Digital computer control of the milling circuit at Buffelsfontein Gold Mining Company Limited

by K. C. GARNER*, Ph.D., M.I.E.E.,
P. C. VAN ASWEGEN†, B.Sc., M.S.A.I.M.M., and
J. D. SMIT,‡ B.Sc., A.M.S.A.I.M.M.

SYNOPSIS

The initial results obtained from the implementation of computer-controlled strategy on the milling circuit are reported. An analysis of these results showed that a peak-power pebble-mill controller on a high-throughput hard-rock wet-milling circuit reduces the stability of the system. It was concluded that the milling circuit should be regarded as a single system in which the measurement of grinding efficiency, circulating load, product size distribution, and feed rate should minimize the product variance and maximize the feed rate according to the grinding power available. Work is proceeding on such a system.

SAMEVATTING

Daar word verslag gedoen oor die aanvanklike resultate verkry deur die toepassing van 'n rekenaarbeheerde strategie op die maalkring. 'n Ontleding van hierdie resultate het getoon dat 'n spitskragklippiesmeulkontrolleerder in 'n harderotsnatmaalkring met 'n hoë produksie die stabiliteit van die stelsel verlaag. Die gevolgtrekking is gemaak dat die maalkring as 'n enkele stelsel beskou moet word waarin die meting van die maalrendement, die sirkulerende lading, die grootteverdeling van die produk en die toevoertempo die produkvariansie behoort te minimeer en die toevoertempo volgens die beskikbare maalkrag behoort te maksimeer. Die werk aan so 'n stelsel gaan voort.

Introduction

The purpose of this paper is to report on the initial results obtained from the implementation of a digital-computer unit-control strategy on the milling circuit at Buffelsfontein Gold Mining Company. A description is given of the milling circuit, as well as of the computer installation. This is followed by a description of the initial control strategy adopted, including an analysis of the results obtained and the modified approach currently being developed.

Description of the Milling Circuit

Primary milling is carried out in three rod mills, all 3,658 m by 2,743 m (diameter) in open circuit. Crushed ore is reclaimed from an 11 000 t stockpile by means of 12 cross conveyors feeding onto feed conveyors at a total rate of 340 t/h. The feed rate is monitored continuously by three nuclear belt-weighers, the signal from the belt weighers being used to control the dilution water and so maintain a fixed liquid-to-solids ratio in the mill feed. The rod mills are charged with 100 mm- diameter rods to approximately 100 mm below the mill axis.

Secondary milling is carried out in seventeen pebble mills 3,658 m by 3,048 m (diameter) and three pebble mills 3,658 m by 3,175 m (diameter) in closed circuit. The milling plant is split into three separate circuits: A and B rod mills each serve a bank of six pebble mills, and C rod mill a bank of eight pebble mills.

The discharge of each rod mill and its bank of pebble mills is transferred via a common sump by means of two-stage pumping to a distributor, which in turn feeds a hydrocyclone associated with each pebble mill. For each bank, the cyclone overflow is combined in a common launder, where an on-stream particle-size monitor provides a continuous record of particle size and pulp density.

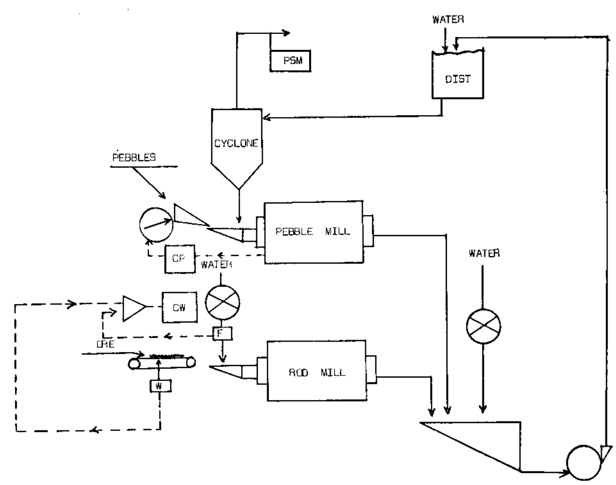

Fig. 1—The milling circuit at Buffelsfontein Gold Mine

CP	**Controller of the pebble feed**	**CW**	**Controller of the liquid-to-solids ratios**
DIST	**Distributor**	**F**	**Magnetic flowmeter**
PSM	**Particle-size monitor**	**W**	**Nuclear weigher**

The efficiency of the cyclone is controlled manually by the adjustment of the dilution water added to the circuit via the sump, distributor, and cyclone feed. Pebble feed is by vibrating feeders, the feed rate of which can be set by local potentiometer or remote current signal, thus allowing for computer control.

