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Optimized multivariable control of an industrial run-of-mine milling circuit

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SYNOPSIS

This paper describes the application of a throughput-optimization strategy to a run-of-mine (ROM) milling circuit that is controlled by a multivariable controller. The objective of the optimization strategy is to maximize the ROM throughput at a specific product size. Results from long-term tests, which indicated how 'steady-state' optimization can be achieved, were used for the throughput optimization. This strategy increased the ROM throughput by 11,4 per cent. A mathematical relationship relating residue to grind can be used to calculate the economic benefits of stabilizing control.

It was estimated that the throughput optimizer could result in an increase in gold production worth R1,4 million per annum when waste rock is treated, and that stabilizing control could increase the treatment plant's annual revenue by R150 000. If the extra milling capacity brought about by the optimizer is interpreted as a capital cost saving of 10 per cent on the price of a new mill, then a capital cost saving of R1 million could result.

SAMEVATTING

Hierdie referaat beskryf die toepassing van 'n deurvoeroptimeringstrategie op 'n maalkring vir onbehandelde erts wat deur 'n veelveranderlikebeheerder beheer word. Die oogmerk van die optimeringstrategie is om die deurvoer van onbehandelde erts vir 'n spesifieke produkgrootte te maksimeer. Die resultate van langtermyn toetse wat getoon het hoe 'bestendige' optimering bewerkstellig kan word, is vir die optimering van die deurvoer gebruik. Hierdie strategie het die optimering van onbehandelde erts met 11,4 persent verhoog. Daar is 'n wiskundige verhouding bepaal om die residu met die produkgrootte in verband te bring wat nodig is om die ekonomiese voordele van stabiliserende beheer te bereken.

Daar word beraam dat die deurvoeroptimeerder 'n verhoging ter waarde van R1,4 miljoen per jaar in goudproduksie tot gevolg kan hê wanneer rommelrots behandel word en dat stabiliserende beheer die behandelingsaanleg se inkomste met R150 000 per jaar kan opskuif. As die ekstra maalvermoë wat die optimeerder tot gevolg het, vertolk word as 'n besparing van 10 persent op die kapitaalkoste van 'n nuwe meul, kan dit 'n kapitaalkostebesparing van R1 miljoen beteken.

INTRODUCTION

This paper reports on the final phase of an extensive project in which a run-of-mine (ROM) milling unit at No. 7 shaft of Vaal Reefs Exploration & Development Co. Ltd was used to study the feasibility of optimized multivariable control of ROM milling.

This project was divided into two sections. In the first section, multivariable control of an industrial ROM circuit was achieved[1]. In particular, the particle-size control described by Hulbert *et al.*[1] is believed to be a world first. The aim of the second section was the optimization of the ROM circuit, and the economic evaluation of stabilizing control and throughput optimization. The optimization of the ROM circuit included extended particle-size control and throughput optimization. The throughput-optimization algorithm, together with the economic evaluation of this algorithm and stabilizing control, is described in this paper. Extended particle-size control is covered by Craig *et al.*[2].

Milling circuits are used to grind material to a fine product, and the 'quality' of this product determines the ability of the downstream processes to extract the maximum possible benefit—in this case gold recovery—from the processed ore. A milling circuit can thus be said to operate in an optimized manner when it is producing a 'high-quality' product at the maximum possible rate and efficiency. This statement appears to be deceptively simple, but significant practical hurdles have to be overcome before such optimized operation of a milling-circuit can be achieved.

The first step towards the optimization of a milling circuit was the introduction of particle-size monitors (PSMs) to continuously measure the quality of the milling-circuit product on-line. The next step was the control of the milling-circuit product, utilizing the measurements provided by a PSM. As milling circuits are inherently multivariable in nature, techniques of multivariable-controller (MVC) design had to be applied to effectively control the product size to a setpoint. Hulbert[3] showed that a multivariable-control scheme could be employed to control the product size of a conventional milling circuit. Such a scheme has been operating successfully at East Driefontein gold mine since 1981[4].

Product-size control of ROM milling circuits is difficult since the main grinding medium and the feed rate of the ore to the mill are not independent. Owing to the ROM nature of the feed material, there is no control, or very little, over the size and hardness of the grinding medium. This results in significant uncontrolled disturbances entering the circuit. However, Hulbert *et al.*[1] have shown that product-size control of a ROM milling circuit is possible. An MVC that

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controls the product size of a ROM milling circuit was implemented at Vaal Reefs No. 7 shaft. This control scheme has been operating successfully since 1987, and has been developed into fully optimized control of ROM milling, as described in this paper.

The objective of the optimizing control strategy that will be discussed in this paper can be summarized as follows. A suitable PSM setpoint is chosen by the mill operating staff. This setpoint can be selected so that the downstream process can extract the maximum amount of gold from the milling-circuit product, or so that some other production requirements can be met. The MVC will then control the PSM to its setpoint, and the optimizer will maximize the throughput of the milling circuit at that specific PSM setpoint. Because of limits on the plant inputs, the MVC can control the PSM to its setpoint only when this setpoint is within a specific operating region. Some work has been done to extend the band of influence that the MVC has on the PSM, so that the circuit optimization will hold over a greater region of operation. This work is described by Craig *et al.*[2]. A throughput-optimization scheme was also developed to maximize the throughput of a milling circuit at a specific PSM setpoint by the selection of the optimum setpoint for the mill load.

