# ADVANCING COMMINUTION AND FLOTATION PERFORMANCE WITH ADVANCED PROCESS CONTROL

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## 1. ABSTRACT

Often plant performance suffers as a result of poor control. Poor control leads to low mill throughputs, poor classification and less than satisfactory concentrate grades and overall recoveries. By using the appropriate control tools, substantial gains in plant performance can be made.

Mintek's MillStar and FloatStar controllers have been implemented at various sites across the world.

The MillStar controller incorporates leading technology that controls process units from the mill feed through to the flotation feed. Typical results show that milling circuit throughput is increased by 6-10 % and the final product grind size is tightly controlled, thereby enhancing flotation performance.

The FloatStar controller is aimed at stabilising and optimising flotation circuits. Through improved level control alone, recovery improvements of up to 1 % have been achieved. Furthermore, by using on-line grade analysers, the controller stabilises final concentrate grades, whilst maximising flotation recovery.

## 2. INTRODUCTION

Plants are generally designed for a certain throughput. All process units are sized to handle the design throughput, with an over design safety factor. However, over time, most plants end up ramping up production and exceeding the design capacity of the plant.

In these cases, the plant is driven to its limit of operation. Mills start overloading, sumps overflow and flotation performance suffers. The trick is to operate a circuit as close to its operating limits as possible, without compromising on stability. This is impossible to achieve manually, since plant operators do not respond quickly enough to large process upsets, etc.

Advanced process control tools are required to search for the maximum performance limits and ensure that the circuit controls well at that point of operation. Mintek's MillStar and FloatStar controllers are designed to do just that. This paper will introduce the MillStar and FloatStar technologies and present some case studies of each controller.

## 3. WHY DOES BETTER CONTROL IMPROVE PLANT PERFORMANCE?

In the minerals processing industry, process control is challenged by many factors. Due to the abrasive nature of slurry streams, it is often difficult to find instrumentation that can firstly endure the abrasive conditions and secondly deliver a good quality measurement. Therefore, instrumentation is relatively basic and many process conditions are completely unknown, and have to be inferred or estimated from available instrumentation, often with large errors and low confidence.

Apart from sparse and unreliable instrumentation, minerals processing circuits also suffer from many other problems including interaction between process units, large dead times, slow communications between field units and the controllers, non-linear systems, disturbances entering the process, processes with varying dynamics and many more.

Control is mostly implemented on PLC or DCS systems, with operator interaction via a SCADA system. Although vital in running a plant, these systems often do not have the tools or intelligence to cater for most of the problems encountered on minerals processing circuits. As a result, control performance suffers.

Poor control affects plant performance. Figures 1 and 2 illustrate this point. Consider a flotation cell with the optimum operating point near the lip of the cell (close to sliming). Poor, oscillatory level control (Figure 1), with a wide distribution around setpoint, would not be able to consistently achieve this optimum point, since standard deviations are too high and the cell would often slime. As a result, a conservative setpoint needs to be chosen, compromising flotation recovery.

Tight control (Figure 2) would ensure far less scatter about setpoint. As a result, the cell can be controlled much closer to its optimum point, without the risk of sliming.

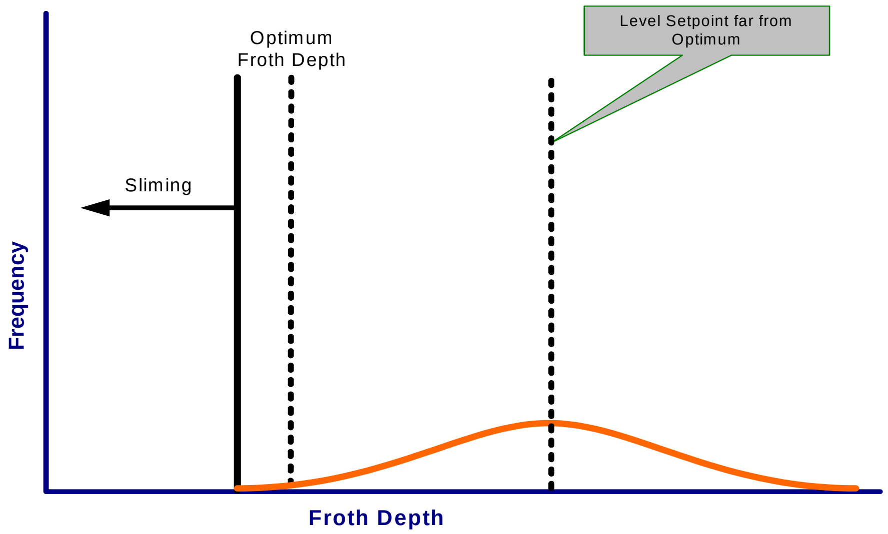


**Figure 1. Illustration of poor control**

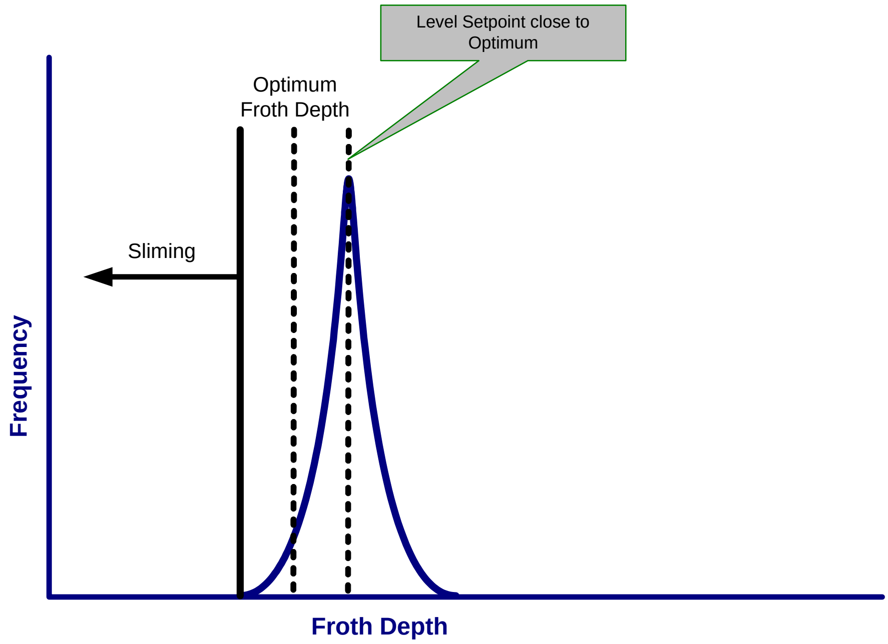


**Figure 2. Illustration of good control**

Other examples where tighter control benefits circuit performance include:

- *Mill Feed Control*

  Circuit stability begins at the feed to the mill. Oscillatory control of the mill feed compromises grinding circuit performance. Depending on the size of the oscillations, the mill may overload if the setpoint is overshot. Furthermore, the grinding efficiency of the mill decreases and the throughput of the mill suffers. Improved control will increase mill throughput and stabilise downstream operations.

