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*Xiaowei Pan**

DEVELOPMENT OF STOCKPILE SOFT SENSOR

1. Introduction

A lot of efforts have been made in the development of level measurement for stockpiles, used commonly in mining/mineral processing and cement industries. Stockpiles, see in Figure 1, are used as an intermediate buffers between inventory and production. Their sizes vary in according with the scales of production, typically above 10 m in height. Issues, such as safety, reliability and accuracy, remain crucial, and meanwhile the level measurement technologies need to be easy to install and operate, at a low cost of ownership.

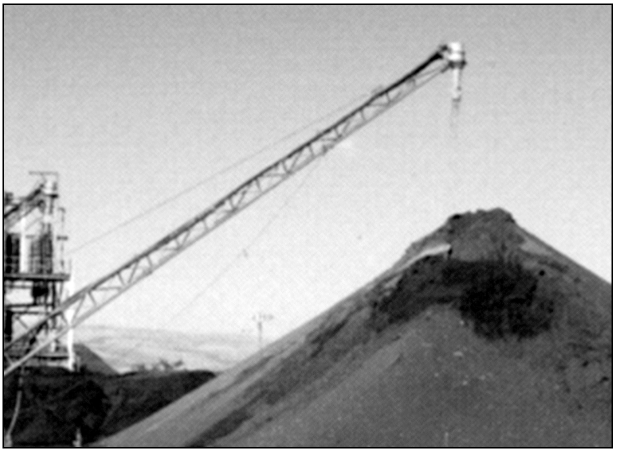

Fig. 1. Illustration of a stockpile widely used in mining, mineral processing and cement industry [1]

* Department of Metallurgy, University of Johannesburg, South Africa

The techniques for measuring stockpile levels range from basic to the high tech. Before instrument based measurement became widely used, stockpile levels were often determined by mechanical means. One such technique, such as Yo-Yo or plumb Bob [2], required the lowing of a measuring rope attached to a weight from the stockpile top, showing the distance to the surface by how much rope was used. Such measurement is categorised as contact level measurement. When level measurement requires more precision, instrument based technologies are widely used, including ultrasonic, radar and laser [3].

It is difficult to measure the stockpile level using those measurements as mentioned above, when its shape and location are not in a fixed pattern. For instance, when a stockpile is fed by a stacker or is discharged by a reclaimer, see Figure 2 and 3.

