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Automatic Feed Rate Control with Feed-forward for Crushing and Screening Processes

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Abstract: Crushing and screening processes for aggregates are purpose-designed processes for producing aggregate fractions with pre-specified quality specifications. An aggregate production plant, crushing station, basically involves crushers in series for crushing rocks and screens for classifying and separating fractions measured in size. The specifications on the end-products affect the plant layout including a number of the required crushing stages. However, one thing being in common with all plants is that the first stage of the process is human-based excavator or dumper feeding. A load of rocks are fed onto a primary feeder on an irregular basis. Then, the feeder carries the rocks to the primary crusher determining the maximum achievable production rate. The automatic control of the primary feeder is in the scope of this paper. A new feed-forward control -based approach is presented for allowing a non-interruptible and a more productive aggregate production.

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1. INTRODUCTION

Aggregate production has long roots in modern civilisation and building infrastructure such as roads, railways, runways, houses, bridges and harbours. The aggregates are used for producing concrete, asphalt, railway ballast or for land-filling and playgrounds. According to the European Aggregates Association (UEPG, 2015), the aggregates demand in Europe alone is as high as 2.7 billion tons per year making it 5.2 tonnes per capita annually. When measured in national tons per capita, Finland and Norway are the biggest European aggregate producers with more than 16 tons per capita annually.

According to UEPG, the aggregates in Europe are produced in 25 000 quarries and pits making a number of production plants rather astonishing. A typical aggregate production plant produces hundreds of thousands or millions of tons of aggregates annually. Most of the processed aggregates come from blasted rocks (53 %) while other sources are sand and gravel from pits (39 %) and recycled or marine aggregates (8 %).

The aggregate production plant processing blasted rocks typically has several crushing stages with intermediate and final screening. As a result, there is a pre-specified number of required end-products measured in both size and quality. It is exactly the targeted end-products that give specifications on the plant layout when designing a new crushing and screening plant. The plant layout not only involves a number of required crushers and screens and material flow routes with recirculation paths but also crusher and screen types, feeders, conveyors, hoppers, silos and planning of charging (loading) and discharging (unloading) of the produced aggregate fractions that are produced in piles.

A typical crushing and screening plant consists of a primary feeder with volume capacity, primary crusher, secondary and tertiary crusher(s) with recirculation for oversized, non-crushed aggregates and, also, screens for aggregate fraction classification. A simplified process layout example is given in figure 1. The primary crusher is either a jaw or an impactor crusher, while secondary and tertiary crushers are gyratory or cone crushers.

The crushing and screening plant's primary feeder is loaded with blasted rocks by human-operated dumper or excavator. By default, this makes stabilisation of the aggregate production process rather essential as the process is loaded on an irregular basis. Consequently, the volume or mass flow entering the process changes affecting the material flows through the entire process. Therefore, it is of the great importance to manipulate the primary feeder speed to stabilise the feed rate to the primary crushing but also to maintain a targeted production rate avoiding undesired interruptions due to overloaded crushers, conveyors and screens.

In a crushing plant, the primary feeder is the first manipulated actuator. But, also, it is probably the most vital actuator as it determines the flow rate to the process and, thus, the maximum available throughput. There are often other bottlenecks restricting the plant capacity but without

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automatic feeder manipulation, not even the limited plant capacity can be reached.

The significance of automatic feed rate control has been recognised several decades ago by Flavel (1979). In his patent, Flavel addressed the need for controlling the feed rate to the process. Later, the feed control was revisited by Laukka et. al (2009) with a more elaborate description on tackling the challenge. Also, Sbarbaro (2005) in his paper studied feed control acting on feeders with variable speed drives.

It is assumed in this paper that when speaking of feeder operability and manipulation, the feeder comes with a variable speed drive allowing its smooth and analogous computer-based operation. The paper treats a modified automatic feed control method relying on a number of predictive PI and standard PI feedback controllers as described by Airikka (2012b) for mobile track-based crushers and screens or, as in general, as described by Airikka (2013) for any plant type (stationary, portable, mobile). This paper deepens the work published earlier by Airikka (2015).