ROM MILLING CIRCUIT AND THE MVC SCHEME

The ROM milling circuit installed at Vaal Reefs No. 7 shaft is depicted in Figure 1. About 100 t/h of gold-bearing ore is milled by the circuit to give a product containing 70 to 75 per cent material smaller than 75 μm (%<75 μm). The ROM mill is operated in closed circuit with a hydrocyclone, and the product is pumped to thickeners. The gold is subsequently extracted by a leaching process.

The mill is 9,15 m long and 4,88 m in diameter, and is supported by pressurized-oil circumferential bearings. It is operated at 91 per cent of critical speed, and has lifter bars and solid white-iron liners. Pulp flows out of the mill through an end-discharge grate and is discharged into a sump, where it is mixed with dilution water. The diluted pulp is pumped to a hydrocyclone with an internal diameter of 1,05 m. The underflow from the cyclone, additional water, and fresh ore are fed into the mill.

The inverse Nyquist array (INA) method[5] was used to design a 3 x 3 MVC[1]. To control the mill load (mill mass), sump level, and product size, the MVC uses three control actions: the feed rate of water into the sump (SFW), the feed rate of solids (MFS), and the flowrate of slurry to the cyclone (CFF). The plant is inherently multivariable, i.e. any one plant input can have an effect on more than one plant output. The MVC compensates for the complex interactions between plant inputs and plant outputs by effectively making the plant–controller combination look like three single-loop systems, one for each plant output. As shown in Figure 2, each single-loop system is controlled by a proportional-integral (PI) controller.

The MVC controls the ROM milling circuit by means of on-line measurements and control actions. A number of manual actions such as steel additions, cyclone-spigot changes, and the stopping and starting of the mill are left to the operating personnel of the plant. Other important manual settings are constraints within the control system such as the minimum and maximum values for the control actions, and the mill-load setpoint. It is up to the operating and maintenance staff to ensure that all the instruments are in good working order, and that the down-time is kept to a minimum in the event of an instrument failure. The control system must operate under the conditions described above and deal as best it can with plant disturbances (the largest being variations in the size and composition of the feed material).

The control strategy is implemented as a hierarchy of levels. At the lowest level is the control of plant inputs or control actions such as the control of the water addition by a valve and flowmeter. At the next level is the MVC, which uses the plant inputs to control the mill load, sump level, and product size to their setpoints. The third and highest level of the control strategy optimizes the choice of setpoints for the mill load, which is controlled by the MVC.

LONG-TERM PERFORMANCE

The 'short-term' linear time-invariant model of the milling circuit derived by Hulbert *et al.*[1] gives a reasonable approximation of the plant. However, the actual plant is non-linear and time-varying, with slowly changing optimum operating conditions due to changes in the characteristics of the feed , and in the liner and spigot wear. Long-term tests were thus carried out to determine how the operating point at which the milling circuit should be controlled for optimum results changes with changes in the unmeasured variables mentioned. There are two 'free' variables (mill-load setpoint and mill feed water) that can be manipulated to 'drive' the plant towards the optimum operating point. The long-term test described in this section was aimed at determining the 'steady-state' response of

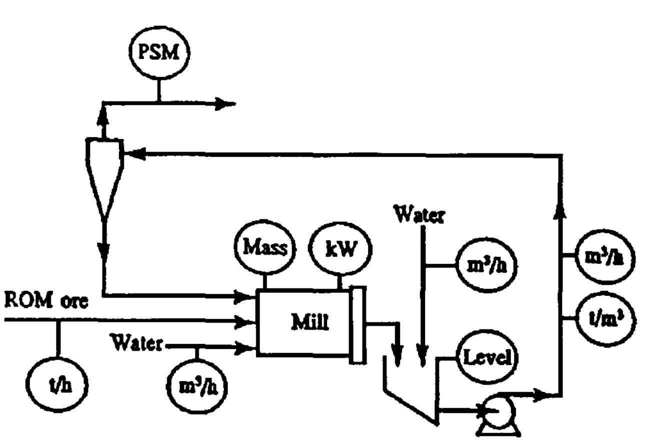

Figure 1—Milling circuit and measurements

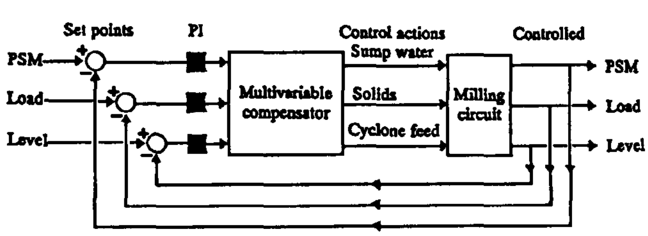

Figure 2—The multivariable control scheme

important plant variables to changes in the mill load.

