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A fundamental model of an industrial-scale jaw crusher

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ABSTRACT

In this study, an analytical perspective is used to develop a fundamental model of a jaw crusher. Previously, jaw crushers were modelled in regard to certain aspects, for example, energy consumption (Legendre and Zevenhoven, 2014) or kinematics (Oduori et al., 2015). Approaches to date have been mainly property specific. In this work a physical modelling approach has been used to derive the modules, which are based on established facts of comminution machines, from the literature. A modelling methodology mainly inspired by Evertsson has been applied (Evertsson, 2000). The modules are divided into kinematics, flow, breakage, capacity, pressure and power. Each module has been derived and tested decoupled from the other modules to provide increased transparency of the module and its behaviour. The results of the modelling are presented for a baseline case of one industrial-scale jaw crusher and compared to manufacturer data. Future work will include validation and DEM simulations.

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1. Introduction

In a comminution plant where the reduction of rock material or ore sizes is desired, two machines are commonly used for primary crushing: the jaw crusher and the gyratory crusher. In primary crushing, the material is typically fed directly from the blast sites and dumped into the crusher from a dump truck. This implies that the size range of the material is large and can differ by up to three orders of magnitude between the smallest and largest particles (1–1000 mm). Both gyratory and jaw crushers can handle very large incoming feed sizes due to their design. In a jaw crusher, the material is crushed between two plates: a static plate and a moving plate. Compression is applied by the moving plate, and the material becomes crushed. The size reduction obtained by a jaw crusher is form conditioned crushing due to the nature of the machine. There are two main types of jaw crushers, single toggle and double toggle. The difference being the resulting motion of the jaw depending on the design (Wills and Napier-Munn, 2015). Jaw crushers have proven to be a workhorse in the aggregates industry and are machines that reduce the top size but do not create fines or cubical particles to the same extent as, for example, a cone crusher. Jaw crushers are mainly used in operations where the volumes involved do not justify a gyratory crusher. The throughput of a jaw crusher ranges between 30 and 1200 tph (Wills and Napier-Munn, 2015).

Jaw crushers have been modelled previously; in 1953, Gauldie conducted a performance study of the jaw crusher, including a capacity model that handles varying speeds and closed side setting (CSS) (Gauldie, 1953). The kinematics of the single-toggle crusher has been modelled by Oduori et al. (2015). An energy efficiency study was performed by Legendre and Zevenhoven (2014). In their study, energy was estimated with the Bond work index, and an online optimization algorithm was used to increase the efficiency of a laboratory crusher. A similar study was conducted by Tosun and Konak (2015) with a broader perspective, including blasting, primary crushing and secondary crushing, as an energy assessment study for two limestone quarries. The output product of a jaw crusher was studied by Olaleye (2010) and Mu et al. (2013) in terms of how it varies with ore body strength as well as using Discrete Element Modelling (DEM) techniques.

A useful and trustworthy model requires an understanding of the modelling approach and the involved physics. Mathematical modelling of complex systems can be performed in many ways. Ljung and Glad (1994) defined two main types of mathematical models: physical models and identification models. Identification models are best suited to cases where large amounts of data are available and the changes to the system are small over time. On the other hand, physical models obtain inaccuracies of 10–20%; however, the trends in such models should be similar to those of real systems. A physical model should be valid for a much broader range of operations in comparison to an identification model. Physical models are derived using available physical relations and usually divide the system into multiple subsystems. For crushing devices, the different types of physics that occur inside the

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machine will be separated. Models in the literature are often decoupled approaches focusing on one specific aspect of the crusher, for example, population balance models focusing on particle size, (Nikolov, 2002 and Whiten et al., 1979) or flow as Gauldie (1953) did. In dynamic simulations and predictive control, there is a need to include a full model of the machine, where all parts of the system are connected and arranged in the proper manner. This study has attempted to develop a fundamental model including performance aspects of the jaw crusher for both potential future adoption in simulations and prediction purposes and as a tool for use during the design evaluation. The modelling attempts to provide key insights into the performance mapping of the jaw crusher. For the realization of this model, the approach will be numerical, and the implementation is realized in MathWorks MATLAB.

2. Method

To achieve a model using physical modelling techniques, the machine of interest, a jaw crusher in this case, has to be broken down into smaller subsystems and modelled separately, for example, breakage, dynamics or pressure, as seen in Fig. 1. For this research, the modelling approach is similar to the approach used by Evertsson (2000) when developing an analytical model for a cone crusher. With this as the starting point, the work has been structured in the following order, as illustrated in Fig. 1. Each block in the block diagram is briefly explained here and fully explained in each subsection. First, a model of the kinematics was developed. Second, a flow model was developed using a particle approximation. The flow model and the kinematic model are used to calculate the nominal capacity. Third, a breakage model was used to predict output product size distributions. From there, a pressure model was used to estimate the energy usage of the crusher. The approach was chosen mainly so that the different phenomena present in the crusher can be decoupled and analyzed separately. The final model has been used to model the performance of an industrial-scale crusher geometry with varying closed side settings (CSS), rotational speed of the flywheel and eccentric throw of the main shaft. All modelling and post-processing has been performed in MATLAB. The geometry of the crusher used in this study has been estimated from images and simple drawings. The modelling was initiated by gathering geometric data.

