

Underground Mine Profiling

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Introduction

The location of underground positions in mines has usually fallen to their survey department's. Their usual tasks include:

- installation of a high-precision peg network like the National Survey grid as beacons
- offset measurements to the sidewalls, and sometimes hangingwall and footwalls, of development tunnels and excavations
- offsetting of stoping panels for the calculation of face advance and the square meterage of area removed.

Other departments build their observations into the plans produced by the surveyors. If more precision is required, they ask the surveyors to 'elevate' their points with a theodolite.

Apart from the survey peg network and 'elevations' these measurements are usually planer measurements suitable for producing plans, sections and projection sheets. When the only representation medium was a sheet of paper or transparency, this was perfectly suitable. However the development of CAD models of the workings has changed all this. Full 3D representation is not properly catered for in the tool sets in current use, and needless hours are spent converting analogue-type observations into digital form.

The basic survey models need to be augmented by the observations of other disciplines that are also required to locate positions underground. These include:

- the need for geologists to plott their mapping and borehole logs into 3D space
- the need for samplers to position their sample points accurately because the geostatistical models are biased and inaccurate
- the need for stoping width recorders to position their thickness observations to prevent errant evaluation and bonuses
- the need for rock engineers to place their mappings into 3D to build true geotechnical models to manage geotechnical stresses
- the need for production officials to receive updated face positions during the month so that they can manage the production and utilize their resources properly.

This paper covers a new method of positioning profiling points to a suitable degree of accuracy. I believe the method is sufficiently simple and cheap for all to use.

Historical methods

Platinum and gold orebodies, especially in South Africa, are generally narrow tabular deposits. This made them suitable for depicting on a 2D medium like paper. The determination of stoping or face widths was not a problem, as the ore is removed in a single stoping process. Such 2D

representations could be easily positioned using tape offsetting between survey pegs or points tied in from survey pegs. Problems of dip were handled by using 'Stope Sheets' which chose a best fit projection for the whole area depicted or by using true dip section sheets for inclined tunnels. Rolling reef and potholes were the common areas of difficulty.

Most mines now model their orebody and plan the extraction in computer graphics. This means that the representation of the current workings has to change to support this trend. It now becomes a truly 3D problem. Mining officials find it inconvenient to have their actual workings in single-line depictions while their orebody is depicted with top and bottom contacts and the planned tunnels in 3D shapes. Geological models which form the basis for the resource model and planning process are often out of date, as the updating process is slow. The geological mapping has to be plotted onto sections and plans. These are then digitized into graphics by a draughtsman and checked by the geologist. Only then does the interpretation and model update take place.

Potential methods to create 3D 'Actuals'

Global positioning systems (GPS)

Surface mines have been blessed by the advent of GPS technology. These simple-to-operate pieces of equipment and compatible software make it possible for all types of mine employees to locate themselves, and therefore to locate their observations. GPS are often inexpensive and give an acceptable degree of accuracy. Only in deep pits or close to the highwalls are observations hindered. Such technology cannot however, work underground.

Ground penetrating radar (GPR)

GPR is reported to be very useful for estimating the positions of potholes and faults. However it is still considered as providing an estimate, not a definite measurement. GPR is good for seeing into solid rock, not into open spaces.

Inertia reading devices

Experiments with inertia reading devices have been conducted on the mines. They were the forerunners of GPS for military guidance systems, and were even used for city navigation in the early 70s. They do however work best with heavy or fast-spinning gyros. AngloGold Ashanti's attempt to use them were discontinued in the mid-90s when the developers asked for an additional few million rand for a device that would weigh more than 12 kg and have a limited operational life.

Traditional survey instruments

These are proven equipment and have been used in mines with varying effect. They can be used by a number of different people, but overall it is expected that a trained surveyor be left to operate them. A team of carriers are also assigned to their operation, which not all mines have at their disposal. A more detailed explanation of their suitability appears later in the paper.

The need to measure against the plan

Mine management expend large amounts of effort on managing their ore reserve and trying to plan the optimal extraction of its content. They do this to set targets for the production officials, and to apprise the shareholders of the returns they can expect on their investments. Recent legislation is putting more emphasis on the responsibility of mining house officers to guarantee the accuracy of this information.

