The Novel EDS Multishaft Mill – A Case Study

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ABSTRACT

Energy & Densification Systems (EDS) has developed patented novel crushing/milling equipment. The EDS Multishaft Mill is a compact vertical mill – utilising high-speed impacts to break down particles with large reduction ratios, low energy consumption and improved liberation.

A single pass pilot plant with the EDS Mill was then installed at an Anglo American UG2 mine in South Africa.

The aim of the pilot plant and the project was to test the EDS Multishaft Mill based on various metrics such as reliability (availability, utilisation, mean-time-between-failures and mean-time-to-repair), throughput, wear rates, energy consumption per ton, as well as the output particle sizing distribution. Grade engineering effects were also considered.

Results from the project were positive, with almost all metric targets exceeded.

Keywords: Comminution, High-speed impact, Liberation, Energy efficiency, Novel, Crushing, Milling, Grade engineering, Multishaft Mill

1. Introduction

Ore comminution entails the reduction in size of the run-of-mine raw material to that at which the valuable mineral can be economically recovered. Three key elements have a significant impact on the economics of mineral recovery: Size reduction, energy efficiency; and enhanced liberation.

1.1. Energy and efficiency considerations

It is well known that the comminution of ore can often account for up to 60% of the total electricity consumption (Tromans, 2008; La Nauze and Temos, 2002) for most cement and mining operations and there are suggestions that it could be as high as 4% of global consumption (Napier-Munn, 2015; Feurstenau, 1981). The reason for this high energy requirement is due to the use of crushing and milling machines with large electric motors. Most of the equipment needs to rotate extremely heavy components as well as media which in turn impact into each other which wastes a lot of energy.

1.2. Liberation

Liberation is defined as the separation of valuable mineral from gangue minerals and is mostly done during the comminution stage (Leißner *et al*, 2013). Much research has focused on reducing the operational costs of grinding, as if the most important role of grinding, i.e. liberation, is sometimes forgotten (Wills and Atkinson, 1993). Liberation of valuable minerals from the gangues occurs in different types of breakage.

The most common breakage type would be a compressive force breakage. This is when a particle has two forces acting at two different points (generally opposite each other) and acting towards each other. The other breakage type to consider is impact type breakage. This is when a particle is impacted by or against another object or particle. In this case, there is only one force acting on the particle at the point of impact.

2. EDS Multishaft Mill as an Alternative Comminution Technology

Energy & Densification Systems, a company based in South Africa and founded in 2005, has developed and internationally patented the novel EDS Multishaft Mill. The mill utilises a series of rotating horizontal shafts with flingers attached, which impact gravity fed material at very high speeds as pictured in Figure 1. The material is subjected to numerous impacts in an unpredictable and chaotic environment (milling chamber) before ejecting out the bottom of the mill (discharge section).

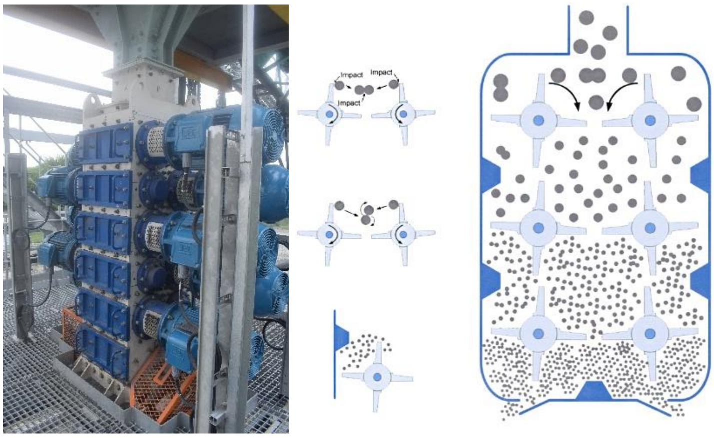

Figure 1. EDS 10 Shaft Multishaft Mill (left), principle of operation (middle) and schematic sketch of the mill internals (right).

Primarily, the mill operates by opposing flingers rotating towards one another, as depicted (Figure 1), in order to impact and accelerate particles and ultimately increase particle interactions. The novelty lies within the numerous stages, which provide high energy impacts. By including additional stages, as well as the discharge gates, retention time can be varied, thus allowing, on average, each particle to be impacted 24 times per second before exiting the mill (Bracey *et al*, 2016). Therefore, providing significant potential to break down particles and create a high ratio of fines.