2. CRUSHING AND SCREENING PROCESS

A crushing and screening plant, that is, an aggregate production process, starts with human-based material feeding ending to aggregate fraction piles each of them with a pre-specified fraction size interval e.g. 6-8 mm. However, for feed rate control purposes, it is not necessary to consider the whole process with the last crushing stages and material flows. It suffices to have a look at the primary and the secondary crushing stage as in figure 1.

It is assumed that the primary feeder (fig 1.) is equipped with a variable speed drive allowing feeder speed manipulation. The feeder can be vibrating enabling screening out small particles that do not benefit from crushing. Then, only large particles are crushed in the primary crusher into smaller particles. A discharging conveyor of the primary crusher combines both the crushed particles with the bypassed non-crushed fines.

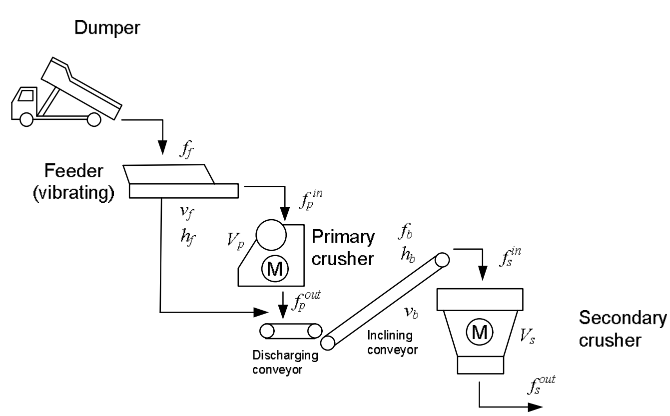

Figure 1. Process layout for primary and secondary crushing.

Next, the crushed material enters an inclining conveyor feeding a secondary crusher. The secondary crusher crushes the material into even smaller particles which are then taken to fine crushing circuit not shown in the figure 1. Sometimes, there may be a recirculation conveyor after the secondary crusher taking oversized and non-crushed particles back to the secondary crushing. In this paper, it is assumed that there is no such a material flow but, instead, the material coming out of the secondary crusher continues to fine-crushing. In this paper, this assumption is made primarily for simplifying math required, but the assumption could be relaxed for allowing automatic feed rate control for closed material circuits.

Most of the material flows (fig. 1) are typically not measured on-line. However, for automatic feed rate control, it is essential to design and to implement appropriate sensors with transmitters for providing on-line information on the material flows. It is of a good practice to have ultrasonic sensors for measuring flows and volume levels at least in both primary and secondary crusher and, more importantly, on a inclining conveyor between the crushers. The latter is for indicating feed rate whereas the other two measurements are for indicating crusher volume loads. In parallel to the loads, crusher power draws and pressures are most often used for indicating their crushing load.

3. MODEL OF FEEDER FLOW

It is fundamentally important to have an insight to process dynamics for understanding process behaviour and interactions. Equally, it is vital to have descriptive process models for allowing process control design with decoupling. Finally, the process model parameters can be identified if needed using on-line identification methods such as presented by Airikka (2012a). However, for process control engineering it is adequate to have first-principle models without real, on-line estimated or identified coefficients and parameter values.

The material volume flow F_f (m^3/sec) on a feeder can be given using feeder width w (m), material height h (m) and feeder speed v (m/sec):

$$F_f(t) = wh(t)v(t) \tag{1}$$

As the feeder speed is the manipulated variable which is used for regulating the volume flow, it is substituted by a following static equation:

$$v(t) = \alpha u(t) \tag{2}$$

where u is controller output (0-100 %), that is, a command signal to a variable speed drive and α is a feeder characteristic coefficient (α << 1). Typically, there may be also dead-band, saturation limits and hysteresis affecting but, for simplicity, they are neglected here.

The material height is a two-dimensional variable in real (machine- and cross-direction). However, typically, the material height on conveyors and crushers is measured using a fixed-point sensor providing with a single value only. To calculate the volume flow as given in (1), there should be a cross-directional material height profile available. Yet, as this is obviously not realistic, the height measurement is only an

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