GRINDING CIRCUIT EXPANSION AT KIDSTON GOLD MINE

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Abstract. *Increasing ore hardness led to a gradual reduction of mill throughput rates. This, combined with declining head grades and low gold price, prompted a review of milling practice at Kidston. Plant trials and computer simulation of the grinding circuit indicated the potential to increase mill throughput by up to 45% by reducing SAG mill feed size. Secondary crushing and additional ball milling capacity were installed. Commissioning was carried out successfully in September/October 1992. Design, operation and problems of the expanded circuit are discussed, and recent operating results are presented.*

Introduction

Kidston Gold Mines Limited is 70 % owned by Placer Pacific Limited which is a subsidiary of Placer Dome Inc (75.7 %).

The Kidston mine is located 280 km south west of Cairns in northern Queensland, Australia. In the 1992/3 fiscal year it was Australia's fifth largest gold producer (224 367 oz). Current mineable ore reserves are 33 557 000 tonnes at a gold grade of 1.13 g/t.

The mill was commissioned in January 1985 and the first gold poured in February. Since commissioning there have been two major plant modifications.

Brief history and description of the comminution circuit

Original design

The comminution circuit was installed as a conventional primary crushing/SAG mill/ball mill circuit.

Major equipment comprised a 1.07 m x 1.65 m gyratory crusher feeding the 25 000 t (live) stockpile, a 8.53 m diameter x 3.65 m semi-autogenous mill driven by a 3.95 MW variable speed dc motor, and a 5.03 m diameter x 8.34 m secondary ball mill driven by a 3.73 MW synchronous motor.

Crusher product at 80 % passing 175 mm was reclaimed from the live stockpile via four in-line vibrating feeders discharging onto the SAG mill feed conveyor.

The SAG mill was fitted with grates of 13 mm slot width, later increased to 20 mm. The ball charge was 10 to 12 % of mill volume using 120 mm diameter steel balls. The mill was operated in closed circuit with two 1.83 m x 6.71 m stationary screens with 13 mm wide slots parallel to flow; recirculating load was 3 to 5 % of new feed.

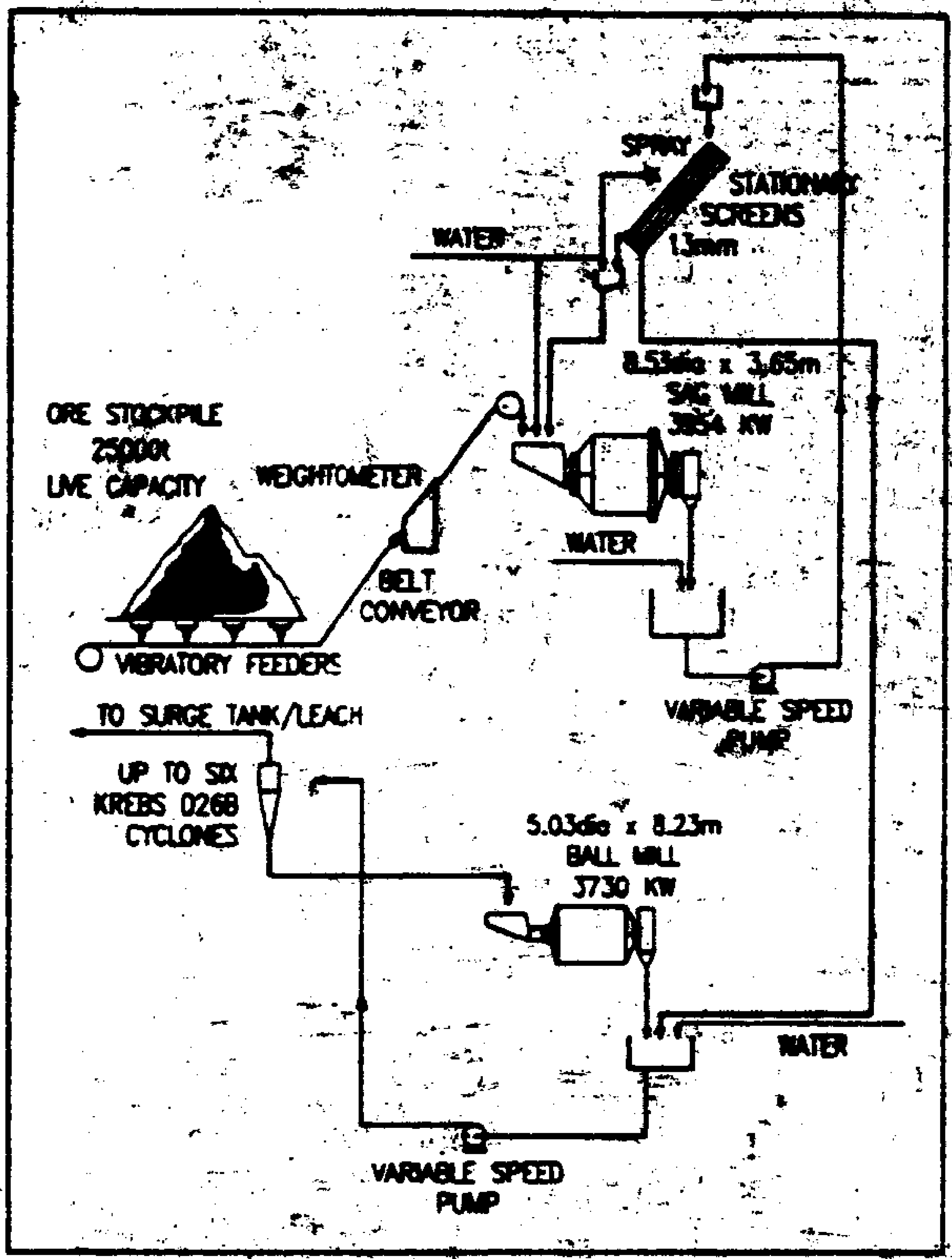
Design throughput was 355 t/h, average, for fresh ore of Bond Work Index, $W_i = 20$, ranging up to 660 t/h for oxide ore of $W_i = 14$.

The circuit configuration is shown in Fig. 1. Design and operation was described fully by Bartrum, Bowler and Butcher (1985).

