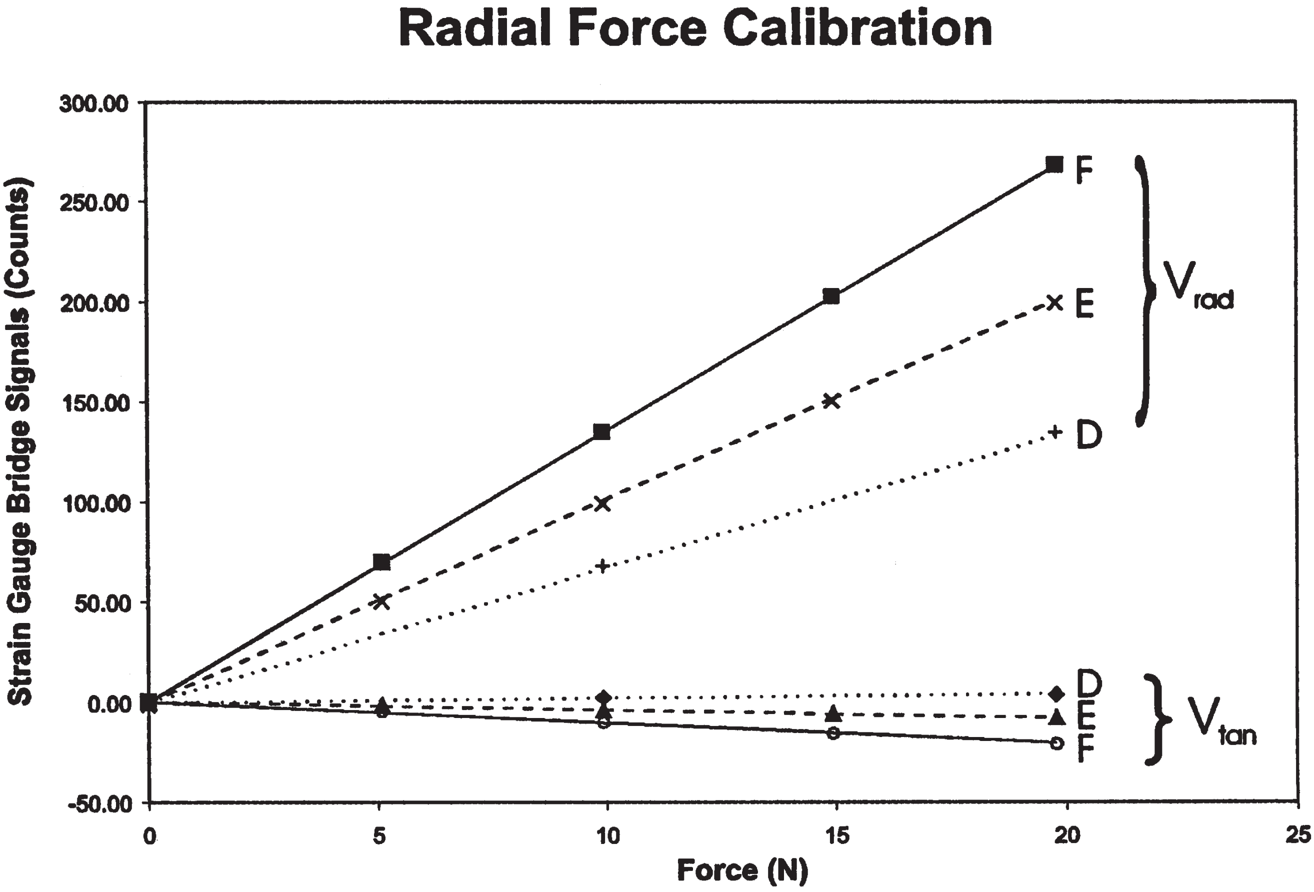

Figure 3—Results of the calibration of the strain gauge bridge attached to the lifter. Signals produced in this Figure were as a result of radial forces applied to the lifter. The lines represent the model fitted to the measured data points (symbols)