The test consisted of a 30-day series of mill-load setpoint changes, with two-day runs at three repeated sets of five setpoints. Other variables that could affect the operation of the plant were kept as steady as possible. The conditions under which the test was carried out were as follows:

- MVC on
- PSM setpoint 72%<75 μm
- Sump-level setpoint 60%
- Solids feed rate, sump water, and cyclone feed flow varied by MVC
- Mill feed-water setpoint 10 m^3/h (manual setting)
- Logging of 10-minute averages of measurements
- Manual recordings of steel additions and other relevant data.

The setpoints for the mill load were changed at 2 a.m. every second day to one of five setpoints ranging from 55 to 70 per cent. (The range of the mill-load instrument is arbitrary and is only indirectly related to the volumetric loading of the mill.) It is important to note that the timing and choice of the mill-load setpoints were pre-determined, and were not influenced by extraneous factors such as the way in which the milling circuit performed during the test. This was done to ensure that the test results are not correlated to secondary effects such as the grindability of the feed ore.

The 10-minute averages of the logged data were processed to eliminate the effect of plant shutdowns, and to eliminate the periods when an important instrument was known to have been out of order. Data of the three 10-day cycles were superimposed and averaged to produce 1-hour averages, shown in Figure 3. This diagram illustrates the effect of load-setpoint changes on the PSM, feed solids, and mill power.

During this series, similar quantities of steel balls were added once per 8-hour shift. To eliminate the effects of steel additions, the data were consolidated into 8-hour averages for further analysis. The 8-hour periods immediately after the setpoint changes were also eliminated so as not to include transient effects in the determination of steady-state models. Steady-state models were fitted to the valid data points using least-squares regression, and these are shown in Figure 4 for the feed solids, mill power, and kWh/t<75 μm. The model coefficients and related maxima are given in Table I.

The mill-load series produced results describing the performance of the ROM milling circuit at different mill-load levels under controlled conditions. (The mean values of PSM at the five mill-load values ranged from 72 to 75%<75 μm.) The most relevant results previously published on the same subject were produced by Flook and Plasket[6]. They obtained long-term measurements over a range of mill-load values, but the product size varied widely (the eight 24-hour averages ranged from 52,5 to 87,5%<75 μm), and the way in which the water additions to the plant were varied was not made clear in the paper.

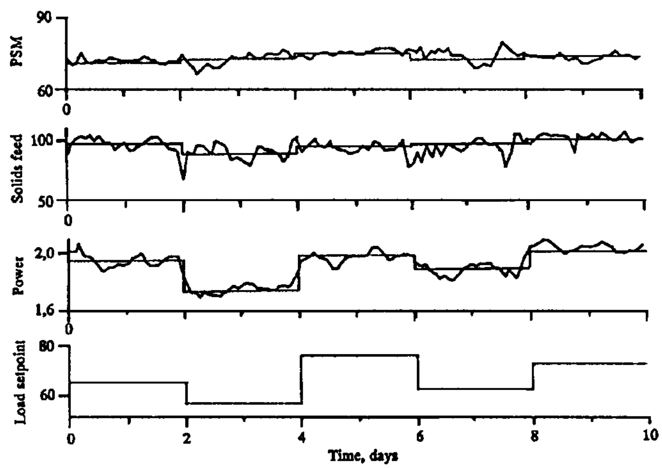

Figure 3—1-hour averaged measurements corresponding to a cycle of five load setpoints

Table I

Parameters of models of the form A + B x load + C x load²

Variable	A	B	C	Load*
Power, MW	–2,859 e + 0	1,363 e – 1	–9,579 e – 4	71,1
Feed solids, t/h	–1,880 e + 2	8,540 e + 0	–6,384 e – 2	66,9
kWh/t<75 μm	2,350 e + 1	6,613 e – 2	0	–

* Load at maxima of model

The plot of mill power versus mill load in Figure 4 shows that maximum power is attained when the load is in the region of 71 per cent. The throughput of solids was found to have a maximum value at a load of about 67 per cent. The results obtained with the MVC indicate that, on average, more efficient energy usage occurs at lower mill-load levels, as can be seen from the relationship between mill load and kWh/t<75 μm. It would also appear that the solids throughput can be maximized if the mill load is operated below the level where the maximum power is drawn. These results are different from those obtained by Flook and Plasket, who claimed that maximum grinding efficiency occurs at the load level where maximum power is drawn from the mill motor.

The models relating the mill power and mill-feed solids to mill load were used to construct a throughput optimizer, which is described later in this paper.

OPTIMIZATION OF THROUGHPUT

The throughput of a milling circuit, or 'tonnage milled', is a very important parameter in the gold-mining industry. Throughput figures are reported to plant management on a daily basis, and they can also be found in quarterly and yearly reports sent out to shareholders. Mine management sets monthly throughput targets based on economic objectives and operating constraints, and incentive schemes are often employed to encourage plant personnel to exceed such targets. It is thus evident that, under such a scenario, a successful throughput-optimizing scheme will be welcomed by the mining industry.