- *Cyclone Control*

  Stable flows and densities of the feed to a cyclone are vital for efficient classification. Unstable feed conditions could drive the cyclones into roping/choking conditions. The particle size of the flotation feed becomes variable and flotation efficiency decreases. Better control would stabilise the re-circulating load in the milling circuit (thereby improving grinding efficiency), improve the cyclone operation and stabilise the particle size to the flotation circuit.

- *Flotation Feed Control*

  Tighter control of the feed flow to the flotation circuit is important for flotation stability and performance. Oscillatory control of the flotation feed results in surging flotation levels, variable residence times and ultimately poor flotation performance.

As important as tight loop control is the correct selection of setpoints throughout the circuit. Optimisation strategies can be deployed to ensure that peak performance is achieved for each process unit.

## 4. ADVANCED COMMINUTON CONTROL STRATEGIES

Efficient control of a milling circuit is essential for optimal overall circuit performance. Generally, there are a number of process indicators that determine how well the milling circuit is performing:

1. *The tonnes per hour milled*. The more tonnes milled during stable operation, the more product and revenue are generated.

2. *Stable product quality*. Downstream processes, especially the flotation process, require a stable grind size, flowrate and density from the milling circuit for proper operation. A variable product quality will result in variable tailings and concentrate grades.

3. *Plant stoppages*. Unscheduled plant downtime due to mill overloads, pump trips, etc, can be avoided by incorporating safety control loops that monitor the state of critical process units and take corrective action if process limits are violated.

Due to the complex nature of milling circuits, standard control techniques typically found on PLC and DCS systems are inadequate in addressing many of the control challenges found on milling circuits. Mintek has developed and commercialised MillStar, a comprehensive suite of milling control tools that significantly improves milling circuit control performance. These control tools are presented below as case studies.

### 4.1. ADVANCED STABILISATION TOOLS

As illustrated previously, tight control of process units can improve overall circuit performance. Furthermore, it is an essential first step in the path to optimisation.

#### 4.1.1. Improving Mill Feed Control

Large dead times are a commonplace on milling circuits. A case in point is the typical ore feed arrangement to a mill. The point of measurement (weightometer) is far away from the control point (ore feeders). The dead time induced by the physical distance between the control and measurement points make controlling the solids feed to the mill very difficult. It is important to stabilise the feed to the mill, since a disturbance at this point is likely to affect the entire process. Standard PID controllers have to be detuned to maintain stability. As a result, there is sluggish setpoint tracking and poor disturbance rejection.

Mintek's Mill Feed Controller is aimed at improving the performance of feed control systems. It includes a time delay compensation algorithm to accommodate for large dead times. This method makes use of advanced model based techniques to compensate for the affects of the process dead time. The advantage of this algorithm above PID controllers and the standard Smith predictor algorithm is that it can quickly follow setpoint changes even with long dead times, but still remain stable and robust in disturbance rejection and handling model errors. These qualities are crucial on milling circuits due to the many disturbances and model changes. Furthermore the mill feed controller offers advanced ore feeder ratio control. This is important where stockpiles are segregated and the coarse: fine ratio to the mill can be controlled by the ratio between the ore feeders.

Stable milling circuit operation demands the following qualities from a mill feed controller:

- Tight control around setpoint
- Quick start-up responses
- Quick recovery from feeder chokes
- Fast response to setpoint changes

Two case studies will be presented that highlight how Mintek's Mill Feed Controller improves feed stability to the mill as well as improves response times to setpoint changes.

*Improved Feed Rate Stability*

Control was implemented on a plant with up to 8 feeders discharging onto the feed conveyor. The time delay from the feeder to the weightometer was in the order of 90 seconds. As Figure 3 shows, Plant PID control struggles to maintain the feed rate within reasonable bands around the setpoint.

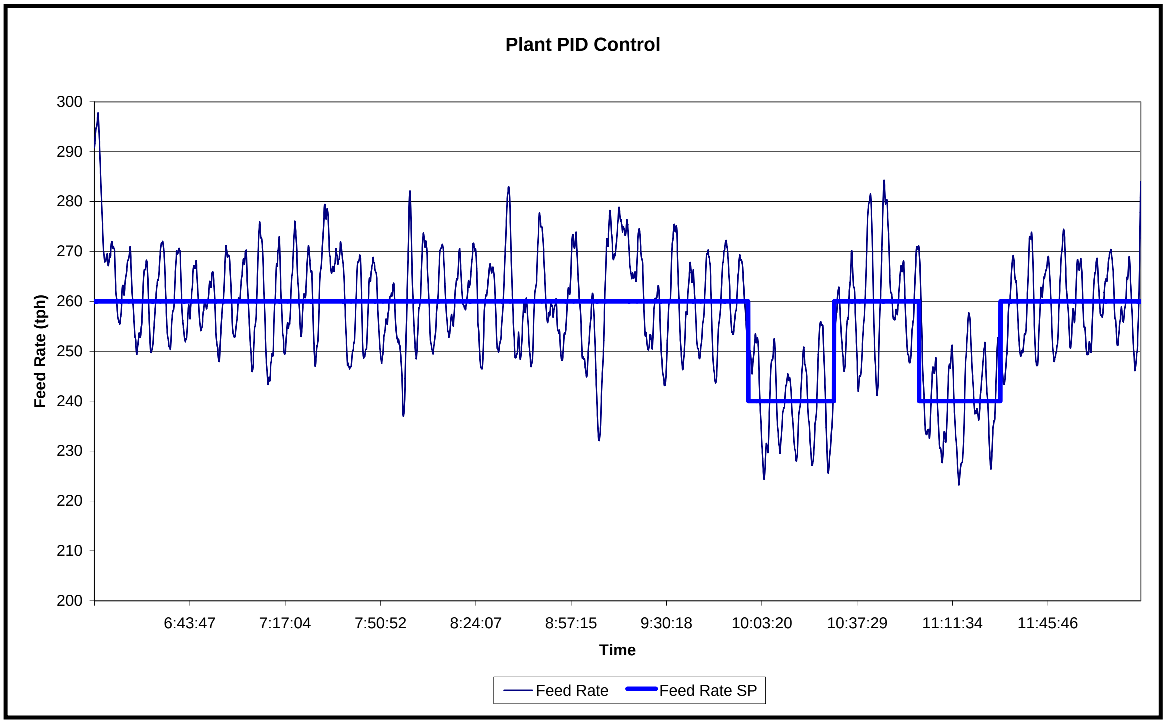


**Figure 3. Oscillatory Plant Mill Feed Control**

A summary of the control performance of the PID controller is summarised in the table below.

| | |
|---|---|
| Average Solids Feed Rate (tph) | 257.2 |
| Solids Feed Rate Standard Deviation | 13.3 |

By deploying Mintek's Mill Feed Controller on the same feeder system, large improvements in control have been achieved, as illustrated in Figure 4 below.

