The influence of control and mechanical conditions of certain parameters on jigging

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Synopsis

Jigging is a process of particle stratification in which the particle rearrangement results from an alternate expansion and compaction of a bed of particles by a pulsating fluid flow. The rearrangement results in layers of particles that are arranged by increasing density from top to bottom of the bed. The particles, in addition to the vertically expanded and compacted bed motion, move continuously, horizontally across the supporting screen and helped and influenced by the feed material that is introduced at one end. Following the particle stratification, the particle bed is physically 'cut' at a desired horizontal particle density plane to separate the desired product from the less dense gangue material.

The issue of correct pulse characteristics (shape, amplitude and frequency) for the optimal metallurgical stratification of air pulsating jigs has been the subject of much discussion over the years. The accuracy of the dissymmetric stratification depends on the control parameters and the mechanical condition of specific equipment used.

This paper will touch on some of the control and mechanical parameters affecting the separation efficiency.

Keywords

Jigging, stratification, density, pulse characteristic, air pulsating jigs, control parameters, layers, screen, feed rate, metallurgical, segregation, product quality, calibration, chemical.

Introduction

Kumba Iron Ore's Sishen Iron Ore Mine in South Africa produces 40 Mt iron ore per annum from its beneficiation plants. The ore body consists mainly of laminated and massive type haematite ore of which 28 Mt per annum is crushed down to –90 mm material before being beneficiated by means of a combination of Wemco drums and dense medium cyclones. Twelve Mt per anum is crushed down to -25 mm material for beneficiation with the new 8 module, 3 jigs per module jig plant. The feed to each module is screened into three fractions that feed three different jigs. The coarse jig receives a -25 mm +8 mm material, the medium jig is fed with a -8 mm +3 mm material, and the fine jig receives the -3 mm +1 mm material.

During the test phase all the material was treated in a side-pulse test jig (3 m length x 0.620 m width). After the coarse fraction (-25 mm +8 mm) was succesfully tested, the fine fraction (-8 mm +1 mm) was treated. After the first test on the fine fractio, the material was spit into two fractions (-8 mm +3 mm and -3 mm +1 mm). The two separate fractions resulted in a 12% improved yield compared to the single fraction (-8 mm +1 mm). This is caused because the finer -2 mm material is lost to the waste because of its particle size and the necessary control parameters needed to succesfully separate the top size 8 mm particles in the band.

The jig plant with its 24 jigs was in full production towards the end of 2009 providing an equvalint of 12 Mt product per annum. The jig plant was designed to receive lower grade material from the mine that needs a cut density of 4 200 kg/m^3 and higher to be able to produce the product to the set specification.

Jigging theory

Jigging is a process of particle stratification in which the particle rearrangement results from an alternate expansion and compaction of a bed of particles by a pulsating fluid flow. The rearrangement results in layers of particles that are arranged by increasing density from top to bottom of the jig bed.

The particles, in addition to the vertically expanded and compacted bed motion, move continuously and horizontally across the supporting jig screen helped (influenced) by the feed material that is introduced at one end. The feed rate influences the retention time of the material in the jig and thus the number pulses the material will receive before exiting the jig as waste or product. During the test phase, with this specific type of material, a

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maximum feed rate was established for the different size fractions to achieve optimum separation efficiency. For the coarse jig (-25 mm +8 mm) the maximum feed rate is 80 t/h/m width, for the medium jig (-8 mm +3 mm), 50 t/h/m width and for the fine jig (-3 mm +1 mm), 30 t/h/m width. The maximum feed rate would be influenced by the percentage of near density particles. Near density in this case means the mass percentage of material in the feed with particle densities between 4 000 kg/m^3 and 4 400 kg/m^3. If the percentage near densities increases above 15%, the maximum feed rate to the jigs must be reduced for optimum separation efficiency.

Following the particle stratification, the particle bed is physically 'cut' at a desired horizontal particle density plane to separate the desired product from the less dense gangue material.

The issue of correct pulse characteristics (shape, amplitude and frequency) for the optimal metallurgical stratification of air pulsating jigs has been the subject of much discussion over the years[1,2,3]. The size ratio of the feed particles (as mentioned in the introduction) and the water velocity are two important parameters to improve segregation during fluidization[4] thus improving the beneficiation characteristics of the jigging process. It was also noticed in the plant that the amplitude of the pulse would increase with increasing particle sizes treated by a specific jig.