A Power-based Throughput Optimizer

It is a widely held belief in the mineral-processing industry that optimum grinding occurs when maximum power is drawn from a mill motor[6,7]. Results from the long-term tests described earlier show this to be a reasonable first approximation. In these tests, a steady-state relationship between the mill power and the mill load was determined, and it was found that the mill does indeed pass

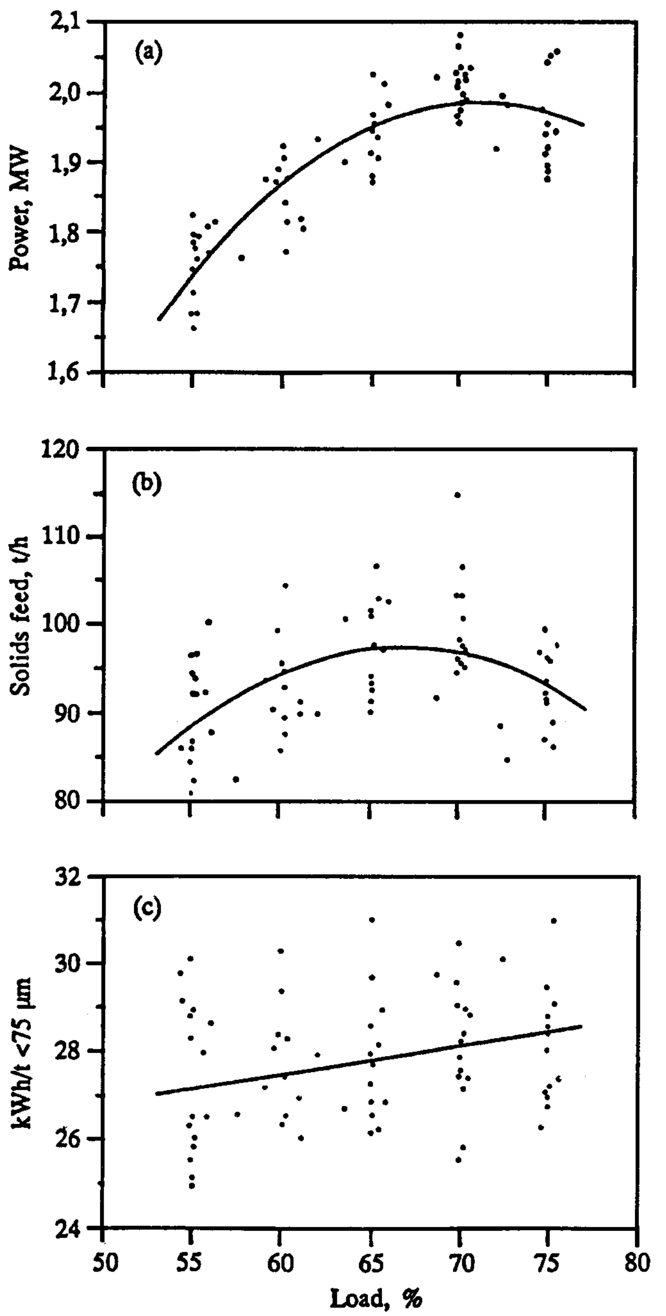

Figure 4—Measured and derived variables as a function of load

through a power peak as the mill load is taken from low to high levels. A very interesting result from these long-term tests is that the solids-throughput peak was found to be about 4 load-percentage points lower than the power peak. This result implies that a higher throughput can be achieved when the load is operated slightly below the power peak.

A power-based throughput optimizer was developed based on the relationship shown in Figure 4. The optimizer uses the directions of the changes in the mill load and power to determine the direction of the next step in the mill-load setpoint. For example, if the load setpoint is stepped up and the power decreases as a result, Figure 4 shows that the power peak has been passed. Therefore, the next load-setpoint step has to be in the opposite direction.

As a first approximation, the throughput optimizer is a power-peak-seeking algorithm but, by the proper selection of the load-setpoint limits, the size of the load-setpoint changes, and the time interval between load setpoint changes, the optimizer can be made into a 'refined' throughput optimizer. The refined optimizer actually utilizes the results described earlier by letting the load operate slightly below the power peak, and thus closer to the throughput peak.

This whole exercise would be trivial in a hypothetical case where the power/load relationship is known exactly. A throughput optimizer would then need only a few steps to find the load setpoint at which maximum power is drawn, and the mill load would be kept at a fixed value below this setpoint. In reality, the power/load relationship is known only partially, since it changes owing to disturbances such as changing feed-ore size and composition and other unmeasured dynamics in the system. As a result, the 'optimum' load setpoint and the maximum power drawn are functions of time. Also, the power/load relationship is only on average (i.e. not all the time) a parabolic one. The following can be said to relate these statements to Figure 4. Not only does the parabola move around the power/load plane in a seemingly random fashion, but individual 'points' that make up the parabola can also move randomly, thus distorting its shape. Given such inexact knowledge of the power/load relationship, it is clear that the throughput optimizer can be expected at best only to step in the 'right' direction most of the time.