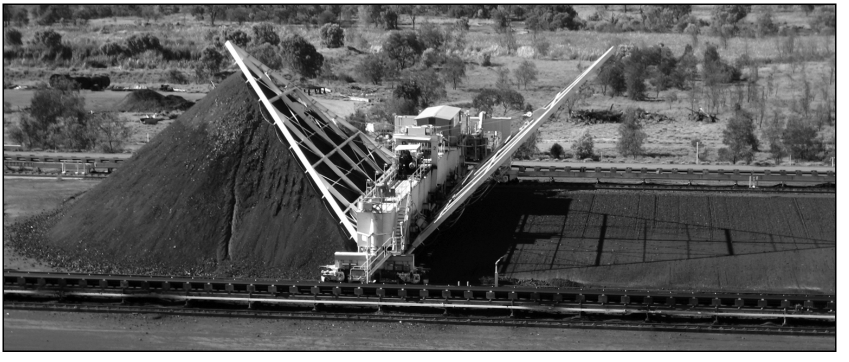

Fig. 2. Krupp bridge reclaimer at RTCA Kestrel Mine

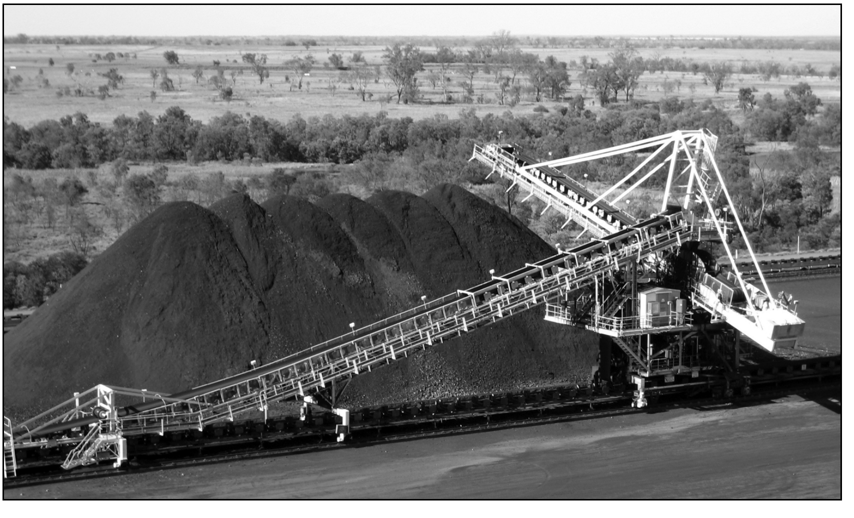

Fig. 3. Krupp coal stacker featuring tripper conveyor and non-slewing, luffing boom at RTCA Kestrel Mine [4]

Another crucial challenge for stockpile measurement is to measure the mixing behaviour of different materials charged to the stockpile. The attributes of mixing behaviour include when and how the mixing takes place in the stockpile and when the mixed materials with certain portion are discharged out of the stockpile.

There are some technologies available, used to determine the different materials in a stockpile. Darrell [5] reported the installation of an online analysis at Mitsubishi cement plant, California, USA. The analyser generates neutrons from a radio isotope and then uses the neutrons to interrogate materials and interact with the nuclei of the materials. In doing so, gamma rays are emitted. Each generated gamma ray comes from the nucleus of an element such as calcium (Ca), silicon (Si) or aluminium (Al), and has a unique energy associated with the element from which it was generated. The gamma rays are counted and their energies sorted by a detection mechanism. A spectrum of energies is created and is analysed by software algorithms and gives the concentrations of the different elements. The online analyser generates an analysis of the full material stream in transit to the pre-blending stockpile once per minute, which allows 100% of the raw materials to be analysed while in continuous motion on a conveyor belt.

Geoscan by Scantech, is another online analyser for a wide range of bulk materials, used in mining, coal and cement sectors [6]. The Geoscan analyser uses the technique of prompt gamma neutron activation analysis to perform a minute-by-minute elemental analysis of bulk material passing through it on a standard convey belt. The online analyser can be installed with convey belt sizes from 600 to 2020 mm with unlimited flow rate of material. The lump size of material has no influence on the results. It can measure many element contents, such as Ca, Si, Al, Fe, K, Ti, Mn, S, Cl, Mg, Na, P, moisture, and ash. It provides continuous monitoring of accumulated composition for immediate stockpile management information and improves the feedback to mining operations for better control of stockpile analysis. Due to the cost concern, the online analysers can only be installed before a critical process units, where the composition of the material plays important role, such as raw mill, pre-blending, see Figure 4.

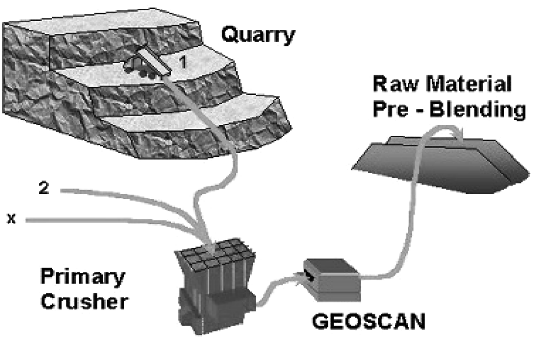

Fig. 4. Geoscan tracking the cumulative composition of pre-blending piles in real time, such as Ca, Si, Al, Fe, K, Na, Ti, Mn, S, Cl, Mg, P, moisture, and ash [6]

With the advancement and the wide usage of measurement instruments associated with stockpiles, a soft sensor can be developed to monitor the level of a stockpile. Furthermore the stockpile soft sensor can be used to estimate the mixing behaviour of different materials charged in the stockpile. The mixing behaviour of different materials includes when and how the mixing takes place, and more important, when the mixed materials with a certain blended portion is discharged out of the stockpile.

