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MillScan installation report: Glencore Xstrata, Lion Ferrochrome (Steelpoort)

Summary

Glencore Xstrata selected to evaluate and test the MillScan G4 mill vibration fill level measurement system proposed for implementation at the Lion Ferrochrome plant in Steelpoort, South Africa. The objective of the installation was to evaluate the performance of the MillScan G4 system on Mill B in lowering the energy consumption during milling and to evaluate the overall viability of the system for future installation on Mill B. During November 2013, the installation was completed without any problems. After approximately two months in operation, the mill operating data was attained to verify the energy savings and mill product mesh quality. The report summarises the technical considerations pertaining to the installation of the MillScan G4 systems and the results of the test.

The installation of the MillScan G4 panel board was set up within one day. The inlet and outlet sensors were mounted on the bearing housing, but only the inlet sensor was used for mill fill level control. The outlet sensor was only installed to aid in attaining more information on the mill. The information can be utilised in a preventative fault finding if the signals are analysed appropriately. The MillScan G4 unit is a fourth generation model of the trustworthy successor models. The fourth generation system does not require a computer at the initial setup of the sensitivity and gain. All the installation settings are done on the G4 unit at the mill. A PI-controller was implemented to control the mill fill level together with a “bump-less transfer” feature to prohibit accidental deviations in the set-point if the controller is switched from manual to automatic control.

The installation was successful and the test period confirmed a specific energy consumption reduction just under 9.0 % as a result of the vibration fill level measurement system. This is equivalent to energy savings in excess of R 590 000.00 per year. The standard deviation in the

product mesh size was reduced by 61.0 % as a result of the stable mill operation provided by the MillScan unit. The payback period for the MillScan unit is 8 months.

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1. Introduction

The amount of material that a mill can effectively grind at every moment is variable due to several factors that influence the capacity of the mill. The flow rate of material entering the mill must be carefully selected at each moment to maximise grinding efficiency whilst conserving energy. Traditional methods of monitoring the fill level in ball mills are commonly based on electro acoustic sensors that are positioned close to the mill shell at the grinding media impact point. The electro acoustic systems are susceptible to crosstalk from adjacent mills, temperature and dust. A better approach is to monitor vibrations in order to determine the fill level in a mill. The subjects of vibration and acoustics definitely overlap, but the measurement tools and theory behind the subjects are very dissimilar. Vibration monitoring is not affected by the aforementioned factors and therefore permits an easy way to accurately monitor the mill fill level.

MillScan is a field instrument that uses the vibration signal of a ball mill bearing housing to generate an accurate and instantaneous signal of the mill fill level. This signal can be used to run the mill under automated loop control or greatly assist control room operations under manual control.

The following sections are devoted to conveying the implementation procedures and methodologies used in the installation of a MillScan G4 digital mill vibration fill level measurement system at the Xstrata Lion Ferrochrome plant situated in Steelpoort, South Africa. The result of a two month long trial is additionally discussed to indicate the short term effects of the MillScan G4 system at the Lion Ferrochrome plant.

2. MillScan G4 configuration

The MillScan G4 system comprises of two fixed position sensors and a main unit. Sensor 1 was placed on the inlet bearing housing and sensor 2 on the outlet bearing housing as indicated in Figure 2-1. The main unit was mounted between the two sensors such that the cable of each sensor could reach the main unit without the need to extend the cables (Figure 2-1).

The main unit was connected to a 90 – 240 VAC, 1 A power system. In addition, two 4-20 mA output cables were connected to the PLC in the electrical boardroom. The 4 mA output corresponds to a 0 % fill level in the mill and the 20 mA corresponds to a 100 % fill level. The cable installation was conducted by the Xstrata staff on 14 November 2013.