This power-based throughput optimizer was incorporated into the general MVC scheme, as is shown in Figure 5. The inputs of the optimizer are the mill-load and power measurements, and its output is the mill-load setpoint. It outputs a mill-load setpoint every 30 minutes. The optimizer is not in the multivariable-control loop and, since the MVC causes an essentially completed response over a shorter time span, the optimizer does not alter the stability characteristics of the multivariable-control scheme. The optimizer relies on the MVC to control the mill load to its setpoint.

Evaluation of the Optimizer

The optimizer was evaluated through two tests: the first was based on a comparison of throughput data during times when the optimizer was switched on and off, and the second consisted of showing that the optimizer does step towards a steady-state peak on average.

Table II summarizes the results from the first test and gives the ROM throughput figures for two consecutive 20-

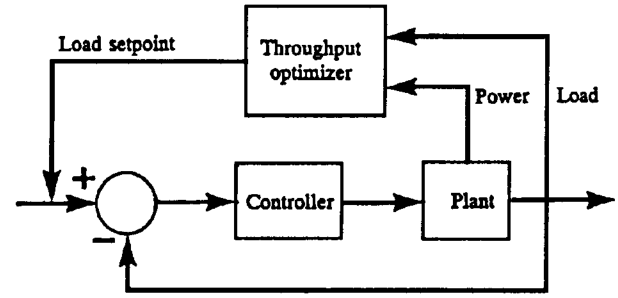

Figure 5—The throughput optimizer and the MVC scheme

day periods. The dashes in the power and PSM columns indicate that, for the particular day in question, the mill was off for a significant part of the day or that the PSM was not working. During the first 20 days when the optimizer was switched on, the load setpoint was stepped up and down by the optimizer algorithm. During the second 20-day period, the optimizer was switched off, and it was up to the operators to select load setpoints at which the ROM mill would perform optimally.

As Table II indicates, when the optimizer was switched on, the average throughput was 112,79 t/h, which is 11,4 per cent higher than the average throughput of 101,23 t/h achieved when the optimizer was switched off. What makes these figures most encouraging is that the higher throughput occurred at a lower power and a slightly better grind. The lower power for the period with the higher throughput is to some extent consistent with the results of the long-term tests discussed earlier, in which it was found that the throughput peak occurs below the power peak.

Table II

ROM data for the periods 25/7/90 to 13/8/90 and 16/8/90 to 4/9/90

Date	Plant data			20-day averages
	Throughput t/h	Power MW	PSM %<75 µm	
Optimizer on:				
25 Jul 1990	100,8	1,79	77,6	**Throughput =**
26	111,5	1,85	74,1	**112,79 t/h**
27	106,3	1,87	77,8	
28	106,3	1,93	72,9	**Power =**
29	108,6	1,92	71,5	**1,887 MW**
30	116,7	1,91	63,7	
31	108,1	1,89	65,5	**PSM =**
1 Aug 1990	109,0	1,95	62,8	**69,21%<75 µm**
2	121,9	2,01	66,3	
3	132,6	2,02	63,2	
4	110,8	1,87	65,9	
5	112,6	1,87	70,1	
6	109,9	1,70	66,3	
7	98,0	1,93	76,1	
8	108,8	–	–	
9	114,0	–	–	
10	117,0	1,88	71,6	
11	125,1	1,93	69,5	
12	122,3	1,76	61,7	
13	115,5	–	–	
Optimizer off:				
16	112,3	1,90	66,4	**Throughput =**
17	101,7	1,84	–	**101,23 t/h**
18	106,2	1,87	–	
19	109,3	–	–	**Power =**
20	85,7	1,87	–	**1,916 MW**
21	86,9	1,84	–	
22	97,6	1,89	–	**PSM =**
23	109,6	1,76	61,3	**67,94%<75 µm**
24	102,8	2,01	68,2	
25	110,3	1,95	65,2	
26	109,2	–	–	
27	99,8	1,93	74,0	
28	104,3	–	–	
29	91,7	1,88	–	
30	91,4	1,95	68,0	
31	100,7	2,03	73,8	
1 Sep 1990	104,5	1,94	70,2	
2	102,0	1,92	65,1	
3	94,6	1,99	68,3	
4	103,9	2,00	66,9	

The throughput-increase figure of 10 t/h could, of course, be influenced by a host of factors such as operator skill, availability and accuracy of instruments, cyclone-spigot changes, the amount of steel added, the type of ore milled, and lengthy plant stoppages. Of these, the type of ore is probably the most significant. Two main types of ore are milled by the ROM mill: ore from the Ventersdorp Contact Reef (VCR) and ore from the Vaal Reef. VCR ore is much 'harder' and therefore takes longer to grind down to a fine size than Vaal Reef ore. Silo figures for the ROM mill showed that, during the period in which the throughput tests were conducted, less VCR ore was milled when the optimizer was off than when it was switched on. This implies that the throughput-increase figures cannot be attributed to changes in the type of feed ore.