Conversion to SAG mill/Ball mill/Crusher (SABC) circuit

Early in 1986, difficulty in maintaining design throughput was experienced on processing particularly hard ore. The throughput rate

Figure 1: Original Kidston Grinding Circuit

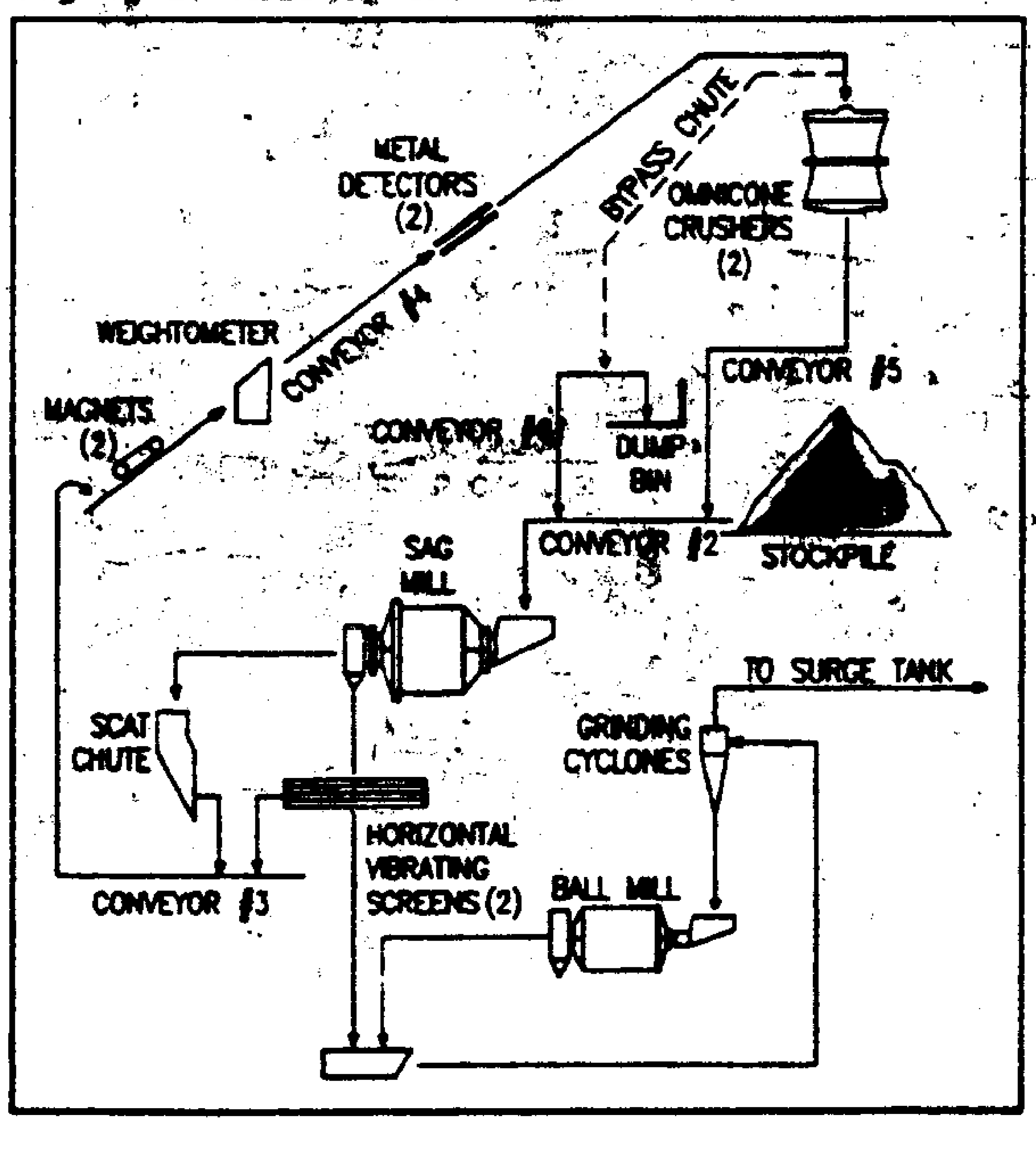


dropped as low as 280 t/h due to a critical size build up in the SAG mill charge.

The chosen solution was conversion to SABC. Plant testwork was carried out in 1986 to determine the design parameters for the proposed modifications. This was described by Bartrum, Plyley and Butcher (1987).

The conversion was completed and commissioned at the end of 1987. The circuit configuration is depicted in Fig. 2.

Figure 2: Kidston SABC circuit



The discharge grates of the SAG mill were replaced with pebble ports. Two 1.56 m cone crushers were installed in the circuit, one on standby. The stationary screens were replaced with two 4.9 m x 2.4 m horizontal vibrating screens, one on standby.

Hard ore throughput rates increased by 30 to 35 %. SAG mill recirculating load increased to around 20 %.

Ore hardness and milling rates: establishing the trend

Fig. 3, showing monthly average milling rates over the period from April 1989 to February 1991, well illustrates the effects of both localised variations and the overall trend of increasing ore hardness with depth.

Mill feed samples at a range of throughput rates were subjected to comparative work index testing. Thus the relationship between throughput and work index was quantified (see Fig. 4). The scatter of results is explained by variations in size distribution as a result of inconsistencies in blasting.

Deep ore drill core samples were also subjected to comparative work index testing and the results (see Table 1), when evaluated against the information in Fig. 4, indicated that milling rates would continue to decline. Exacerbated by declining head grade and low gold price, the long term viability of the mine came into question.

Development of expansion concepts

In order thoroughly to evaluate the SABC circuit and determine the most effective approach to improve throughput and comminution efficiency, the following approach was decided upon:

- Carry out full grinding circuit surveys, producing data such as stream flows, density, particle size distribution, mill load, power draw and cyclone operating parameters.
- Develop a computer simulation model of the grinding circuit using the JKSimMet mineral processing simulation package.
- Use JKSimMet to adjust circuit parameters and determine their impact upon throughput, mill power draw and grinding efficiency.
- Attempt to achieve a circuit throughput of a nominal 660 t/h, above which downstream processes were believed to be limiting.
- Determine the most economic expansion concept using Net Present Value analysis of capital cost, operating cost and resultant cashflows.

Grinding Circuit Survey 1

A full grinding circuit survey was carried out to obtain sufficient data tc develop an initial computer model. The survey was carried out at maximum achievable throughput on the ore type tested. The results were first mass balanced using the JKMBal program to smooth the data, a necessary preliminary step to setting up a circuit model, as the difficulties in taking a representative sample from a circuit of this size are extreme. Significant parameters resulting from the survey are shown in Table 2.

A JKSimMet model was then developed to reflect the data collected. In order to establish how well the model represented the actual grinding circuit, especially in relation to power draw, various simulations were carried out.

An effort was made to calculate the power drawn by each simulated circuit using the Bond formula, with little success. Of greater benefit was a comparison of the SAG mill load generated by each simulation to the load indicated by the surveyed circuit model. The volume and size distribution of the load were taken to indicate whether a buildup of coarse sized particles would occur and subsequently if mill motor power was likely to be exceeded.

