Control Optimisation of Automatic Reclaimers At BHP Iron Ore Port Hedland

KT Law, PG Rourke
email: law.kim.kt@bhp.com.au
BHP Engineering - Perth, Australia

PK Maresse, DJ Netterfield
email: maresse.peter.pk@bhp.com.au
BHP Iron Ore - Port Hedland, Australia

ABSTRACT

This paper describes the control optimisation of two fully automatic reclaimers located at BHP Iron Ore Nelson Point Port Handling Facilities, Western Australia. These reclaimers are among the largest fully automated slewing reclaimers of their type in the world. Each reclaimer has a 60 m boom, 10.5 m diameter bucket wheel and a reclaiming rate of 4500 m^3/h, which translates to 10,000 t/h for typical iron ore. The first stage of control optimisation achieved a 12% improvement in machine reclaiming performance. This improvement was made possible through the use of model based control theory which included the internal model control technique. The control scheme was implemented using the standard GE Fanuc 90/70 programmable logic controller instruction set.

1. INTRODUCTION

BHP Iron Ore Nelson Point Port Handling Facility is a 240-hectare iron ore processing and stockpiling operation, incorporating facilities for train unloading, screening and tertiary crushing of ore, stockpiling, reclaiming, shiploading, and control of ore quality. It has a 658 m long wharf with two berths each capable of handling ships of up to 260,000 deadweight tonnes (dwt). Average turnaround time for a carrier at Port Hedland is 65-150 hours, while loading time averages 25-34 hours. In the year ending 31 May, 1997, 55 million tonnes were shipped from Nelson Point.

The Nelson Point facility is a highly automated operation. The two automatic reclaimers (namely, Reclaimers 5 and 6) described in this paper are an integral part of the Nelson Point shiploading operation. Being fully automated and unmanned, they are supervised remotely from the Control Tower which is the control center for the whole Nelson Point operation. The stacking and reclaiming operations are integrated seamlessly with a custom designed automatic stockpile management system.

Since the maximum shiploading rate is directly related to the reclaiming rate, the reclaimer performance is very important because it affects the turnaround time for a carrier, the anchorage and demurrage costs.

Reclaimers 5 & 6 are each rated for 4500m^3/hr operation. Each weighs 1750 t and has a 60m boom with a bucket wheel diameter of 10.5m. The stockpiles which they reclaim are typically 150m long, 17m to 19m high and 55m wide.

2. BASIC RECLAIMING MOVEMENTS

A slewing bucket wheel reclaimer has three degrees of freedom in its movement, namely, travel, slew, and luff (refer Figure 1).

Reclaimers 5 & 6 travel motion is along the runway rails which are parallel to the storage yard. This motion is provided by fourteen 22kW long travel motors driving the wheels located at the bottom of both sides of the main support of the reclaimer called the gantry. These motors are controlled by two sets of 219kVA variable speed drives. The maximum travel speed is 0.51 m/s and the maximum acceleration is 0.07m/s^2.

The slewing motion makes the boom swing in a horizontal arc with a radius of 60m centred on the main structure supported by the gantry. This motion is provided by four 30kW electric motors controlled by a single 219kVA variable speed drive. The maximum slew speed is 0.39 °/s and the maximum acceleration is 0.06 $°/s^2$.

The third motion is luffing which allows the boom and digging bucket wheel to be raised or lowered to specific elevations corresponding to the base of each stockpile bench. This motion is provided hydraulically, giving a maximum luffing speed of 0.95 °/s and a maximum acceleration of 0.01 $°/s^2$.