2.1. *Breakage fundamentals*

The application of energy to the material in the EDS Mill is novel and aims to improve the way in which the energy is transferred to the material, effectively improving efficiency and promoting breakage. The high velocity of each flinger tip determines the energy input to the particles. The specific kinetic energy for each collision with a flinger can be quantitatively analysed through the tip speed of each flinger and Equation (1) below:

$$E_{cs} = \frac{E_k}{m} = \frac{0.5 \times m \times V_i^2}{m} = 0.5 \times V_i^2 \quad (1)$$

The specific kinetic energy can range from 0.073 kWh/t to above 1.5kWh/t, yet at lower frequency for higher values. The kinetic energy used for these impacts with the flingers suggests each single impact has a moderate energy level according to general JK Drop Weight Test results. Impacts within the mill above 0.2 kWh/t will cause significant damage to particles (Tromans and Meech, 2003). The nature of the mill generates many impacts per particle, although, as indicated by some E_{cs} values, these impacts may not lead to significant breakage individually, but the sheer number of impacts (average 24 collisions per second) will lead to considerable reduction of feed material.

2.2. *Energy efficiency and power consumption*

Energy efficiency is equated as the ratio of energy that is transferred to the particles or breakage thereof to the total energy input to the system. The power consumption is simply derived as the total power consumed during operation of the specific equipment. Values are taken in kilowatt hours per ton of material processed through the machine (kWh/t).

Total power consumption comparison allows the client to directly compare electricity costs for each machine as this is what would be most important as it affects operating expenditure.

2.3. Liberation

According to Zhang, Y., 2018, the breakage of a conventional compressive force breakage mechanism is from contact point to contact point, no matter what the composition or makeup of the particle is. In most cases, the material would need to be broken down to very fine size ranges in order to get the exposure and liberation of the minerals to allow for high recovery grades. This further means that, in order to get to very fine fractions, more energy must be used to break down the particles.

Under impact loading, the particle has one single impact force acting on it. Unlike compressive force breakage, this force does not have another force point to move towards and hence dissipates to the weakest bonds/points within the particle, which is predominantly the mineral boundaries. An impact force would break on that path if the force was strong enough. In this case, the particle breaks up into its various compositional makeup and this would be regarded as preferential breakage. Figure 2 below shows the typical compressive force breakage of a particle as simulated by Zhang, Y., 2018, as well as the impact force breakage.

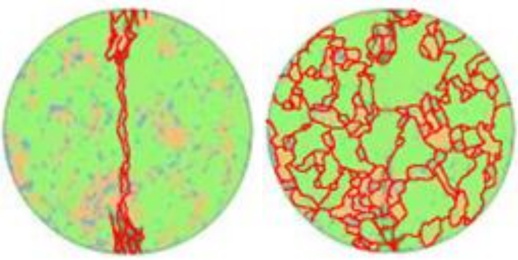

Figure 2. Particle breakage path due to compressive force breakage (left) and impact force (right)

3. Pilot Scale Testing Project

3.1. Scope

A pilot plant was built and installed at an Anglo American Mine in South Africa to determine primarily the reliability, energy efficiency and operational costs (OPEX) of the EDS Mill.

3.2. Target performance

Several performance metrics were targeted in the project:

- Reliability
  - Availability above 80%
  - Utilisation above 80%
  - Average throughput above 80 tph
  - Determine the mean time between failures (MTBF) and mean time to repair (MTTR)

- OPEX
    - Wear consumables costs below $5/ton
- Energy efficiency
    - Specific energy consumption below 2kWh/ton

3.3. Plant setup and process flow

The plant was designed and constructed specifically for the testing of the EDS Mill. Owing to the uniqueness of the equipment, EDS was engaged to provide a team to operate and maintain the plant.

A contract screening plant set up to produce a -50mm screened material from the run-of-mine. This -50mm material was then fed into the EDS Mill feed hopper bin by use of a front-end loader. A variable speed belt feeder was utilized to control the feed rates. This material was conveyed onto a sacrificial conveyor that had a self-cleaning magnet suspended above the belt. This transferred directly onto the main feed conveyor, which had a metal detector as well as a weightometer mounted to it. The weightometer was set up with a proportional-integral-derivative controller (PID) to control the belt feeder and maintain a throughput setpoint.

The material was then gravity fed into the EDS Mill, with a chute specifically designed to allow for a uniform distribution of the feed through the mill inlet. The material was then discharged directly onto a sacrificial conveyor before being transferred onto the main discharge/stockpiling conveyor. This conveyor had a slew drive to allow for a kidney stockpile with maximum capacity to be utilized.