2. Development of stockpile level soft sensor

Soft sensor, or smart sensor, is an online software solution. It calculates or estimates the values of unmeasured variables in real time, using the values of online-measured variables. Some of the unmeasured variables are so important but can not be measured because the measurement technology is not ready yet or because the cost is high to do so. In the last decade, wider usage of measurement instruments has been seen and at the time a greater integration of various process control systems has taken place in mining, mineral processing and cement industries. Using the available measurements, various soft sensors have been developed for mining and mineral processing applications in recent years, including weightometer soft sensor [7], densitometer soft sensor [8], ore type soft sensor [9], particle size soft sensor [10]. Other techniques also are made available to help estimate the mixing behaviours of material in and out of the stockpile, including various modelling and simulation tools. For instance, a stockpile optimization software by Actek can estimate stockpile volume, provides optimal reclaim positions for various stockpile types, including circular, linear telescoping and radial stockpiles [11], see in Figure 5.

A typical stockpile consists of a feeding conveyor, a cone space to pile material and discharging hopper and conveyor feeder at the bottom.

A stockpile level can be presented by the percentage of fullness in two formats, namely by percentage of mass and by percentage of the level. The mass percentage is defined as the actual mass over the total ore mass of a full stockpile (*Mass*%). The level percentage is the actual height of ore over the maximum height of a full stockpile (*Level*%). The definition for both *Mass*% and *Level*% can be expressed in the following equations:

$$Mass\text{-}full\,\% = (Ot)/(Ot\text{-}FS) \cdot 100 \tag{1}$$

$$Level\text{-}full\,\% = (Ol)/(Ol\text{-}FS) \cdot 100 \tag{2}$$

Where:

Ot — actual ore tonnage in stockpile, ton,
Ot-FS — ore tonnage of full stockpile, ton,
Ol — actual ore level in stockpile, meter,
Ol-FS — ore level of full stockpile, meter.

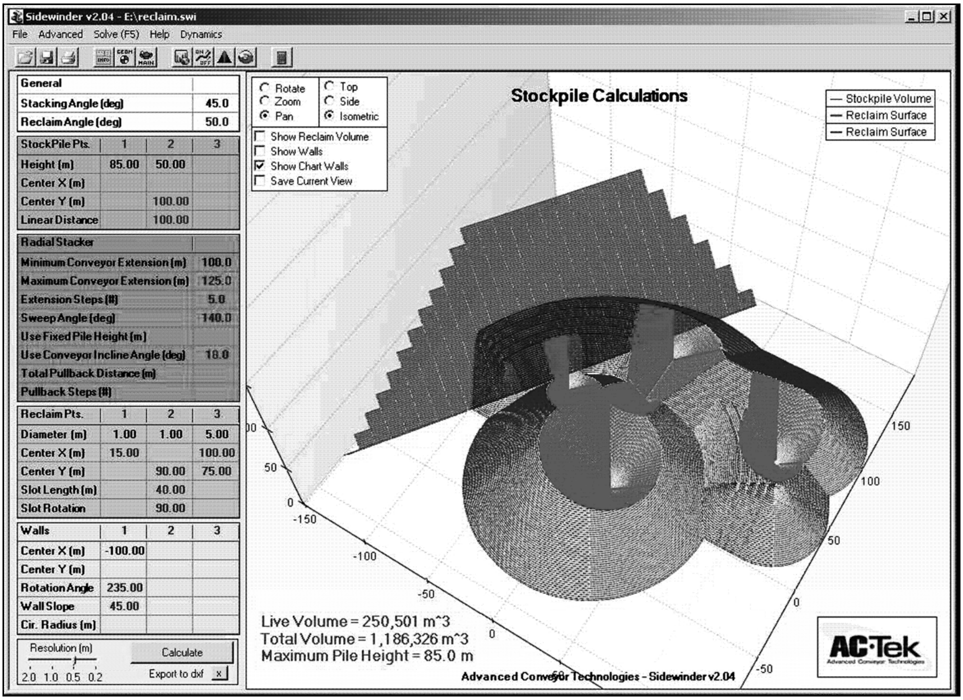

Fig. 5. Illustration of Actek stockpile optimization software, estimating stockpile volumes and providing optimal reclaim positions for various stockpiles [11]