The efficiency of the stratification of iron ore in jigs depends not only on the correct pulse characteristics such as shape, amplitude and frequency as mentioned, but also, to control the pulse, the mechanical condition of the various equipment used must be monitored and measured for optimum stratification.

Plant layout

The jig plant at Sishen Iron Ore Mine consists of a primary, secondary and tertiary crushing circuit crushing the feed material to a -25 mm top size and longitudinally stacking it on two ROM (run of mine) feed beds (Figure 1). The ROM feed bed material is reclaimed by a bucket reclaimer and conveyed to eight feed bunkers. Eight conveyers from the feed bunkers feed each jig module and belt scales on each conveyer control the feed rate.

After beneficiation the lumpy ore (-25 mm +8 mm) is conveyed and stacked on the blending beds while the fine material (-8 mm +1 mm) is conveyed to the dewatering bunkers and then stacked on the fine blending beds.

The jig plant consist of eight modules with three jigs each, the coarse jig (-25 mm +8 mm), medium jig (-8 mm +3 mm) and fine jig (-3 mm +1 mm) (Figure 2). The feed to the plant is spread evenly over the width of the primary double deck screen with a shuttle. The top deck overflow feeds the coarse jig. The overflow of the bottom deck of the primary screen flows to a shuttle that spreads the material evenly over the width of the chute that feeds the medium jig. The underflow of the primary deck flows to a single deck secondary screen where the -1mm material is screened out before the oversize material flows into the fine jig. The waste of all the jigs is conveyed on one conveyer to the waste dump. The coarse jig product is conveyed to the lump product blending bed and the medium and fine jigs product is conveyed with one conveyer to the dewatering bunkers.

The decision to build ROM beds before the beneficiation process was made due to the need to homogenize certain parameters:

- The varying chemical composition in the feed from the mine that can also result in a varying percentage of near density particles depending on the type of ore
- The varying PSD in the ROM feed.

Because of the size of the open pit mine (12 km x 2.5 km) the feed to the plant is trucked from different fronts in the mine with different mineralogical ore types which results in chemical variation in the feed. Different kinds of ore also have different crushing characteristics thus resulting in a variable PSD in the ROM feed.

