

## Modelling of fluid, particle and structure interactions in a tumbling ball mill for grinding of minerals

Pär Jonsén<sup>1\*</sup>, Hans-Åke Hägglad<sup>2</sup>, Bertil I. Pålsson<sup>3</sup>

<sup>1</sup> Department of Engineering Sciences and Mathematics, Luleå University of Technology, 971 87  
Luleå, Sweden, [Par.Jonsen@ltu.se](mailto:Par.Jonsen@ltu.se) and <http://www.ltu.se/staff/p/parj-1.12049>

<sup>2</sup> Department of Engineering Sciences and Mathematics, Luleå University of Technology, 971 87  
Luleå, Sweden, [Hans-Ake.Hagglad@ltu.se](mailto:Hans-Ake.Hagglad@ltu.se) and <http://www.ltu.se/staff/h/hah-1.10645>

<sup>3</sup> Department of Civil, Environmental and Natural Resources Engineering, Luleå University of  
Technology, 971 87 Luleå Sweden, [Bertil.Palsson@ltu.se](mailto:Bertil.Palsson@ltu.se) and <http://www.ltu.se/staff/p/palle-1.10020>

**Key Words:** *SPH, DEM, FEM, Tumbling mills.*

Wet grinding of minerals in tumbling mills is a highly important multi-physical process in the mining industry. To create a numerical model that include pulp fluid and its interaction with both the grinding balls and the mill structure is an interesting challenge. During grinding in tumbling mills, lifters submerge into the charge and create motions in the ball charge. The grinding balls create the structure through which the fluid penetrates, and in its turn creates forces on the grinding balls. Another challenge, in a tumbling mill processes are that many free surfaces formed. This limits the use of methods like the classical computational fluid dynamics (CFD) method with stationary mesh. For a long time, discrete element methods (DEM) have been used as simulation tools applied to tumbling mills. DEM gives an opportunity to study e.g. charge movement and charge size distribution, collision forces, energy loss spectra and power consumption. For structural analysis, the finite element method (FEM) is the most developed and used numerical method. FEM is a numerical solution method based on continuum mechanics modelling, a constitutive relation for the actual material is described and the governing equations are solved. A way to study the interaction between grinding balls and mill structure was taken by Jonsén et al. [1]. They used a combined DEM-FEM model to study the interaction and showed that it was possible to accurately predict the occurrence and patterns of mechanical waves travelling in the mill shell and lining. Previous has the smoothed particle hydrodynamic (SPH) method been used to model a ball charge and its interaction with the mill structure [2]. Experimental measurements on the induced torque were done by Jonsén et al. [3] on a laboratory scale ball mill. The mill was built by SALA (SALA international K706250/1981) and has recently been modernized with new measurement equipment and control logic.

In the present work, a SPH description of the pulp fluid is introduced to predict the pulp fluid interaction in mill simulations. The mesh free Lagrangian formulation and the adaptive nature of the SPH method result in a method that handles extremely large deformations. The grinding balls are modelled with DEM as a mono-sized charge with ball diameter 12.7 mm. Each grinding ball is given a mass and inertia corresponding to a steel sphere of density 7800 kg/m<sup>3</sup>. The mill is modelled with FEM and has a stainless steel drum with four equally spaced lifters. A combined three dimensional SPH-DEM-FEM model is used to simulate a tumbling

ball mill process. The nonlinear finite element code LS-Dyna v971 R7.0.0 (2013) has been used for the mill simulations.

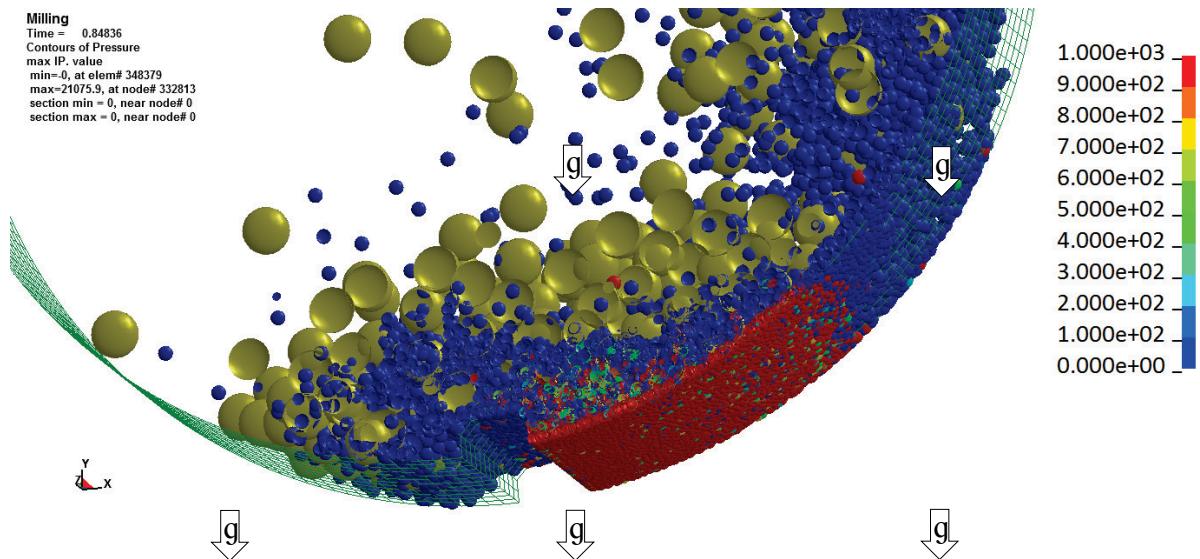


Figure 1. A snapshot of the pressure build up in front of the lifter during its passage through the charge and pulp liquid.

The size of the mill is  $\phi 300 \times 450$  mm, but only a 100 mm slice of the mill is modelled and consists of 5.24 kg grinding balls and a fluid volume of  $0.80 \text{ dm}^3$ . In the first studied case, the fluid has water properties. This case is validated against experimental measurements of charge induced torque in a laboratory-scale ball mill and shows a close relation. The influence of increased fluid density and viscosity on the mechanical response is also interesting; in the second case a liquid with the same viscosity as water but with the density of a magnetite suspension is studied. In the third case, a liquid with the apparent viscosity and density of a magnetite suspension is studied. For all cases, a charge filling of  $J_{\text{vol}} = 22\%$  and a rotational speed of 66%  $n_c = 66\%$  of critical speed is used. An important result from the SPH-DEM-FEM model is that it is possible to predict pressure distributions that occur within a grinding charge, see figure 1. This approach opens up the possibility to predict the volume of the high-energy zone and optimise lifter design and operating conditions. This has the potential to minimize specific energy consumption and increase efficiency of the milling process. Still, there are several challenges for modelling the grinding process and as well as the coupling between SPH and DEM that needs to be further studied.

## REFERENCES

- [1] P. Jonsén, B. I. Pålsson, K. Tano and A. Berggren, Prediction of mill structure behaviour in a tumbling mill. Miner. Eng. **vol. 24**, pp 236-244, 2011.
- [2] P. Jonsén, B. I. Pålsson, and H.-Å. Häggblad, A novel method for full-body modelling of grinding charges in tumbling mills, Miner. Eng. **vol. 33**, pp. 2-22, 2012.
- [3] P. Jonsén, J. F. Stener, B. I. Pålsson and H.-Å. Häggblad, Validation of tumbling mill charge induced torque as predicted by simulations. Minerals and Metallurgical Processing, **vol. 30**, No. 4, 220-225, 2013.