A simplified flow diagram of the system described is shown in Fig. 1.

Description of the Computer Installation

The computer installation is based on a Siemens 330

*Formerly University of the Witwatersrand, Johannesburg; now General Mining and Finance Corporation Ltd, Johannesburg.
†Buffelsfontein Gold Mining Company Limited, Stilfontein, Transvaal.
‡Stilfontein Gold Mining Company Limited, Stilfontein, Transvaal.

process-control computer with a five megabyte moving-head disc unit, which is used by the disc-based real-time operating system and serves as a bulk storage device for the logging of plant data. A Siemens teleprinter serves as the operator's console and, in conjunction with an alpha-numeric visual display unit (VDU), is used for programme development. Plant status is conveyed to the operating staff via a colour graphical VDU, thus enabling symbol flashing and dynamic mimic diagrams of various sections of the plant. It is thus possible for an operator to obtain an assessment of the plant status in its various sections within the confines of one focal point.

Plant input–output information is controlled by a locally developed data acquisition system. This consists of an analogue input–output subsystem that handles 0 to 25 mA direct-current signals and a digital input–output subsystem that operates potential free-relay contacts and senses the status of potential free contacts.

Objectives of the System

The system installed was intended to provide a general data-acquisition facility that could be used for system identification, leading to the design of multiple input–output computer-based control strategies. For such a system to achieve the objectives, substantial input from the metallurgical technologists is required. As they do not generally have any formal training in the use of real-time minicomputer systems, it was decided that all algorithm development would be done in a real-time high-level language (Process Fortran).

The initial phase to be implemented was the data acquisition of the measured variables on the uranium-extraction plant and the milling circuit. These data were displayed with alarm indication on dynamic mimic diagrams of the various sections of the plant. The data were also averaged and saved on an hourly basis for off-line manipulation and daily reporting. The data averaging was done by an exponentially weighted average of the measured data with an averaged deviation about the mean. It was thus possible for the degree of plant fluctuations about the mean, taken over the preceding hour, to be determined. Daily reporting facilities were implemented, thus providing a management aid as well as providing data for off-line analysis.

As the Buffelsfontein Gold Mine experiences a materials flow bottle-neck in the milling circuit, it was decided to attempt digital computer-based process control within this area. It was reasoned that this offered the highest potential rate of return on the invested capital.

Owing to a lack of information on the stability of milling circuits and their dynamic behaviour under various operating conditions, it was decided that a programme of unit control should be implemented prior to the optimization of the whole system. An observation of the plant control by the operating staff revealed that actions that could be quantified were essentially the primary feed variables: the tonnage of feed to the rod mill, the flow-rate of dilution water, the addition of pebbles to the pebble mill, the addition of dilution water to the head tank, and the control of sump level.

Once dilution control had been implemented on the rod mill, the next objective was maximization of the performance of the secondary milling circuit by control of the pebble addition. A review of the literature and observation of the control technique employed by the operators indicated that a peak-seeking controller, which would control the addition of pebbles in such a way as to maximize the power consumed, would be the best technique to be employed. This was in accordance with the belief that the maximum power consumed implied the maximum grind.