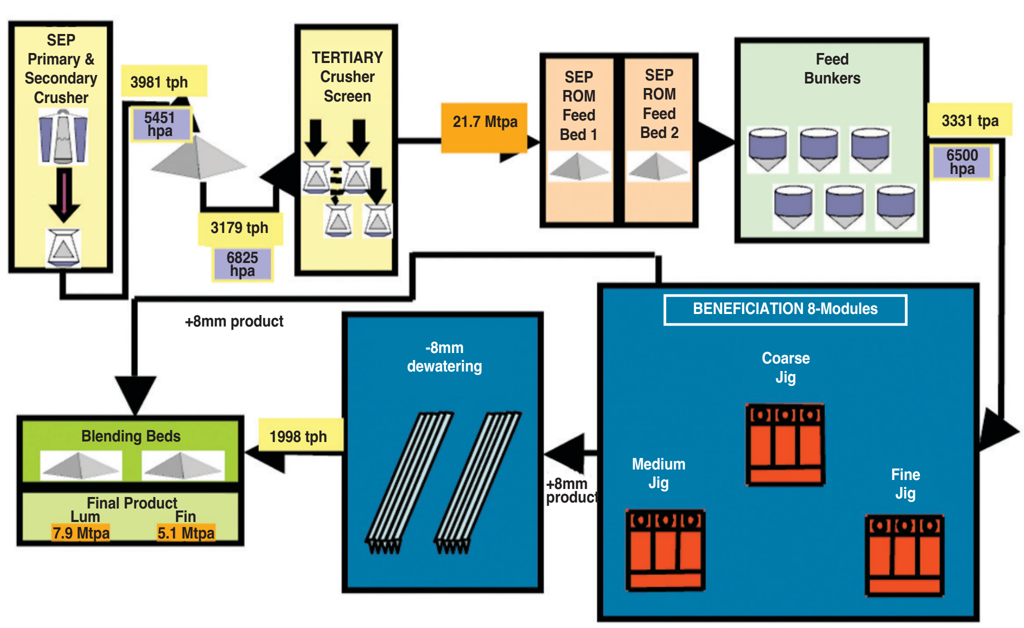

Figure 1—Overall jig plant layout

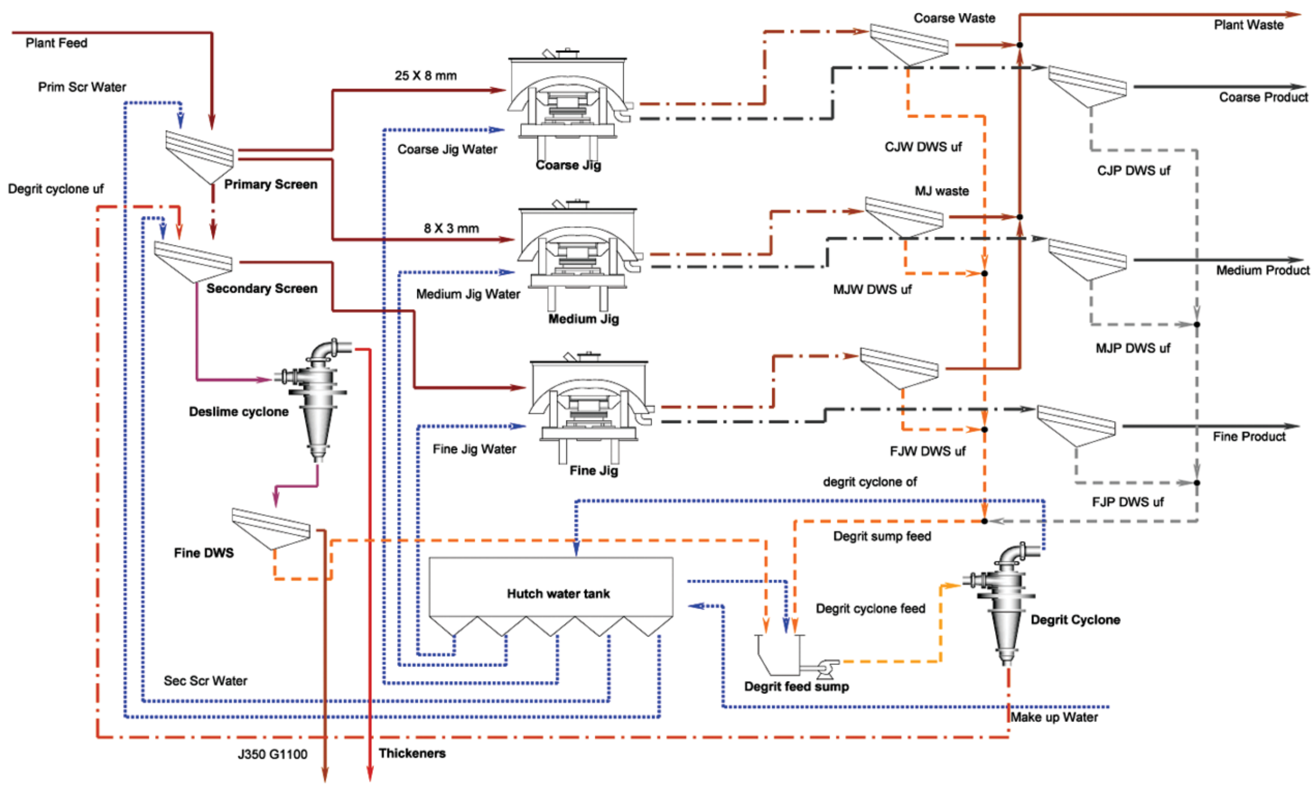

Figure 2—Jig plant layout

Varying chemical and near density material in the ROM feed to a jig would require continuous changing of the jig settings for optimum beneficiation efficiency. With the composite two-hour sample and lab analysis, it would be impossible to maintain the optimum efficiency in the test and some product would be sacrificed due to the requirements of maintaining a constant chemical specification.

PSD variation in the ROM feed means a continuous variation in the feed rate to the plant, with the possibility of exceeding the maximum feed rate to a certain jig lowering the beneficiation efficiency of that specific jig.