The simulations of primary interest are as follows:

- Simulation of 660 t/h primary crushed ore

Figure 3: Monthly average milling rates

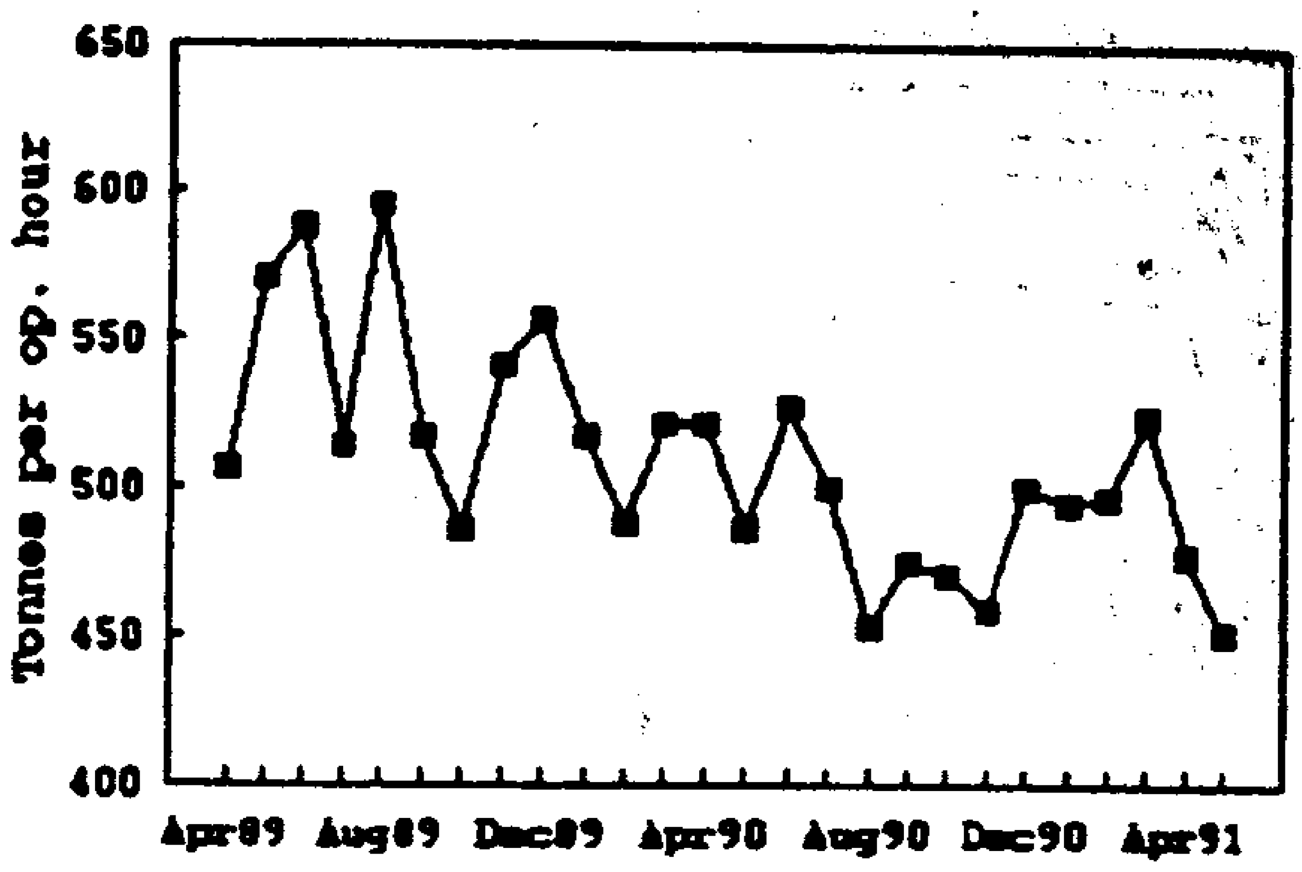


Figure 4: Milling rate vs work index

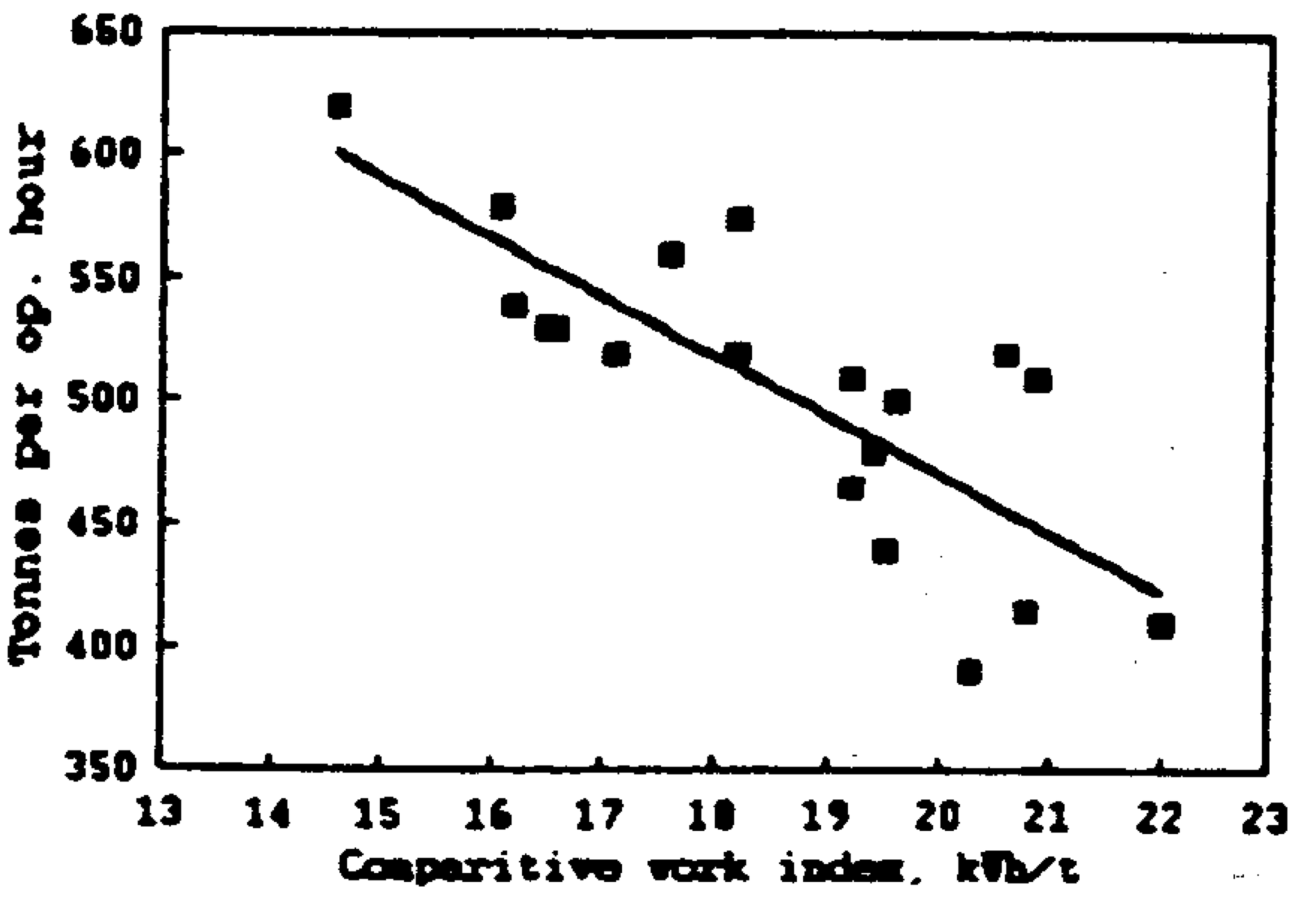


Table 1: Summary of deep ore predictive testwork

Zone	% of ore body	Range of comparitive W_i	Projected t/h
Main ore zone	70	21.5-22.8	400-440
Footwall central	25	18.9-20.8	450-500
Footwall east	5	19.3-20.2	460-490

Table 2: Grinding Circuit Survey 1 Data

SAG mill circuit configuration		Closed
Throughput	t/h	513
SAG mill feed size	80% passing (mm)	130
SAG mill power draw	kW	4150
SAG mill recirculating load	t/h	92
SAG mill pebble port size(max)	mm	300 x 75
SAG mill ball topsize	mm	150
Vibrating Screen Undersize	80% passing (mm)	0.84
Ball Mill recirculating load		215%
Ball Mill power draw	kW	3900
Cyclone O/F size	80% passing (mm)	0.205
Ball mill ball topsize	mm	80

feed to the existing SABC circuit at the current SAG mill feed size, adding extra ball milling capacity to achieve final grind size requirements.

The resultant SAG mill load was 120 % of the surveyed case, indicating an overload situation, as expected.

· Simulation of 660 t/h feed to the SAG mill, however open circuiting the SAG mill by rejecting recycle crusher feed from circuit, and adding sufficient ball milling capacity to achieve final grindsize requirements.

The resultant SAG mill load was 116 % of the surveyed case, also indicating an overload situation.

· Simulation of 660 t/h using the existing SABC circuit but crushing the SAG mill feed to a (nominally chosen) F_{80} of 16 mm, and adding the required ball milling capacity.

The resultant SAG mill load was 55 % of the survey circuit load. This result was considered to be indicative only, as the SAG mill breakage and discharge mechanisms in the surveyed circuit model were not likely to be the same in a crushed feed situation, i.e. without coarse ore contributing to breakage of the finer ore particles.

· Simulation of 563 t/h feed to the SAG mill in open circuit, rejecting recycle crusher feed. This was the approximate throughput gain (50 t/h) achieved by open circuiting the SAG milling circuit and was simulated to determine if the model reflected this ceiling in terms of load sizing and/or power draw.

The resultant SAG mill load was 97% of the survey circuit load. This result supported actual experience that only a small increase in throughput could be achieved before maximum power was again drawn.

Conclusions from survey 1 simulations

It was evident from the circuit survey and simulations that the low breakage rate of coarse ore in the SAG mill was the most significant factor limiting grinding circuit throughput and consuming SAG mill power due to a build up of mill load. Relieving the load via larger pebble ports was not considered an option due to their already large size and the short residence time of the grinding media. The simulations indicated that the only options for increasing the grinding circuit throughput were either to eliminate the coarse ore from the SAG mill feed to a sufficient degree to limit power draw to 4 150 kW, or to install extra SAG and ball milling capacity.