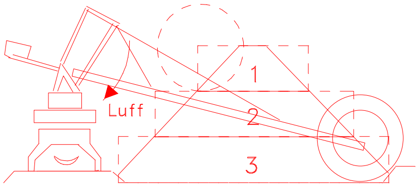
These movements of the bucket wheel position are used to reclaim a stockpile in a manner to ensure homogeneity and blending of the reclaimed material. Since the main stacking algorithm used at Nelson Point operation is a chevron ply, the corresponding reclaiming action to provide good product blending is achieved by:

- firstly, the slewing motion across the stockpile face. Each slew is followed by a travel motion along the rail at every slew reversal (with a step advance of about 0.7-1.2 m - this is dependent upon the bucket height, the material flow characteristics and desired reclaim rate), and
- secondly, reclaiming the stockpile in three benches by pilgrim step, ie. instead of reclaiming each bench completely before changing bench, the reclaimer changes bench at a fixed travel distance - this ensures a

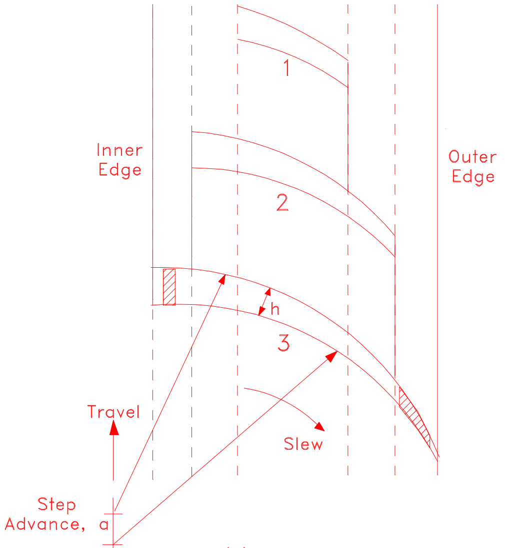
mix of material from the top of the stockpile and the bottom of the stockpile.

The heart of the reclaiming operation is the bucket wheel itself. The bucket wheel has 10 buckets, each with a height of 1.2m. The wheel is powered by a 450kW induction motor operating at constant speed.

The reclaimed material is discharged from the bucket wheel onto a 60m boom conveyor. The boom conveyor then discharges the material into a 120 t surge bin which acts as a small buffer between the bucket wheel and the output apron feeder. The material is then fed out of the surge bin via the apron feeder to the yard conveyor. The yard conveyor in turn discharges the material into conveying and screening stages until it is finally loaded onto the ship by the shiploader.



(a) Side View



(b) Plan View

Figure 1 Geometry of slewing reclaiming action

3. RECLAIMING GEOMETRY

Reclaiming is essentially a volumetric process, hence it is important to understand the geometry of the reclaiming process.

Figure 1 shows the geometry of the slewing reclaiming action. Note that the effective cut depth, h, is a result of the difference in the last cut trajectory and the current bucket trajectory. Since the reclaimer is constrained to travel along the rails parallel to the stockyard, the effective cut has a sickle shape rather than a concentric shape. Consequently, when the bucket wheel is close to the inner edge, a smaller slew angle is required to sustain an equivalent effective cut area compared to when the boom is close to the outer edge (as illustrated by the shaded areas in Figure 1 (b)).

Since the material on the stockpile has a natural repose angle of around 40°, the reclaiming efficiency drops near each edge of the stockpile. This is because within the slope portion at each edge, the effective volume of reclaimed material compared to total theoretical reclaimable area is reduced (refer Figure 1(a) - the dotted line shows the boundary of actual reclaimed area).

For a theoretical stockpile with a repose angle of 90°, the bucket wheel cutting geometry is determined by the helical curve which is produced by superimposing the turning wheel and the forward feed as shown in Figure 2. Note that the effective digging depth, h, is the difference between the last cut position and the current cut after the step advance. Furthermore, h is a function of the slew angle (refer Figure 1(b)). Note that the volume of the helical shape is equivalent to that of a rectangular block with the same height and top dimensions (refer Figure 2). The height of the reclaimed pile section, λD, is chosen depending on the slope stability of the material (D is the diameter of the bucket wheel). Typically, λ has a value of 0.55 to 0.6.