Such a controller was in fact developed and imple-

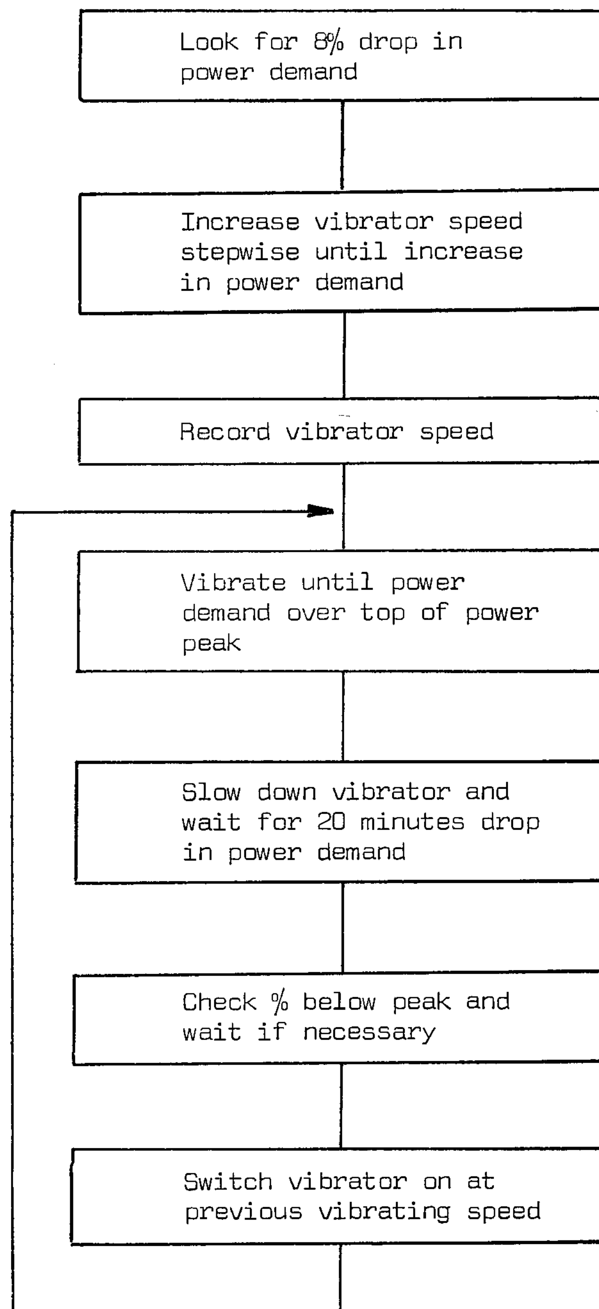

Fig. 2—A simplified diagram showing the computer logic

mented. The programme consisted essentially of a data-smoothing and peak-seeking algorithm, extensive use being made of the computer for checking the alarm conditions, such as blocked chutes on the feeder, heavy circulating loads, mill stoppages, and all indications of overload conditions.

The sampled power signal was low-pass filtered digitally with a cut-off frequency of 3 minutes in an attempt to eliminate fluctuations in the power consumed due to small variations in the circulating load. For the purpose of this description, *power signal* refers to the filtered power signal.

Fig. 2 shows a simplified functional flow diagram of the computer logic, which is described below.

(a) *Initialization of the programme*
The pebble feeder is switched off and the power monitored until an 8 per cent continuous fall is recorded. At that point, the feeder is switched on and the feeder speed is increased step by step until such time as an increase in power demand is observed. This value of vibrator speed is stored to indicate the point at which the addition of pebbles exceeds the loss of pebbles in the mill.

(b) *Initial mill loading*
The pebble feeder is kept on at the initialized feed rate until the rate of change of power becomes zero; at that point the feeder speed is reduced to a predetermined safe limit.

(c) *Detection of loading condition*
The controller waits for 20 consecutive samples of decreasing power demand in a further attempt to eliminate an incorrect interpretation due to fluctuation in circulating load. Having detected this continuous decrease in power, it makes a further check to determine whether at least a 5 per cent drop in power has been recorded.

(d) *Feed condition*
In the event of all the conditions in (c) being met, the feeder speed is increased to 10 per cent below the initialized feed rate, and the feeder speed is increased in steps until a new feed rate has been attained (thus eliminating variations in feeder characteristics). At that point the programme returns to condition (b).

(e) *Alarm checking*
(i) When a condition is detected in which the feed rate is 16 per cent higher than the previous value, a choked chute condition is considered to be present and the feeder speed is set to zero and the controller is reinitialized.
(ii) A rapid drop in power of more than 5 per cent is assumed to indicate a rapid increase in circulating load, and the programme is returned to the initial state.
(iii) For a power signal below the value of an empty mill, the feeder is switched off since the condition is considered to be either a pebble-mill off-line or gross overloading.