Further circuit surveys were recommended to gather information on SAG mill performance using ore recrushed in a secondary crusher.

Surveys 2, 3, 4 and 5

Three further surveys were carried out using a 15 000 tonne parcel of ore crushed in a 1.3 m cone crusher. A fifth survey was completed using only primary crushed ore for a baseline comparison.

Considerable difficulty was experienced in achieving stable circuit conditions, especially around the SAG mill recycle circuit, due to the SAG mill product size in relation to the pebble port size. A summary of survey results is shown in Table 3.

Of note is the baseline (Survey 5) throughput of only 390 t/h with the larger feed size.

Survey 2 data was mass balanced and a JKSimMet model developed to reflect the resultant data. Using this model, the feed size distributions from the remaining three surveys were input to the model and the circuits simulated. The results satisfactorily represented the actual data for each of these surveys. A regression relationship was then determined between the SAG mill load predicted by the model and the power draw recorded in each survey. Using this relationship, mill power draw could be determined from the SAG mill load tonnage predicted by a circuit simulation.

Circuit Simulations: Various circuit configurations and feed size distributions were investigated using the models developed. Configurations used reflected the requirement for any expansion to be of a simple configuration and minimum capital expenditure. The following configurations were investigated.

Feed "Cocktails" - Circuit response was evaluated at 660 t/h using 100 %, 75 %, 50 % and 25 % secondary crushed ore in the feed with the remainder as primary crushed ore.

In order to evaluate the effect of feed "cocktails", the respective breakage rates from Survey 1 and 2 were combined in the same

Table 3: Survey data, surveys 2, 3, 4 and 5

Survey No.		2	3	4	5
SAG Mill circuit configuration		Open	Open	Closed	Closed
Throughput	t/h	660	660	660	390
SAG Mill feed size	80% passing (mm)	35	45	70	146
SAG mill power draw	kW	2510	3940	4030	4170
Recycle crusher feed	t/h	99	187	205	67
Vibrating screen undersize	80% passing (mm)	2.29	-	2.2	-
Cyclone O/F size	80% passing (mm)	0.25	-	-	-

Table 4: Feasibility Study Model Parameters

		KGM model	Harder ore model
SAG Mill Circuit Configuration		Closed	Closed
Throughput	t/h	660	660
SAG mill feed size	80% passing (mm)	35.4	29.6
SAG mill power draw	kW	4100	4050
SAG mill recirculating load	t/h	68	72
SAG mill grate size	mm	35 x 35	35 x 35
SAG mill ball topsize	mm	150	150
Vibrating screen undersize	80% passing (mm)	2.56	2.65
Ball Mills recirculating load	%	270	280
Cyclone O/F Size	80% passing (mm)	0.183	0.184
Number of Cyclones		7	7
Cyclone Operating Pressure	kPa	53	56

proportions as the coarse and fine feed. The results indicated that 660 t/h through the SAG mill in closed circuit could only be achieved if 100 % of the feed was crushed to a F_{80} of 57 mm. A second ball mill would be required with a 3.2 MW motor installed. The inclusion of any coarse ore in the feed at this throughput rate resulted in excess power being drawn. A 35 mm x 35 mm SAG mill grate size was necessary to provide the required residence time in the SAG mill and minimise the recirculating load.