When *Mass*% is 75%, it means the stockpile in tonnage is at 75% full. If the *Level*% is 75%, then it means the stockpile level is at 75% of the maximum height. The values of *Mass*% are smoother than the values of *Level*% in terms of rate of change in real time. Due to the shape of stockpile, the volume is smaller at the top than the volume at the bottom. Consequently the values of *Level*% will change faster when the stockpile is filled up, even the values of *Mass*% is still kept at constant level. It is important to understand the difference between the values of *Mass*% and *Level*%, from the view point of operators and process control. When the stockpile level is used to control the feeders, *Mass*% would be a preferable one, rather than *Level*%. Ironically almost all stockpile levels are measured so far in the format of *Level*% by various measurement technologies, including Yo-Yo (or weight and cable), ultrasonic, laser and radar. As a result, some conversion of *Level*% to *Mass*% is required for the purpose of better process control.

It is worthy knowing that the *Mass*% and *Level*% measurements need some attention when using them for process control, due to the factor of so-called "dad band". A dad band is formed at the bottom around the outside of the stockpile, where the ore stays and stops falling down to the discharging hopper located at the bottom of stockpile, as indicated in the grey area in Figure 6. The capacity of a stockpile includes 'live' and 'dad' volumes.

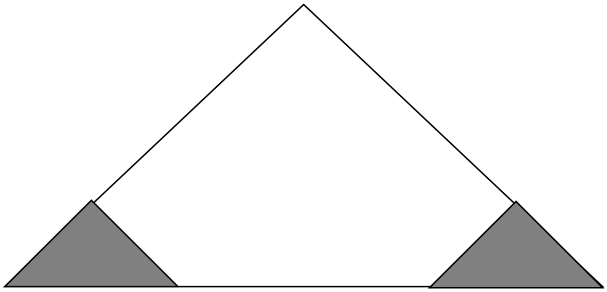

Fig. 6. Illustration of a "dad band" formed at the bottom where ore cannot be discharged from a stockpile without being pushed toward the centre

The ore in the dad band may reach 75% of the total ore mass of a full stockpile. Therefore when the stockpile can not discharge any ore, the value of *Mass*% could be as high as 75%. To discharge the ore in the dad band, extra efforts are required, such as pushing the ore towards the centre so the ore can fall into the feed hopper. Ore fallen in the dad band becomes "dad" and ore not fallen in the dad band can be discharged and is 'live'. For the purpose of process control, the ore in the dad band should be taken into account and the value of *Mass*% should be 0% when no more ore can be discharged from the stockpile even the dad bank is full with ore. The *Mass*% can be altered to an effective mass% (*EMass*%) by equation (3):

$$EMass\% = (AOt)/(AOt\text{-}FS) \cdot 100 \tag{3}$$

Where:

AOt — active ore tonnage in stockpile, ton

AOt-FS — active ore tonnage of full stockpile, ton, equalling to the tonnage of ore in a full stockpile subtracted with the ore in dad band.