A dust extraction system, together with a dust suppression system, were also installed to assist in preventing dust escaping to the environment. Samples were taken by stopping the system and belt cuts performed on the feed and discharge conveyors. Data was recorded directly from the plant motor control centre and human-machine interface.

At set intervals, or when opportunistic moments arose such as plant delays, certain wear parts were removed from the mill and weighed. The wear life of the parts were then plotted against the tons processed. Wear was considered as a percentage weight loss from the original weight. Different components have different change out points in terms of weight loss. For example, flingers change out around 23% weight loss, whereas liners could be up to 35% or more. Figures 3 and 4 below, display the plant setup.

Figure 3: Feed conveyor and EDS Mill (left) and discharge conveyor and kidney stockpile (right)

Figure 4: Aerial view of the entire pilot plant

3.4. Operation

The construction of the plant took place in 2021 and the plant was operational at the beginning of December 2021. It was agreed that the plant would be operated for a single day shift only. Full safety procedures and checklists were performed before any tasks or operation could commence.

The project was split into four main operating periods, namely: baseline UG2, UG2 Design of Experiment (DOE), baseline UG2 Waste, UG2 alternative runs.

3.4.1. Baseline UG2 period

The initial period was set to run the plant on the EDS baseline speed reference (recipe) for the 5 stages and a set gate position. This recipe was 1500rpms on the top three stages and 3000rpms on the bottom two stages with the gates fully open at 0 degrees. Feed rate was ramped up and maintained between 90 and 100tph. The availability, average throughput, specific power consumption as well as wear rates were recorded and monitored with these key mill parameters kept constant.

Over 21,000 tons of material processed by the EDS Mill by the beginning of May 2022, which was sufficient to obtain insight into the wear rates, availability and operation of the mill. Stage 4 flingers were replaced thrice, stage 5 flingers twice, wedges on stages 4 and 5 once, flingers on stage 1 once. Wedges on stages 1 – 3 and flingers on stages 2 - 3 were not yet worn enough to be replaced and their overall performance was extrapolated from the as partially worn data. The same method of extrapolation was used for all the liners There was one breakdown on the EDS mill during this period – a wedge bolt sheared off and this in turn damaged the wedge and flingers. This took approximately 7 hours to repair.

3.4.2. UG2 DOE period

A Design Of Experiments (DOE) was set up with three different throughputs - 50tph, 100tph and 150tph. On each throughput, there were 8 different tests run, whereby only a single parameter was changed on each test. Speeds of the different stages were altered as well as gate positions. New wear parts were installed for this to ensure accuracy on the data results. Samples were taken and sent through to an external lab for PSDs and assays-by-size.

3.4.3. Baseline UG2 Waste period

At the end of May, a decision was made to run waste material through the EDS mill. Consequently, a short campaign on the waste material was run from the beginning of June through September 2022. Over 15,000 tons of this material was processed using the same recipe as the baseline casein order to compare the EDS mill performance with the two different materials.

New parts were installed before running the waste to allow for this comparison. A second failure of a wedge bolt occurred during the waste material run.

3.4.4. UG2 alternative runs period

Several alternative operating conditions were also run with UG2 ore:

High Throughput: The EDS Mill was tested with high throughput rates in an attempt to determine the limits of the material flows through the unit. A maximum throughput of around 233tph was achieved before the feed conveyors were unable to handle the load.

Maximising Target Product Size: Different setups of the EDS Mill were trialed to maximise the -850µm size fraction in the product.

Coarser Feed Size: The top size of the feed was changed to 100mm material to determine if the Mill could handle this larger sizing. Unfortunately, the larger top size resulted in some of the wear coatings on the flingers chipping or breaking off indicating that the EDS Mill in its current configuration is unable to handle UG2 material with a top size of 100mm

3.4.5. Delays and concerns

During the project, it was necessary to remove parts and weigh them to generate wear curves. This time added to some delays on the project, however, there were many other delays not related to the EDS mill availability that contributed to total downtime such as metal pieces not picked up by the magnet but picked up by the metal detector. Some of the items that were not picked up by the magnet are shown below in Figure 5. These metal pieces if allowed to enter the mill could have caused significant damage to the mill internals.

Figure 5: Items in the feed material that were stopped by the metal detector

Ultimately, by the end of the project in December 2022, a total of over 50,000 tons of material (15,000 tons of waste and 35,000 tons of UG2) had been processed through the EDS Mill.

