Metallurgical considerations in the automation of gold-recovery plants

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SYNOPSIS

The advantages of the automation of gold-recovery plants are examined. The various sections of a gold-recovery plant are analysed, and the extent to which instrumentation can usefully be employed is described.

SINOPSIS

Die voordele van geoutomatiseerde goudherwinningsaanlegte is ondersoek. Die verskillende afdelings van 'n goudherwinningsaanleg is ontleed en die mate wat instrumentasie tot voordeel aangewend kan word is beskrywe.

INTRODUCTION

The scope of this paper is restricted to the ore-treatment and recovery plants on Witwatersrand gold mines. To extend the field to plants that process base metals and industrial minerals would result in a paper that would be too lengthy. However, the subject matter of this paper is applicable to most mineral-dressing and recovery plants and will, it is hoped, be a foundation on which to build somewhat more sophisticated control systems required in the base-metals field.

Essentially the function of a gold-recovery plant is to receive rock from the mine and to recover as much gold from it, in saleable form, as economically possible. This is achieved by breaking the ore down to a size at which the gold is either liberated as free particles or is exposed sufficiently to be attacked by cyanide leaching solutions. It is fairly common practice to recover portion of the liberated free-gold particles as a metallic concentrate and to recover the remaining extractable gold by hydrometallurgical processing involving cyanide leaching.

The plant required to achieve maximum recovery of gold is the usual assemblage of equipment and machinery necessary for most comminution-cum-hydrometallurgical operations. In general, a typical works is divided into four broad divisions; namely, crushing, fine grinding, hydrometallurgy, and pyrometallurgical treatment of recovered gold.

This broad-based division has not changed during seven decades of successful mining operations in which the Witwatersrand has dominated the gold scene both economically and technically. Although the broad picture has remained the same, there have been changes in the details of the composition, which have developed to the stage at which it is advantageous and desirable to apply the most up-to-date advances in metallurgical technology to the somewhat aged and stereotyped problem of recovering gold from Witwatersrand ores.

One branch of technology applied with success is that which embraces instrumentation and automation. The last two plants in the Gold Fields Group to be commissioned, namely Kloof and East Driefontein, have been extensively instrumented, and an advanced degree of automation has been introduced into centralized control systems. The basis on which instrumentation and automatic control have been introduced is that of obtaining benefits on a broad basis rather than that of achieving a high degree of sophistication in a limited sphere.

The objectives have been achieved by examining in considerable detail the unit operations that contribute to each of the four main divisions recorded above, particular attention being paid to the items of equipment to be used and the means of controlling the functioning of this equipment. It is common knowledge that gold-recovery plants operated successfully for many decades entirely under manual control with the employment of a large unskilled labour force, reinforced by a generous sprinkling of trained operators, who were supervised by a nucleus of highly trained technicians and engineers. However, the labour supply position is changing rapidly, and plants have now to be designed to operate with a minimum of manual control and supervision. At the same time, the escalation of both capital and operating costs demands that the maximum performance be obtained from all processes and machines in new plants.

These objectives can be met by a high degree of instrumentation applied on as broad a front as possible. In this paper, each of the four main divisions is analysed, and the extent to which instrumentation can be applied is examined.

CRUSHING

This broad division embraces the work that commences with the receipt of run-of-mine rock from shaft headgears and ends with the delivery of crushed ore into mill-feed silos.

The principal functions are as follows:

(a) transport of rock on conveyor belts,

(b) sizing of rock on stationary and/or vibrating grizzlies and screens,

(c) washing of rock,

(d) sorting of sized, coarse rock particles into waste and ore,

(e) crushing of ore in one or more stages, usually in closed circuit

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with screens, to a size suitable for feeding to cylindrical grinding mills, and

(f) storing of rock and ore at one or more points in the circuit to allow for fluctuations in the rate at which rock is delivered from the mine or ore is received by the mill.

In older plants the operations are almost entirely manually controlled, and the typical operation of starting the crusher station would require an individual to start each machine in roughly the following sequence:

Water pumps, probably requiring the opening of valves
Grit pumps, and the opening of gland services
Conveyor belts, starting with the last in a train and finishing with the first
Washing sprays on belts
Screens
Wash water sprays on screens
Crusher lubrication system
Crushers
Ore feed chutes—usually manually operated
Ore feeders—manual or mechanical, but requiring manual regulation.