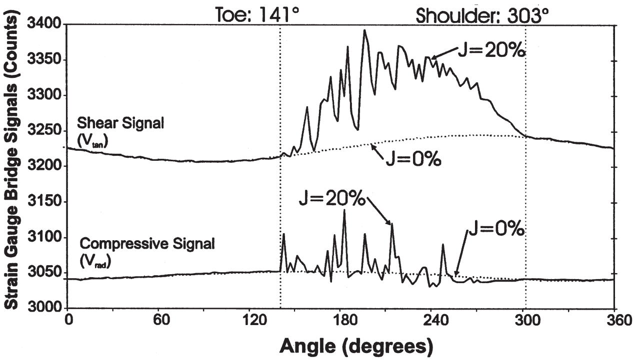

Figure 4—An example of the data collected from the strain gauge bridges. The mill was operated with 90° face angle lifters. These data were collected at a mill speed of 30% of the critical speed. Data were collected with the mill empty (J=0%) and with 96 balls (J=20%)

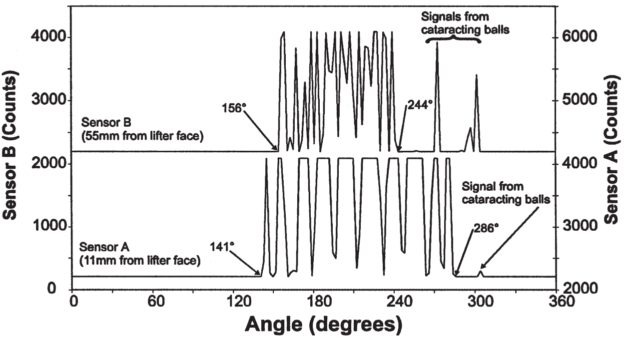

Figure 5—Data from the infra-red sensors at speed N=30% of the critical speed and filling of J=20%. These signals indicate load shape and the presence of cataracting

operating variables. These variables include mill filling (20% to 45%), mill speed (10%–200% of the critical speed) and, lifter profile (50° and 90° face angle).

Results

At this stage of the project only some preliminary measurements have been done. No simulation results were available at the time of publication.

Figure 4 shows the no load (J = 0%) and J = 20% responses from the strain gauges on the lifter for 1 mill revolution at N = 30%. The position of the lifter is indicated in degrees with 0° being at the 12 o'clock position.

The no-load curves are sinusoid as expected showing the effect of the weight of the lifter bar on the strain gauge bridge signals. The response of the strain gauge bridges to the load can clearly be seen. The toe (141°) and shoulder (303°) angular positions are readily detected. The compressive force signal, interestingly, is both positive and negative relative to the no-load signal. This shows the sensitivity of the strain gauge bridge to the point of application and direction of the force.

Indications of the load shape can be obtained from the response to the infra-red light signals. Figure 5 shows the light signal response to the same revolution of data as in Figure 4. The fact that the signals are so noisy is an indication of the slip in the load (if there was no slip of the layer of balls relative to the liner, the signal would either be 'on' or 'off' continuously). The 'toe' and 'shoulder' of each signal gives an indication of the shape of the load at the radial position of the light.

Some of the peaks show the presence of cataracting balls.

Conclusions

This work has demonstrated the ability to measure the forces exerted by the load on a lifter. These forces will be compared to those predicted by the DEM, providing a detailed validity check for the DEM.

Using infra-red detectors and emitters, information relating to the shape of the load can be determined. This gives fuller information regarding load shape than sensors mounted on the mill shell only. These data can also be used to verify the DEM by comparing the load shape predicted by the DEM with the measured data.

Acknowledgement

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Reference

1. Mishra, B.K. Study of media mechanics in tumbling mills by the discrete element method, Doctoral thesis, University of Utah, 1991. ◆