4. Results and observations

4.1. Particle size distribution (PSD) results

All the PSDs measurements were conducted by an external laboratory using standard sieve sizes. A matching feed sample was taken for every product sample collected. Approximately 50 samples were taken through the duration of the project, but, for simplicity, only three PSDs are shown below in Figure 6 for the UG2 ore – maximum, middle and minimum. A fourth PSD is shown, depicting the high throughput tests. The high throughput test PSDs varied minimally from each other, so only one has been shown.

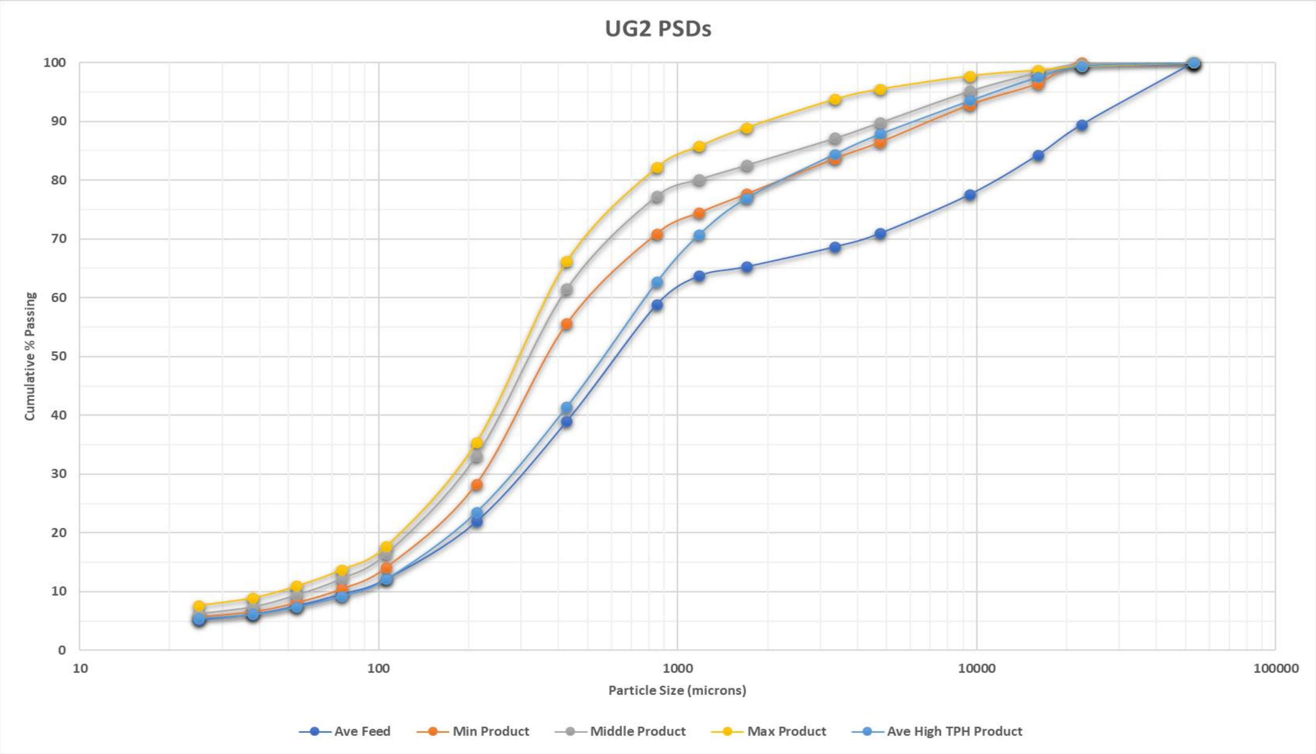

Figure 6: Feed and product PSDs on the UG2 ore

The waste material was only run using the baseline recipe so only two PSDs representing the envelope are shown in figure 7 below.