In addition, labour would be required to report at intervals the quantity of rock in storage bins, surge bins, and stockpiles, and the depth of water in storage tanks, etc.

Operators would be stationed at all transfer points in the belt-conveyor system and would patrol the belts themselves to report overloading, spillages, poor tracking, and other conditions.

Labour would also be employed to report on the rate of feed to grizzlies and screens, and to regulate the feed to crushers in order to obtain, for instance, choke feeding conditions. Pump sumps would have to be watched and water valves adjusted to prevent flooding, and a constant watch would have to be kept on locally placed ammeters to ensure that equipment was not being overloaded. Underloading was seldom brought to the attention of anyone.

Apart from these functions, labour was employed for hand-picking rock of suitable size to be used as tube-mill pebbles, for manual sorting of waste from rock, for picking waste timber, and for locating and removing tramp iron.

It will readily be appreciated that older crusher stations required, and many still require, the attentions of a labour force totalling hundreds of men, particularly when it is borne in mind that operations can extend over two or three shifts.

It will also readily be appreciated that, in the light of knowledge existing today, each of the above functions, without a single exception, can be performed either by instruments or suitably instrumented machinery. In fact, it is possible to mechanize and instrumentally to control a crusher station to such a degree that it can operate entirely without an operator. This would be carrying automation to the extreme limit. It is, however, worthwhile to examine in detail the extent to which automation can be carried out. Firstly, there is the matter of machines performing operating functions that have in the past required manual labour.

To start with the more elementary functions, suitably installed screens readily separate rock for tube-mill pebbles, while others remove large pieces of timber. Magnets remove tramp iron, while detectors signal the presence of iron not removed by magnets and can be made to stop the belt in question. Machines are now becoming available that are capable of sorting waste rock from reef at much greater speeds than human beings can and down to sizes previously thought to be impossible. Modern crushers can be mechanized to the extent that no labour is required to adjust the crushing zone to compensate for wear and other circumstances.

The following control functions can now readily be performed.

All machinery can be remotely started and stopped. Ore can be fed mechanically from bins onto conveyor belts by equipment that can be started from a remote location, and can regulate the feed rate and maintain it at a desired level. Weightometers on conveyor belts with remote indicating dials or recorders report the loading on belts and can be coupled to feeders to maintain optimum conditions. All conveyors can be interlocked and started and stopped in the correct sequence from a remote-control centre. Hooters and bells in the works can give warning that equipment is about to be started, and suitably placed closed-circuit television cameras can detect the presence of trespassers. Probes or supersonic devices can detect the build-up of material in transfer chutes and give warning, reduce the feed rate, or stop the system before the rock reaches a head pulley or damages a belt. Gamma-ray or optical devices can report the condition in surge bins and other places where rock is expected to accumulate.

Suitable interlocking systems are available that will ensure that valves are opened after water pumps are started, that sprays on belts and screens are opened at the correct time, and that gland services are opened before grit pumps are started. They can also report and record which of two duplicate pumps is operating, and can record by suitable means the state of wear of a pump and can automatically switch over to the stand-by in case of failure or any other appropriate reason.

Other interlocking systems will ensure that the lubrication system is functioning adequately before crushers are started. Suitable probes can ensure that crushers are continually choke fed, while a weightometer on the belt carrying the circulating load in a closed-circuit crushing system will report when adjustments to the crusher setting are necessary.

Various devices are available for measuring and indicating or recording remotely the condition of bins, silos, and storage tanks.

Communications between various sections of a plant are no longer a matter of personal contact, but a host of paging systems, telephone networks, and walkie-talkie sets enable contact between individuals to be established extremely rapidly and nobody need leave an important job in order to talk to another operator.

From the foregoing, it will readily be appreciated that a suitably located control centre can be established to which instruments can submit data and from which individual machines or entire circuits and operational sequences can be controlled. This is the basis of the broadly oriented system of instrumentation and control applied by Gold Fields to the Crushing Division of ore-treatment plants. It will be realized that many functions have to be done sequentially or consequentially, and these can either be performed by a number of individual mechanical or electronic control systems or can be fed into a single computer for which appropriate programmes can be written.

The advantages of a system such as that used at Kloof and East Driefontein is not only a dramatic saving in labour but greatly improved operating efficiency. In the first instance it is possible to achieve and maintain a controlled uniform throughput in the plant, with the assurance that ore-transport and pulp-transport systems are being correctly loaded, that screens are being fed to proper advantage, that sorting is carried out at an efficient rate, that crushers are fed under optimum conditions, that plant and machinery are kept under continual surveillance, and that plant management can at all times be fully aware of the state of all processes and units of equipment.