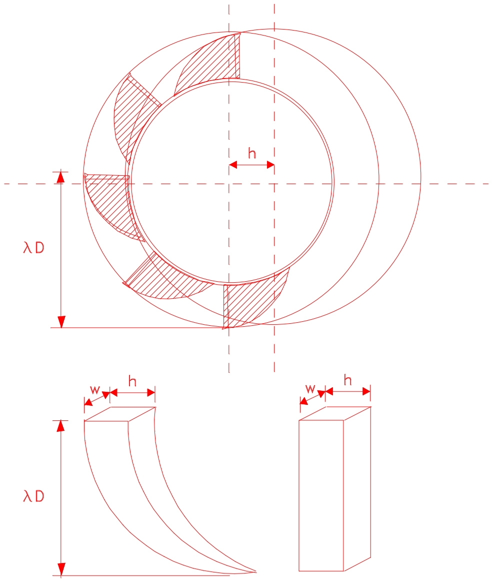


Figure 2 Geometry of the bucket cut in stable slope

4. CONTROL CHALLENGES

The reclaiming geometry characteristics impose certain challenges which makes the control problem interesting:

a) As noted in the previous section, since the reclaimer is a slewing reclaimer on a rail, the slew action cuts a sickle shaped slice. Therefore, the reclaiming rate with respect to the slewing speed is a non-linear function of the slew angle (Note that it can be shown to be a cosine relationship), ie. in order to reclaim the same volume of material, a faster slew speed is required when the bucket wheel is closer to the outer edge than when it is near the inner edge (refer Figure 1).

b) Since the reclaimer is essentially a volumetric machine, the different material density of the different ore-types adds another facet to the control especially when all the operating control and performance measures are specified in t/hr.

c) The ratio between volume of effective material reclaimed and the total active cutting area of the bucket wheel diminishes towards the edges and ends of the stockpile. This is because of the repose angle of the material on either sides, beginning and end of the stockpile.

d) Depending on the type of ore, avalanches of material may occur while the reclaimer is digging. These may occur in front or behind the bucket wheel position. Hence the control system must be fast enough to respond to these avalanches in order to avoid causing the bucket wheel drive to trip due to excessive load.

e) Depending on the flow characteristics of the material, different step advance settings are needed. These are set remotely by the control tower operator.

Besides the challenges imposed by the geometry of the reclaiming action, there are some which are attributed to the physical layout of the equipment:

a) There are significant transport delays in the boom conveyor. There is no belt weigher on the boom to measure the material entering the surge bin. The only indication of material being transported by the boom conveyor is the torque and bucket wheel motor current measurement. This translates to significant delay between measured rates and their effect on the surge bin level.

b) The surge capacity of the surge bin is 120 t. As the typical reclaiming rate of the system is 9000 t/h, this provides less than one minute of surge capacity from empty to full. This small capacity makes the control of the surge bin difficult. Furthermore, there is no direct level measurement, only a weight measurement of the bin (this is because it is difficult to find a reliable level transducer for this application). This together with the conical shaped bin and variety of material types with different densities, further complicates the surge bin level control problem.

In addition to the above geometrical and physical layout, the reclaiming efficiency is also affected by physical limitation of the machine movements:

a) The reclaimer system has a fairly large mechanical inertia. Furthermore, the acceleration and deceleration rates are constrained by the capability of the drives and the structural stability of the machine. Therefore, each slew reversal requires a finite increment of time to occur, typically, several seconds. Hence, for short slew passes the ratio of reversal time to the time slewing at normal reclaiming speed can be significant.

b) Since the size of a step advance is relatively small, the achievable reclaiming efficiency during a step advance is limited. This is because the large mechanical inertia of the reclaimer and its finite travelling acceleration and deceleration rates. Consequently, it is difficult to achieve a significant travel speed and hence a good reclaiming rate during a step advance.

c) The bench change process is another source of inefficiency. This is because of the necessity to interrupt reclaiming operation during pilgrim step reclaiming to travel the reclaimer backwards and then luffing to the next bench (typically takes more than a few minutes). Hence, the choice of the pilgrim step size has significant impact on the overall reclaiming efficiency.