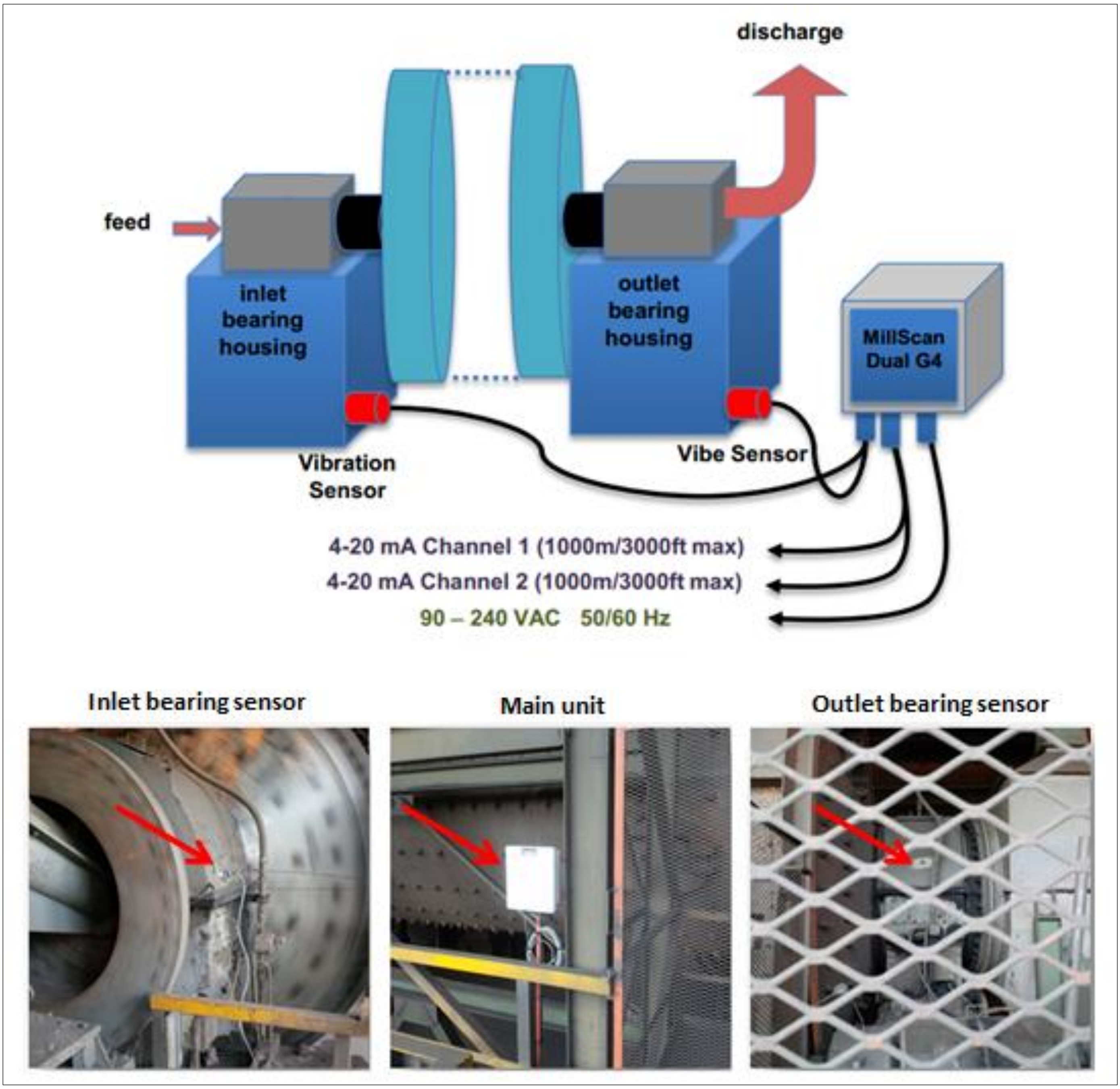

Figure 2-1: MillScan G4 components and configuration (Images taken at Xstrata Lion Mill B).

3. Unit calibration

After the unit configuration was completed the calibration was conducted. The calibration was performed in three steps for each of the two vibration sensors:

1. The fill level in the mill was set equal to an arbitrary value of 80 % when the mill reached normal operating conditions (i.e. stable circuit conditions at an ore feed rate of 90 tonnes per hour). The arbitrary fill level of 80 % does not necessarily mean that the mill is 80 % full of ore and grinding media. The value only represents a reference point as to the operating condition of the mill and whether the feed rate can be increased or decreased in order to maintain efficient comminution.
2. Acquire a signal at the estimated fill level.
3. Save the acquired signal to the main unit.

The entire process took less than 5 minutes to complete and a computer attachment was not required. The calibration process was repeated for the second sensor and was completed within 5 minutes.

The mill fill level trends of both the inlet and outlet sensors were monitored in the control room. The sensitivity of the inlet sensor signal was slightly adjusted on the main unit to pick up small variations in the fill level with step changes in the ore feed rate. The final signal sensitivity parameters of the inlet and outlet sensor were changed to 7 and 10 respectively. The difference in sensitivity parameters between the inlet and outlet signals is attributable to the sensor location on the bearing housing. It is important to always recalibrate the unit if the sensors are detached from the bearing housing because of slight differences in vibration frequencies over the bearing housing. The sensitivity adjustment was also completed within 5 minutes.

The unit calibration was finally verified by altering the ore feed to the mill. The fill level signal was receptive to the feed change operations. After calibration, the mill operation was analysed for a few hours to track the functioning of the fill level signals.

The detailed reference to the calibration can be found in Appendix A. Because of the installation and calibration simplicity, a manual is provided, but is not required. Instead, a single sheet is used for calibration as contained in Appendix A.

