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Development of a pilot roller test machine for investigating the pulverizing performance of particle beds

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ABSTRACT

Various types of pulverizers are commonly used in power plants for the purpose of breaking coal particles into fine powders to achieve optimum combustion for the boilers. To investigate the effects of factors that may influence the pulverizing efficiency, this study presents the development of a pilot roller test machine, which can significantly simplify the grinding conditions in actual pulverizers whilst the key variables involved in a rolling compression can be considered. The monitoring and data acquisition systems allow real-time monitoring of the pulverizing induced roller movements. Through parametric numerical analyses on an elastic feed bed of 5–30 mm in thickness and 500–1000 MPa in elastic modulus, it is found that the machine is capable of providing a maximum contact pressure stress in a range of 4.5–17.5 MPa. A series of fundamental tests have been conducted by the developed machine using a type of bituminous coal and typical bound values of roller weight and speed. The size reduction results as well as the measurements of roller movement demonstrate the capability of the machine as a suitable tool for testing grinding performance. Some discussions of the potential extension of the machine are also given in the final part.

1. Introduction

Fragmentation or size reduction of brittle material particles by various types of compression loading is of considerable scientific and industrial interest, particularly within the disciplines of mining, civil, and chemical engineering. Typical processes include mineral processing, thermal power generation, cement manufacturing, and pharmaceutical processing. In mining industry applications, comminution of mineral blocks or particles for a finer powder, such as grinding of ores and mineral particles in pulverizer machines, is widely accepted as an energy intensive process and many efforts have been devoted to better understanding of the particle breakage behaviour and improvement of energy efficiency of comminution (Tavares, 1999; Schaefer, 2001; Bourgeois, 1993).

Single particle and particle bed breakage tests are commonly used for investigating the comminution mechanism in industrial operations (Liu and Schönert, 1996, Eksi et al., 2011; Barrios et al., 2011). Various compression testing methods have been proposed and applied to measure the breakage characteristics of single particle, which can be classified into single impact, double impact and slow compression according to the mode of application of stresses and the number of contact points (Gotoh et al., 1997). A comprehensive review of single-particle breakage tests was given by Sankara (1985). He compared the single impact, double impact and slow compression tests. The materials investigated varied from nearly defect-free materials, such as single crystals, to complex industrial granules. Similar to the basic mechanism of particulate attrition by Paramanathan and Bridgwater (1983), macroscopic effects of grinding induced size reduction may include particle impact on containing walls, particle to particle abrasion and fracture due to external stresses and internal stresses within the particles which form the bulk bed, whilst the microscopic effects include particle size, particle shape, particle structure and adhesion behaviour. A list of techniques commonly employed for testing the susceptibility of particles to attrition were summarized by Bemrose and Bridgwater (1987).

Vertical roller mills have been well accepted for grinding of cement raw materials, clinker and slag, coal particles for cement kilns and power plants for several decades. Although much progress has been made in understanding the grinding process of various types of mill feeds (Schaefer, 2001), to the best knowledge of the authors, a systematic study of the grinding mechanism and comminution efficiency of particle beds by a pure roller compression cannot be found in literature. As one step toward such a goal, a pilot roller test machine has been developed in this study, which

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can significantly simplify the grinding conditions in actual pulverizers whilst the key variables involved in a rolling compression can be considered. Firstly, main design issues about the test machine, including the mechanical realization, measurement and data acquisition systems are introduced in the main portion of this paper. A rough estimate of the range of maximum contact pressure stress is also given based on some fundamental finite element analyses. Secondly, elementary pulverizing tests have been conducted using the machine considering variable roller weights and speeds, from which typical results of size reduction and roller movement are provided. Some discussions on the coming extension of the machine and concluding remarks are given in the final part.

2. Design and setup of a roller test machine

The working principle of the roller test machine developed in this study is schematically shown in Fig. 1. The motions of the roller and the support table components are controlled by an AC servo motor, of which the rotation movement follows the order given from a control computer through the controller unit. The mobilized roller up-and-down displacements and its rotation speed, shall be monitored using photoelectric sensors and be recorded by a data acquisition system, which digitizes the analog sensor signals and transfers to the control computer for visualization and post-processing purpose. Main components for the mechanical realization of the test machine, the control and measurement system, as well as parametric numerical analyses for an estimate of the maximum contact pressure stress are described below.