Results

After the initial implementation of the controller, the milling efficiency was improved under the conditions of a total mill feed rate of 325 t/h. Fig. 3 shows the improvement achieved by automatic over manual control. A much narrower operating band is indicated for the automatic control, the mill power being 9 per cent higher than for manual control. These improved milling efficiencies were maintained for a three-month period during which the mill feed rate was maintained at 325 t/h. Pebble consumption increased by 13 per cent, and milling efficiency improved, from an average of

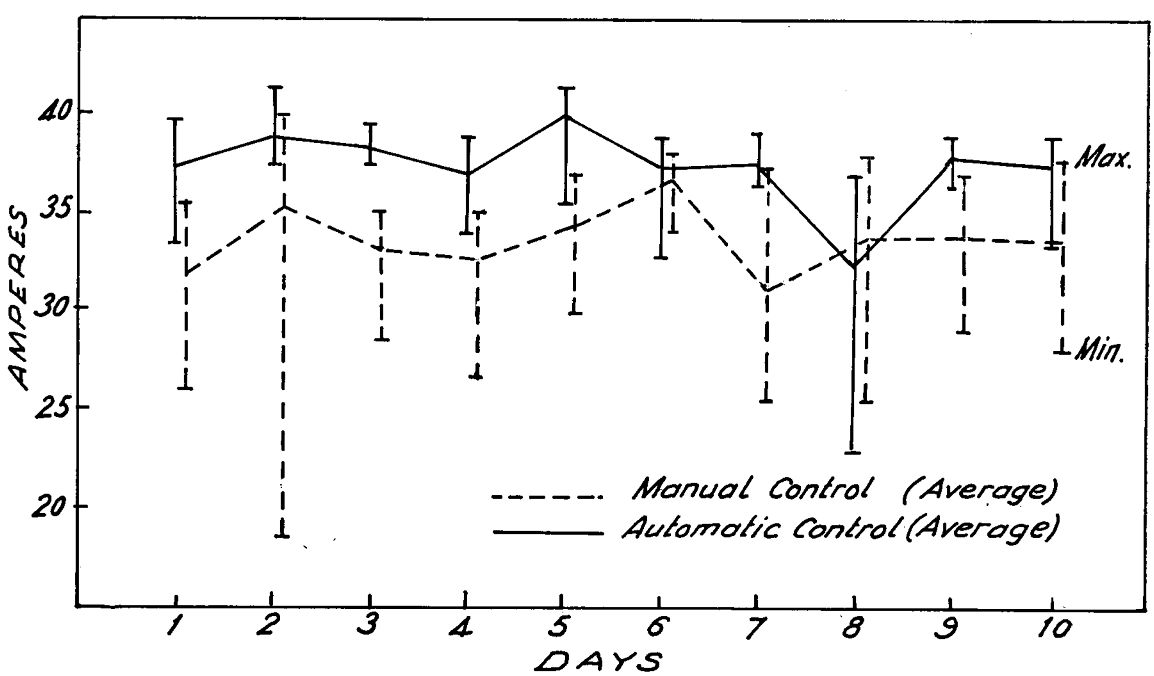

Fig. 3—A comparison of automatic and manual control

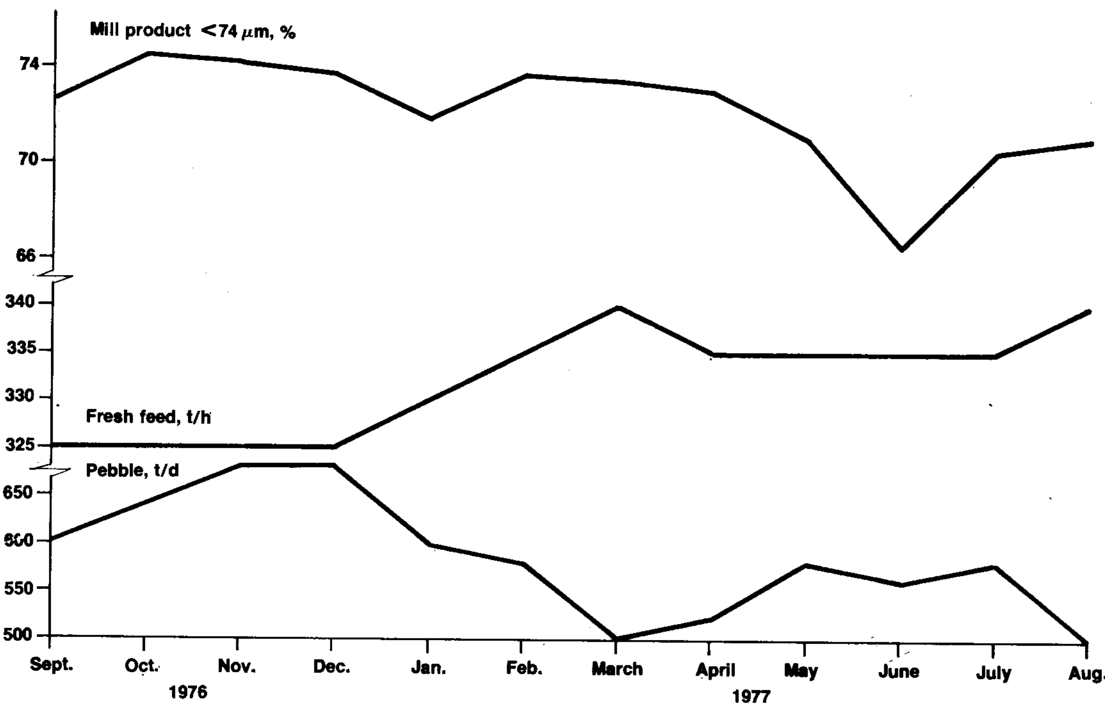

Fig. 4—Effect of the implementation of the mill controller

27,5 per cent material larger than 75 μm to 26 per cent (Fig. 4).

At that stage, the tonnage milled was increased as a result of management requirements, and overall efficiencies deteriorated. It was observed that the circuit became unstable, a number of pebble mills being in an overloaded state at all times. Computer control of the pebble mills was discontinued, and the system returned to manual control, which resulted in better conditions than under computer control.

When the circuit was returned to computer control, it was shown that the controller would perform well for 3 to 4 days, after which the circuit once again became totally unstable.

Discussion of Results

The major conclusion from the results obtained is that a peak-power pebble-mill controller on a high-throughput hard-rock wet-milling circuit reduces the stability of the system. This conclusion can be explained as follows.