There were slightly more mill stoppages of more than an hour in the period when the optimizer was off, than when it was on. Also, the PSM was out of order for six days during the period when the optimizer was off, and only for half a day when it was on. This could result in some lowering of the throughput, because the MVC tries to get the PSM down from its default ('breakdown') value (90%<75 µm) to the setpoint. However, the averages shown in Table II do not change significantly if the periods when the PSM was out of order or when the mill was off for a significant part of the day are eliminated. The steel additions and spigot changes were normal for both periods.

A test was specifically designed to show that the throughput optimizer does indeed step towards a steady-state peak on average. The test conditions were as follows:

- MVC on
- Load-setpoint limits 58 to 78%
- PSM setpoint 70% <75 µm
- Sump-level setpoint 60%
- Mill feed water 10 m^3/h.

The large range for the load setpoint was necessary so that the optimizer algorithm did not request setpoints that would hit the limits. Data generated over a 4-day period from 12:00 pm on 16th November, 1990, to 12:00 pm on 20th November, 1990 (191 setpoint changes) are summarized in Figure 6. This diagram displays the number of times that the optimizer selected a specific setpoint (no. of occurrences), the number of times that the optimizer chose to step up from a specific setpoint, and the percentage of steps up (100 x steps up/ no. of occurrences).

From Figure 6 it is evident that the limits on the load setpoint (58 to 78 per cent) never came into play during this test. This, in itself, is an indication that the optimizer algorithm did not do a pure random 'walk', and shows that the optimizer was 'driving' the load to some preferred region of operation. Thus, when the load was too high, the load setpoint was stepped down more often than up (percentage steps up fewer than 50 per cent) and, conversely, when it was too low, it was stepped up more often than down (percentage steps up more than 50 per cent). If the power/load relationship was totally masked by process noise, there would not necessarily have been this tendency to drive the load away from extreme values, and the steps up would have been close to 50 per cent for all the

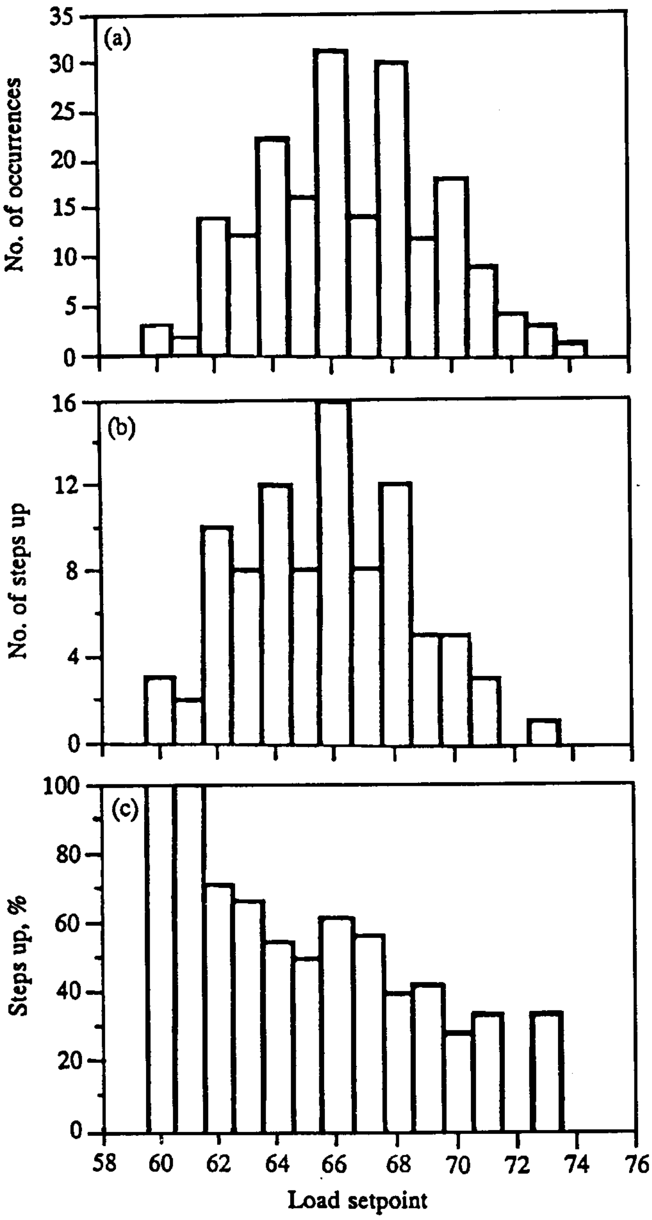

Figure 6—Data for the evaluation of the throughput optimizer

load-setpoint values in the operating range. One can thus conclude that, on the average, the throughput optimizer is indeed stepping the load setpoint towards the 'optimum' setpoint.

RESIDUE VERSUS GRIND

Hulbert *et al.*[1] reported that the use of multivariable control resulted in a reduction in the PSM standard deviation of 2%<75 µm, when compared with manual operation. In order to determine the economic benefits of this reduction in standard deviation, a mathematical relationship between the grind (%<75 µm) and the residue (g/t) is needed. As a suitable relationship of this form was not available in the literature, part of this project was dedicated to the determination of such a relationship.