With the ROM beds of 80 000 t capacity or more per bed, the plant can run for almost two days with minimum changes to the jig settings and maybe only slight adjustments to maintain chemical specification on the product beds. This means that the optimum yield and maximum product tonnage is extracted from the feed material if the pulse characteristics are maintained in the jigs.

The shuttles used in the plant are needed so that the feed material and PSD is evenly introduced into the jigs. If the mass is not evenly distributed into the jig the forward movement of the bed on that side would be faster, thus reducing the retention time and causing ineffective beneficiation. It is also important that the PSD spread over the width is even so as to maximize the effectiveness of the separation process.

Jig construction

The jigs at Sishen Iron Ore are under bed pulsating jigs that are fully PLC controlled. All the jigs are 3 m long and the width varies from 4 m for the coarse jig, 3.5 m for the medium and 2.2 m for the fine jig. The different widths for the Jigs were chosen because of the expected PSD from the crusher circuit.

The jig has a screen deck to support the jig bed and allow the pulse through to lift the beds the set height. At the end of the jig, a float will measure the stroke of the bed as well as the product bed height, and control the height of the product bed around the set value by opening or closing the product gates. The waste will flow over the weir at the end of the jig while the product is collected in the hopper underneath the jig. High and low level probes will start and stop the feeder control the extraction of the product (Figures 3 and 4).

The pulse is created by air that enters and exits the air chambers situated underneath the screen deck. The air forces the water in the air chamber down, creating the pulse in the beds and let, the air out to allow the bed to set before the next pulse begins. The air generated by a blower and stored in the working air vessel. Poppet valves control the air that enters and exits the air chambers. The air-water interface level in the air chambers is measured by level probes, which control the poppet valves to keep the stroke in the air chamber constant.

Pulse control

The efficiency of the stratification of iron ore in jigs depends only on correct pulse characteristics (shape, amplitude and frequency) as mentioned, of which the mechanical condition of the equipment used to create the pulse has a direct influence.

As long as the pulse characteristics are correct, the beneficiation efficiency will be optimal. The outside factors that can influence the efficiency are the feed rate, chemical