(i) At peak power consumption by the pebble mill, the bulk density in the mill has been optimized, i.e., for a fixed circulating load (feed density), the possible load has been maximized. Any increase in feed density above this value results in a condition requiring a lower pebble load. As pebbles cannot be removed, the mill moves into an overloaded condition.

(ii) Given a condition of good peak-power control, i.e. the described pebble-mill controller with all pebble mills operating close to the maximized pebble-load conditions, a transient increase in circulating load due to events such as the breakaway of sediment in the pump sump results in all the mills moving into an overloaded condition.

(iii) The circuit has now moved into a positive feedback condition. As the pebble mills have moved into an overload condition, the grinding efficiency is reduced, resulting in an increase in circulating load, which in turn pushes the mills further into overload, a phenomenon that increases to the point at which the circulating load is reduced artificially. The self-regulating mechanisms within the circuit for achieving reduction in circulating load are cyclone roping and mill pulping. It can thus be seen that, in isolation, peak-prove mill control results in a marginally stable circuit and should therefore be avoided.

Current Work

The experience gained during the implementation of the above-mentioned control strategy has led to a redefinition of the problem: a milling circuit must be seen as a single system in which the measurement of grinding efficiency, circulating load, product size distribution, and feed rate should minimize the product variance and maximize the feed rate according to the grinding power available. Towards this end, a post-graduate student has been actively studying systems identification in order to design a model reference adaptive controller. This work is at an advanced stage, and the model is currently being implemented.