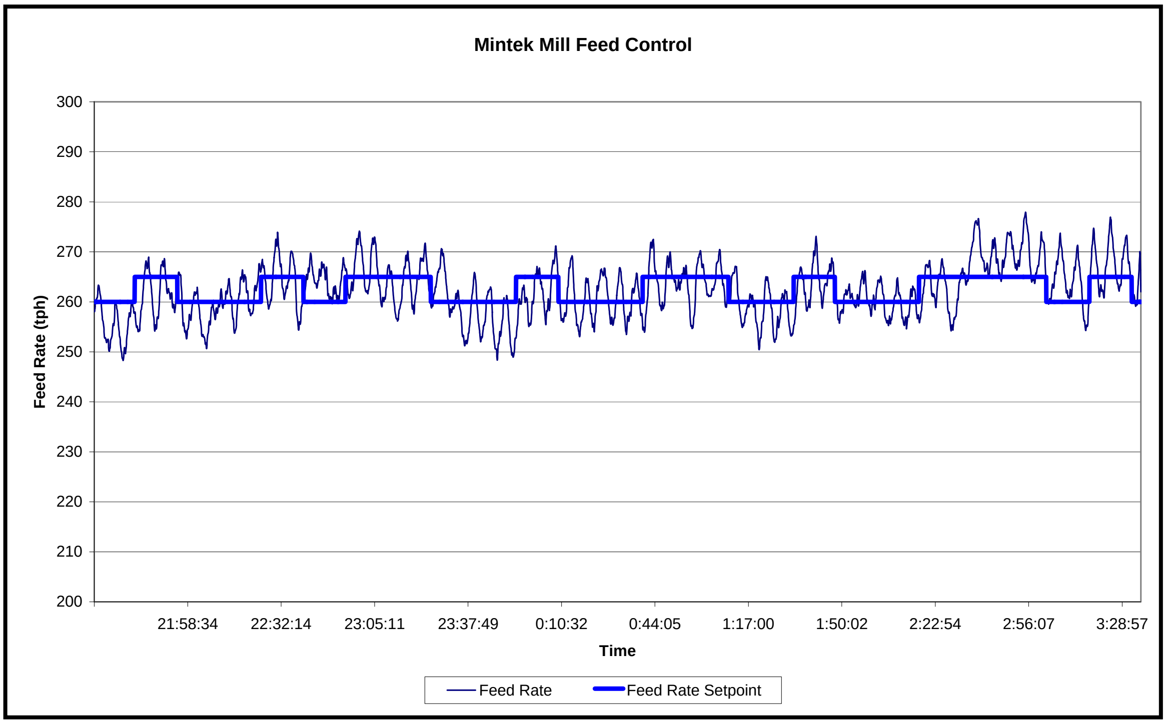


**Figure 4. More Stable Feed to the Mill with Mintek Control**

Control performance can be summarised as follows:

| | |
|---|---|
| Average Solids Feed Rate (tph) | 260.1 |
| Solids Feed Rate Standard Deviation | 6.1 |

This represents a greater than 50% improvement in mill feed stability.

*Improved Response Time to Setpoint Changes*
Fast tracking of setpoint changes is very important especially during circuit start-ups and where optimisation controllers are in operation, continuously adjusting the setpoint as the ore characteristics change.

A test was performed on both plant control and Mintek control, whereby the feed rate setpoint was systematically stepped up and down. The test results are displayed in Figures 5 and 6. From this it can be seen that plant PID control responds to setpoint changes slowly and takes up to 5 minutes to achieve the new setpoint. On Mintek control mode, the feed reaches its new setpoint within a period of 1-2 minutes.

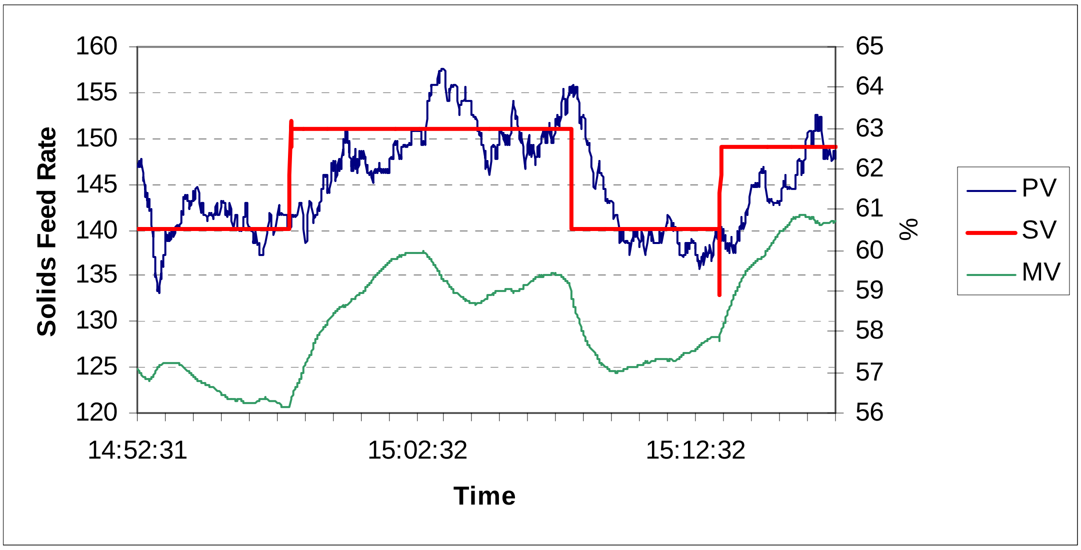


**Figure 5. Sluggish response to setpoint change on plant control mode (PV = Measured feed rate; SV = Feed rate setpoint; MV = Feeder Output)**