5. CONTROL OPTIMISATION

The control optimisation can be subdivided into a number of tasks targeting different areas of reclaiming inefficiencies, namely:

- the basic reclaiming control loops
- the movement control sequencing and the operator practices

5.1 Reclaimer Control Loops

Prior to optimisation, the reclaiming controller had the following structure:

- A constant surge level PID regulator was used for setting the slew speed reference.
- The difference between the maximum allowable bucket torque and the measured bucket torque was used as a multiplication modulating factor for reducing the slew speed reference generated by the surge bin level regulator.
- The yard conveyor belt weigher feedback was used in a PID regulator to control the apron feeder speed.

The achievable performance of this structure is limited because:

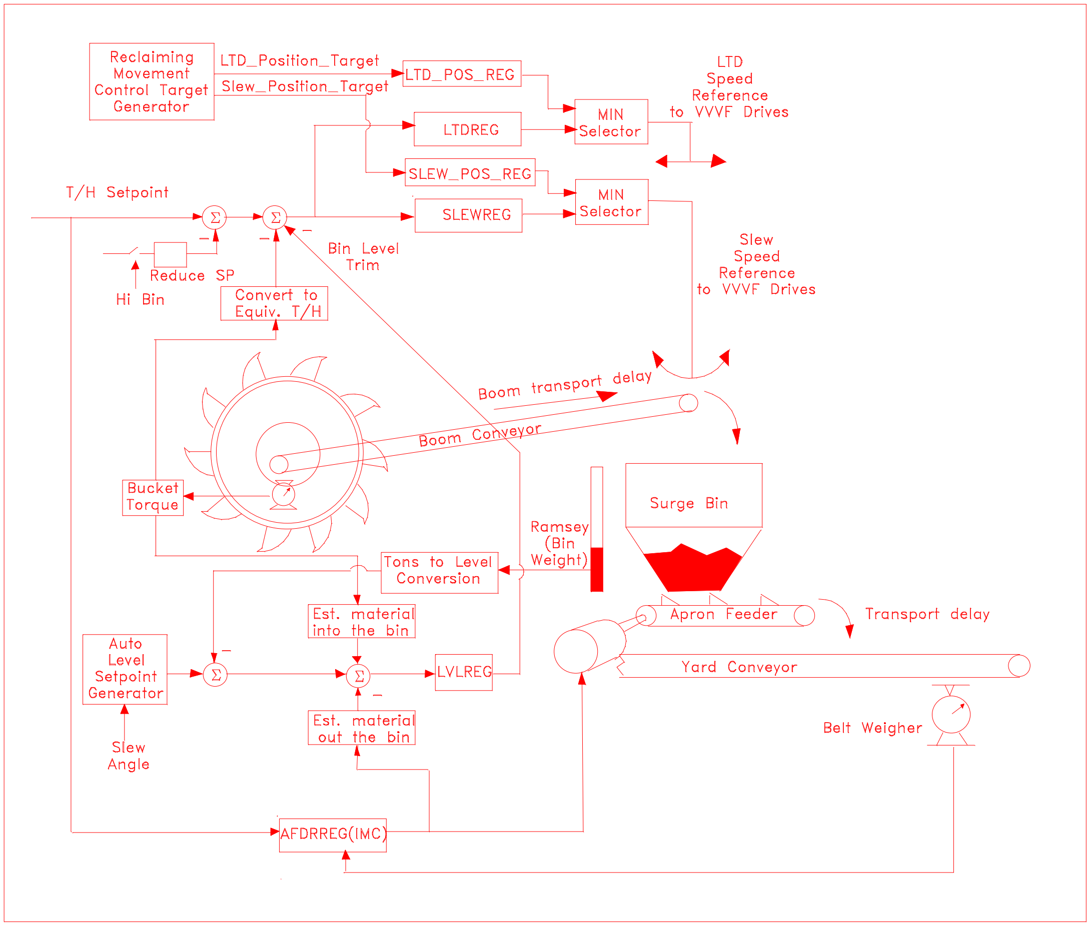


Figure 3 Control Block Diagram

- The small capacity of the surge bin relative to the normal reclaiming rate makes this configuration of the surge bin level regulator inadequate to effectively cater for the disturbances in the system. Furthermore, the control problem was complicated by the significant transport delay of the boom conveyor, the conical shaped bin, and level feedback in terms of weight and not level.
- The use of bucket torque feedback as a multiplication factor to the output of the surge bin regulator introduces unnecessary non-linear gains into the control loop. Furthermore, the signal noise from the bucket torque was amplified through the control loop.
- A mixture of ad hoc discrete switching and gain scheduling were mixed with the continuous control algorithm.
- There were little use of model-based gain scheduling, controller windup protection and delay compensation.

In order to overcome these problems, the reclaiming control loops were replaced by a completely new structure which was based on a physical and geometrical model of the reclaiming process. Figure 3 shows the block diagram of the new control structure.

The bucket torque is used as a feedback for regulating the slew and travel speeds to achieve a controlled reclaiming torque at the bucket wheel. A gain scheduling scheme based on the inverse model of the reclaiming geometry and material characteristics is embedded in the torque regulators (SLEWREG and LTDREG). Both the slew and long travel regulators have facilities for automatically presetting the controller states to recover and minimise any problem associated with controller windup (this is in addition to the windup protection due to controller saturation)arising from large disturbances such as avalanche and the edge regions of the stockpile. Minimum selector gates are used to enable bumpless and smooth switching between the torque regulators (SLEWREG and LTDREG) and position regulators (SLEW_POS_REG and LTD_POS_REG) which control the slew reversal and long travel step advance movements.

The apron feeder regulator (AFDRREG) is based on internal model control (IMC) [1]. The IMC structure allows for incorporation of delay compensation for the measured belt weigher signal.