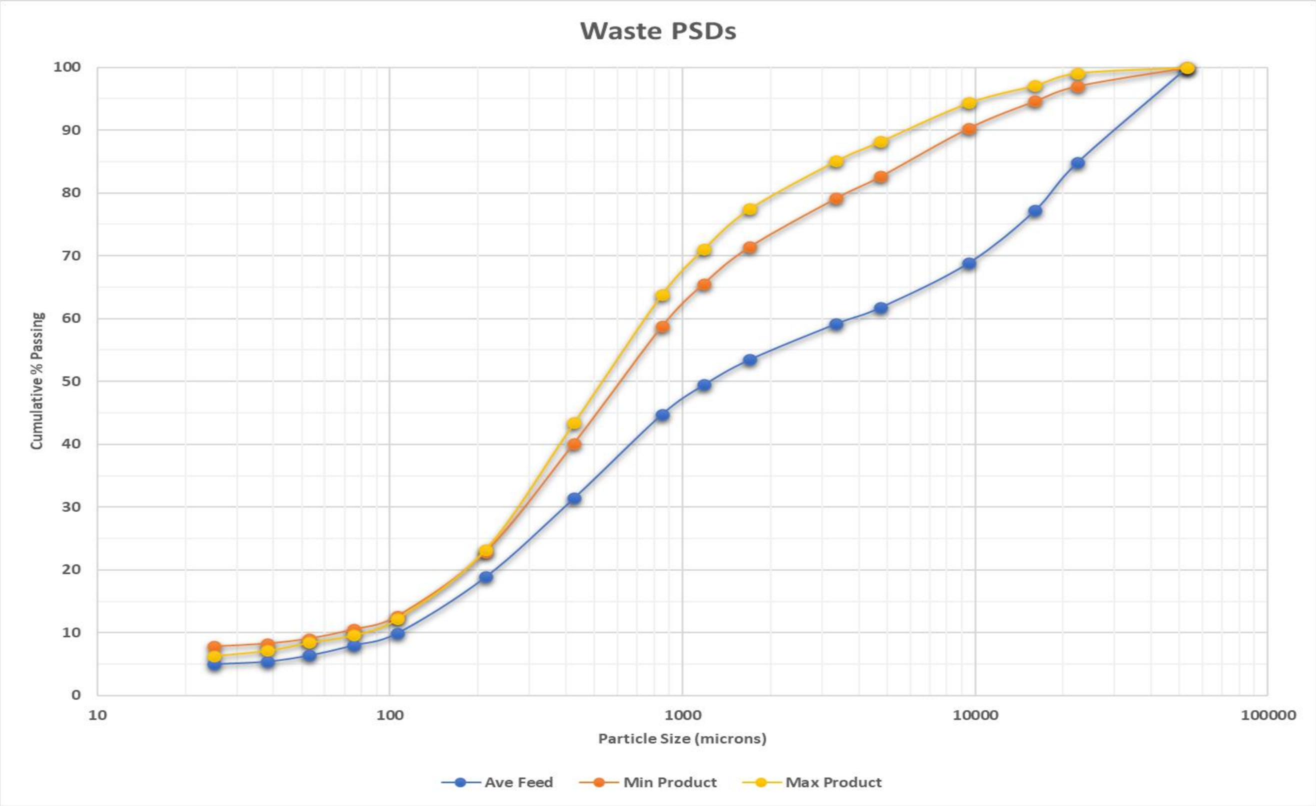

Figure 7: Feed and product PSDs on the Waste ore

The PSDs in Figures 6 and 7 show the EDS Mill was able to significantly reduce the coarse end (+850 µm) of the size distribution without appreciably increasing the fine end (-75 µm). Most of the broken material ended up in the -850 µm + 106 µm fraction. All of this was achieved in a single pass through the mill.

The single pass reduction ratios of around 10 for UG2 were achieved by the EDS Mill with one recipe able to achieve a reduction ratio of almost 18. The reduction ratios for waste and at higher throughputs were lower (around 7.5) likely due to the increased competency of the material and reduced impacts results from the larger number of particles in the mill. Two sets of power data were recorded on the site. The first was for the entire plant, the second only for the mill itself. The first set was not relevant as the consumption of the conveyors, feeder, and other equipment does not provide any insight into the mill and how it is performing.

4.2. Power consumption

The power consumption for the mill was recorded directly from the MCC. The power calculations were zeroed before each run. Then the power (in kWh) was accumulated as the plant was operational. The end power reading was then taken for that specific run. Knowing the tons processed during that period, the power consumption per ton processed could be calculated.

The power consumption per ton was taken as an average over the project and resulted in 0.76 kWh/t. This value compares favourably with conventional comminution equipment indicating to the energy efficiency of the EDS Mill. If the cost per kWh of electricity is known, then the operating cost for the power consumption could be calculated from this figure.

4.3. Wear results and operating costs

The total wear cost for the various components in the EDS Mill could be calculated taking into account the wear curves plotted, the change out points for specific components as well as extrapolated data from parts that were not replaced during the project.