4. Level controller setup

The block diagram of the level controller setup is displayed in Figure 4-1. The MillScan G4 vibration sensors were mounted on the mill bearing housing and the sensors measure the vibrations arising from the grinding media striking the ore material and the inner shell of the mill. The vibration signals are correlated to a certain fill level within the mill.

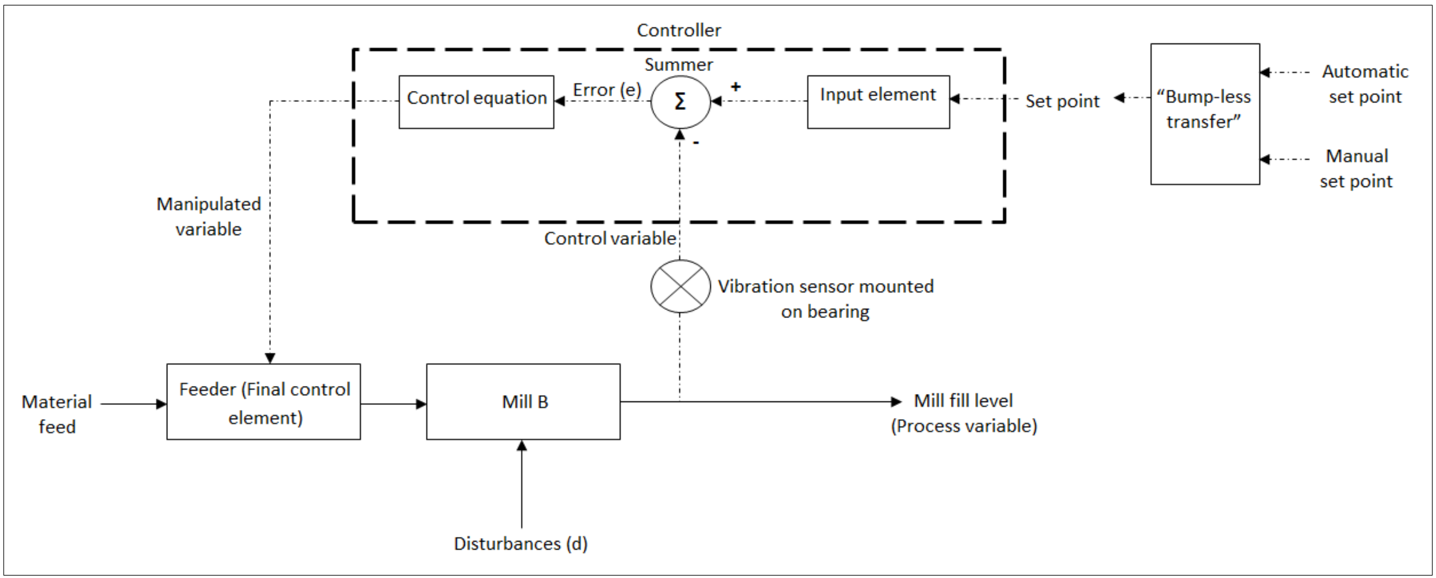

Figure 4-1: MillScan level controller block diagram.

A PI-controller is used to control the mill fill level via the final control element, the feeder. The controller output that manipulates the final control element can be adjusted manually by the operator or automatically by the controller. In switching between manual and automatic control, certain conditions may arise that cause incorrect set-points and outputs to be generated. The operator can directly manipulate the output when the controller mode is switched to manual and the set-point will not affect the output, therefore the operator can keep the loop stable. The loop may however become unstable when the operator switches the controller mode to automatic. During the switch the controller algorithm adjusts the output in response to the difference between the set-point and the process variable. The resulting effect can possibly be a large upset in the process if the operator failed to set the set-point similar to the process variable prior to switching from manual to automatic control.

To eliminate the risk of a process upset a "bump-less transfer" feature was implemented to assist the operator. The "bump-less transfer" feature prevents a sudden "bump" in controller output when the controller mode is switched from manual to automatic. The set-point is effectively set equal to the process variable before the control algorithm manipulates the output.

The disturbances indicated in Figure 4-1 represent the ball mill charge that is supplemented daily while the mill is running. The grinding media wears down quickly and influences the grinding efficiency. The reduction in the grinding media size will result in fewer vibrations on the bearing housing and consequently the feed rate will be decreased to uphold the best production. If the grinding media is supplemented with new balls, the vibrations will increase; therefore the controller will increase the feed to sustain the best production at the specific operating conditions. The effect of the grinding media disturbance is discussed in greater detail in section 9.2.

5. Control methodology

Feedback control is used to regulate the fill level in the mill. The controller works by measuring the process variable (i.e., the fill level) and comparing it with the set-point to produce an error as is illustrated in Figure 4-1. The error, inured by a PI-controller, drives the appropriate changes in the final control element (in other words the manipulated variable; in this case the ore feed) so as to force the present value back to the set-point. The majority of controllers found in plants are PI-controllers [1].