Note that the desired output t/h set-point is used in both the bucket wheel torque and apron feeder controls. Hence, under normal operating conditions, if the bucket torque conversion to t/h has been calibrated correctly, the net change in the surge bin level should be negligible when changing the reclaiming rate.

Instead of controlling the surge bin to achieve constant level, the new surge bin level regulator (LVLREG) aims to control the surge bin level to maximise its use as a material buffer prior to the slew reversal point (ie. attempt to achieve maximum level) so that it can sustain the apron feeder output rate while the output from the bucket wheel drops during the deceleration and re-acceleration phase of the slew reversal. When the bucket wheel is slewing in the main body of the stockpile, the system aims to maximise the available surge capacity of the bin in an attempt to cope with any occurrence of avalanche. The surge level regulator (LVLREG) acts as a trim to the torque regulators (SLEWREG and LTDREG) which control the slew and long travel speed. Furthermore, this regulator is only active if the desired level is below the auto bin level set-point, ie. it does not attempt to slow down the slew to decrease the surge bin level unless there is a danger of over filling the bin, in which case, in addition to the bin level regulator trim, the t/h set-point to the torque regulator (SLEWREG and LTDREG) is also temporarily lowered until the bin level starts to drop.

In order to overcome the problems related to the significant transport delay of the boom conveyor and the small surge capacity, a model-based estimation scheme has been included to provide a feedforward estimate of the effective incremental change in the level due to changes in the bucket wheel reclaiming rate and the apron feeder output rate (Due to the integral nature of the surge bin process, IMC controller structure was not used for this level regulator).

This surge bin level regulator structure not only facilitates effective use of the surge bin, but also improves the robustness of the bucket wheel torque regulator (SLEWREG and LTDREG); compensating for any error in the torque to t/h calibration.

5.2 Movement Control Sequencing

In addition to the control loop re-structuring, the movement control sequence of the reclaimer has also been improved.

Instead of executing the step advance alone, the step advance movement is combined with the slew reversal movement to improve reclaiming efficiency at the edges.

Furthermore, the manual facility for leaving windrows at the edges of each bench was improved. Leaving a correctly sized windrow improves not only the efficiency of reclaiming near the edge of the current bench, it also improves reclaiming efficiency near the edges of the bench below. Another benefit of leaving the windrow is that it improves the surge bin regulator performance (Note that by leaving a windrow, the time the bucket wheel slews in the edge of the stockpile is reduced.). Hence it helps to minimise/avoid the dip in the system output rate during a slew reversal.