To test the execution, effectiveness, and accuracy of planning methods it is necessary to measure production against the plan. This tests both the accuracy of the geological and evaluation models on which the targets are based and the efficiency of the ore and metal recovery departments. Key to these is accurate positioning of the excavations mined, and the geological and evaluation features encountered. Unless this is achieved it is impossible to gauge the progress made with any accuracy. Also, there can be no improvement in the base data used for evaluating the next planning cycle.

Timing is also a fundamental part of the control issues on a mine. Operations are in effect continuous, so snap-shots have to be taken to measure planned production against actual outputs. The monthly measuring period is the time-consuming part of this operation. The longer it takes to measure, the harder it is to equate the ore broken to the metal produced.

Enterprise resource planning (ERP) systems are very popular mechanisms used for reporting on business achievements. Mines are also trying to adapt these systems for their use. However, they do not readily accept the staggered timetable for monthly cut-off. It would be of great advantage if the measuring could be completed on the day of month-end, comparable with the way a factory does its stock-take to calculate the work in progress and production achieved against consumption of raw materials.

A new solution

Many people have been investigating methods of locating underground positions and speeding up their representation in models of the orebody. The criteria for such a solution include

- ease of use
- ease of transport to the workings
- interfacing with software for representation in models
- accurate to reasonable tolerances.

Mines use software to convert their measurements into computer graphics which form representations of the measurements taken. This process has to convert tape offsets to x,y,z coordinates. If the measurements are taken from a single tape stretched between two pegs the calculations are simple, even though the input is time-consuming. An added complication comes when marks that anchor the main tape have to be tied in from the survey pegs. So many variations are possible that it is inevitable that extra information needs to be put in. Ties are again

two-dimensional measurements; the third dimension is added by assuming that the ties are made in the plane of the reef. This is much easier said than done, especially in stopes where the reef is rolling in all directions. I recently checked a stope outline that was claimed to be out by 0.5 metres on both the updip and downdip sidings. The answer was that the offsets had been taken at a convenient angle to the strike tapes rather than in the plane of the reef. (This was the work of an experienced surveyor.)

To speed input and avoid the machinations of converting analogue-style tape measurements into digital form it is necessary to find a method of taking measurements that can be easily converted into 3D coordinates. As mentioned before, GPS systems have been the answer for most surface mines. Underground mines do not, however, have access to the satellite networks, although they can work from fixed beacons. The placement of sufficient radio beacons to facilitate a complete coverage of the mine would, however, be particularly onerous and expensive. There is also the problem of rebound signals which would distort the vector calculations. Beacons would also have to be in direct line of sight of the point being measured.

If radio waves are impractical for measurement, then we need an alternative medium. It is suggested in the term 'line of sight'. Light waves are not easily distorted, and do not rebound off multiple rock walls. Therefore the direction in which an object is seen is the shortest distance to it. The pulsed laser beam is a well-accepted distance-measuring method of high accuracy. It has the added advantage of remotely reading objects without a reflector.

Survey pegs are plentiful underground and within direct line of sight of each other. Not all points in a mine are in direct line of sight of a survey peg, but are within direct line of sight of a point that can itself see two or more pegs. This is better for underground workings than a GPS which has to be placed at the point being measured. By being able to sight to a point such measurements can be taken remotely. The majority of survey pegs are placed within development ends and stope gullies; all measurements can therefore be taken from these positions. This is much more convenient than methods that involve clambering through stopes etc.

These considerations lead to many types of instrument that can be used for performing the 3D measurements that are now required in mining.

Laser scanners

The most comprehensive method of making 3D measurements is by using a laser scanner. Several types have been used in this country. They can read up to:

- approximately 15 000 points per second
- an accuracy of 2 mm,
- 360° of horizontal arc and 190° vertical
- a range of 3 000 km.

These machines have extensive capabilities, and can even coordinate individual pixels on a digital photo, allowing it to be morphed onto a digital terrain model (DTM) of the observations measured. They give what is the best representation possible short of standing and viewing the site first-hand. Mapping and analysis can be done straight onto the image produced by the top end equipment.

Such devices do not come cheap. A price tag of between R1–2 million would be expected, especially with the software added. The sheer volume of data would fill several server hard disks in days. It also takes time for planners to digest the information. Although reasonably portable, laser scanners are total overkill for the average use underground.