Stockpile soft sensor can calculate the values of *EMass*% in real time, using values of ton/hour from 2 weightometers. One weightometer measures the feeding rate of ore and another measures the discharging rate of ore at the associated stockpile. The algorithms used to calculate the effective mass percentage, *EMass*%, can be described in the following equations when time changes from t_0 to t seconds:

$$EMass\%_t = A + B\cdot(dt)$$

$$A = EMass\%_{t0},\ \ (EMass\% \text{ at time } t_0)$$

$$B = d(EMass\%)/dt$$

$$= (EMass\%_t - Emass\%_{t0})/dt$$

$$dt = (t - t_0)$$

When dt is kept at a constant sampling rate of 1 second, then

$$EMass\%_t = EMass\%_{t0} + B$$

$$B = [(ore\text{-}ton)_{\mathrm{t}} - (ore\text{-}ton)_{t0}]/M$$

$$= [(W1_t - W1_{t0}) - (W2_t - W2_{t0})]/M$$

Where:

$EMass\%_t$ and $EMass\%_{t0}$ — is the value of $EMass\%$ at time t and time t_0, respectively,

$W1_t$ and $W1_{t0}$ — is the ore feedrate (ton/hour) of feeding weightometers at time to and time t,

$W2_t - W2_{t0}$ — is the ore feedrate (ton/hour) of discharging weightometer at time t and time t_0,

W — is the total ore tonnage of a full stockpile.

The value of $EMass\%_{t0}$ can be assigned whenever the soft sensor is initiated first time and it can be re-set when the value is known. For instance, $EMass\%_{t0} = 0\%$, when the stockpile is empty, and $EMass\%_{t0} = 100\%$, when the stockpile is full.

The value of the total ore tonnage of a full stockpile, M can be obtained from the design document of the stockpile, or it can be calculated from the following equation:

$$M \text{ (in ton)} = Va \cdot \rho$$

$$Va = 1/3 \cdot \pi \cdot R_2^2 \cdot (H_0 - H_1) + 1/3 \cdot \pi \cdot H_1 \cdot (R_1^2 + R_2^2 + R_1 \cdot R_2)$$

$$R_0 = D_0/2$$

$$R_1 = D_1/2$$

$$R_2 = D_2/2$$

Where:

M — is the tonnage of ore in a stockpile, ρ is the density of bulk ore,

Va — is the live volume of stockpile (excepted the volume of dab band),

D — is the diameter,

R — is the radius,

H — is the height of the stockpile respectively,

H_1 — is the height of dad band, as depicted in Figure 7.

The diameter and the height of the stockpile D and H are at constant values, and the diameter and height of actual ore in the stockpile, d and h, are not constant, and they are changing with time.

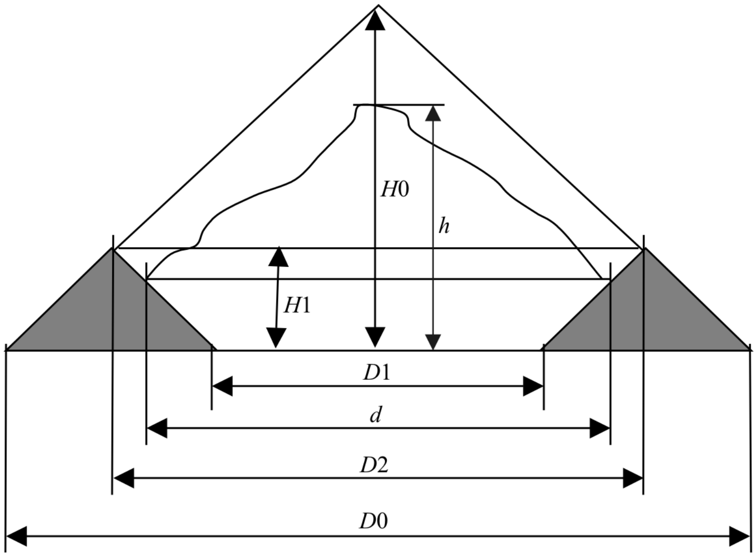

Fig. 7. Illustration of a stockpile with 'dad band', where *D* is the diameter, *R* is the radius and *H* is the height of the stockpile

Therefore, based on the real time measurements of 2 weightometers (W_1 and W_2), the effective mass percentage in a stockpile can be estimated with the ore tonnage (*EMass*%), existing in the live capacity of a stockpile at any time. The accuracy of the mass percentage is dependent on the accuracy of the weightometers mentioned above. Those weightometers, measured the feed rate and discharged rate for a stockpile, are normally regarded as critical weightometers at the mine, because their values are used to indicate the production over a period of time, such as a day, a month, which are linked to the key performance indicators (KPIs). In most cases, an extra weightometer is installed in redundancy to each of those weightometers. A cost effective way is to implement weightometer soft sensors for those critical weightometers, as mentioned in those detailed reports [7, 8, 9].