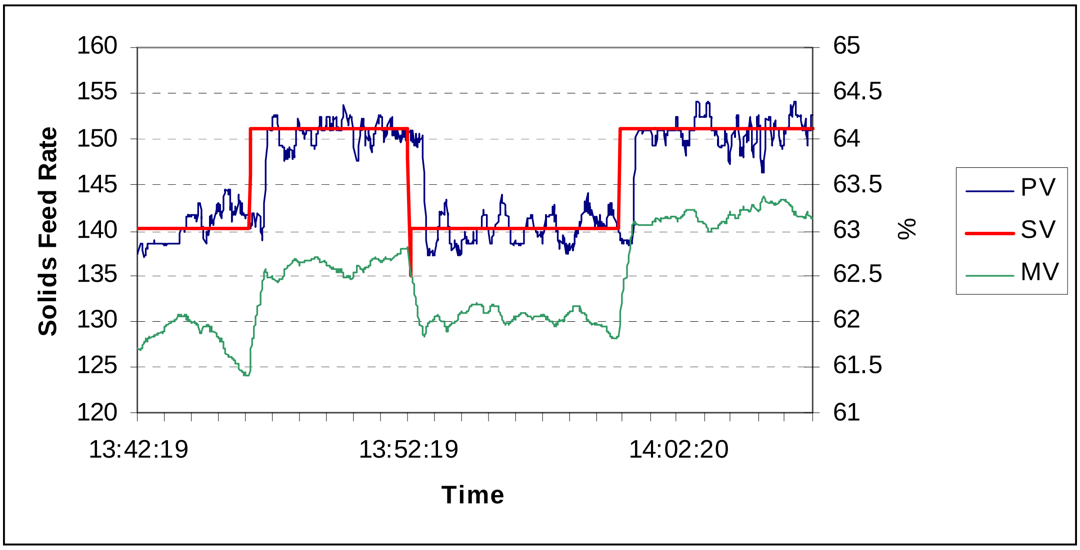


**Figure 6. Improved response times with Mintek control (PV = Measured feed rate; SV = Feed rate setpoint; MV = Feeder Output)**

These improvements in feed end control have the following positive spin-offs for overall circuit performance.

- Faster milling circuit start-ups
- Less conveyor belt overloads and mill feed chute chokes
- More stable feed to the mill, improving grinding efficiency
- More stable flow and density of the mill discharge

#### 4.1.2. Improving Mill Discharge End Stabilisation and Product Quality

The discharge from the mill flows into a sump, where dilution water is added. Thereafter, if it is a closed circuit mill, the slurry is pumped up to a classifier (typically a cyclone(s) or a screen). The oversize of the classification stage is sent back to the mill (re-circulating load) and the undersize is sent to the next stage of the operation (typically flotation), representing the product from the milling circuit.

The classification stage is vitally important for various reasons:

- *Re-circulating load*

If the classification is unstable or inefficient, these instabilities manifest themselves in the re-circulating load to the mill. If this re-circulating load is unstable, it affects the efficiency of the mill, since the flow through the mill (residence time) becomes variable and the density within the mill becomes variable.

- *Mill Product Quality*

A poorly controlled classification stage results in a milling circuit product of variable product quality (both particle size and density). As a result of this, the efficiency of downstream processes suffers.

- *Flow stability*

Downstream processes, particularly flotation, require a stable feed flowrate, since this affects the circuit residence time, level control and the dosage of reagents. A poorly controlled classification stage will result in variability in the flow feeding the flotation circuit.

Mintek has developed a Sump/Product Stabilising Controller with the objective of stabilising the classification stage whilst keeping all other process variables with limits (sump levels, classifier feed densities, etc).

The controller utilises Model Predictive Control (MPC) technology. This control technique easily compensates for multi-variable interactions between the various input and output variables and keeps all process variables within limits.

The Sump/Product Stabilising Controller has recently been installed on a platinum mine in South Africa. Figure 7 illustrates the circuit layout. The mill discharges into a sump, where dilution water is added. From here, slurry is pumped up to a screen. The screen undersize discharges into a conditioning tank from where it flows to the flotation circuit.

The objectives of the control were as follows:

- Stabilise the flowrate to the flotation circuit
- Stabilise the density to the flotation circuit
- Ensure that all the sump and surge tank levels are within boundaries.

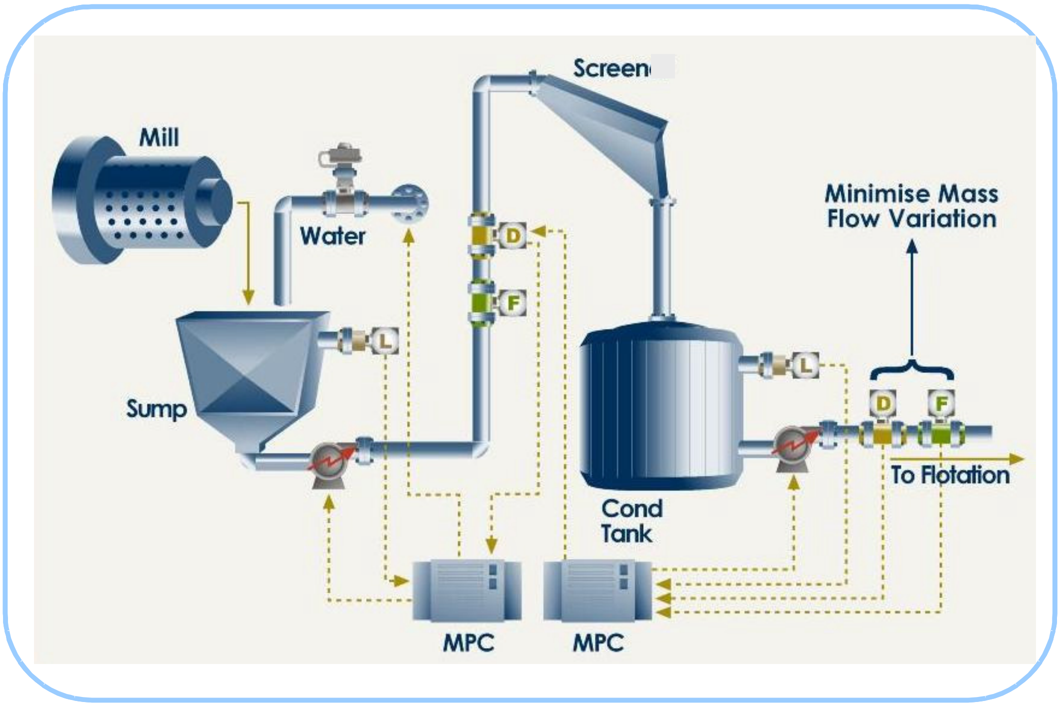


**Figure 7. Circuit schematic for Sump/Product Stabilising Controller**

Mintek control was compared against conventional plant control. A comparison is presented in Figure 8 below.