A sample of cyclone overflow was taken from the conventional circuit at Vaal Reefs West (56%<75 µm and 6,5 g/t). This sample was split into thirty 500 g samples: 3 samples were used for the determination of the head grade, and 3 samples were roll-leached in bottles (but not milled), for the determination of the first point on the curve of residue versus grind; the other 24 samples were milled in a laboratory mill in batches of 3 for specific periods of time in such a way that regularly spaced grind points could be obtained (a curve of grind versus milling time was drawn for this purpose). The samples were then leached. After the leaching, each of the 30 samples was divided into four sections (one of 200 g and 3 of 100 g each). The 200 g section was used for sizing, two of the 100 g sections were assayed, and the remaining 100 g section was kept as a backup.

Figure 7 shows the results in graphical form, with the function

$$Residue = \frac{a}{b - grind} + c$$

fitted to the points for grind versus residue (a = –0,221; b = 52,4; c = 0,272). The 95 per cent confidence interval of the residue at each grind point is indicated in Figure 7.

ECONOMIC EVALUATION

The economic benefits derived from an optimized MVC can be divided into two categories: benefits resulting from stabilizing control, and benefits obtained from the optimum selection of setpoints. The work on throughput optimization falls into the latter category, whereas the work on the grind/residue relationship is aimed at determining the benefits of stabilizing control.

Throughput Optimization

It was shown earlier that, with the throughput optimizer switched on, the average throughput of the ROM circuit was 11,4 per cent higher than the average throughput achieved when the optimizer was switched off. This 11,4 per cent increase in ROM milling capacity can be interpreted in numerous ways. What follows is a crude attempt at a quantitative analysis of the economic benefits resulting from the throughput optimizer.

The data given in Table III indicate that it will cost R 93 600 per month to treat an extra 7200 t of ore. With a head grade of 1 g/t and a recovery rate of 92 per cent,

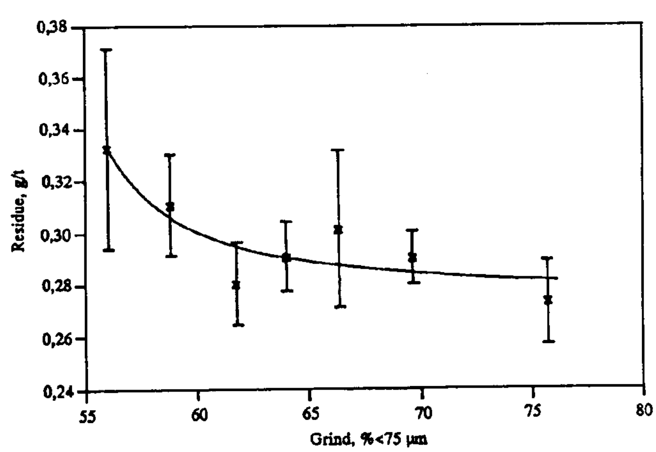

Figure 7—Residue versus grind

Table III
Data used in the calculation of the economic benefits

Head grade, g/t		1
Treatment-plant recovery, %		92
Gold price, R/kg		32 000
Treatment costs, R/t	ROM	4
	rest of plant	9
Total cost, R/t		13
Increase in throughput		10 t/h = 7200 t per month

6,624 kg of gold can be recovered from the treated ore. With a gold price of R 32 000 per kilogram, the extra monthly revenue from gold minus the extra treatment costs amounts to R 118 368. Thus, if the 11,4 per cent extra capacity (extra 10 t/h) is used to treat waste at 1 g/t, the throughput-optimization scheme, in conjunction with the MVC, could increase the revenue of Vaal Reefs West from the 100 t/h ROM circuit by R 118 386 per month, or about R1,4 million per annum.

The extra milling capacity could also be interpreted as a saving in capital costs of 10 per cent on the price of a new mill. So, instead of putting in a mill with a capacity of 1,1*X* t/h, a mill with a capacity of *X* t/h, together with a multivariable-control scheme, would suffice. With the price of a new ROM mill installation of the order of R 15 million, this would amount to a cost saving of about R1 million.

Based on the discussion above, it is believed that the economic benefits brought about by the throughput optimizer will result in a payback period for a multivariable-control scheme of less than six months.

Stabilizing Control

The relationship between the residue and the grind, which was determined earlier, was used in a quantitative analysis of the economic benefits brought about by stabilizing control. The MVC was found to reduce the standard deviation in the PSM by 2%<75 μm when compared with manual operation.

Two PSM signals with means of 61 per cent and standard deviations of 2 and 4 per cent, were generated by computer. These signals were then used in the calculation of the resulting mean residue, using the residue/grind relationship derived earlier. It was found that a reduction in the standard deviation of the PSM from 4 to 2 per cent could lead to an increase in the processing plant's revenue of R200 000 per annum through an increased gold recovery. In the calculation of this value, the feed rate of solids was assumed to be constant.