A complete system such as the one described here is dependent upon a large number of reliable sensors with attendant transducers and data-transmission circuits. Each of these is an expensive item, and discretion has to be used about the degree to which instrumentation will be implemented at any particular period in time, when due consideration is given to the state of the labour market and the cost of instrumentation must be weighed against the cost, inconvenience, and unreliability of unskilled labour. However, provided adequate basic equipment is installed when a new plant is built or a change-over is made to instrumentation, it is possible to start with the more profitable applications and then introduce a greater degree of instrumentation, particularly automatic control, as the supply of labour becomes more difficult and expensive.

FINE GRINDING

Great importance is rightly attached to this division, because it is here that the degree of liberation of gold particles or exposure to leaching solutions is achieved. However, in spite of this importance, there are relatively few unit operations involved. These are as follows: ore transportation and controlled feeding, controlled addition of water, pumping of ore pulps, grinding of ore particles in cylindrical mills, and classifying to desired size. Essentially, the objective of this division is to accept crushed ore and to reduce it to the most economic size for the extraction of gold by leaching with cyanide solutions, with or without the assistance of gravity concentration and amalgamation. The decision on the optimum size range to which the ore must be ground is made in the design stage and is based on a combination of experience and small-scale extraction tests. Other parameters that are fixed at the design stage are the size and type of grinding mills, their speed, the means by which ore and water are introduced into them, and the means by which they discharge ground pulp. Further design decisions relate to the configuration of the grinding circuit, which may contain one or more stages of mills in open or closed circuit, the types and dimensions of the classifiers, and the size of pumps required for moving ore/water suspensions at various points in the circuit.

The decisions relating to plant design having been taken, consideration is then given to the controlling factors that determine the efficiency of the milling-cum-classification operations.

In *milling* the important factors are as follows:

(1) The type, size, and weight of grinding load in each mill. Decisions on the first two factors, namely type and size, are usually on a long-term basis and do not enter into the day-to-day operating controls. On the other hand, maintaining the weight of the grinding load at the optimum level is a matter of continuous concern. It has been shown that the optimum load is that with which the mill draws peak power under optimum grinding conditions. In a continuously operating mill, it is desirable to operate the mill as constantly as possible under conditions of peak power demand. This means that the grinding load must be replaced as rapidly as it wears. When steel rods or balls make up the load, the rate of wear is slow and it is usually sufficient to make up the load once per shift or once per day. However, when the grinding load consists of rock pebbles (autogenous grinding), attrition of the load is rapid and it may be necessary to add as much as 10 tons of pebbles per hour to the mill on a continuous basis. Williamson and others have devised control systems that monitor the power demand of a mill and regulate the rate at which pebbles are fed. It is considered essential for large pebble mills to be provided with controllers of this type.

(2) The consistency of the ore/water mixture in the mill. There is an optimum consistency for every individual type of mill, at which maximum production of desired finished product is achieved. Although it is by no means certain that a fixed ore-to-water ratio will at all times result in maximum work being done, experience has shown that it is possible to determine a ratio which will, on average, give the best results and at which a particular mill should at all times be operated.

Where a mill is designed to operate in open circuit and it is fed only with relatively dry ore and water, provision must be made for a water-proportioning system that maintains the correct ratio, irrespective of the rate at which the solids are fed. This arrangement has been found to be more satisfactory than one in which the density of the pulp leaving the mill is measured and used as a basis for proportionate water additions.

Where milling in closed circuit is practised, an additional product is fed to the mill, namely, oversize product from the classifier. This is a solids/water mixture, which could complicate the water-proportioning system previously mentioned unless the solids-to-water ratio in the classifier product were maintained at the same level as that required in the mill. This desired ratio in the classifier return product is achieved by the use of a cyclone classifier provided with a gamma-ray density meter actuating a variable spigot.