A PI-controller is accordingly employed because an offset in the mill fill level cannot be tolerated. The existence of disturbances means that a PI-controller is appropriate for the control requirements, instead of a PID-controller. The PI-controller will yield a longer response period compared to a P-only controller, but shorter than an I-only controller.

The general equation for a PI-controller is relayed in equation 1[1]:

$$MV = K_c e + K_c \frac{1}{T_i} \int e \ dt \qquad \text{Equation 1}$$

MV is defined as the manipulated variable, K_c is the controller gain, *e* is the error (set-point – control variable) and T_i as the integral time (the amount of time it takes the controller output to change by an amount equal to the error).

The typical settings for PI-controller parameters are $K_c = 2 - 20$ and $T_i = 1 - 5$ minutes [1]. The controller gain and integral time are usually the same for ball mills in different industries and the standard settings was used as a reference point to optimise the loop. The loop optimisation procedure is described in the subsequent section.

[1]: Svrcek, W.Y., Mahoney, D.P. & Young, B.R. 2006. A real-time approach to process control. 2nd ed. Chichester: Wiley.

6. Control loop optimisation

The mill was brought close to the normal operating point while the controller was in manual mode. The following procedures were subsequently followed to tune the controller:

- Small steps were made in the manipulated variable and the effect on the controlled variables (fill level) response was observed. The magnitude of the process gain and the length of time the response took to settle made it possible to estimate a value for the process time constant. The process time constant is defined as the amount of time it takes the output of the system to reach 63.2 % of its steady state value (i.e., roughly one third to one fifth of the time to settle after the change in manipulation) [1].
- The integral and derivative actions of the controller were switched off by setting the integral time to a very large value and the derivative time to zero. Once the controller was switched to automatic the controller gain was set to a relatively small value. Adjustments in the controller gain were made according to the increments of money (i.e., 0.1; 0.2; 0.5; 1; 2; and 5 etc.).
- Small changes were made in the set-point and the response of the controlled variable was monitored. For oscillatory responses the gain was reduced and for sluggish responses the gain was increased. This procedure was followed until the response had a decay ratio from one quarter to one half (the decay ratio is the ratio of the amplitude of an oscillation to the amplitude of the proceeding oscillation) [1].
- Thereafter the controller gain was reduced by around 25 % and the integral time was set equal to the process time constant.
- The system was checked for stability. When an unstable system was encountered the integral action was decreased and then the controller gain until the system was stable again.
- The integral time was adjusted in order to get a one quarter decay ratio.
- The controller gain was finally changed by small amounts until the desired response was attained.

Due to the introduction of the integral term the loop with the PI-controller had a reduced stability compared to a proportional only controller. To compensate for the adverse effect, the controller gain was marginally reduced. Finally, the controller was checked for stability by changing the set-point and observing the controller response.

[1]: Svrcek, W.Y., Mahoney, D.P. & Young, B.R. 2006. A real-time approach to process control. 2nd ed. Chichester: Wiley.

The final parameters of the main unit and PI-controller are:

- Sensitivity (Sensor 1) = 7
- Arbitrary fill level (Sensor 1) = 80 %
- Sensitivity (Sensor 2) = 10
- Arbitrary fill level (Sensor 2) = 80 %
- Controller gain = 0.2
- Integral time = 200 seconds

7. Disturbances

An earlier concern expressed by the control department at Xstrata highlighted the possible adverse effect that the lack/problem with the grinding media can have on the level measurement and control system. The system is designed to overcome such obstacles and Pro-Op Industries assured Glencore Xstrata that the system will perform adequately throughout varying process conditions.

The concept is illustrated in Figure 7-1 and Figure 7-2. Case A in Figure 7-1 represents the mill conditions at the time of the sensor calibration. At a certain stable fill level, arbitrarily referenced as 80 %, the sensors pick up distinct vibration patterns that are stored and used to correlate the fill level at different feed rates.

An example of the distinct vibration patterns are illustrated in Figure 7-2. If the grinding media amount in Case A diminishes with time, the vibration count will decrease when the ore feed rate stays constant. The controller will automatically reduce the ore feed rate to attain an optimal ratio between grinding media and ore material that represents a similar vibration frequency to the arbitrary 80 % fill level. Quintessentially the MillScan signal will provide a fill level signal that represents a fill level in excess of 80 %, meaning that the controller will therefore decrease the feed rate to sustain the arbitrary referenced 80 % fill level signal.

For a situation where the grinding media is insufficient and the mill fill level below 80 %, as illustrated by Case B in Figure 7-1, the vibration frequency will differ from the reference pattern. If the grinding media is supplemented the vibration pattern will change, but still indicate that the mill fill level can be increased to permit efficient milling.