Simulating 50 % of feed crushed to 80 % passing 35 mm, a crusher product size considered easily produced by a secondary crusher, and using the existing SAG and Ball mills, a maximum of 500 t/h was achievable before overloading of the SAG mill occurred.

<u>Two SAG Mills</u> - Simulations carried out using another identical SAG mill in circuit, and evenly splitting 660 t/h of feed between the two mills, showed that the existing ball mill would accommodate approximately 580 t/h to produce a cyclone overflow size of 80 % passing 0.2 mm. Additional ball milling capacity would therefore be required to increase circuit throughput to 660 t/h.

<u>Feasibility Study Model</u>

As a result of the simulations carried out, it was decided to take the 100 % secondary crushed feed scenario to feasibility study evaluation status. The final model parameters are shown in Table 4. In case the ore trialled during the surveys was not yet to be the most resilient material encountered, a simulation was carried out using model parameters from a harder ore type at another mine within the Placer Pacific Limited Group. The results for this scenario are also shown in Table 4.

Final circuit configuration

Design considerations

Fig. 5 shows the flowsheet of the upgraded crushing plant. The design criteria for the crushing and milling areas are listed in Tables 5 and 6.

When designing the expansion, consideration had to be given to the limited space available.

Figure 5: Expanded Kidston crushing circuit

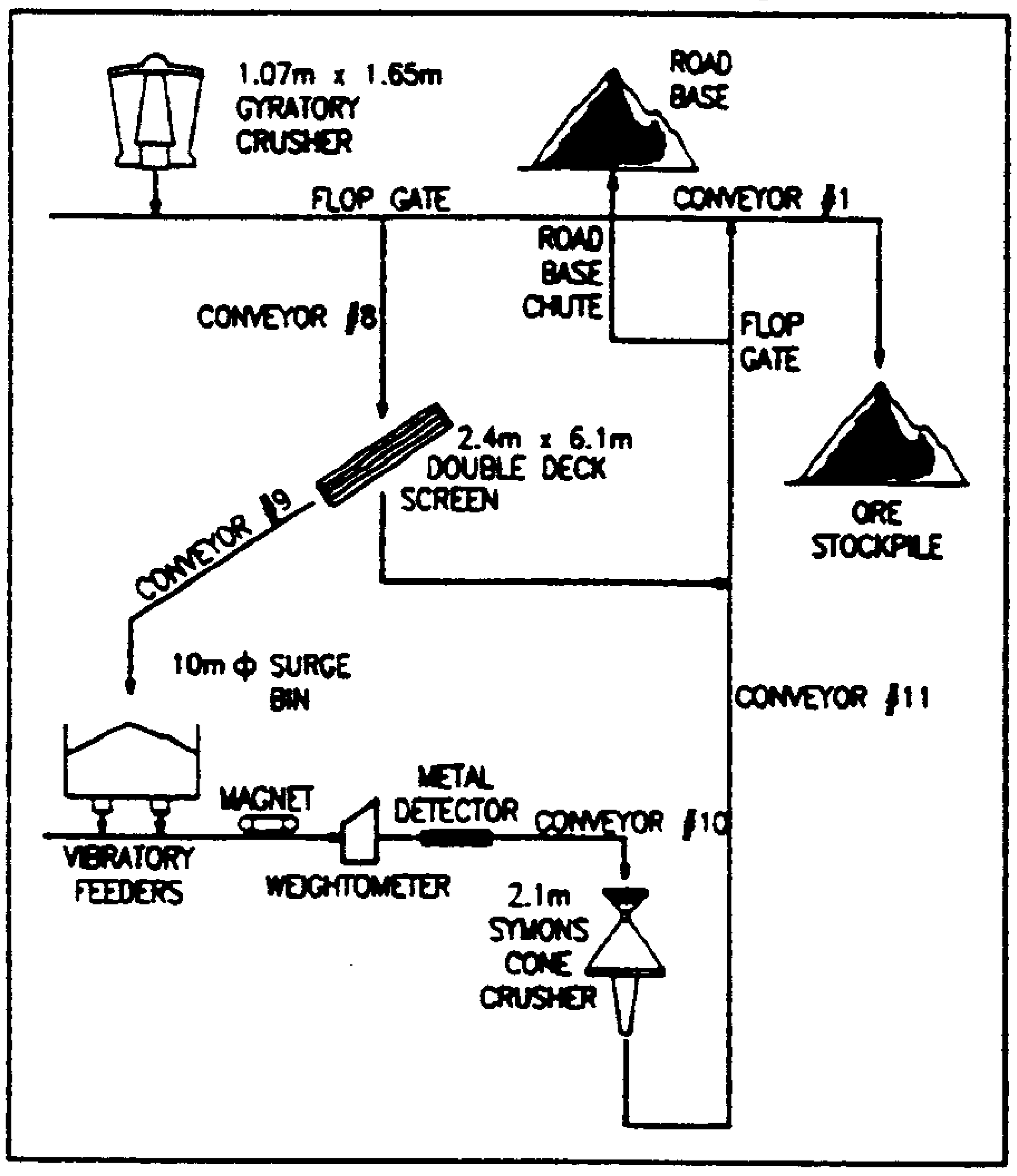


Table 5. Crushing circuit design criteria

Annual throughput		5.5 Mt
Crusher availability		80 %
Primary crusher		
throughput	(max)	2000 t/h
	(ave)	800 t/h
Primary crusher P_{80} (nom)		130 mm
Secondary crusher P_{80} (nom)		40 mm
Crusher screen		
aperture (nom)		45 mm
% screen feed passing 45 mm		
	(min)	30 %
	(ave)	40 %
	(max)	60 %
ROM ore bulk density		1.6 t/m³
ROM ore rill angle		36°
Secondary crusher surge bin		
capacity		30 mins
volume		250 m³
Secondary crusher annual		
operating time		7008 h
Secondary crusher		
throughput	(max)	550 t/h
	(min)	315 t/h

Secondary crushing

The secondary crushing circuit had to fit into an area bounded on four sides by the coarse ore stockpile, the stockpile feed conveyor, the primary crusher and waste dumps.

A tripper system was installed on the stockpile feed conveyor to enable ore to be diverted, via another conveyor, to a 2.4 m x 6.1 m inclined, double-deck, vibrating screen. A flop gate was included so that the secondary crusher may be bypassed if necessary. The screen was sized to accommodate feed rate fluctuations up to 2 000 t/h, whilst maintaining sufficient screening efficiency to ensure no reduction in crushing efficiency occurs.

A 10 m diameter, 400 tonne (live) capacity, surge bin was included in the circuit to ensure continuous operation of the secondary crusher, allowing for breaks in primary crusher operation due to truck cycle times.

Two variable frequency drive vibrating feeders were provided to ensure choke feeding of the secondary crusher regardless of ore hardness or size distribution.