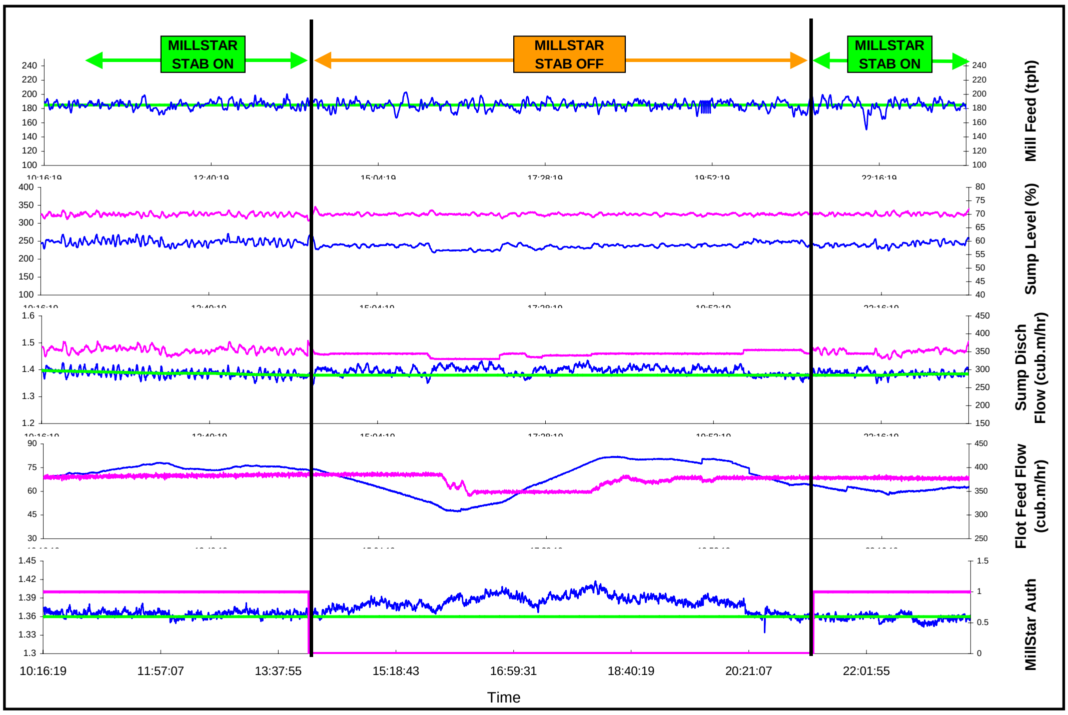


**Figure 8. On/Off Comparison of Mintek Product Quality and Discharge End Controller**

The feed to the flotation circuit in terms of volume flow and density (mass flow) is much more stable. This is summarised in the table below.

| | Plant Control Std Dev | Mintek Control Std Dev |
|---|---|---|
| Flotation Feed Flow ($m^3/h$) | 15.77 | 2.77 |
| Flotation Feed SG | 0.0107 | 0.0048 |
| Mass Flow (tph) | 0.169 | 0.013 |

Stabilising the product quality from the milling circuit leads to improved recovery downstream. In the case of flotation processes, improvements of between 0.5 and 1.5% in recovery have been shown.

### 4.2. ADVANCED OPTIMISATION TOOLS

Once the operation of the milling circuit has been stabilised, optimisation strategies can be deployed. In most cases, an attempt is made to maximise mill throughput without compromising downstream stability.

#### 4.2.1. Mill Power Optimisation

It is often the case in grate discharge mills that there is a strong relationship between the mill load (or solids feed rate) and the power draw of the mill. The mill power is usually a parabolic function of the mill load, with a maximum power at a certain load value. As the solids feed rate is increased, the mill load will increase, causing the mill power to increase. The region of maximum power draw is often the ideal region of operation. If the mill load is increased further, there is a sudden drop in the mill power, due to a mill overload. This is a dangerous area of operation since mill overloads could cause considerable downtime. This relationship is shown in Figure 9.

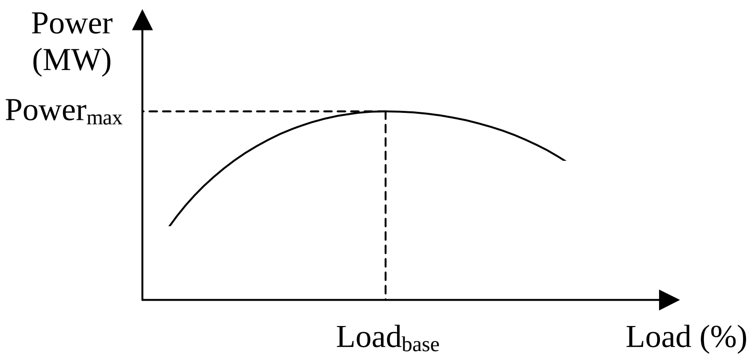


**Figure 9: Power vs. Load relationship in a Mill**

Mintek has developed a Mill Power Optimisation Controller. The objective of this controller is to dynamically find the zone of optimal grinding efficiency (i.e. the zone of peak power draw). The purpose of this non-linear controller would therefore be to use the solids feed rate to keep the mill operating at maximum power. What complicates matters is the fact that the whole parabola shown in Figure 9 can shift around as the feed conditions change. This means that the $Load_{base}$ and $Power_{max}$ are not fixed values.

The controller employs a peak-seeking algorithm that continuously searches for the peak power and adjusts either the load or the feed rate setpoint to maximise the power draw.

The controller also has features built in to bias it to operate at a slightly overloaded condition, as well as a safety controller that kicks in if the mill overloads and a sudden power dip occurs. Once the controller detects a sudden dip in the power, it automatically cuts the feed rate to the mill. In so doing, it gives the mill the chance to purge the overload and return to normal operating conditions.