6. IMPLEMENTATION AND ACHIEVEMENTS

The control algorithms were implemented using the standard GE Fanuc 90/70 programmable logic controller instruction set. The algorithms were implemented in such a way so as to allow bumpless switch over between the old and the new control algorithm during the commissioning phase of the project.

A real time model of the reclaimer and the reclaiming process was developed using a real time control/simulation package called UNAC [3]. The model was then verified and calibrated by a site system identification based on signal measurements from the reclaimers. The calibrated model was then connected to the GE Fanuc 90/70 programmable logic controller to test and pre-tune the control algorithms.

Extensive off-site simulation testing culminated in achieving a smooth transition to the new control algorithm with total effective production down time of less than one hour.

Figure 4 compares the reclaiming control performance before and after optimisation of the control algorithm.

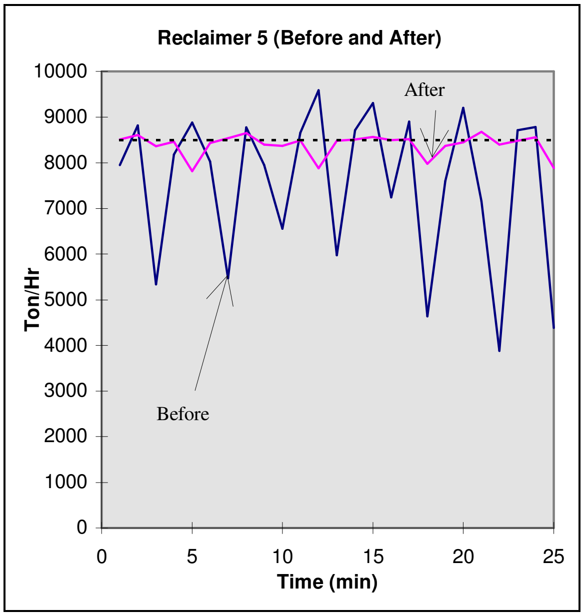


Figure 4 Control Performance

The plotted points on Figure 5 show the average monthly reclaiming performance over the period before and after the control optimisation. The line on Figure 5 shows the average performance.

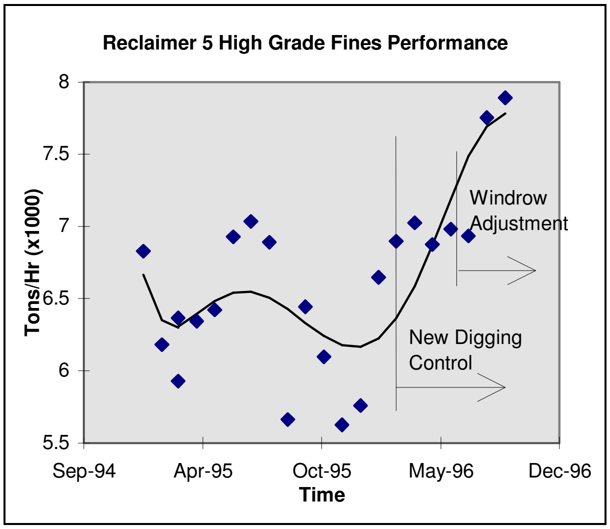


Figure 5 Average Reclaiming Performance

7. FUTURE OPTIMISATION PLAN

Currently, we are in the process of formulating further optimisation on the overall stacking and reclaiming operation. Examples of these activities are:

- Investigating the use of various technologies to enable automatic and reliable edge tracking of the stockpile so that consistently shaped windrows can be left to further improve reclaiming efficiency at the edges.
- Co-ordinating reclaimer bench change with hatch change of the shiploader to further improve reclaiming efficiency.
- Using global positioning system (GPS) technology to allow stacking and reclaiming machines to work closer together.

8. REFERENCES

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