If one assumes a constant production rate of %<75 μm material (e.g. a higher throughput is achieved at a lower grind), then the ROM throughput will be slightly higher when the PSM standard deviation is 4 per cent, than when it is 2 per cent. By taking this slight increase in throughput into account, the increase in plant revenue due to stabilizing control will be of the order of R150 000 per annum. Thus, for a reduction in PSM standard deviation from 4 to 2 per cent, the ratio of the value of the gold lost versus the value of the throughput increase (as determined earlier) is about 4:1. This ratio can be expected to increase significantly as the size of the PSM fluctuations is increased, e.g. a reduction from 7 to 5 per cent in PSM standard deviation, instead of 4 to 2 per cent.

This estimate of revenue increase is based on a PSM mean of 61%<75 μm, which is at the lower end of the PSM range chosen for the analysis (56 to 76%<75 μm). This was done to accentuate the fact that benefits derived from finer grinding are more than offset by the losses made by coarser grinding. The reduction in PSM standard deviation will have a less significant effect on the mean residue when a higher PSM mean is chosen for the analysis. All the monetary figures given above will, of course, depend on the gold price and the head grade of the ore being processed.

SUMMARY

The results shown in this paper indicate that optimized multivariable control of an industrial ROM milling circuit can be achieved.

The objective of this optimizing control strategy is to maximize the throughput of a ROM milling circuit at a specific product-size setpoint. The results of a long-term test indicate how the mill-load setpoint can be used to achieve the objective given above. By the appropriate automatic selection of mill-load setpoints in a throughput-optimization scheme, the throughput optimizer can increase the throughput of the ROM milling circuit by 11,4 per cent. A mathematical relationship relating residue to grind can be used to derive the economic benefits obtained from stabilizing control.

The increase in ROM throughput capacity brought about by the throughput optimizer could lead to an increase in gold production worth about R1,4 million per annum if waste rock were treated. If the extra milling capacity is interpreted as a capital cost saving of 10 per cent on the price of a new mill, then a saving of R1 million in capital costs could result. Stabilizing control that leads to a decrease of 2 per cent in the PSM standard deviation could increase the treatment plant's revenue by R150 000 per annum through increased gold recovery. It is believed that the economic benefits brought about by the throughput optimizer will be such that the payback period for a multivariable-control scheme will be less than six months.

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New bilateral mining agreement*

Grinaker System Technologies (GST) has announced the signing of a bilateral agreement with BICC Transmitton, a British supplier of mining-control systems. Speaking in Pretoria, the Managing Director of BICC Transmitton, Dave Moore, said that the agreement added a commercial dimension to the relationship, bringing the two companies together as business partners in the world mining market.

The Managing Director of Grinaker Electronics Limited, Sybrand Grobbelaar, said that BICC Transmitton was recognized as a worthy and reputable partner, had supplied mine-wide control to many mines internationally, and has been active in the South African market for many years. 'For this reason, we have extended the partnership and granted BICC the right to represent, distribute, and sell GST's mining products to the European market, and by mutual agreement to the world market', he said. 'On the other hand, BICC Transmitton has products and systems relating to applications outside the South African market, which they would like to promote in the mining market. It has also been agreed that manufacturing licences may be granted to GST to produce certain products in South Africa', he added.

* Released by Grinaker System Technologies, P.O. Box 50994, Randburg, 2125 Transvaal.

GST has established a range of products to improve productivity, safety, and planning in mines. These include outstations, underground audio-communication systems, cage-monitoring systems, radio-communication systems, gas sensors, conveyor-belt control equipment, energy-management systems, environmental-monitoring systems, underground vehicle-monitoring systems, and electronic winch-control systems.

The latest addition to the Grinaker range is a haul-truck management and dispatch system for opencast mines. The system makes use of a uniquely designed data radio to ensure high-speed data transfer from each haul truck to a central control room. Each truck is equipped with a GPS receiver to establish truck position with an accuracy of about 5 m.

INFACON 6, 1992*

This highly successful Conference was held in Cape Town from 8th to 11th March, 1992. INFACON 6 incorporated both the International Ferro-alloys Conference and the Internal Conference on Chromium and Stainless Steels. It was organized by a committee comprising members from The South African Institute of Mining and Metallurgy, Mintek, and the Ferro Alloy Producers' Association. The Conference Division of Mintek provided the secretarial and conference management services under the direction of Mrs Barbara Watkins, and the SAIMM provided the publication services under the direction of Mr John Austin.

Over 600 delegates and over 100 affiliates attended, and a unique feature was that over half of the delegates were from overseas, illustrating the high level of interest in the potential status of the South African metallurgical industry.

* Issued by Dr R.E. Robinson, Chairman of INFACON 6 Organizing Committee.

The Conference enjoyed the privilege of a plenary address by the State President, Dr F.W. de Klerk, who also attended a special luncheon to meet local and overseas dignatories. Many other plenary addresses were presented by invited overseas speakers.

The full proceeding of the Conference, in two volumes, are available from the SAIMM *(see inner front cover for details)*.

The Conference was held under the auspices of the International INFACON Committee, who are responsible for allocating future conferences to appropriate venues. The next INFACON will be held in Europe in 1995.