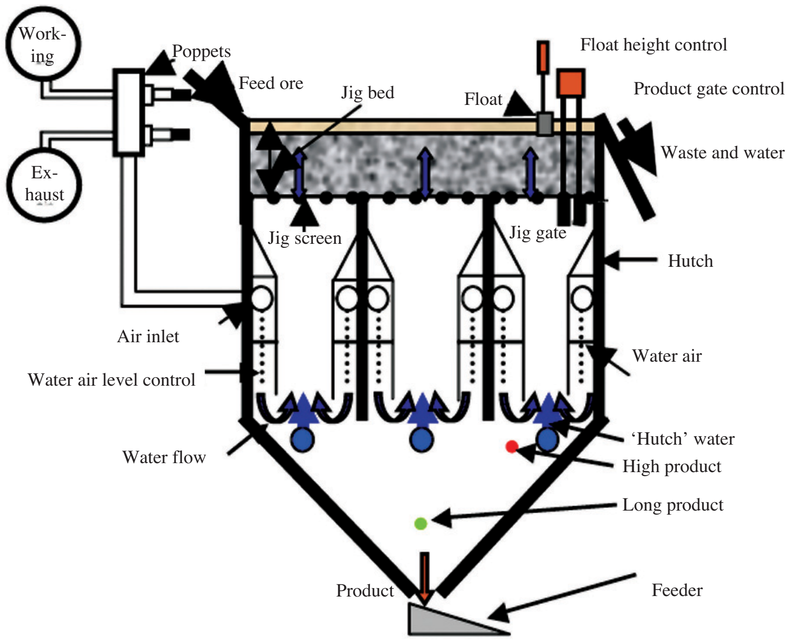

Figure 3—Jig construction

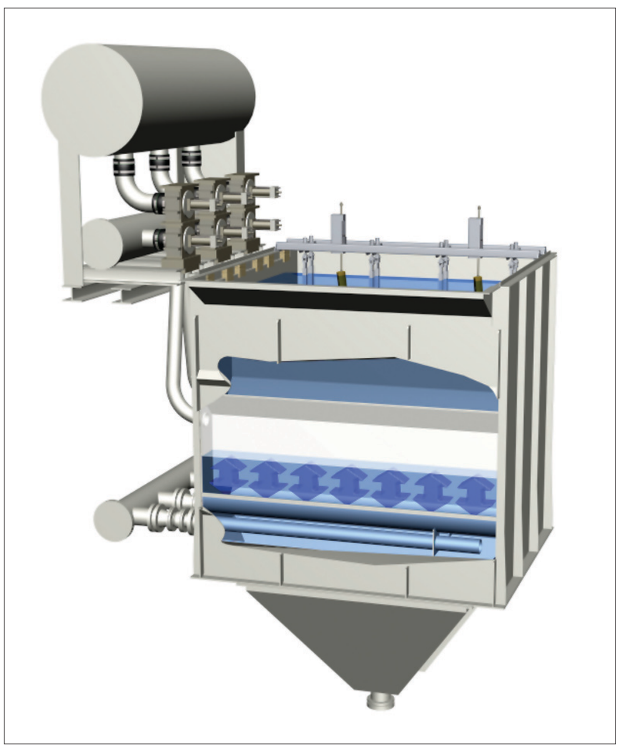

Figure 4—Jig construction

quality of feed and percentage near density material. The effect of the percentage near density can be controlled by reducing the feed rate and/or increasing the weight on the floats. By reducing the feed rate, the retention time is increased, giving the material a longer time to separate. By increasing the weights, the cut density is increased and more near density material is removed to the waste, decreasing the layer thickness of the near density particles that will form underneath the float and thus increasing the efficiency of the separation process. The effect of varying chemical feed composition will have an effect on the product quality and can be controlled by increasing or decreasing the product bed height that forms underneath the float, forcing more or less near density particles to the product. Most of these problems will be compounded if the shuttles are not working correctly and the PSD and mass feed into the jigs is not even over the width of the jig.

Some of the internal jig factors that can affect the pulse characteristics that were encountered during the commissioning phase and afterwards are as follows:

- Punch plate blocking
- Training/experience of maintenance and operational personal
- Accurate calibration of all instruments
- Rubber on jig gates
- Fine jig screen decks blocking
- Poppets:
  - Rubbers
  - Dirt in pipes—instrument air
  - 5 mm solenoid screen block
  - Poppet oil distribution (heat, wear)
  - Electrical connection (solenoid)
  - Electrical connection (connection boxes)
  - Poppet timing over certain distance
  - Wear on poppets
  - Distance that poppets move.

Training is very important for the operational and maintenance personnel: they need to understand the process and the effect their reaction will have on the process efficiency. The instrument technicians must calibrate all the instruments correctly and monitor them from time to time to assure an effective process.

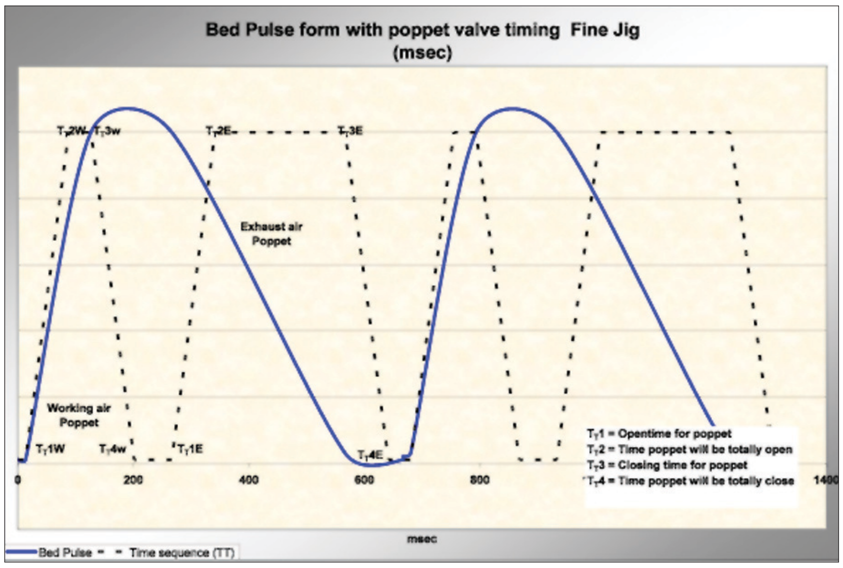

Figure 5—Form of pulse during cycle

The punch plates (part of the gate system) and screen decks (polyurethane decks) must never block because of the effect it will have on the lift of the bed and thus the separation efficiency.