The flingers and wedges are calculated per stage and then taken as a total for the mill. The liners are split into four categories and calculated accordingly. This is done due to the variable wear rates for the different components within the mill, depending on their positions.

All costs were taken in South African Rands and converted to US Dollars through the exchange rate shown to obtain a more standard metric. Furthermore, from the weight loss data, the wear mass lost per ton processed has also been obtained.

The following tables 1 and 2 show the wear costs for these various items.

Table 1: UG2 wear costs

OPEX COSTS – UG2		
Description	Rand/Ton	Grams/Ton Loss
Flingers	R14.43	3.787
Wedges	R11.68	4.784
Discharge Gate Liners	R0.18	0.026
Door Liners	R0.22	0.074
Deflector Liners	R0.16	0.066
Side Liners	R1.63	0.284
Total	**R28.30**	**9.022**
	$1.58	@ R17.88/$

Table 2: Waste wear costs

OPEX COSTS – WASTE		
Description	Rand/Ton	Grams/Ton Loss
Flingers	R10.83	2.474
Wedges	R16.33	7.113
Discharge Gate Liners	R0.15	0.022
Door Liners	R0.46	0.154
Deflector Liners	R0.91	0.370
Side Liners	R1.63	0.284
Total	**R30.32**	**10.418**
	$1.70	@ R17.88/$

These figures are well below the target of $5.00/t for the project. Considering that conventional equipment, such as ball mills, mass loss per ton can be from 500g up to 2.5kg, the EDS Mill is far below that. With low mass loss, the contamination into the product of unwanted elements would be minimal and there will not be any effect on downstream processes.

4.4. Reliability

Standard reliability calculations (see Appendix A) were used to determine availability, utilization, mean-time-between-failure (MTBF) and mean-time-to-repair (MTTR). The utilization of the mill was very low, due to the extensive downtimes caused by other operations or equipment, that impacted the availability of feed material. But, on the other hand, the availability of the Mill was high. Table 3 below shows the figures for the different ores.

Table 3: Summarised reliability metrics

RELIABILITY METRICS		
Description	UG2	Waste
Availability (%)	96.12	94.99
Utilisation (%)	29.07	32.83
Ave Throughput (tph)	93.82	83.12
MTBF (hours)	124.29	62.88
MTTR (hours)	5.12	4.39

The MTBF and MTTR results are worrying, however, these are failures that can easily be redesigned and alleviated. EDS has embarked on an investigatory design process to understand the failure through analysing the failed bolts and conducting finite-element-analysis on the assembly. A new design for the wedges and shafts has been approved and shows significant reduction in bolt loading and will heavily reduce the risk of failures in the future.

4.5. Grade engineering

The assay by size results showed good grade engineering response and deportment of the materials being tested.

5. Conclusions and recommendations

The current version of the EDS Mill was able to perform well within the set performance metrics with an availability above 90% for the UG2 material. Ongoing design optimisation should improve the performance of the mill even further.

Overall EDS considers the project a success with most metrics having been met and surpassed during the project.

It is recommended that any future EDS installations include:

A good dust extraction or suppression system to mitigate the significant amount of dust produced, which is certain operations would contain valuable minerals.

A suitable online metal detection and removal system to ensure the feed material is free of any tramp metal going into the EDS Mill.

A standby unit for redundancy, so that when one mill is operating, the other one is being maintained, which should increase availability even further.

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Declaration of Interests

This project was funded by Anglo American through a joint development agreement with EDS. All data, samples and analysis remain the property of Anglo American. EDS is the OEM designer, manufacturer and patent holder of the EDS Multishaft Mill.

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Appendix A – Reliability calculations

The EDS calendar time was set as 6:00am to 15:00pm as this was the only operating times/shift that was utilized on the project.

Equipment Availability = Percentage uptime over controllable time

$$EQA = \frac{Uptime}{Controllable\ Time} \tag{2}$$

Equipment Utilisation = Percentage direct operating time over uptime

$$EQU = \frac{Direct\ Operating\ Time}{Uptime} \tag{3}$$

Mean Time Between Failure (MTBF) = Ratio of direct operating time to the number of failure events reported in hours (hrs)

$$MTBF = \frac{Direct\ Operating\ Time}{Number\ of\ Failure\ Events} \tag{4}$$

Mean Time To Repair (MTTR) = Ratio of unscheduled maintenance time to number of failure events reported in hours (hrs)

$$MTTR = \frac{Unscheduled\ Maintenance\ Time}{Number\ of\ Failure\ Events} \tag{5}$$