The final situation is represented by Case C in Figure 7-1. If the fill level is greater than 80 %, but the grinding media insufficient, the vibration count will increase the moment the grinding media is supplemented. Intuitively, it would seem that the controller will increase the ore feed rate to compensate for the increased vibration count. The distinct vibration pattern will however indicate that the feed rate cannot be increased, because the fill level is above the normal operating level of 80 %. Irrespective of the immediate operating conditions of the mill, the controller will automatically adjust the ore feed rate to attain the desired set-point. In reality, Case C would not even be possible to occur if the controller is switched to automatic control, because the ore feed rate will have been decreased the moment the fill level exceeded the normal operating condition of the arbitrary 80 % fill level.

The effect of zero grinding media supplementation was tested and the results are discussed in section 9.2.

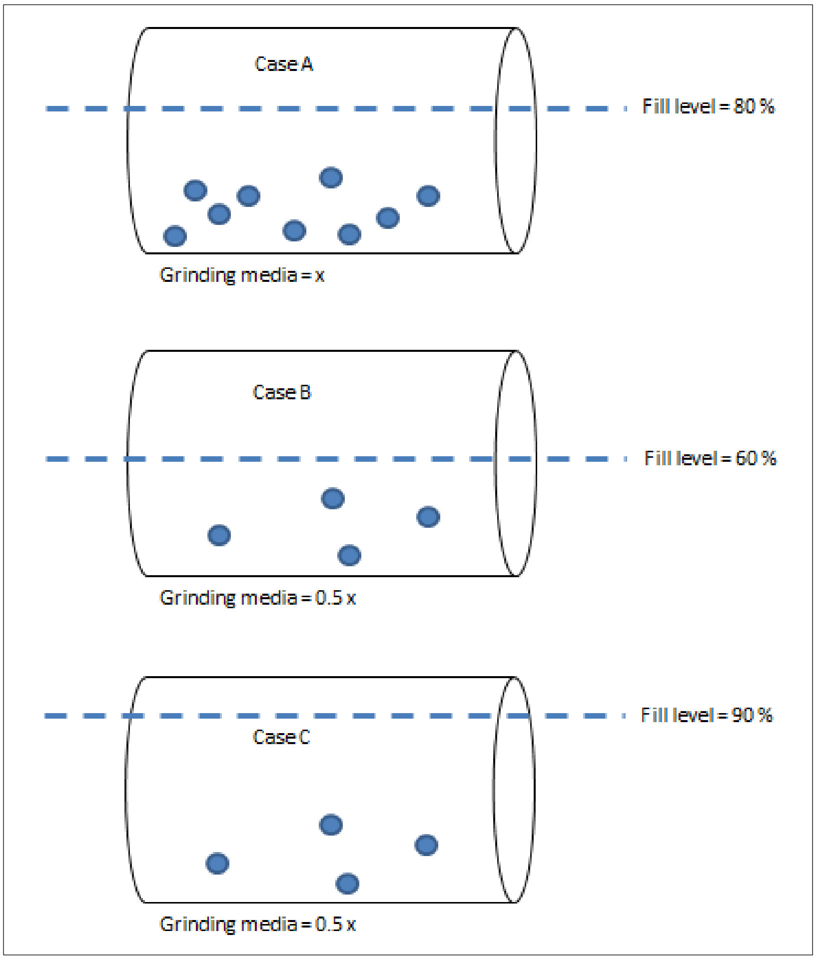

Figure 7-1: Mill operating scenarios.