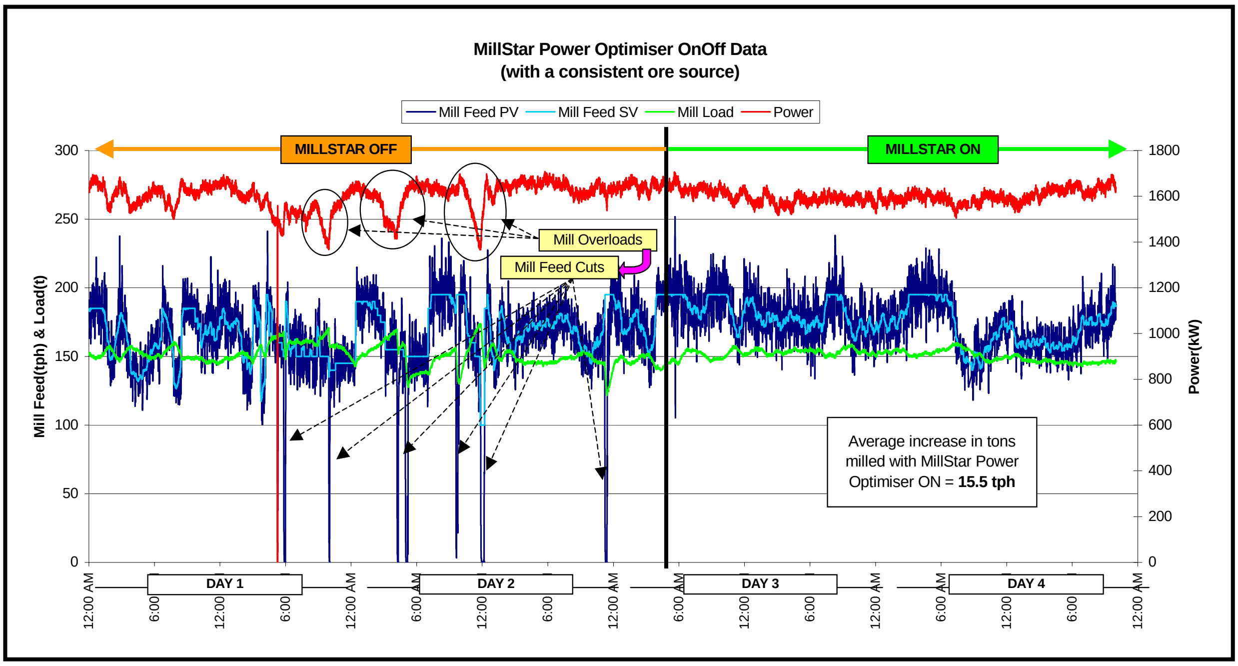


**Figure 10: The Mill Power Optimising Controller On/Off periods**

Figure 10 illustrates how the Mill Power Optimising Controller eliminates mill overloads and achieves a consistently higher mill throughput of 15.5 tph. This represents a throughput increase of approximately 10%.

## 5. ADVANCED FLOTATION CONTROL STRATEGIES

It is possible to obtain good performance from a flotation plant but it has proved difficult to maintain such performance. Recovery rates on a flotation plant are typically around 90 % and often lower, making flotation one of the least efficient processes in the concentration path. Hence over the last few decades much research and development has gone into the stabilisation and optimisation of flotation circuits.

Studies conducted by Mintek concluded that although factors such as reagent addition and aeration rates affect flotation performance, the first step towards improving flotation performance is to stabilise the pulp levels in each cell. Only once the flotation levels are stable, should optimisation be considered.

## 5.1. ADVANCED STABILISATION CONTROL TOOLS

Levels in flotation cells are conventionally controlled by PI (proportional and integral) control loops. This technique works well when the cell being controlled is stand-alone and not connected to others. However, flotation cells are connected in a network and the tailings stream from one cell is likely to be fed to another cell. Similarly, the concentrate flows will generally be fed into banks higher up in the circuit. This results in strong interactions between levels in a flotation circuit. Thus if a change in control action is made at any point in the circuit this would result in the disturbances being propagated to both upstream and downstream units. Figure 11 shows how typically a level oscillation propagates down a bank of cells under PID control.

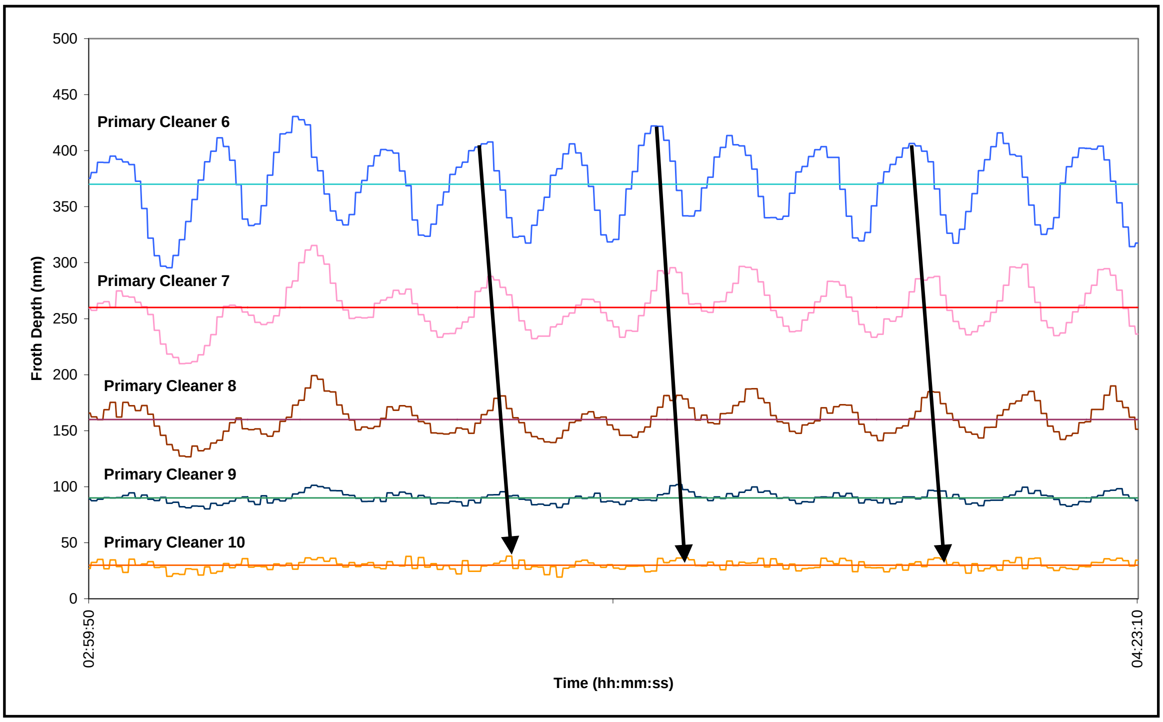


**Figure 11. Typical propagation of a level oscillation down a bank of Primary Cleaners**

To counter this problem, Mintek has developed and commercialised a level controller called the FloatStar Level Stabiliser. The controller monitors all the levels in the circuit and acts on all the control valves, taking the interactions of levels into account. The advantage is that the control valves on banks further downstream in the circuit can be opened as soon as the disturbances enter the respective banks. The FloatStar Level Stabiliser has been implemented on a number of plants within and outside of South Africa.