The secondary crusher is a 2.13 m Symons SXHD cone crusher.

The crusher feed conveyor is fitted with a a moving belt magnet and a metal detector for protection of the crusher. It is also fitted with a belt scale.

Crusher product is returned to the stockpile feed conveyor via a return conveyor. A flop gate was provided at the transfer point so that the stockpile feed conveyor may be bypassed. This allows the system to be used for producing road base for use in the open pit.

Both the crusher and vibrating screen installations are fitted with dust collection systems.

Grinding

SAG milling: The only change required in the SAG mill circuit was replacement of the 75 mm pebble port with a 35 mm grate. This change had to be scheduled to coincide with commissioning of the secondary crushing circuit.

Ball milling: The original cyclone cluster, containing six 0.66 m diameter cyclones, was replaced with an eight cyclone cluster to accommodate the increased throughput. Underflow is split between the two ball mills and may be diverted to either mill singly if required.

Location of the new ball mill presented some difficulty. The existing cyclone overflow surge

Table 6. Milling circuit design criteria

Mill availability		95.5 %
	(1992)	93.4 %
Mill throughput		660 t/h
SAG mill feed size, F_{80}		35 mm
Recycle crusher		
throughput	(max)	180 t/h
Ball mill work index		20-22 kWh/t
Ball mill P_{80}		180 µm

tank, originally provided as a buffer between the grinding and leach circuits, had to be removed and replaced with a much smaller tank. This was not considered a problem as, by design, feed flows to the leach circuit were expected to be more consistent with the new circuit.

Discharge from the new mill is pumped to the discharge hopper of the original ball mill from whence the combined discharges are pumped to the cyclones.

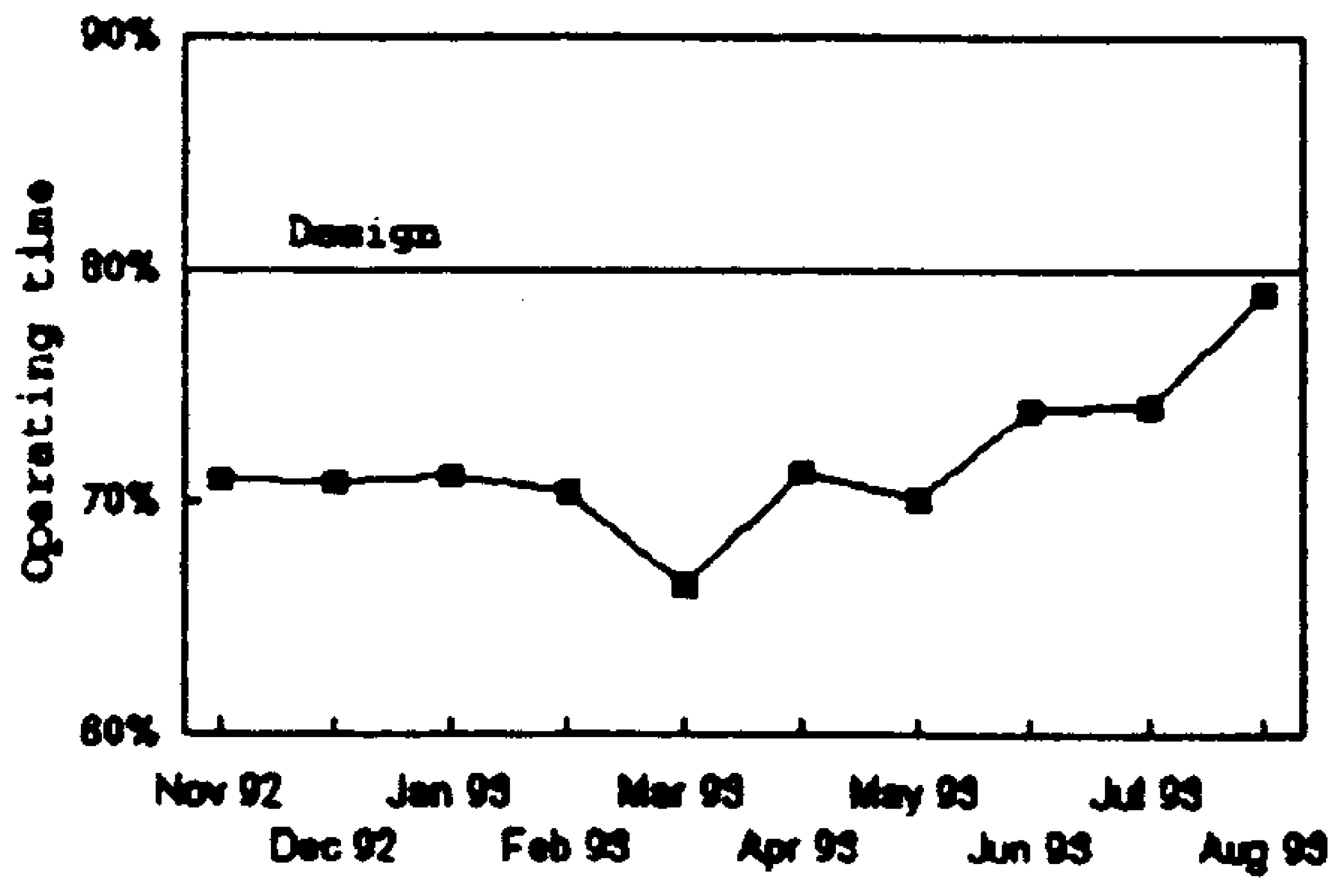
Circuit operation

Commissioning was carried out during September and October, 1992. No major problems were encountered and the project was completed two months early and A$1.7 million under budget.

Crushing circuit design throughput of 800 t/h (average) was exceeded immediately. Throughput for the ten months since commissioning has averaged 891 t/h.

The design operating time of 80 % has not yet been achieved. An average 70 % operating time was maintained during the first seven months. It has been steadily increasing since May 1993 (ref. Fig. 6).

Figure 6: Crusher monthly average operating time



Many factors contributed to the poor operating time. Change out of cone crusher liners was anticipated every five weeks. Actual experience was initially every fourteen to sixteen days which, by redesign of the liners, has been extended to every three weeks. The feasibility study assumed a value of 0.40 for the ore abrasion index, A_i. This has increased to A_i = 0.59 resulting in accelerated wear rates throughout the plant.

Excessive downtime of the vibrating screen resulted from deficiencies in the design of the screen deck hold down arrangement. Manufacturing problems with the screen decks themselves exacerbated this.

The secondary crusher feed conveyor had to be replaced when a chute liner fell out and damaged it beyond repair.