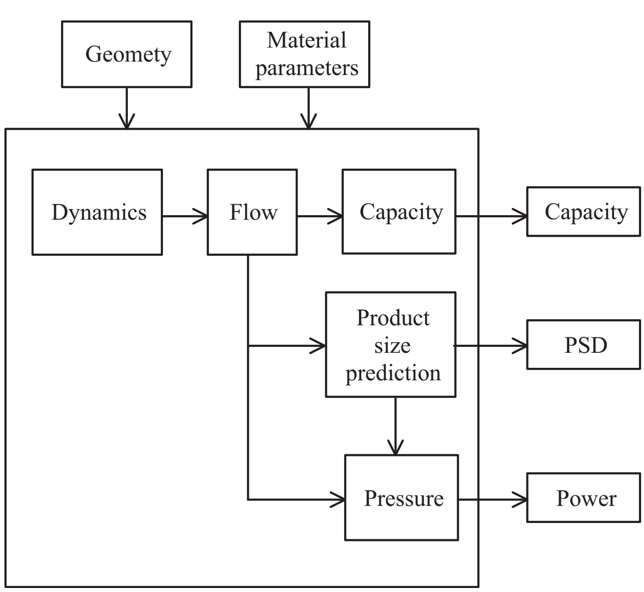

Fig. 1. Overview of the jaw crusher system in a physical modelling approach.

2.1. Geometry

In order to simulate the crusher, a set of geometrical parameters has to be obtained. In this work, the dimensions of the modelled geometry were measured from available drawings and images of an industrial-scale crusher. The width of the modelled crusher is 925 [mm]. All other parameters of the model can be found in Fig. 2, where the parameters that do not vary over time are inputs into the model. The separation of the geometry from the kinematics of the jaw allows for easy changes in the parameters.

2.2. Kinematic model

The moving jaw of the crusher is suspended in the link arm at the bottom and in an eccentric bushing at the top. The position of the jaw over time can be determined by modelling the link arm system. The values of **B**, **C**, α, β, and γ from Fig. 2 can be calculated using the cosine theorem, leading to the formulations in Eqs. (2)–(4). Point **A** is known from the geometry, and all parts, including the toggle plate, have been modelled as rigid bodies. Parameters a and c are constants as are the respective sides of the triangle *ABC*. From the points $\mathbf{B}'$ and $\mathbf{C}'$, which are determined by Eqs. (9) and (10), the liner profile can be implemented as a profile between points $\mathbf{B}'$ and $\mathbf{C}'$. In this work, a straight line has been used as the liner profile; however, any feasible geometry could be used in principle. The liner profile has to be an invertible function because it needs to be able to be used to calculate both the Z position and the X position depending on the state of the calculations. Eqs. (1)–(10) are derived from the cosine theorem and are needed to solve the kinematic problem. Bold symbols are vectors, and regular symbols are scalars.

$$\mathbf{C} = R\begin{bmatrix} cos(\omega(t)) \\ sin(\omega(t)) \end{bmatrix} \tag{1}$$

$$b = |A - C| \tag{2}$$

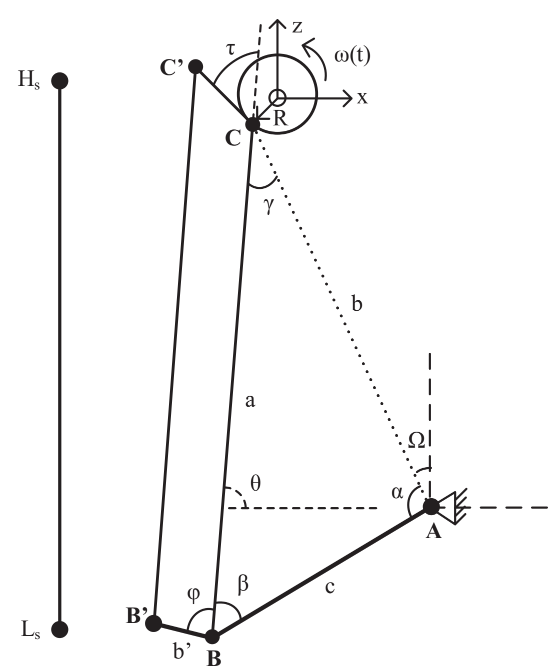

Fig. 2. A schematic illustration of the system, including the parameters and variables used to derive the kinematics of a single toggle jaw crusher.

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