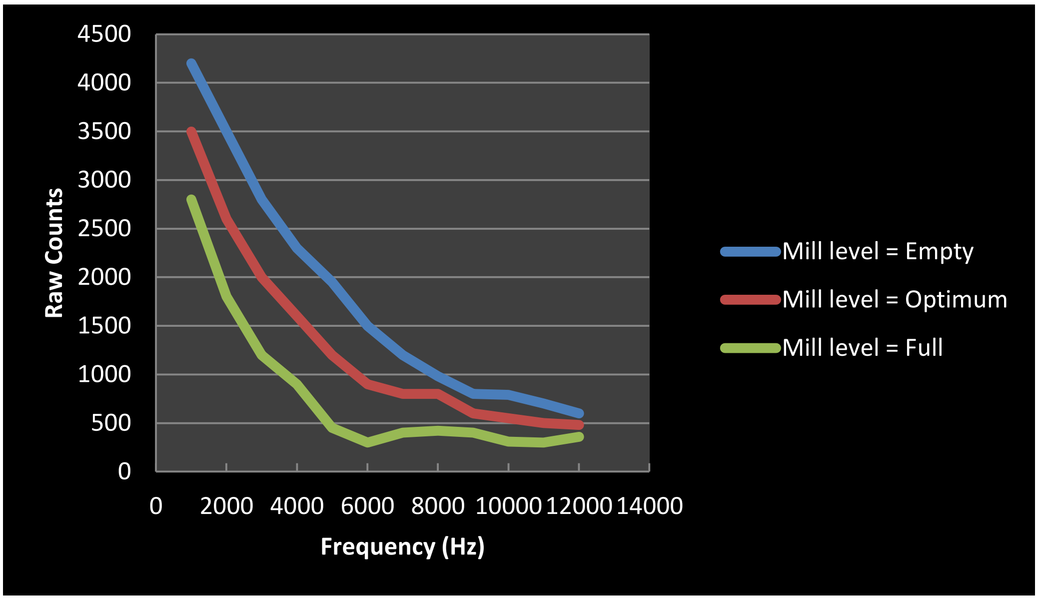

Figure 7-2: Vibration snapshot of various mill fill levels.

8. Performance analysis methodology

This section describes the procedural aspects that were executed to analyse the effect of fitting a mill fill level measuring device on Mill B at Xstrata Lion Ferrochrome.

8.1 Baseline analysis of Mill B operation without MillScan G4

The key parameter readings, prior to the MillScan G4 installation, was retrieved from Xstrata in order to set up a baseline report of the mill operation. The obtained parameter readings extended over a period of 49 days prior to the MillScan G4 installation and configuration between 13 and 18 November 2013.

8.2 Retrofit MillScan G4 installation analysis of Mill B

The key parameter readings were retrieved as per the same procedure as the baseline analysis after the MillScan G4 unit was installed and configured on Mill B. The data attained with the MillScan unit covered 58 days.

8.3 Assumptions

The average electricity tariff used in the computations is R 0.44 per kilowatt hour (R/kWh) as provided by Glencore Xstrata in Steelpoort. The average utilisation rate of Mill B, according to the acquired data, is 76 %. The utilisation rate was used to compute the operational time of the mill per year. The average amount of material milled per day is 1 765 t. The aforementioned feed rate per day was also calculated from the attained mill operation data.

8.4 Accuracy of measuring devices

The accuracy of the measuring devices at Xstrata Lion can compromise the test results if they are not maintained correctly. It is assumed that the correct care and maintenance have been exerted by Xstrata Lion to keep the measuring devices in proper working condition.

9. Results and discussion

The trial was conducted without any difficulties and the resulting data was sufficient to provide an insight as to the effect of the MillScan unit on the operation of Mill B.

9.1 Specific power consumption

The comparison between the specific power consumption for the baseline and retrofit operating periods is illustrated in Figure 9-1. The histogram in Figure 9-1 indicates the incidence of the specific power consumption at particular levels throughout the operation of Mill B. The retrofit specific power consumption is more positively skewed and varies less than the baseline specific power consumption. The occurrence signifies that the mill was operated in a more constant manner with fewer deviations in the day-to-day feed rate as opposed to the baseline mill operation.

The more constant operation of the mill is attributed to the MillScan unit that provided an accurate and constant fill level signal. Together with the PI-controller the mill was kept operating at the most efficient process conditions.

9.2 Effect of grinding media on mill control

The effect of the grinding media on the mill control (formerly discussed in section 7) was also established during the trial period. Table 9-1 indicates the effects of two totally different scenarios involving the grinding media. The cells highlighted in blue indicate the scenario where the grinding media in the mill was not replenished during operation. The reduced grinding media content in the mill caused the PI-controller to decrease the material feed rate. The occurrence is illustrated in Table 9-1 by the feed rate value highlighted in blue. The feed rate on 10 December was much lower than the feed rates on 9 and 11 December.

The other occurring scenario was the addition of a significant amount of grinding media. The cells in Table 9-1 highlighted in red represent the scenario where over 4.0 tonnes of grinding media was added to the mill. The addition of the grinding media caused the PI-controller to increase the feed rate in order to keep the milling operation steady and efficient. The feed rates on 22 December and 15 January were appreciably higher in comparison to the respective feed rates on 21 December and 14 January.

In both the scenarios the mesh did not vary considerably in relation to the periods before and after the grinding media addition, or lack thereof.

Table 9-1: Mill B operating data at different grinding media additions (extreme conditions are highlighted).

