1. Modelling of the interaction between charge and lining in tumbling mills

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The comminution process in tumbling mills is complex and several parameters do significantly influence the effectiveness of the grinding operation. Many of these parameters are either difficult or laborious to measure. Grinding in tumbling mills is also an energy inefficient process; much of the energy is absorbed in low-impact contacts that do not break particles. An important point in optimising the process is to understand the charge motion within the mill. Both the breakage of ore particles, deflection of the lining and the wear of liners/ball media are closely linked to the charge motion. To include all phenomena that occur in a single numerical model is today not possible. One approach to overcome some of the numerical issues is to combine different numerical methods. To combine models the commercial software LS-DYNA R 5.0 has been used. In this work, the lining is modelled with the finite element method (FEM). The smoothed particle hydrodynamic (SPH) method is used to model a ball charge and its interaction with the mill structure. SPH method is a point-based method which has an adaptive nature and together with the non-connectivity between the particles results in a method that is able to handle very large deformations. This computational model makes it possible to predict the deflection of the lining in a pilot ball mill and the mechanical waves travelling in the mill system. This model also makes it possible to predict charge pressure and shear stresses within the charge and the contact forces. The deflection profile of the lifters obtained from SPH-FEM simulation shows a reasonably good correspondence to pilot mill measurements as measured by an embedded strain gauge sensor. Each methods has its strength and weaknesses, but combined they may successfully model the main features of the grinding process.

1.1 Potential for the industry

The main scientific objective of this project is to combine element-based methods like FEM together with particle-based methods like DEM and SPH to a complete mill model. Such model should give a better understanding of the physical and mechanical behaviour of particulate material systems during grinding in a tumbling milling. This is very important in order to develop future high quality mineral products. The industrial benefits of the research will be improvements in mineral process plant performance through generic advances in knowledge and provision of engineering tools and methodologies. A numerical tool that captures some of the main features of the grinding process will be vital

in the optimisation of the process and in product development. It should result in a better control of the grinding process and in improving the knowledge of the mechanical and physical behaviour of the whole comminution process.

1.2 Numerical modelling

DEM have been used in simulations of tumbling mill processes for many years. A pure DEM model provides useful information on charge motion, collision forces, energy loss spectra and power consumption. This is important for improving the milling efficiency and gain more understanding of the process itself. For improved estimations of the complex nature of the milling process better and more physically precise models are desirable. For structural analysis, the FEM is the most developed and used numerical method. The method originated from the need for solving complex elasticity and structural analysis problems in civil and aeronautical engineering. 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. Varieties of different constitutive models for a large number of materials are implemented in a modern finite element (FE) code.
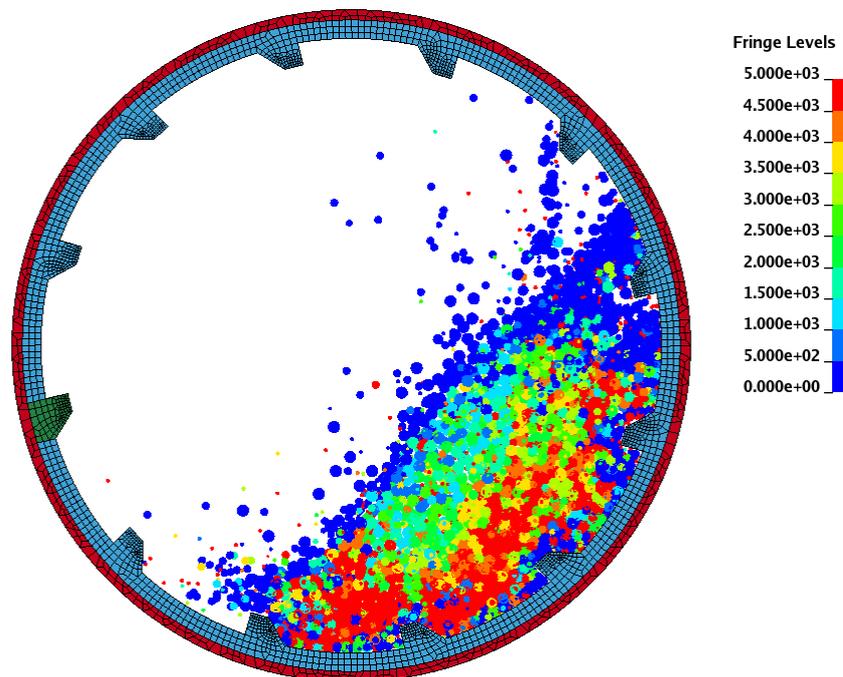

Figure 1-1. A snapshot of the pressure distribution in the charge.

Steps towards more physically correct numerical descriptions of mill systems are combined DEM-FEM models, see Jonsén et al. (2011a). With a DEM-FEM model, structural response and its influence of the charge motion can be studied on the whole mill. The SPH-FEM model can also show that mechanical waves travel in the charge, see Jonsén et al. (2011b). In Fig 6, the pressure distribution in the charge is shown. As the lifter submerges

into the charge, a pressure builds up in front of the lifter and an induced pressure wave travels through the charge. As the pressure wave travel through the system, the charge is compressed and unloaded several times. These waves create fluctuations in the lifter load that is shown in the experimental study. The highest pressure is found as the lifter goes into the charge.

With a SPH-FEM model, structural response and its influence on the charge motion can be studied in detail. As the charge and lining are modelled with deformable material the interaction and the resulting mechanical waves that travels from the lining to the charge and vice versa, could be properly reproduced in a numerical model. By that, critical parameters like material stress etc. could be evaluated and optimized. The model gives not only the opportunity to optimize the material selection of the mill structure but also to study the internal workings of the charge. FE-codes are well developed and already used for optimisation of mechanical response of structural parts.

In the next step towards more physically correct models the pulp will be included. The SPH method or the particle finite element method (PFEM) are some interesting methods for modelling fluid flows. The method can be combined with FEM and should be suitable for modelling pulp. Today, SPH and PFEM are used in areas such as fluid mechanics and solid mechanics (for example; free surface flow, incompressible flow, compressible flow, high velocity impact, penetration problems and high explosive detonation over and under water). The main advantage with these methods is the ability to virtually reproduce free surface flow, which is known to be a difficult problem in CFD with the classical Euler approach. The mesh free formulation and the adaptive nature of the SPH method and PFEM result in methods that handle extremely large deformations.

1.3   Validation

Validations of the numerical result are very important in the project. To ensure accurate behaviour of the models each step in the development has to be validated against experimental data. Experimental studies of Continuous Charge Measurement system (CCM) are exploited to validate the combined numerical models and to determine the material parameters. The industrial partners provide data to the models and initially data from pilot mill measurements has been used for the initial calibrations of the DEM-FEM model. In addition, the test work on pebble charges in the same pilot mill will provide data sets that will validate the accuracy of the combined numerical models.

REFERENCES

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