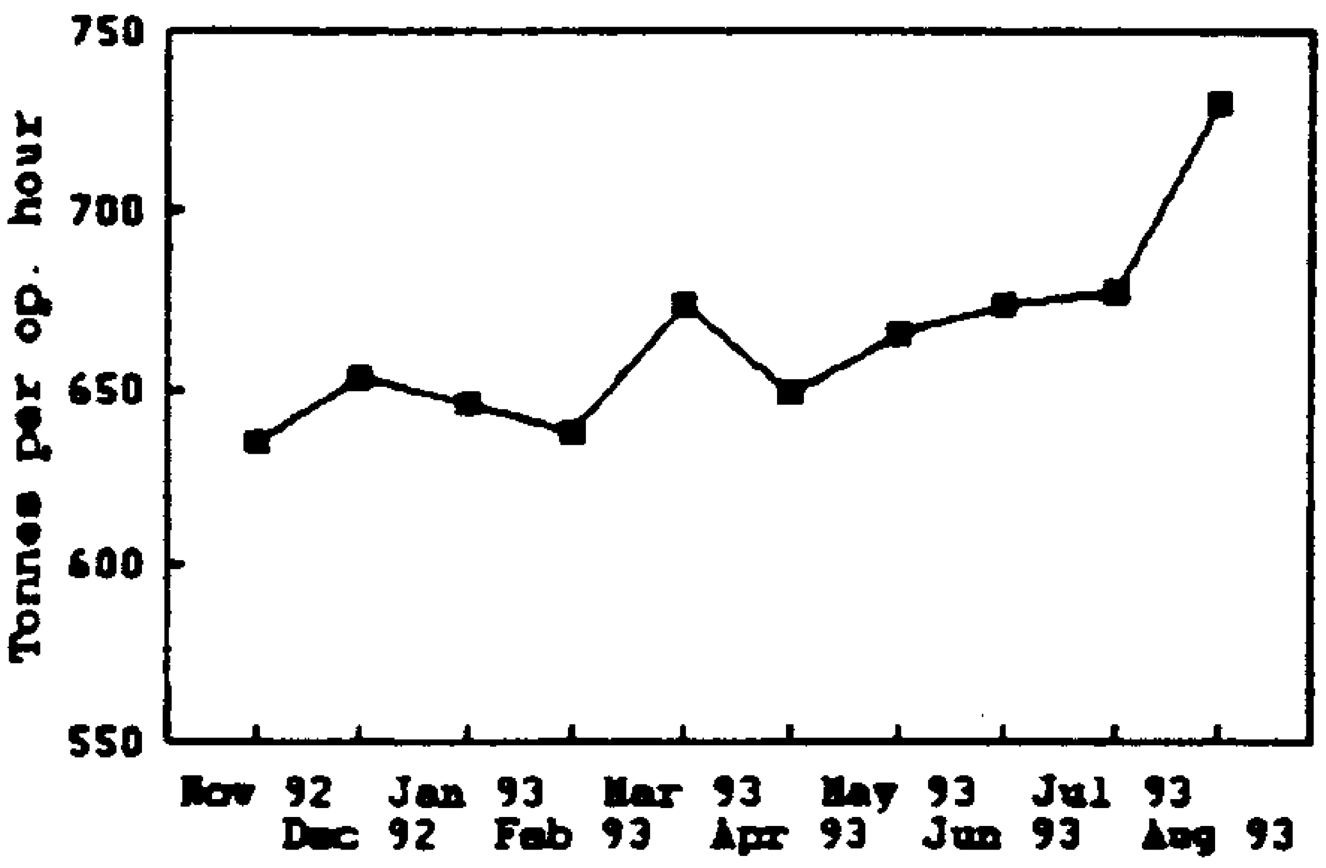
Recent improvements in operating time are largely due to the development of preventative maintenance programs.

As a result of the low operating time, crusher throughput initially could only just match milling capacity. This resulted in low stockpile levels and unstable stockpile operation. This in turn led to poor SAG mill control and reduced mill throughput.

As a temporary measure, whilst solutions to the low operating time problem were sought, a 1.3 m cone crusher, previously used for producing road base, was installed in parallel with the 2.13 m cone crusher.

Fig. 7 shows how mill throughput has been steadily increasing. The average milling rate in the ten months since commissioning is 664 t/h compared with the design of 660 t/h. Design throughput was first achieved after five months.

Figure 7: Post expansion milling rates



Production exceeded 500 000 tonnes milled for the first time ever in July 1993, at a record milling rate of 677 t/h. These records were improved upon in August with the milling rate reaching 730 t/h.

<u>SAG mill control</u>

The change in SAG mill feed size has brought about a significant change in the way the SAG mill is controlled. In order to understand the changes an explanation of the old control strategy is pertinent.

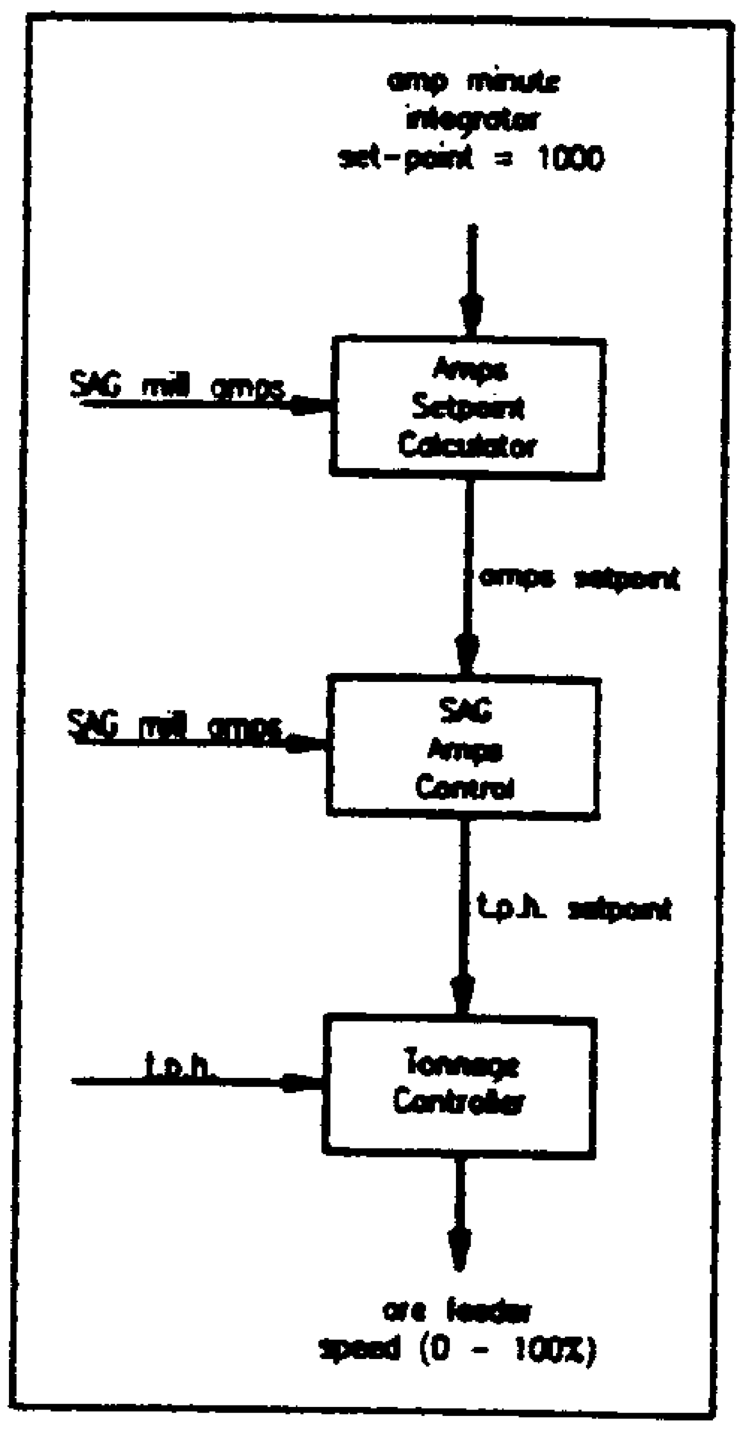
<u>Pre-expansion</u>: SAG mill control was effected principally by an automatic control loop using a motor current measurement and set point to control feed rate.