	Total feed	Mesh	Grinding media addition	Specific power consumption
Date	**t/d**	**µm**	**t/d**	**kW/t**
08-Dec	2146,00	92,16	2,63	1,32
09-Dec	1976,00	92,16	2,81	1,41
10-Dec	1517,00	91,63	0,00	1,83
11-Dec	1656,00	91,44	3,13	1,67
12-Dec	1833,00	90,60	3,19	1,50
20-Dec	1977,00	90,50	3,45	1,37
21-Dec	2148,00	91,23	1,92	1,27
22-Dec	2443,00	91,30	4,17	1,14
23-Dec	1939,00	92,06	3,43	1,44
24-Dec	2032,00	92,38	3,13	1,38
13-Jan	896,00	93,60	1,65	3,27
14-Jan	1857,00	92,40	2,57	1,56
15-Jan	2188,00	92,10	4,15	1,32

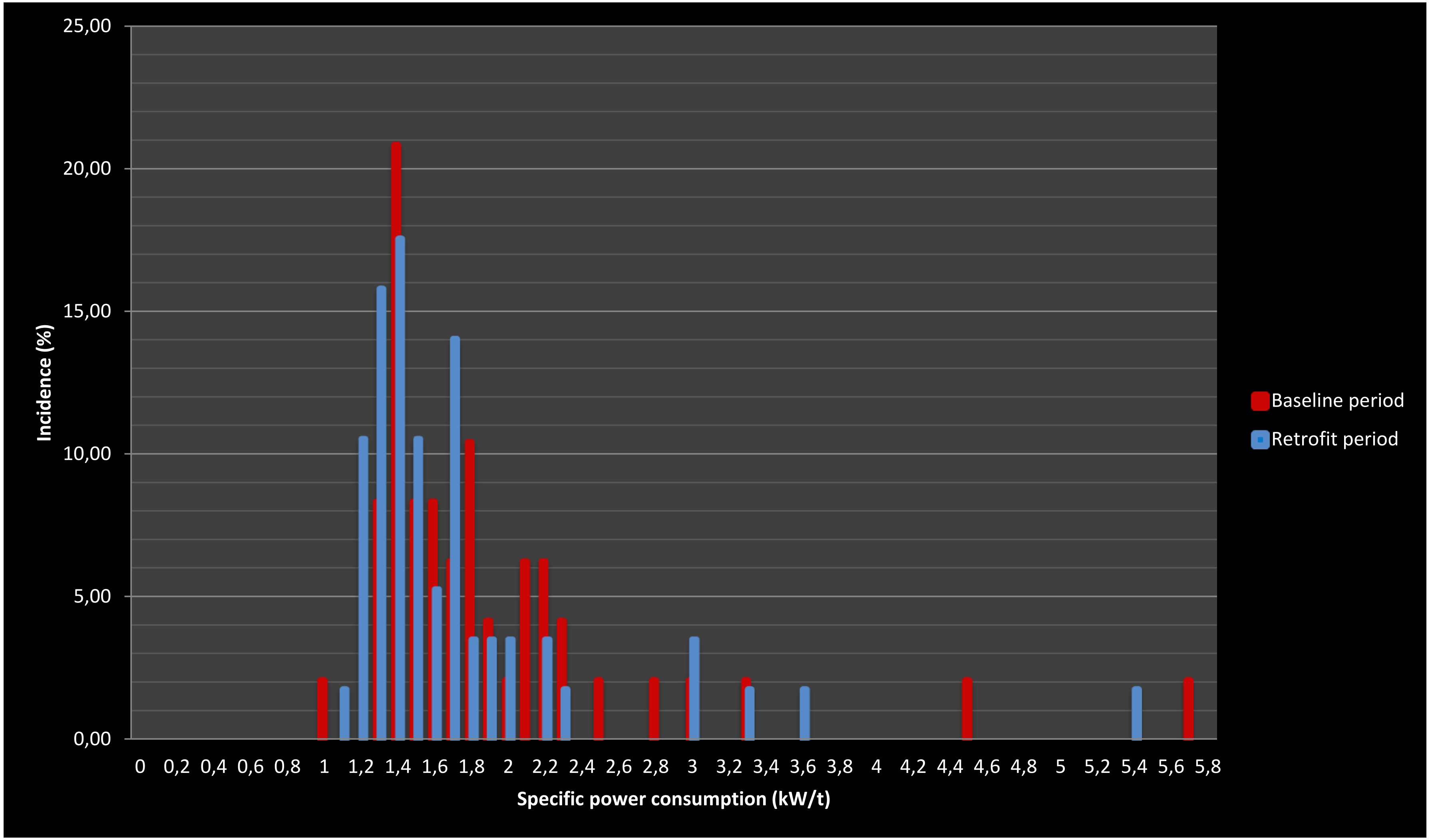

Figure 9-1: Histogram of the specific power consumption data from mill B.

9.3 MillScan effect on mesh size of mill outlet material

The outlet material mesh was also examined during the baseline and retrofit operations. Table 9-2 indicates the standard deviation in mesh for the two operations. The standard deviation in the material mesh size was 61.0 % less when the MillScan unit was operational in comparison to the baseline operation. The reduction in the standard deviation can also be attributed to the accurate and constant mill fill level signal provided by the MillScan unit. The precise level signal allowed the PI-controller to effectively control the milling operation at the most stable and efficient conditions possible.

Table 9-2: Particle size deviation.