Cavity monitoring devices/systems

Equipment frequently used on massive orebody mines where it is impossible and dangerous to get close to the workings, are cavity monitoring systems. These are really remote control theodolites/total stations. They can be pushed into open spaces either on a beam, through a borehole, suspended on a cable or mounted on a 'carriage'. Set-up time usually comprises surveying a peg to orientate the machine. The device then rotates through its cycles to complete a coverage about of $360 \times 260^\circ$. Again the price is well above that of a theodolite. It is bulky and takes several people to carry unless a conveyance to the site is available. Fewer observations are taken than with a scanner, and software normally has to be used to reduce and clean the data to create the wireframes of the excavation. This is not the quickest method of operation, and users find it tiresome.

Total stations

Now that they have been equipped with electronic circles, pulsed laser distance measuring, data recording and onboard software, theodolites can also double as profiling devices. Some are even motorized to offset a fixed pattern like the cavity monitoring systems. The dual purpose of these pieces of equipment makes them attractive to mines. They can be used to extend the survey network and offset the workings in true 3D. The onboard software will output x,y,z coordinates to the computer graphics. Wireframes can then be produced to create volumes for comparison with plans, and to prepare evaluation information. This equipment is still heavy, slow to set-up and usually needs an experienced surveyor to operate it. There is also the issue of precision. A survey peg needs to be placed with millimetre accuracy. A tunnel sidewall, with its rough shape, is good enough to the nearest decimetre. A tenth of a metre's difference in elevation could easily mean 0.07 difference in either x or y. Millimetre accuracy is overkill because of the irregularity of the excavation roof and sidewalls. Total stations are in a price range between R70 000 – R200 000.

FAKAWI (a specialised mine profiling device)

A new piece of equipment called the FAKAWI has been developed that can be put into the hands of any mine official. It is lightweight (less than 3 kg) easy to carry and assemble, quickly set up and operated. No special training is required and the complete package, including tripod, can be carried by a single person. Orientation is done by sequentially directing the laser pointer onto at least two survey pegs and pressing the trigger to measure distance, and vertical and horizontal angle readings. The device can then be used to record similar observations to any point that needs measuring. The observations are downloaded through a radio link to a computer. Simple trigonometry converts the observations into x,y,z coordinates.

The miniaturization of the components that make up a total station has limited the accuracy of the FAKAWI's readings. The distance reading is limited to approximately 60 metres in range off most non-reflective surfaces. The reading is accurate to within ± 10 mm. Angular readings are to the nearest 0.1 of a degree, which is 600 times less accurate than the outputs of a good-quality total station. Are these serious deficiencies? We think not. The average surveyor will tell you that although a theodolite will read to 1 second of arc, he/she seldom, if ever, manages to repeat such a measurement: 30 seconds of arc is more common. Over an average stope length of 30 metres, a reading of



Photo of a FAKAWI device

potentially 0,05 degrees error will lead to a maximum distance difference of 0.026 metres. This is far better than tape measuring, and infinitely quicker. On a 30-metre panel with a 15-metre face advance, the difference in area measurement would be a maximum of 0.638 sq metres. This is 0.14%, which is much better than the 4% accepted from tape surveying.

In a worst-case scenario, where there are not two pegs for orientation, the FAKAWI can be used to extend a temporary traverse, rather like high accuracy stope plugging.

Compatible software and links to mine plans and planning

It is very important to marry the outputs of these measuring devices to the environments in which the geological model, mine planning and production actuals are produced. Many of them have specialized software to create coordinates of the data collected. The export of this data is normally interfaced with solids-modelling software to obtain production volumes. The planning, production, and the official plans are often not produced in these same computer graphics environments. Software therefore has to be created to provide interface from one system to another. FAKAWI is designed to fit straight into the standard systems used by most South African platinum mines.

Potential uses of this new device

The FAKAWI device can be used in two different modes. It can do exactly what is currently achieved with tape offsetting, but using fewer people, or it can produce full 3D shapes of the orebody that tape offsetting cannot achieve. The following are potential applications for this device.

Tunnel offsetting

Surveyors spend a large proportion of their time offsetting tunnels between their survey pegs. If this is done in conjunction with extending the survey peg network, then this task is achieved using the total station, if they have one. Normally this is done by merely taking sights to the sidewalls along the grade line. With the increased infrastructure and infrastructure planning going into the access tunnels, it would be better to profile these ends fully. The total station can be used for this, but the FAKAWI is a cheaper and quicker alternative to catch up on the backlog.