The case study below illustrates how the FloatStar Level Stabiliser improves level control on a platinum flotation circuit in South Africa.

FloatStar was installed on the entire flotation circuit. The feed to the Primary Rougher circuit was oscillatory and these oscillations manifested themselves in the levels of the Primary Rougher bank. Figure 12 shows this. Due to the variable pull rate of the Primary Roughers, the feed to the Primary Cleaner Bank is also oscillatory, causing the levels to oscillate.

When the FloatStar Level Stabiliser is turned on, the oscillations disappear and tight level control is achieved.

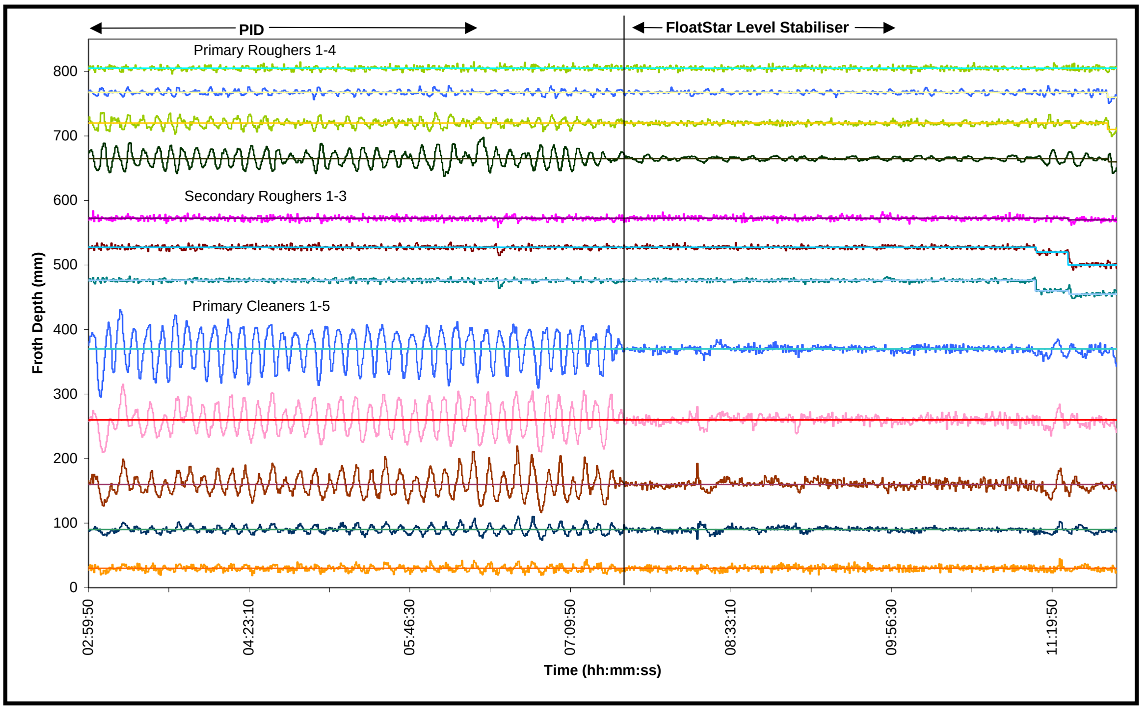


**Figure 12. Comparison between PID control and the FloatStar Level Stabiliser (trends have been shifted up or down for clarity)**

The FloatStar Level Stabiliser has been installed on various circuits including platinum, copper and copper/gold, lead/zinc/silver, nickel and phosphates. The controller has shown benefits on all installations.

In particular, benefits relating to the following have been achieved:

- *Improved controllability of the circuit*
  Especially on large flotation circuits, the level oscillation from one cell to the next can amplify to the point where cells are unstable. The FloatStar Level Stabiliser reduces these oscillations and restores stability around the flotation circuit.

- *Increase in recovery*
  With improved level control, the froth zone becomes more stable and the pulp level setpoint can be set closer to the lip of the cell, without the risk of sliming. As a result, the circuit can pull harder and recoveries can be increased. Typical recovery increases attributed to the FloatStar Level Stabiliser range between 0.5 and 1 %.

- *Faster circuit start-ups*
  Improved level control also enables faster circuit start-ups. The FloatStar Level Stabiliser typically stabilises a circuit in half the time that conventional PID control does. During a circuit start-up, the FloatStar level stabiliser stabilises the tailings grades to normal tails grade much faster than PID control mode. This represents a substantial saving during each start-up. Figure 13 shows how FloatStar stabilises the tails grade much faster than conventional PID control on a copper/gold plant in Australia.