In a two- or three-stage grinding circuit, the flow diagram often calls for an arrangement in which ore is fed into a primary mill that discharges into a classification system that, in turn, does not separate the finished product but makes a cut at a pre-determined, much coarser split. This overflow product then proceeds to a further classification step, which separates a finished product and makes a coarse return product, which, in turn, is delivered to a second-stage grinding mill. The product from this grinding mill is delivered into the second classifier system, and the mill is consequently in closed circuit with the second classifier. Thus there is a primary mill in closed circuit, which receives new feed, and a secondary mill in closed circuit, for which the feed is partially ground material from the first mill. In this case, each cyclone classifier must be controlled by a gamma-ray density meter that is fitted across the conical portion and is set to deliver a product of the correct consistency for each mill. This arrangement can be repeated as many times as desired in a multi-stage system. However, proliferation is expensive, and Gold Fields practice is to use as few stages as necessary and to increase the size of mills in order, among other good reasons, to reduce the number of control systems.

The two-stage grinding circuit preferred by Gold Fields consists of a primary (rod) mill in open circuit with an uncomplicated ore/water-proportioning feed system, followed by two second-stage pebble mills in closed circuit with cyclone classifiers that are operated in such a way as to eliminate finished product and return coarse feed of the desired consistency to the pebble mills. This simple system is exceedingly versatile. It is capable of handling large tonnages but at the same time requires a minimum of control functions.

(3) To feed new ore into a milling circuit at as uniform a rate as possible and at the correct rate. The correct rate at which to feed ore into a milling circuit, whether that ore is run-of-mine material, crushed ore, or pebbles, is the rate at which the system consumes such feed. The feeding of mill pebbles has previously been dealt with, and, as the author has no first hand knowledge of dealing with run-of-mine feed, only crushed new feed will be discussed.

In any rock-breaking or ore-grinding system that incorporates closed-circuit operation, one of the most important control parameters is the circulating load, whether the classifiers are screens or cyclones. An increase in the circulating load is a signal that the crusher or mill is producing less finished material than the quantity of new feed it is receiving, whereas a decreasing circulating load means that the mill (in this discussion) is producing finished material at a greater rate than that at which it receives new feed. Fluctuations in circulating load can therefore be used to regulate the rate at which new feed is fed into a system and, when the circulating load is steady, the circuit will be in balance, the feed rate matching exactly the rate at which the finished product is being removed from the circuit. This feed-control system, regulated as it is by circulating load, automatically takes care of all the factors that affect the grindability of ore and it is able at all times to match the work capability of the mill.

In the Gold Fields system of mill control, which embodies cyclones fitted with variable spigots and in which the cyclone spigot product is maintained at a constant density, it follows that the area of the spigot opening is a measure of the circulating load, and that an opening spigot indicates an increasing circulating load, while a closing spigot indicates a decreasing circulating load. The behaviour of the spigots is therefore used as the controlling factor that regulates the new ore fed into the grinding circuit. In practice this is achieved by a system of hydraulic and electronic transducers that control the variable-speed drive on the ore-feed belt. A typical grinding circuit consists of a rod mill that receives new feed via a controlled variable-speed belt and into which a correctly proportioned quantity of water is delivered to result in a product of correct consistency in the mill. The mill discharge is delivered into the sump of a pump, which, in turn, feeds two cyclones whose duty is to separate finished product and to deliver coarse spigot product of correct consistency to two secondary mills with which the cyclones are in closed circuit. It will be appreciated that the highest degree of efficiency will be reached when the two secondary cyclones are evenly matched and follow parallel operating paths. In practice it has been found that a simple splitter chamber at the end of a vertical pump-delivery column is able to divide the pulp delivered by the pump into two streams having almost identical characteristics and that it is necessary to use only the information from one of the two cyclones for controlling primary mill feed. The information that is relevant to the circulating load to one mill is therefore utilized to control the rate at which new feed is introduced into the circuit via the rod-mill feed belt. The other mill is, nevertheless, controlled by the instruments, which assure that it is maintaining a proper pebble load and a pulp feed of correct consistency.

In practice it has been found advisable to allow the spigot opening to fluctuate to a limited extent about a predetermined mean, before causing changes in ore-feed rate to be initiated. This free variation in circulating load is well within the limits of the mill's ability to accept variations, and it does help to eliminate hunting within the closed-loop control system.

A variation of the control system described above has been introduced in the newest Gold Fields plant. In the new system, the cyclones operate with fixed spigots and changes in the spigot pulp density are used to regulate the new feed into the system. This means that a uniform volume of circulating load is maintained and that changes in circulating load are measured by changes in the spigot density, which is allowed to fluctuate within limits that practice has proved to be satisfactory. The density of the spigot is measured by the usual gamma-ray meter attached to the conical portion of the cyclone.

