Abstract

Overflow ball mills have found popular application in the ore dressing process for post-primary grinding firstly owing to their ability to produce finer grinds, necessary for efficient mineral liberation and better flotation recovery and secondly due to lower initial capital outlay. However they are inefficient and intensive energy consumers. This trend has been exacerbated in the wake of increased installation of large diameter ball mills to benefit from economies of scale, coupled with diminishing ore quality currently being experienced by mines worldwide. To fully utilise the available mill capacity and achieve optimal performance whilst maintaining energy efficiency for these large devices, closer and more effective control is needed. Satisfaction of this need would result in stability of the entire mineral processing circuit, thereby reducing the overall cost in mineral extraction. Clear and deeper understanding of the in-mill behaviour is fundamental to the realisation of the above objective.

This thesis explores several experimental and modelling techniques to obtain deeper understanding of the internal behaviour of an overflow ball mill. A direct load sensor comprising an inductive proximity probe and a conductivity probe installed through the mill shell has been utilised to collect information of the media and slurry dynamic positions inside a laboratory ball mill while a commercial on-line ball and pulp sensor was employed to collect similar information on an industrial overflow ball mill. Useful insights were acquired that can help the design of control strategies for optimal mill performance. Four feature variables, i.e. dynamic media angle, slurry pool angle, conductivity signal amplitude and the slurry pool depth, derived from the sensor signals data were characteristically influenced by changes in mill operational conditions. Therefore the possibility of using these features to predict the associated mill operational variables is feasible. In view of the findings, two multivariate models, one based on the concept of data projection to latent space (PLS) and the other combining PLS and radial basis functions neural networks (RBF) were built and applied to predict the in-mill slurry density and ball load volume. Both models yielded adequate predictions, albeit the hybrid PLS-RBF model displayed marginally better prediction performance. The results are indicative of the available potential for mill on-line monitoring and control by multivariate techniques based on relevant features contained in the media and slurry sensor signals data.

In another endeavour, a gamma camera was successfully employed to study the flow and mixing behaviour of slurry inside a laboratory mill using Technetium-Tc^{99m} radiotracer as a flow follower. The effects of slurry viscosity and mill rotational speed on slurry mixing rate within the ball charge and slurry exchange rate between the pool and the ball charge were assessed, yielding insightful data. However, the results remain inconclusive as only qualitative information could be obtained owing to the radiation attenuation effects by the steel ball charge.

In the quest to improve the understanding of material transport inside the mill, the data acquired on an industrial mill through salt tracer tests was adequately analysed to assess the variation of slurry residence time distribution (RTD) and volumetric holdup inside the mill as affected by changes in slurry concentration and ball load volume. A model based on the concept of serial stirred mixers with a plug flow component produced fairly accurate predictions of the RTD data. Also, equations derived from a mathematical description of the dynamic load profile produced good estimates of the in-mill slurry volumetric holdup.

Further, an improved mixing-cell model was developed and applied to characterise the in-mill slurry hydrodynamic transport based on the measured RTD data. The model was able to account for the effects of non-ideal flow conditions such as slurry back-mixing, slurry exchange between the pool and ball charge and bypass flows on the main flow of slurry thus giving correct description of the inherent in-mill slurry transport dynamics. Note that failure to tune the mill appropriately to achieve desirable in-mill slurry transport behaviour may result in poor milling performance and corresponding high energy expenditure.

Thus, the results obtained in this thesis clearly demonstrate that, a combination of experimental techniques and mathematical models is a viable route to enhance understanding of mill internal behaviour, which in turn enables development of better control schemes for optimal mill performance.