Full load motor current is 5 600 A. The current set point was dynamic and was calculated by another loop which monitored motor current compared with full load current. Operation above or below full load current was recorded as an integration of amp minutes. Current set point for the tonnage controller was calculated from the value held in this counter and was designed to hold the count at a set point of 1 000. An alarm would activate at a count of 4 000 whilst at 6 000 the mill motor would trip.

The advantages of this approach were two-fold. Firstly, heat generation in the motor during periods of operation above full load current was countered by an equal time of operation below full load current which allowed cooling of the motor windings, thus protecting the motor. Secondly, the average power draw was maintained close to the full load value, maximizing power utilization. In practice, power utilization approached 100 %.

The control loop is illustrated schematically in Fig. 8.

Figure 8: SAG mill auto-control loop



Bearing pressure was not used in automatic control loops but was used by operators to detect mill overloads and thus indicate the need for manual intervention.

Mill speed was controlled manually. Optimum mill speed varies mainly with ore hardness and size distribution. Speed was normally kept within the range 11.0 to 11.4 r.p.m., representing 75 to 78 % of critical speed. When treating particularly soft, fine ore, when full power draw could not be maintained, lower mill speeds could be used to protect mill linings and grinding media from breakage.

Ball load was maintained between 10 and 12 % by volume. Muck load was around 10 %. Ball top size was 150 mm.

<u>Post-expansion</u>: It became apparent very quickly that, with the finer feed size, the SAG mill had to be operated with a much lower muck load. If the muck load exceeds 4 to 5 % by volume (with a ball load of 11 to 12 %) grinding efficiency drops away rapidly and the mill overloads.

The increase in muck load which results in overloading is too small to be detected by a change in the bearing pressure. If such a change is detected the mill is already overloading.

As a consequence of the low volumetric load in the mill, the motor power draw is now typically in the range of 90 to 95 % of installed power. Attempts to increase power draw by increasing ball load have only resulted in an increase in ball breakage, with no concomitant benefit in milling rate. This means that maximizing power draw is now inappropriate. In addition, lack of resolution in measurement precludes the use of bearing pressure for control purposes.

An alternative was available in the form of an existing sound level monitoring system. An industrial microphone located adjacent to the mill shell transmits a sound level measurement to the PLC used for mill control. An automatic control loop uses this measurement to vary ore feed rate to maintain a noise level set-point, noise level being inversely proportional to volumetric muck load. The optimum mill speed has increased to 81 % of critical speed.

Mill control has been very successful using this strategy.

The loop previously used for calculating the motor amps set-point is now redundant, but the excess current counter is still used for protection of the motor on occasions when hard, coarse ore results in full power draw being achieved.

The smaller SAG mill grate aperture, resulting in a smaller feed size to the recycle crusher and reduced recirculating load, has permitted a change of liner profile in the crusher. As a result, the closed side setting has been reduced to 6 mm from 10 mm.

<u>Future Development</u>: The computer model of the circuit is being updated using data from plant surveys carried out since the expansion. The updated model will be used as an aid to optimize parameters such as:

- SAG mill feed size for different ore types to ensure optimal utilization of available power in both crushing and milling circuits.
- SAG mill grate size.
- Grinding ball size.
- SABC vibrating screen aperture.

It will also be used to determine the potential benefit of redirecting recycle crusher product, currently returned to the SAG mill, to the ball mills.

<u>Operating Costs</u>

Table 7 shows direct operating unit costs for the ten months prior to commissioning (October 1991 to July 1992) compared with both the feasibility study and actual costs for the ten month period since commissioning (November 1992 to August 1993. Note: August 1992 is excluded as production was affected by drawing down of the stockpile in preparation for the finer crushed product.)

The cost per tonne crushed is 12 % higher than expected due to higher than anticipated maintenance costs and consumable usage.

The total grinding cost per tonne milled is very close to predicted, though the distribution between SAG and ball milling has shifted. SAG milling costs were unfavourably affected by the requirement for additional relines due to the reduction in mill load resulting in increased wear of liners. This was more than offset by a reduction in grinding media costs as a result of market influences.

Overall milling costs have been adversely affected by higher than expected wear rates,

Table 7: Throughput and Costs

	Pre-expansion (10 months)	Feasibility Study (10 months)	Post-expansion (10 months)
Tonnes Crushed	3 387 342	4 600 833	4 669 325
Crushing rate, t/op.h	862	800	891
Tonnes milled	3 300 528	4 600 833	4 545 349
Milling rate, t/op.h	485	660	664
A$/t crushed:			
Crushing circuit	0.35	0.51	0.57
A$/t milled:			
Total property	17.25	13.10	13.85
Total mill	7.60	6.35	6.48
Total grinding	4.07	3.44	3.45
SAG milling	2.68	1.78	1.69
Recycle crushing	0.25	0.15	0.14
Ball milling	1.14	1.51	1.62

associated with the increase in the ore abrasion index, as well as a once-off tailings line replacement not anticipated in the feasibility study. This has been tempered by the effects of other cost cutting measures carried out in parallel with the mill expansion.

Conclusion

The concept of combining secondary crushing with SAG milling to improve comminution efficiency and increase mill throughput has been notably successful.

The project was completed ahead of schedule and below budget. Target production levels were achieved quickly with plant downstream of the grinding circuit now being fully utilised.

Unit costs have decreased to the point where Kidston is now one of the lowest cost gold mines in Australia in terms of cost per tonne milled.

Acknowledgements

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