Based on the indication of the effective mass percentage in a stockpile, the mixing behaviour of the ore can be estimated as well, using the result of discrete element modelling [9], see in Figure 8, 9.

The stockpile soft sensor can help estimate accurate residual time for different group of ores charged to the stockpile. The soft sensor makes it possible to monitor the behavior of different ore types in real time in a stockpile, including when and how the different ores are mixed in the stockpile and when the mixed ores are discharged with certain mixing portion. Using the soft sensor system, the information on ore types can be provided for ores that are discharged from the stockpile. The ore type information includes ore grade, density, hardness, strength, etc. The results can be seen in Figure 10 for the stockpile levels and ores types, being fed in and discharged at four stockpiles (main stockpile, coarse stockpile, fine stockpile, re-crush stockpile). Those results are displayed in a SCADA system of a diamond mine where the stockpile soft sensors and ore type soft sensors are implemented [9].

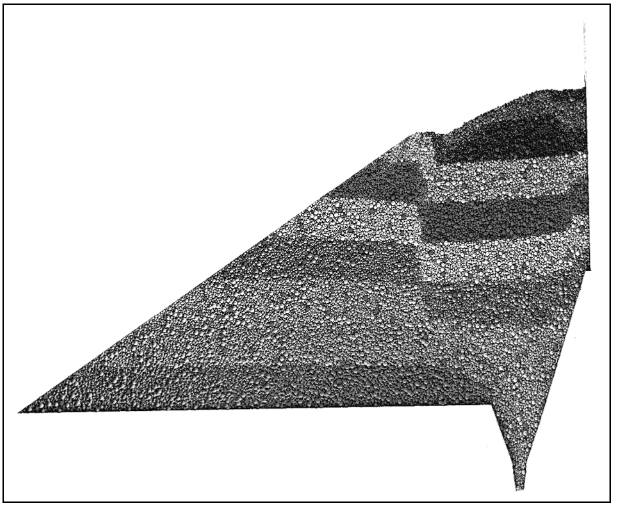

Fig. 8. Illustration of the mixing behaviour of ore in a stockpile, moving down layer by layer, and no mixing when discharged

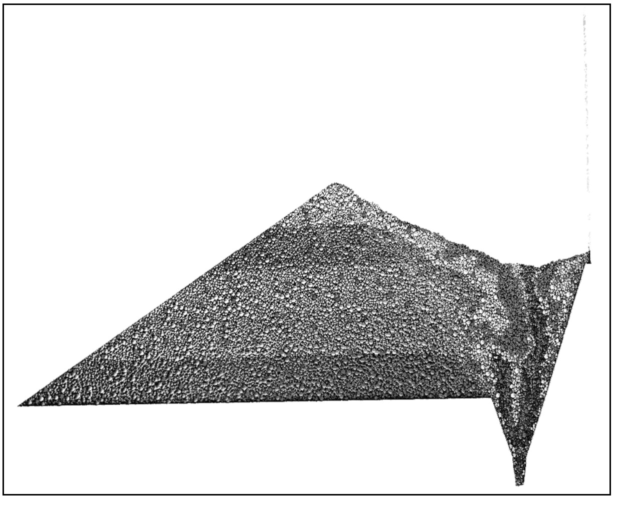

Fig. 9. Illustration of the mixing behaviour of ore in a stockpile, started mixing completely when the level of ore below the height of the dad band