Classification is, next to milling, the most important unit process in the fine-grinding division, and it is essential to possess a classification system that can consistently separate a uniform finished product and return to the milling circuit a 'clean' circulating load for re-grinding.

The discussion on milling stressed the advantages to the milling circuit of the use of cyclones in a control system, and experience has shown that they are efficient classifiers when operating under controlled conditions. The main drawback is that a single cyclone cannot in a single pass produce both a clean finished product and a clean spigot product. However, the advantages outweigh this drawback, and the use of cyclones in automated systems has become widespread. It is generally accepted that a cyclone will deliver uniform products provided the following conditions are met: steady feed rate, constant feed pressure, uniform spectrum of particle sizes, constant liquid-to-solids ratio, and uniform spigot opening. (It is assumed that the dimensions of the cyclone and of the vortex finder are parameters that have been fixed at the design stage.) In practice the above conditions are seldom met, but instrumentation can assist considerably in providing the desired operating conditions. Speed control of the feed pump can ensure that the feed rate and pressure are maintained at a correct level, particularly in an automated milling system in which a reasonably uniform product is delivered by the mills at a controlled rate. Under these conditions, what is required is the correct proportion of water to solids to provide the correct conditions within the cyclone for the satisfactory separation of a finished product of desired size. When the behaviour of the feed pulp is considered, it is readily seen that the coarse particles will migrate to the walls of the cyclone and will find their way by following a spiral path to the spigot. Their removal leaves a dilute suspension that contains all particles of finished size and some coarse material that ranges in size from near-finished product to tramp oversize, and the opposing forces acting within this suspension determine the degree of separation. These forces are centrifugal force (by which particles are driven away from the vortex finder) and transportation within the moving liquid (by which particles are carried towards the vortex finder). This latter movement is a function of the velocity of fluid flow and the volume of liquid that leaves the vortex finder. It is also a function of the viscosity of the liquid that leaves the vortex finder. These last two factors naturally point to the advantages of monitoring the density of the cyclone overflow pulp and of using the information to regulate the quantity of water that enters the system with the feed via the pump sump. The other circumstance to be catered for is that the oversize fraction must be able to leave freely via the spigot without at the same time taking with it some of the suspension that should be leaving via the vortex finder. This condition is met by attaching a gamma-ray pulp-density meter across a chosen plane of the cyclone about one-third of the height of the conical portion above the discharge spigot and by causing this meter to regulate the size of the spigot opening in such a way that the concentration of solid particles at the chosen plane remains constant.

These controls, allied with the uniform milling conditions attained by the controls previously described, result in the following advantages:

(1) a uniform finished product with a known size spectrum,

(2) controlled dilution of the spigot product with finished product, and

(3) controlled density of circulating load delivered to the grinding mills.

As with the separate control systems in a crushing plant, automation may be achieved in a milling circuit, either by the installation of a number of small control centres or by transmitting all the data to a control computer.

HYDROMETALLURGY

In this division the unit processes involved are pumping of liquids and liquid/solids suspensions, solids/liquids separation, leaching, and gas/liquid relations.

Each of these operations involves both chemical and physical considerations.

Pumping

The liquids to be handled are large tonnages of alkaline water, large tonnages of dilute cyanide solution, small volumes of hydrochloric and sulphuric acids, and small volumes of other chemical solutions such as flocculants and wetting agents. In addition, quantities of suspensions varying from dilute suspensions to thick pulps are pumped, and the liquid phase is alkaline water or cyanide solution. A great deal of instrumentation and a considerable measure of control are required over the transfer of fluids.

(1) Pumps must be started by remote control and in a correct sequence, and valves must be remotely opened and closed.

(2) The flow rates and masses of liquids and suspensions must be measured and controlled, or be made to control subsequent operations. This calls for the installation of flow meters, density meters, and mass flow meters, which are required to indicate and register the information gained as well as transmit it to a distant control centre.

(3) Instruments must be provided to measure and monitor the con-

tents of many tanks and vessels, and must transmit their information to a control centre where it is displayed, recorded, and used for control purposes. These instruments must operate under vacuum and under relatively high pressures, as well as under normal atmospheric conditions.

(4) Means must be provided for the accurate removal of samples of suspensions and liquids from pipes and launders.

(5) Instrumentation is required to remove accurately controlled dosing liquids such as solutions of flocculants and lime suspensions or strong cyanide solutions and suspensions from ring main systems.