The feed to the fine jig is a -3 mm +1 mm material and if the product gate of the fine jig cannot close properly, the product bed that should form underneath the float will not form and the total feed will be lost to the product side. Rubber (5 mm thick) was put on the gate, keeping a bed in the jig for effective separation.

Most of the problems were encountered around the poppet valves that maintain the pulse and control the lift of the jig bed. Any of the project value problems identified have an affect on the speed/time and distance the poppet must travel and thus on the pulse form and lift of the bed, with a negative effect on the separation efficiency. The poppets use instrument air (clean air) at 6 bar pressure to be able to function correctly.

Pulse timing

A pulse cycle starts when the working air poppet receives a signal to open and allows air to enter the air chambers. The air will push the water-air interface in the air chamber downwards, carrying the energy over to the ore bed and lifting the jig ore bed the desired stroke upwards. The cycle ends after the water-air interface in the air chamber has moved back to its original position, implying that the ore bed has settled back down to its original position and just before the air enters the air chamber to start the next cycle (Figure 5).

Two poppets per chamber control the inlet and outlet of the air in the air chambers and the timing is controlled by a PLC. During the pulse cycle the working air poppet must open and close before the exhaust poppet will open and close. This indicates that the time to open and the distance the poppet must travel are very important to be able to control the pulse and lift (stroke) on the bed for proper segregation to take place (Figures 6 and 5).

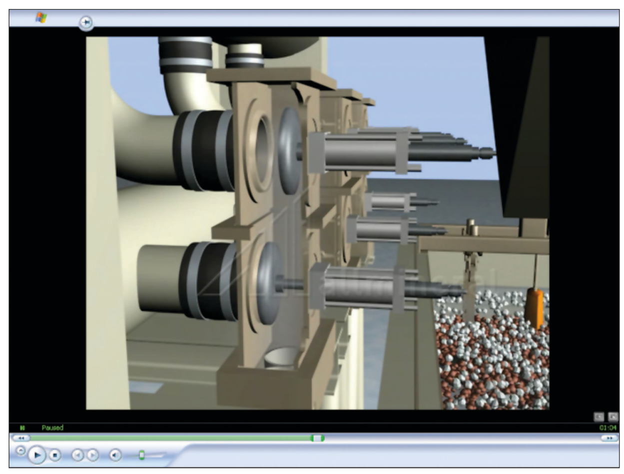

Figure 6—Poppets that control the pulse in the jig

The frequency of the jigs at the moment is set at:

- Coarse jig = 60 pulses per minute
- Medium jig = 70 pulses per minute
- Fine jig = 90 pulses per minute

The time for each pulse cycle to be completed is as follow:

- Coarse jig = 1 000 ms
- Medium jig = 857 ms
- Fine jig = 667 msec

The fine jig poppets have the shortest cycle period. The poppet construction and functioning, for all three jigs, is the same, therefore it can be assumed that if the poppets' travel speed and distance is correct for the fine, medium and coarse jig, then the control of the pulse forming and the lift (stroke) of the ore bed will be optimized.

The distance set for the poppets to travel for all the jigs is 55 mm and can be readjusted if necessarily. By keeping this value constant for all the jigs, the maintenance personnel can set the values on new and refurbished poppets before they are installed.

The graph in Figure 7 illustrates the poppet timing (black dotted line) and the reaction of the water-air interface (blue line) in the air chambers. It takes a new poppet 75 ms to travel the 55 mm set distance. At time T_T1W the working air receives a signal to open and will be fully opened at time T_T2W, well in advance of the order to close reaches the poppet at time T_T3W. At time T_T4W the poppet is closed. At this stage the water-air interface reaches the set value after time T_P2 in the air chamber and the bed reaches the maximum lift required for optimum separation. A graph on the ore bed will differ from the blue graph, especially at the beginning of the pulse because of the inertia of the ore bed at the beginning of the cycle. After the working air poppet closes and before the exhaust poppet opens at time T_T1E, the bed will be in suspension and will start to settle. During this period separation takes place as the heavier ore particles will settle faster than the lighter waste particles.