Mesh standard deviation	
Baseline period (µm)	2,14
Retrofit period (µm)	0,84

9.4 Operational, financial and future aspects of the MillScan unit

The specific energy consumption of the mill was accordingly calculated for both the baseline and retrofit mill operations. The data is summarised in Table 9-3. The use of the MillScan unit led to a specific energy consumption reduction of nearly 9.0 %. Over a period of a year, approximately R 590 000.00 can potentially be saved in associated energy costs. The payback period for the MillScan unit investment is 8.1 months.

Table 9-3: Operational data and financial summary of the baseline and retrofit operations on Mill B.

Summary of operational data and finances		
Average specific energy consumption, Baseline period (kWh/t)		30,89
Average specific energy consumption, Retrofit period (kWh/t)		28.13
Energy consumption reduction (%)		8.92%
Electricity cost at Steelpoort ferrochrome operation (R/kWh)		0.44
Mill utilisation assumption (76 % based on procured data)		76%
Total run time per year (days)		277
Average tonnes of material milled per day (t/d)		1 765
Total tonnes of material milled per year (t)		489 546
Electricity consumption per year, Baseline (kWh)		15 121 106
Electricity consumption per year, Retrofit (kWh)		13 771 598
Milling cost per year, Baseline	R	6 653 287
Milling cost per year, Retrofit	R	6 059 503
Total energy savings per year accredited to the use of MillScan unit	R	593 784
Total MillScan price, including installation costs	R	399 570
Payback period (months)		**8.1**

10. Conclusion

As the ferrochrome industry continues to seek new techniques to push towards lowering energy consumption whilst maximising their assets, a comprehensive testing and evaluation process is necessary to ensure continued reliability and efficiency in the comminution sector. To that end, MillScan with support of Pro-Op Industries planned and executed a test to validate the use of a mill controller to lower energy consumption and increase the product quality. During November 2013, the MillScan G4 system was installed on Mill B of Glencore Xstrata Lion Ferrochrome plant in Steelpoort and operated for 2 months. The most significant findings of the MillScan unit trial were:

- An overall specific energy consumption reduction of 2.76 kWh per tonne of material milled.

- Lower standard deviation on mill product mesh.

The installation of the MillScan unit resulted in a more stable operation of Mill B. Together with the PI-controller the mill was kept operating at the most efficient process conditions. The stable operation of the mill will ensure that the maintenance schedule can be compiled with greater accuracy in the future, whilst keeping the production value at the prerequisite target.

The trial indicated that the MillScan unit performed as expected.

Appendix A

The calibration procedure requires running the mill in normal operation and waiting for the mill circuit to become stable. Select a sensor for calibration by pressing the **Sensor Select** button. Next, estimate the amount of material in the mill as a percentage value (e.g., 80 % full), then acquire the waveform and save the results.

Here are the steps in this process:

1. *Load Current Mill Fill Level in G4* - **press/hold A** and use the **+**, **–** buttons to set your current estimated fill level percent for the mill. **Release A** to store this value.

2. *Acquire a Mill Vibration Waveform* – **press A** and **S** simultaneously and then **release**. Wait 15 seconds and then observe **A** flashing, indicating a waveform has been acquired.

Special note: If you are not satisfied with the acquired signal or think your mill fill level estimate is off, repeat steps 1 & 2. Otherwise, continue on to Step 3.

3. *Save the Acquired Waveform* – **press + and –** simultaneously and **release** to save the acquired vibration waveform to G4 memory. You should now see **d** for dump to memory on the status digit. **Repeat steps 1-3 for all remaining sensors.**

Calibration Button Definitions/Functions:

Sensor Select => selects a particular sensor to acquire a waveform and calibrate.

A => press/hold to display or change the fill level set point for an acquired waveform.

S => press/hold to display or change the sensitivity set point for the calibration.

+ => while pressing **A** or **S**, this is used to increase the fill level set point or sensitivity.

- => while pressing **A** or **S**, this is used to decrease the fill level set point or sensitivity.

A and **S** => press both to acquire a vibration waveform for a given fill level percentage.

+ and **–** => press both to save an acquired waveform or sensitivity to G4 memory.

Changing the Output Fill Level Sensitivity:

After the sensors have been calibrated, you should observe the sensor trends to determine if the output Sensitivity (**S**) needs to be increased or decreased for a given 4-20 mA output. **S = 7 (default)**. Increasing **S** increases sensitivity and decreasing **S** decreases sensitivity.

1. To change the sensitivity for a given sensor output, use **Sensor Select** to select the sensor.

2. To make the output fill level signal **more sensitive**, increase S by pressing **S** and **+** or to make the output fill level signal **less sensitive**, decrease S by pressing **S** and **–**.

3. **Save the new sensitivity** by pressing the **+** or **–** buttons simultaneously and then release.