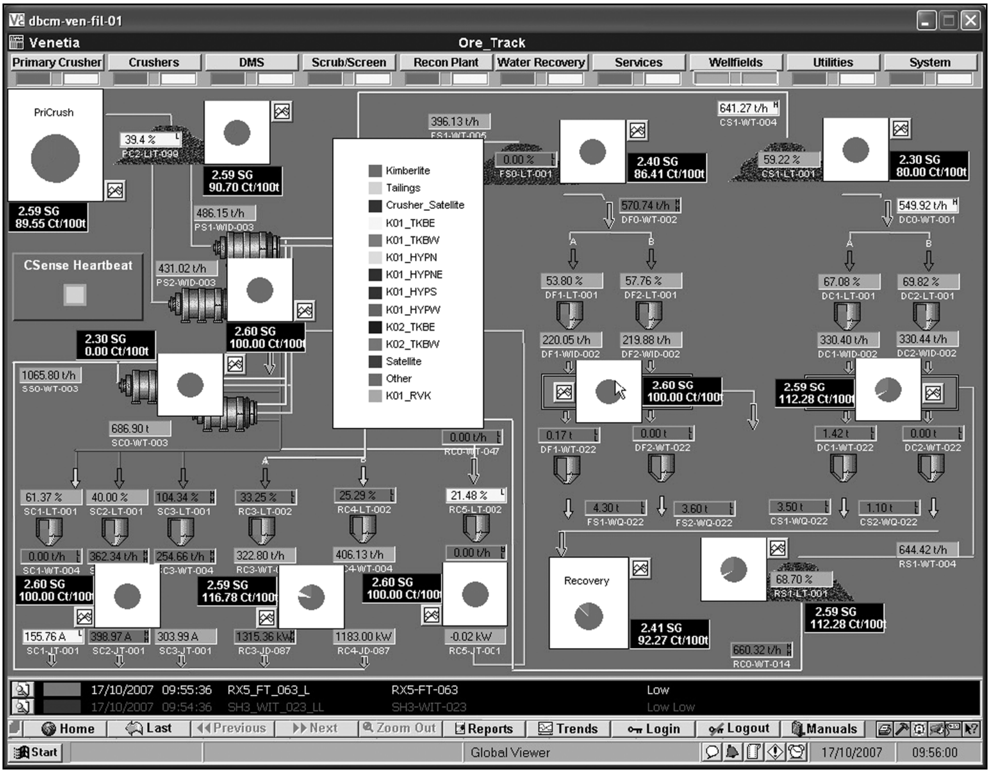

Fig. 10. Display of levels and ore types at various stockpiles at a diamond mine

3. Stockpile level measurement

Many different technologies are available today to measure stockpile levels, and it is important to know that no one technology is suitable for all applications [1]. Therefore it is imperative to understand fully the required process needs and the capabilities of various level measurement technologies, before deciding on a level measurement solution for a solid stockpile.

3.1. Plumb Bob

This technique uses an automated mechanical rope and is referred to by numerous names, including a Yo-Yo (a registered trademark of Bindicator), plumb-bob, and weight and cable [2]. A weight is suspended by a cable from a drum operated by a motor, see in Figure 11, and the motor unwinds the cable until the weight reaches the material surface. The length of the unwound cable is the measured distance to the material, calculated using electrical pulses from an encoder assembly.

The advantage of this technology is that it is reasonably accurate, easy to install and low cost. Its disadvantages include mechanical wearing on parts, resulting in high maintenance costs and the damage to the weight and/or cable during the filling of the stockpiles because the weight can be become stuck under failing material, particularly when the material poses a high density or big size, such as mineral ores.

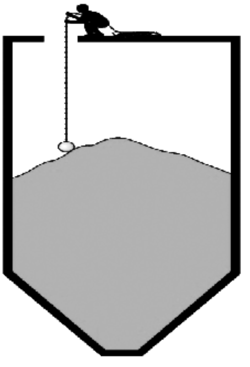

Fig. 11. Stockpile level measured by a Plumb Bob, or Yo-Yo device [2]

3.2. Ultrasonic Technology

Ultrasonic technology uses high frequency sound waves directed to the material by a transducer and measures the time-of-light to and from the material in the stockpile, see in Figure 12. It offers a very cost effective high performance solution for these applications given the following characteristics:

- Measurement ranges are usually short, less than 10 m;
- Dust levels are not severe;
- High shock and high vibration;
- Unrestricted use in “open air” environments;
- Material with low dielectric;
- Material with high density.