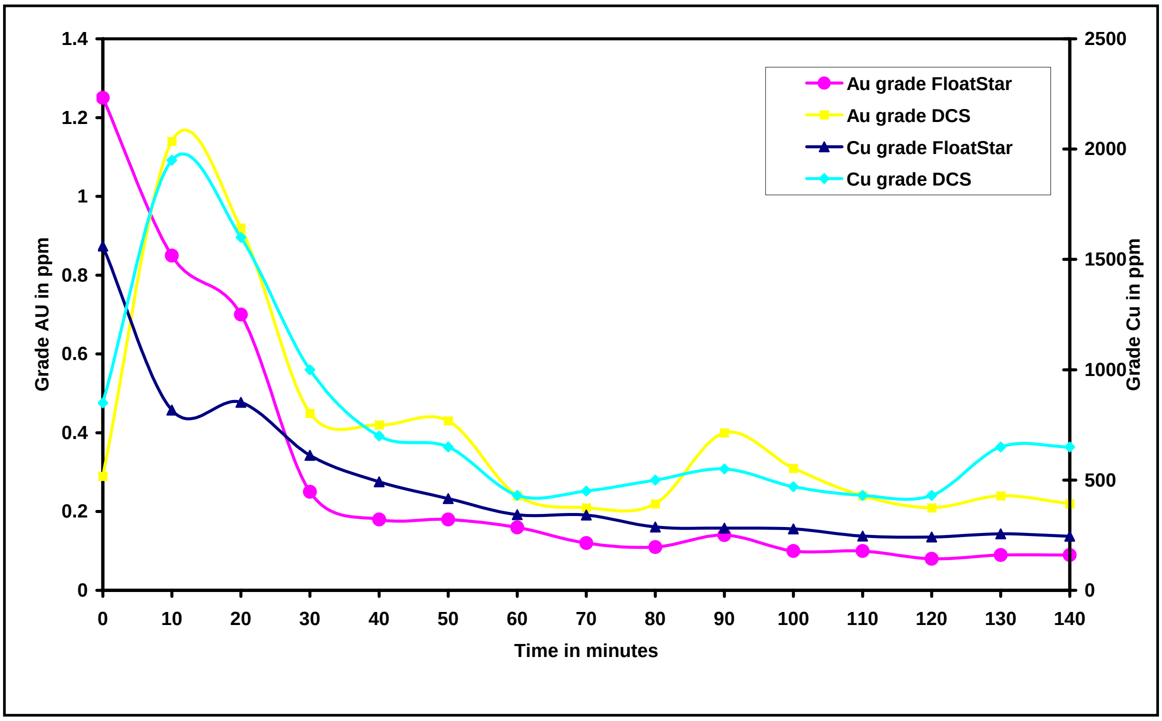


**Figure 13. Comparison between PID (DCS) and FloatStar Start-ups**

The savings with FloatStar on start-up are summarised below

| **Cost of Gold** | **Cost of Copper** | **Mass flow of tailing Stream** |
|---|---|---|
| USD 279/oz | USD 1528/ton | *1469531 tons/mth<br>1975 tons/hr |
| **Gold Lost during Start-up by PID control** | **Copper Lost during Start-up by PID control** | **Time period of loss** |
| 0.2 ppm | 250 ppm | 1.6 hrs |
| **Mass of gold lost** | **Mass of Copper lost** | |
| 527 g<br>18.6 oz | 0.66 tons | |
| **Cost of Gold Lost** | **Cost of Copper lost** | |
| USD 5183 | USD 1006 | |
| **FloatStar™ Savings on Start-up** | | |
| USD 6189 | | * Obtained from plant |

## 5.2. ADVANCED OPTIMISATION CONTROL TOOLS

With the flotation levels properly controlled, proper grade/recovery control can be implemented.

If on-line grade analysers are available, the final concentrate grades can be controlled tightly within a specification that satisfies downstream processes. Furthermore, overall circuit recovery can be monitored. If the recovery drops below a certain economical limit, the circuit can be adjusted to achieve its recovery objectives.

Mintek's FloatStar Grade/Recovery Optimiser does just that. Concentrate grades are controlled by adjusting the level setpoints and/or aeration rate setpoints of the concentrate producing cells.

If the circuit recovery drops below a set minimum value, the controller increases the pull rates of the cells, thereby recovering more valuable mineral.

Figure 14 shows FloatStar control of the grade and recovery on a large copper circuit in South America. The grade is controlled well around its target and the recovery is well above its maximum.

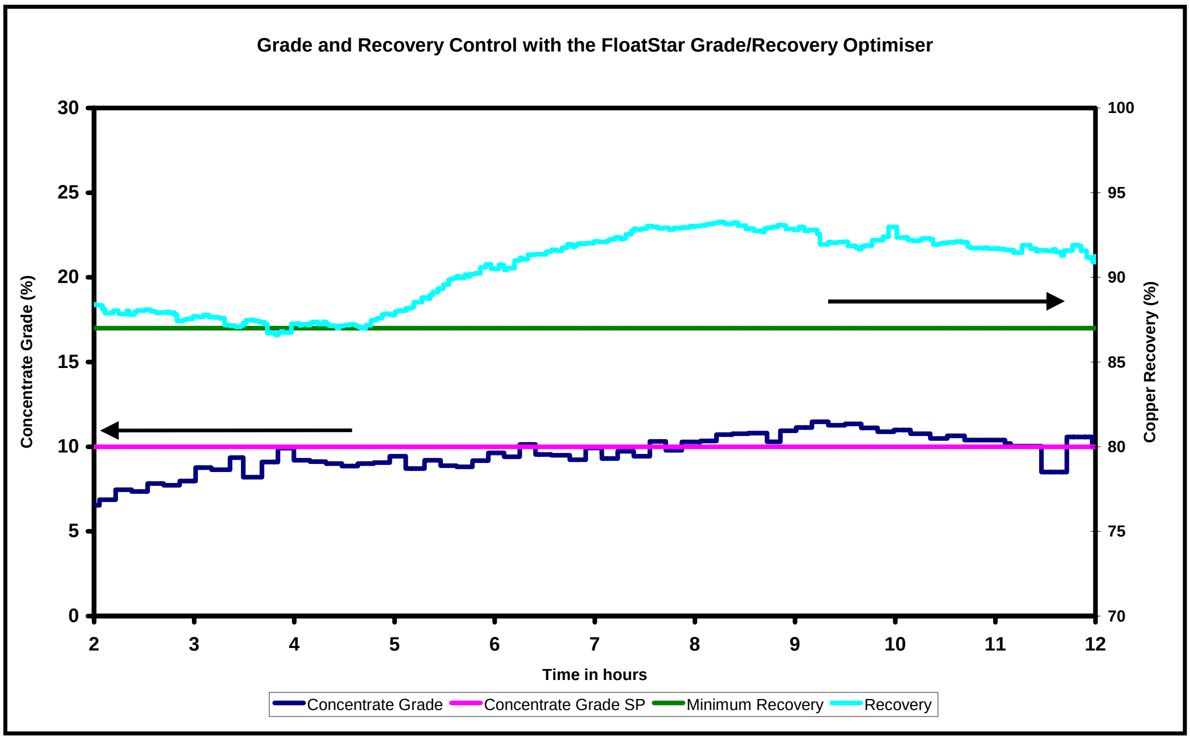


**Figure 14. FloatStar control of grade and recovery on a copper circuit**

## 6. CONCLUSIONS

To achieve optimal performance from a mill-float circuit, intelligent stabilisation and optimisation control tools need to be used. These tools will firstly ensure that the circuit can operate in a stable fashion around a certain point. Once stability is achieved, the controllers will search for the optimum conditions where milling throughput is maximised and flotation grade and recoveries are optimised.

Mintek's MillStar and FloatStar controllers have all the tools necessary for the effective stabilisation and optimisation of the circuit.