2.1. Mechanical realization of rolling compression

As mentioned above, three main parameters that were deemed to be mostly influential in the pulverizing process were focused in the design of the test machine, including the roller weight, the kinematics of the roller (especially its rotation speed), and the thickness of the feed bed. The test machine was purposely designed such that each of these three factors can be controlled individually for simulating various grinding conditions in actual practice. As shown schematically in Fig. 1 and in photo in Fig. 2, the machine consists of three main parts: the base frame, the support table and the loading roller. The features of these main parts are described as follows (from bottom to top):

(1) A 5000 mm long steel-made base frame of sufficiently large stiffness was fixed onto the ground, which comprised a 150 mm thick concrete layer on a solid soil foundation and was deemed strong enough for supporting the overall weight of the machine as well as vibration loads mobilized during the rolling tests. A straight and horizontal support table, which was also made of steel material and 2400 mm in length, was arranged on the base frame and its movement was constrained along the longitudinal direction through two liners installed on both lateral sides of the base frame (Fig. 3). A 2875 mm long ball screw was installed within the base frame and connected to the support table, which serves a purpose of driving the support table along the longitudinal direction.

(2) A horizontal groove was purposely built into the support table for containing the particle bed during pulverizing tests (Figs. 2 and 3). A small width of 32 mm was chosen for the groove in order to obtain a higher pressure stress acting on the feed bed by the overburdened roller weight. The groove is 35 mm in depth, which poses a limit on the maximum layer thickness and the largest vertical motion of the roller part.

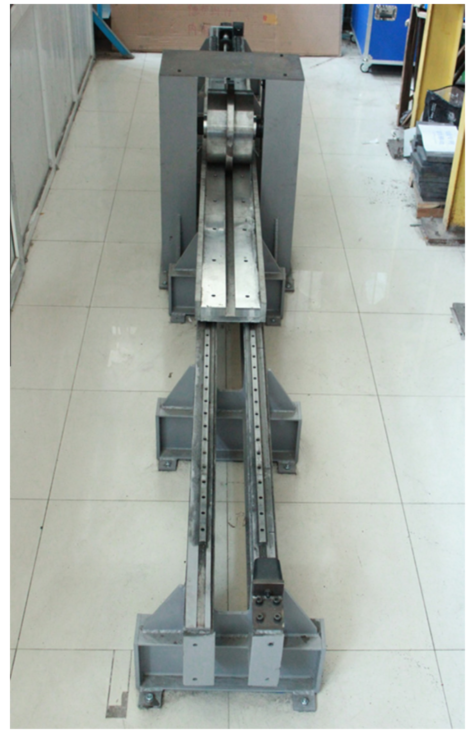

Fig. 2. A front view of the roller test machine.

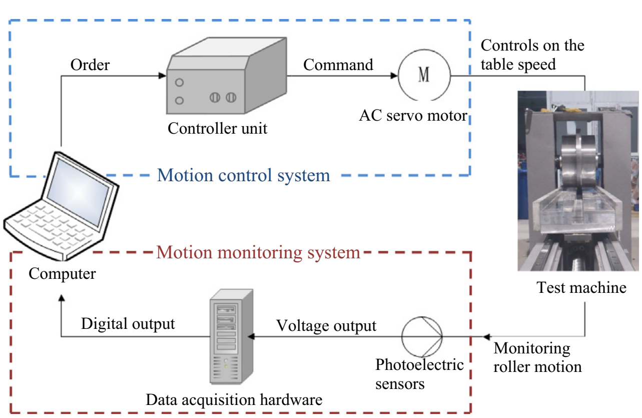

Fig. 1. The working diagram of the developed roller test machine.

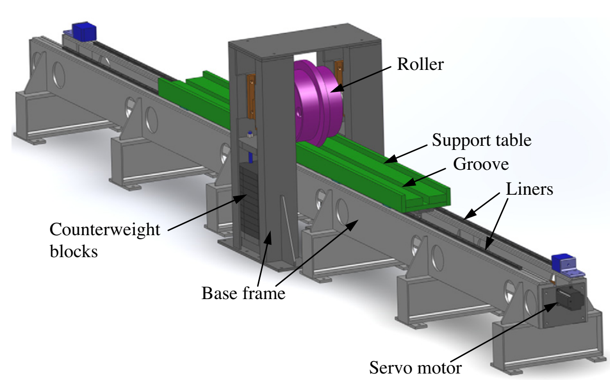

Fig. 3. An iso-metric view of the test machine (3D design model).