The main advantages of ultrasonic technology are that it is low cost, non-contacting and highly reliable. Ranges of up to 60 m are typically promoted, however, this maximum range quickly deteriorates with the intensity of dust on the stockpiles. Since ultrasonic technology required a carrier medium (normally air), any change to this medium has an effect on the measurement. High temperature of the materials in the stockpile also changes the speed of transmission and leads to accuracy problems. Other factors also create accuracy problems for the level measurement, such as material echoing, sloped surfaces of the material.

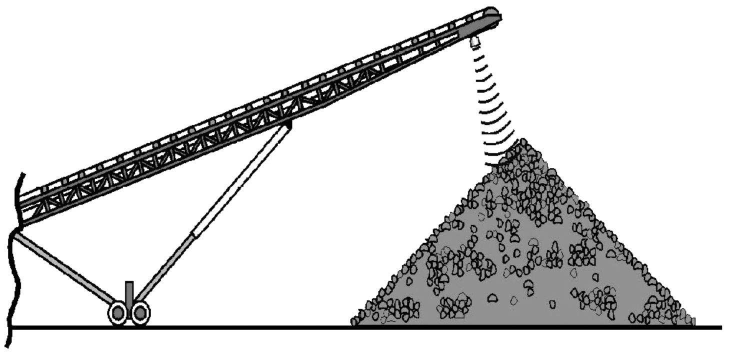

Fig. 12. Stockpile level Measured by an Ultrasonic Device [2]

3.3. Radar Technology

Radar (Radio Detection And Ranging) technology has been used successfully for liquid level measurement since the mid 1970s on large storage vessels, but the cost were high (T. Little, non-contact level measurement in "open air" applications). More recently, as the cost decreased and the technology developed further, radar devices have gained wide acceptance and have achieved high growth rates on solid level applications, such as stockpiles in mining/mineral processing and cement industry. It uses electromagnetic waves in the microwave spectrum between 1 and 300 GHz, which travel at the speed of light and are virtually unaffected by the environment it travels through, such as vapour, pressure, temperature, and dust. Radar works well in solid stockpiles where other technologies cannot handle, such as the stockpiles of cement industry due to the existence of intensive dust. In fact radar has become the preferred level measurement technology today in the cement industry for long range dusty applications.

4. Conclusions

Knowing the material or ore level in a stockpile is extremely important in mining, mineral processing and cement industries. Depending on the users, some are satisfied with approximations while others require specific and very accurate knowledge of the material in a stockpile, including levels and mixing behaviour. Accuracy challenges are presented mainly by the types and sizes of a stockpile and the ore in the stockpile. Various technologies are available to provide the level measurements for a stockpile, including Yo-Yo or weight and cable, laser and radar. It is important for users to understand the required measurement task and the process need before deciding on a level measurement solution. Safety and reliability, and accuracy remain crucial, while at the same time, the specific measurement equipment needs to be chosen with the consideration of easy to install and operate at a low cost of ownership. A software based level measurement, level soft sensor, proves an attractive alternative.

With the advancement and the wide usage of measurement instruments associated with stockpiles, a soft sensor can be developed to monitor the level of a stockpile. The soft sensor makes it possible to monitor the behavior of different ore types in real time, including when and how the different ores are mixed in the stockpile and when the mixed ores are discharged with certain mixing portion.

The stockpile soft sensor forms part of an ore tracking system, which utilises the real time information available in both SCADA and database of a mineral processing plant or a mine. Using the ore geological data and the tonnage of ore being treated, the ore tracking system calculates and provides ore type information to all process units at a mine, including stockpiles, crushers, screens, storage bins, separation, mills and etc.

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