(6) Means must be provided for the accurate division of streams of flowing liquids and suspensions, whether in pipes or launders, into smaller streams, and it is necessary to control the degree and extent of subdivision.

Solids/liquid separation

The principal operations in this field are thickening, filtration, and clarification.

Thickening

This area requires both hydrometallurgical and purely mechanical control measures. The objective is to receive dilute suspensions of finely ground ore in slightly alkaline water and to remove as much of the water as possible. The recovered water is re-circulated to the milling system, and the de-watered sludge is leached with cyanide. It is necessary to separate the water and solids as efficiently as possible to minimize the addition of cyanide and to maintain a favourable liquid-to-solids balance in subsequent operations.

Four major operations are continually being carried out in a thickener tank, namely, flocculation, free-fall sedimentation, hindered settling, and de-watering of mud. Adequate manual control of these functions is not possible because they occur inside the tanks and cannot be observed. Instruments are therefore provided to record the position of the interface between supernatant clear water and the dilute underlying suspension, which is the floc bed. This information is used to control the addition of flocculant into the system. Further instruments locate and monitor the position of the interface between the floc bed and settled mud. This information can be used to control the rate of feed to the thickener or, alternatively, the rate at which the thickened pulp is removed. Instruments monitoring the density gradient within the mud zone deliver information that is of considerable assistance in assessing the behaviour of a thickener at any time and give warning of impending trouble in the zone in which most mechanical problems start. Finally, mass flow meters on the pulp discharge system supply information on the density and mass of the pulp being discharged. This information is used for controlling the leaching operation that follows thickening.

The mechanical operations that need to be controlled and monitored are as follows: the torque developed within the rake drive mechanism, means for automatically raising and lowering the rakes, and means for stopping and starting the operation, not only as a routine operation, but also to prevent damage to rakes and the drive mechanism. In the latter event, audible and visible warning signals are also necessary.

A thickener is called upon to operate under widely fluctuating conditions of feed and loading, and, in the light of the fact that its duty is that of de-watering, the rate at which delivery of thickened pulp takes place can also fluctuate considerably. The pumping system for thickened pulp must be capable of dealing with this condition, and a variable-speed drive, controlled both manually and automatically by the instrument(s) that monitor the mud zone, is called for. Other solids/liquid separation functions are filtration and clarification or polishing of filtrate. These will be dealt with in the chronological order in which they occur in the hydrometallurgical sequence.

Leaching

This is undertaken in continuous-flow pachuca tanks arranged in series in either single or duplicate rows. The basic requirements here are controlled pulp density, controlled cyanide and lime strengths, monitored and controlled depth of pulp in the tanks, controlled aeration, and controlled rate of withdrawal to the next operation, which is filtration.

The feed to the agitator system is the dense, dewatered pulp from the thickeners, which must be diluted with barren cyanide solution to the density required for maximum gold dissolution in the agitators. The specific gravity of the pulp in the first agitator tank is continuously monitored by an S.G. controller, which regulates the flow of diluting solution. An alternative system uses the information from the thickened pulp mass-flow meter to actuate a solution-proportioning control. The S.G. in the agitators is that which experience and experiment have proved to be the optimum for each ore and installation.

Controllers are now available that monitor the strengths of cyanide and alkalinity in the first agitator of the series, and that control the addition of these bulk chemicals to the circuit in order to maintain the correct concentration in the last agitator and in the solution that is subsequently delivered to the gold-precipitation section. Experience has indicated that the addition of chemicals to only the first agitators is sufficient to maintain the desired strengths. Pulp-depth monitors are readily available and inform the operator or controller of the need to increase or decrease the rate of feeding the filters.

Compressed air is an expensive commodity, and the quantity used should be no more than necessary to maintain adequate agitation and the required concentration of dissolved oxygen in the leaching solution. These are parameters that have not yet been instrumented and towards which attention should be directed.

Filtration

The filter section of a gold plant has not been instrumented to the degree required for maximum efficiency. The requirements to be met are as follows: effective control over the pulp level in filter pans, controlled addition of washing spray solution, effective monitoring of the vacuum applied across filter medium for individual filter segments, and monitoring of pressure build-up during the blow-off period.