At time T_T1E the exhaust poppet will get the signal to open and will be fully opened at time T_T2E, well before it receives the signal to close at time T_T3E and will be fully closed at time T_T4E. During this period the water-air interface in the air chamber will move back to its original set position, forced only by the water in the jig and the ore on the jig screen. After a rest period the cycle will start again to create and form the next pulse.

Time T_T1W and T_T1E are fixed time settings and can only be changed only on the PLC. Time T_T3W and T_T3E have three values, a normal, maximum and minimum value. In the air chamber a certain stroke is needed to get the right stroke on the ore bed in the jig (Figure 8). If the water-air interface drifts off the normal of the two set values (height values) in the air chamber to the maximum or minimum side, the PLC will change the poppets timing by a few milliseconds faster or slower to try and keep the two set values at the normal set value and thus maintain the stroke in the air chamber and the stoke on the ore bed in the jig.

The effect on poppet timing caused by malfunctions in the poppets

As mentioned, the efficiency of stratification of iron ore in jigs depends on the correct pulse characteristics and stroke on the ore bed in the jig. The poppets control the pulse, and also control the stroke on the ore bed and are influenced by their mechanical condition.

The poppet problems mentioned earlier have an effect on the speed of the poppet and thus the distance it needs to travel. Figure 9 demonstrates the effect poppet speed will have on the poppet timing. At point A, when the working air poppet has opened only 75% of the set distance, it will get a signal to close and will immediately start to close. Not enough working air will enter the air chamber and the downwards stroke of the water-air interface will not reach the set value that will decrease the stroke in the air chamber and thus on the ore bed in the jig affecting the ore separation efficiency. While the working air poppet is closing, it will reach point B where the exhaust air gets the signal to open and for a short period, the working air is short-circuited directly out of the exhausted poppet. At point C while the exhaust poppet is closing, the working air poppet will get the signal to open again, short-circuiting the working air through the exhaust poppet.

Thus, total control will be lost on the pulse in this case, resulting in a too low stroke on the ore bed and affecting the separating efficiency negatively. There are three working and three exhaust poppets on a jig. If only one of the poppets is not functioning correctly, it will have an effect on all three chambers and will affect the separation process.

Most of the problems identified could be rectified, but occurrences like wear on poppets and rubber life can only be lengthened but will not be totally alleviated. It is thus important to measure the poppets weekly and rectify the poppets showing symptoms of incorrect functioning.