Conclusions

The investigation of a plant by the use of a process-control computer operating on high-level language and real time can be achieved within a short period of time. The value of such a system in the acquisition of relevant data and the analysis of a plant's dynamic performance is invaluable.

It is considered that, without the aid of the computer, an understanding of the critical dynamic performance of the Buffelsfontein milling circuit would not have been achieved. Further, the computer will provide the environment for the implementation of modern control strategies such as that provided by the model reference controller currently being implemented on the Buffelsfontein milling circuit.

It should be noted that the account given here is essentially qualitative because it has been felt necessary to convey the qualitative nature of the system dynamics, which are by no means confined to the Buffelsfontein milling circuit. The quantitative results will be published at the completion of the current phase of the project.

Acknowledgements

The authors acknowledge with gratitude the opportunity offered them by the management of Buffelsfontein Gold Mine to undertake this work and the permission to present it. They are also grateful for valuable dis- discussions with Mr Wyatt-Mair, a post-graduate student at the University of the Witwatersrand.

Financing and management of mining projects

A colloquium, entitled 'Mining Projects: Evaluation, Financing, and Management' and organized by the South African Institute of Mining and Metallurgy, will be held at the National Institute for Metallurgy, Randburg, on 30th May, 1980.

The following papers are to be presented:

Ore Reserve Estimating and the Appropriate Geological Involvement, Mr H. H. Bird, Falconbridge, Canada.

The Role of Computers in Geological Mineral Evaluation and Mineral Project Management, B. K. Cross, Executive Consultant.

Assessment of Shaft-sinking Projects on Existing Coal Mines, by P. Janisch, Gold Fields.

An Analysis of Rates of Return Realized on Investments in the Orange Free State, Klerksdorp, West Witwatersrand and Evander Gold Mines, D. G. Krige and J. D. Austin, Anglovaal.

Project Management in the Coal Division of General Mining & Finance Corporation, G. C. Thompson, General Mining.

The Evaluation, Design and Construction of the New Uranium Plant — Chemwes, B. Viljoen, General Mining.

The Planning and Management in the Construction of the Elandsrand Gold Mine, C. Hefer, Anglo American Corporation.

Further information is available from the Secretary, the South African Institute of Mining and Metallurgy, P.O. Box 61019, Marshalltown 2107.

Accreditation of testing laboratories

Over the past few years there has been a worldwide tendency towards establishing accreditation of laboratories involved in test work. Most of these laboratories undertake work of a commercial nature, and not all of them use the same standards and test methods. In order to ensure uniformity in the testing work, as well as the necessary credibility, such laboratories are assessed by an impartial body, and, if the laboratory complies with all the requirements, a certificate known as an accreditation certificate is issued. This system is generally referred to as laboratory accreditation.

In view of the fact that there are a few hundred testing laboratories for civil engineering and construction in South Africa, representations were made to the SABS by certain consulting engineers to look into the possibility of establishing a system of laboratory accreditation for these laboratories. The Council of the SABS granted the request, and a consulting committee, consisting of representatives from the industry, has already been formed. At present a number of committees are being appointed to prepare the test methods and other criteria.

The worldwide interest in laboratory accreditation resulted in an international conference on this subject in Copenhagen in 1977. The conference was called ILAC, which is an abbreviation of International Laboratory Accreditation Conference. In 1978 a second ILAC meeting was held in Washington, followed by another in Sydney in October 1979. The fourth meeting is planned for October 1980 in Paris, France.

The International Organization for Standardization (ISO) has a natural interest in the work of ILAC and is represented at ILAC meetings. In fact, ISO's guide (No. 25) entitled 'Guidelines for assessing the technical competence of testing laboratories', was published at the end of 1978. In addition, with the aid of a working group of ILAC, the Standards Committee of ISO (STACO) is compiling a list of definitions in connection with laboratory accreditation for approval by the ILAC meeting in 1980.

The SABS hopes soon to accredit testing laboratories in South Africa. After a laboratory has received an accreditation certificate, inspectors will be sent out regularly to ensure that the required standards are maintained. This will give users of such accredited laboratories the assurance that their test results and reports can be accepted with confidence.