As regards pulp level in the filter pan, it has been found that displacement of residual gold solution in the cake is greatly assisted by the presence of a supernatant layer of wash solution on top of the pulp in the pan. This layer gives a displacement wash and leaves less gold solution in the cake to be displaced by the spray wash solution. The most effective means of creating the supernatant layer is to apply excess spray wash solution and to allow it to run down the back face of the filter onto the surface of the pulp. The level controls now required are, firstly, a controller that regulates the height of the solution/pulp interface and is coupled to the pulp feed column from the agitators and, secondly, a controller that regulates the quantity of spray wash solution applied in accordance with the level of the supernatant solution.

Monitoring of the vacuum in individual segments would provide information relevant to the effective solution pressure across the cake, the formation of dry spots, the formation of cracks, the blinding of cloths, the holing through of division strips, and the existence of leaks. Similarly, a history of the behaviour of segments after the application of blow-off air would supply much information that could improve efficiency and gold recovery.

One further control in the filter circuit that must improve efficiency and result in monetory savings is the provision of a turbidity meter to monitor the solids content of the filtrate.

Clarification

For efficient precipitation of dissolved gold, it is necessary to polish the filtrate for complete removal of suspended solids. In modern plants this is carried out in pre-coated pressure filters that are supplied completely automated as packaged units. In a fully instrumented gold-recovery plant it is possible to transfer to the central control system those functions that have been performed in the separate system supplied with the clarification plant. In fact, it is necessary for all the information indicated on the on-site control panel to be transmitted to central control. This information applies to flow rates, pressures, changes in the filtration cycle, and the state of the operating sequence.

Precipitation

In modern plants, precipitation of gold from filtrate is carried out in installations similar to those used for clarification, and the requirements in respect of instrumentation are similar. Additional controls relate to the addition of zinc dust and to provision for integrating mass flow. A very necessary operation between clarification and precipitation is the removal of dissolved oxygen from the gold-bearing solution. Instrumentation required in the de-aerating section relates to vacuum, flow rates, and the oxygen content of solutions. The first two requirements are readily met, and instruments are now becoming available for recording the oxygen content.

PYROMETALLURGICAL TREATMENT OF RECOVERED GOLD

Mechanization, instrumentation, and automatic control are being used to an increasing extent in the smelt houses in which the final acts of the gold-recovery process occur. However, there is a significant difference of approach in this department. Here all operations are controlled locally, and information is not transmitted to the control centre that is the brain of the remainder of the works. Manual control and manual operation, assisted by mechanization, are the order of the day.

Gold from the precipitation filters is received in a storage tank fitted with a pulp-level warning device, which in this case does transmit to the plant-control centre. The contents of the storage tank are then filtered on a precoat drum filter, which delivers automatically onto a travelling pan conveyor. This pan conveyor is part of the calciner and passes through the muffle furnace chamber at a slow rate. When it emerges from the tunnel, the gold precipitate or cake has been calcined. It is then discharged into hoppers, picked up by an electric hoist, and transferred to the submerged-arc gold-melting furnace, without being handled manually. After the addition of suitable fluxes to the furnace charge (by hand), the arc is struck by the operator, and then an automatic furnace controller takes over. At the end of the requisite time period, the chief smelter mans the controls and, by pulling a lever, is able to withdraw the electrodes and tip the furnace, which discharges its load of gold and slag into a series of moulds arranged in a cascade succession. The gold remains in the moulds, while the slag automatically flows into a water quench granulator. The gold-bar moulds are tipped manually, after which the bars are picked up in hand-held tongs and are washed and scrubbed by hand, albeit with the use of pneumatic scrubbing brushes. Finally, these precious bricks are lovingly picked up by members of the smelting crew, weighed, and placed on trolleys, which roll them safely into the semi-air-conditioned luxury of the local strong room—fitting personal treatment for ingots of precious metal that have a value of approximately R40 000 each.

CONCLUSION

It will be clear that the scope for instrumentation and automation in the operations of a gold-recovery plant is great indeed and that all the machines can be controlled automatically from a remote centre. This degree of almost complete automation has been achieved at the Kloof and East Driefontein Gold Mines, and this has been done by breaking the operations down into their simplest form and by providing equipment to perform each elementary duty and function. This is a far cry from the approach that requires the services of a team of highly qualified scientists, mathematicians, and electronics engineers, who set out to establish mathematical models in the hope that they will end up with a formula suitable to form the basis for a computer programme. A plea is made here for recognition of the fact that almost all control situations can be broken down into simple GO/NO GO decisions and that the computer is an immense assemblage of elements capable of making and acting on these GO/NO GO decisions.