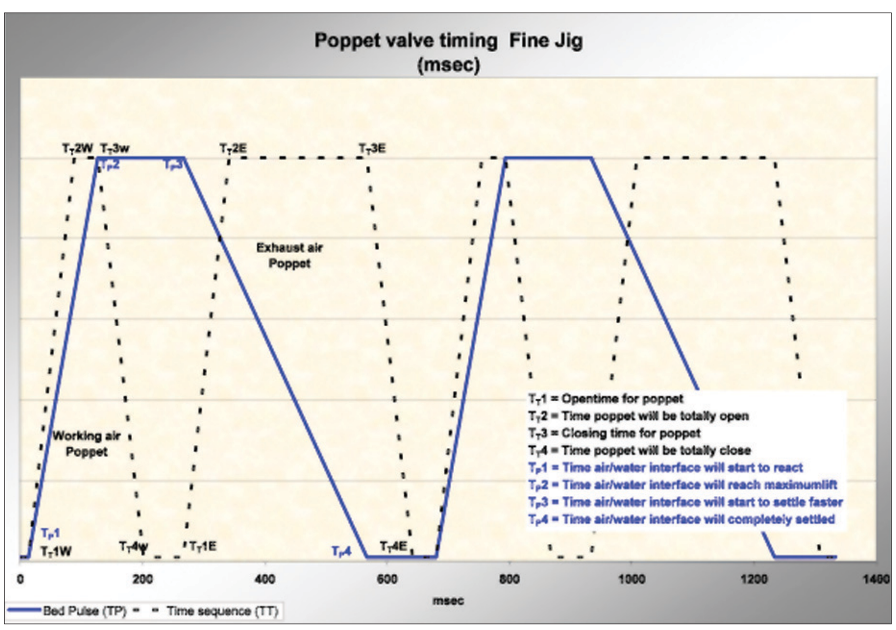

Figure 7—Poppet valve timing of fine jig

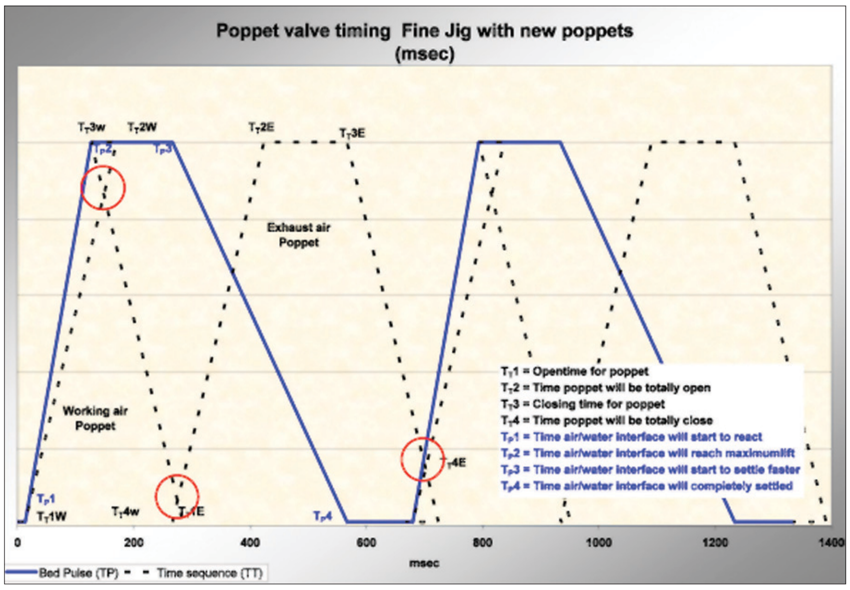

Figure 9—Poppet valve timing of fine Jig

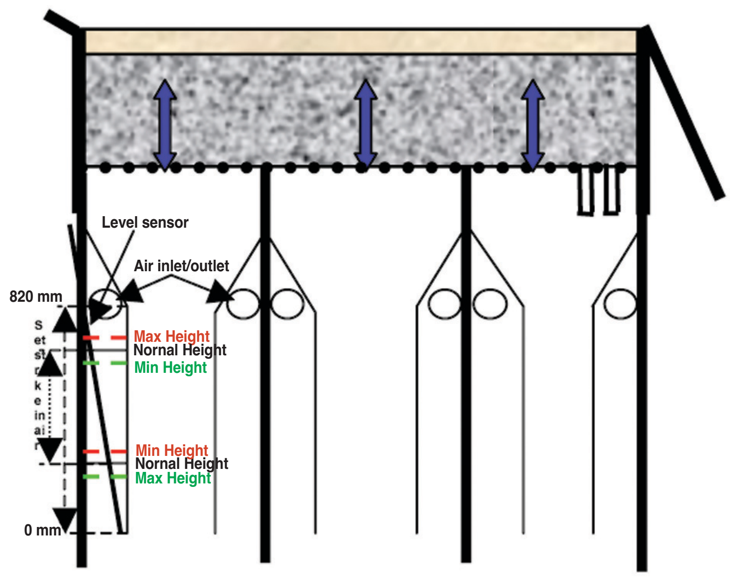

Figure 8—Reaction of water-air interface in air chamber

Conclusion

The efficiency of the stratification of iron ore in jigs depends only on the correct pulse characteristics such as shape, amplitude and frequency as mentioned—but, to be able to control the pulse, the mechanical equipment used must function correctly.

The stroke needed on the jig ore bed must be taken into consideration while setting the pulse. The pulse must be set so that the stroke on the ore bed is at least three times the top size of the ore fed to the jig. If the stroke on the ore bed is less than the needed minimum value, the separation efficiency will not be optimal.

Regular monitoring of the condition of the equipment responsible for the pulse form will lead to optimum separation efficiency.

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