Survey measurement

As has been mentioned above surveyors, and sometimes samplers spend much of each working month performing the tape offsetting of the workings. This could be reduced by using a FAKAWI. Not only will they be able to physically measure the stopes in less time with less people, they will be able to plot their work more quickly. The FAKAWI is designed to plot directly into graphics and measuring packages. Another advantage is that problems like rolling reef are overcome, as a true z elevation is given and not one forced through the use of a best-fit plane.

The above assumes that the mine would require only the usual single-line representation of the stoping workplace. With very little extra work, hangingwall and footwall positions (providing they can be seen) can also be obtained and plotted. A note of caution needs to be sounded here. Standard CAD packages do not handle the volume calculation of irregular solids very well. Additional software are required or another environment such as solids modelling.

Locating sample points

To many people geostatistics is a black art. Even the converted will admit that unless the sample points are correctly located, it is a case of garbage in and garbage out. Platinum producers usually sample only their own reef development, thus misalignment is not too big a problem. Errors will, however, occur where there are changes in dip along the raise, causing distortion in linear measurements. Locating sample sections with FAKAWI will eliminate any errors.

Locating stope width control points

Locating stope width control points is very similar to locating sampling points, except that now the points are in the stope. The potential for error is much greater. By using a FAKAWI to locate the points it would be easy to contour the widths of external broken waste inside the stoped area. This topic is expanded on in the good practice evaluation section below.

Geological mapping

Geologists have had difficulty converting their mapping into 3D structure plans since the adoption of computer graphics began. The most common complaint about planning and ore reserve evaluation is that the geological model is not up-to-date. Mapping is generally transcribed onto paper, then digitized, checked and the analysed before the model is updated with the latest information. With a FAKAWI the geologist will take readings along each feature he/she maps. These points will go straight into the master file. He/she then has only to join the dots and then join the new mapping to the corresponding features in the geological model, a process that will take minutes to perform instead of days.

Rock engineer's mapping

Like the geologists the rock engineer needs to pick up features which affect the geotechnical aspects of the mine. He/she too can also speed up information presentation by using a FAKAWI.

Ventilation reports

Environmental engineering is another discipline in which practitioners need to record where they take their readings,

and where infrastructure items like fans are positioned. Higher precision and 3D representations of awkward angles can be achieved using a FAKAWI.

Accident investigations

Many accident investigations are hampered by poor diagrams of the site. Frequently accidents happen where changes in elevation occur. Surveyors are usually called to the scene with no labour to help do the tape measuring. With a FAKAWI the surveyor can measure up the site on his/her own and create a 3D model rather than plans and sections to satisfy the inspector's information needs.

Good practice evaluation of extraction

The tail-off in values outside the top and bottom contacts of the reef band mean that adjustment of the evaluation depends on how a stope is actually mined. Stope width control measurements are taken to estimate the average overbreak for a panel. If the control points are accurately picked up, it will be possible to contour the overbreak thicknesses instead of just averaging them. This will weight the points by the area they represent, resulting in a better evaluation and allowing for a more realistic mine call factor. The 'grade officers' can augment this information by locating backlog sweeping and places where reef has been left behind.

This is again a possibility that is achievable but requires a change in the software used. The straight histogram of a panel could be used to get the value for each contour area, but inputting all this information would be time-consuming. Block models using 3D blocks in 5–10 cm vertical increments would be better. These blocks would be cut out by the contour plans in a solids modelling environment.

Production official estimates of advances

Mine management is often accused of pouring condemnation on officials who do not achieve their targets. The nasty 'surprise' of not achieving production targets is wide spread. I would advocate that a shift supervisor be asked to profile his mine face with a FAKAWI at weekly intervals. This will give the senior officials an accurate idea of where problem areas are likely to be encountered during the month. They can then spend their time and resources on fixing the problem before it embarrasses them.

If this is taken one step further, it is then possible to get the shift supervisors to do their own month-end measuring. This would be a daunting prospect to many people, but much more likely to succeed if a FAKAWI was used. The surveyor would then put in pegs for the whole month (except for the days on which he/she would require to translate the shift supervisor observations into production actuals). When the surveyor inputs pegs he/she could check the face positions and gauge the accuracy of the measurement against his face position and the blasts booked. This would achieve the Utopian position, where the whole mine could be measured in a day.

Conclusion

The FAKAWI offers anybody on the mine the ability to measure and plot any observations. The simplicity of its mechanism allows the user to speed up and be more accurate in measurement work than currently.

FAKAWI introduces the opportunity to change the ways measurements are made and 3D images are created across a variety of disciplines. It can change the way we work.