The Development of Hydropower at Beatrix 3 Shaft

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SYNOPSIS

The implementation of hydropower at Beatrix 3 shaft has put the claims of this ‘new technology’ to the test. It was found that, practically, no pure hydropower solution is yet possible, and that the implementation of it was more complex than initially anticipated. Due to the higher cost of hydropower, operations have to produce more effectively – not only to cover the higher cost of the new water system and equipment – but also to be profitable.

This paper details Beatrix 3 shaft’s current position of hydropower implementation, its main challenges, successes and projects for the future.

INTRODUCTION

The concept of hydropower was first properly developed in 1985, with commercial units reaching viability in 1992. It is now more than 10 years later, and considering the rate at which new technology is developed and implemented around the globe, hydropower should no longer be called a new development. By this time, hydropower should be able to deliver to expectation.

Hydropower is the term used to describe the use of water as an energy source for a variety of machinery. This is achieved through a water source that is pressurized – usually by virtue of a difference in height – and carried via high pressure pipes to various stopes and development ends, where it is used. Typical end user pressures range from 14 – 18 MPa.

Due to the cost of reticulation installation and equipment, only new shafts can be fully hydropower equipped. While these shafts number less than 5, they are large and potentially risky undertakings. Some have been successful; others are still paying their dues. Unfortunately, no shaft has rid itself completely of pneumatic reticulation – an expensive legacy of the old system.

Beatrix Gold Mine is at the very bottom of the Witwatersrand golden arc, 40 km south of Welkom. It is a shallow operation – 1 and 2 shafts operate at an average depth of 800 m, while 3 Shaft will mine at 1 200 m. A neighbouring mine, Oryx, is now Beatrix 4 shaft. This is an intermediate depth mine at an average depth of 2 000 m. A scattered mining method using conventional pneumatic mining with rail bound transport is applied at these shafts. 3 Shaft currently operates on levels between 1 100 m and 1 350 m deep. Beatrix is a low grade operation, and this makes the location of panels critical to gold output.

Beatrix 3 shaft is an expansion project designed to mine at 30 000 m² per month by 2008 via 1 500 m of development. The production will cover six levels. This will help maintain, and ultimately boost the overall mine production to 70 000 m² per month in 2013. In the ‘final’ proposal for the shaft in 1993, hydropower was not initially considered as a power source. Aside from the immaturity of hydropower at that point, it was planned that the surplus capacity of compressed air and water which was available at the existing shafts, would be made use of until the new shaft required an independent system. The use of redundant equipment and standardization of equipment were also seen as beneficial. On review, it was decided to implement hydropower – and make a concerted effort to discard compressed air entirely.
The sinking of 3 shaft began in July 1996 and was completed in 2001. The shaft is currently in the build up phase. Contractors were used to carry out some of the development up to December 2002, when the mine took over all development operations. Currently, contractors are being used for specialized work.

Geologically, the shaft lies close to extensively faulted ground. The reef has a flat dip of 10 degrees. This presents one of the biggest problems in the effective use of hydropower cleaning – there is very little assistance of gravity when cleaning. The reef is on average 1.4m wide. There is competent quartzite above the reef and soft MF quartzites below it. There is substantial fissure water in some areas and infamous methane in others.

The depth of the shaft has created the first real rock mechanics constraint in layout on Beatrix. Panel face lengths are limited to 30m, localized regional support is provided by widely-spaced stope pillars left on strike. On a larger scale, the area immediately surrounding the shaft was mined out first, leaving four satellite shaft pillars, each 150m x 150m, and 275m apart. Mining the shaft area has just been completed, and backfill has been placed. The weak footwall has affected pillar placements.

**HYDROPOWER POSSIBILITIES**

The various papers written and sales pitches given about hydropower have been upbeat and optimistic. Particularly when combined with rigs and basic machines, water energy is proclaimed as the universal remedy. This information is far from wrong. Some of the more commonly presented advantages are listed below:

- Hydropower equipment is considerably less noisy than pneumatics – and the noise generated is of a higher frequency – more easily dampened by ear plugs.
- Drills operate at a rate much faster than pneumatics thereby increasing productivity.
- Less vaporization of water and no use of oil improve the working atmosphere.
• Cold hydropower water creates a microclimate which saves on cooling costs.

• Rig use allows accurate drilling, which leads to less explosive induced damage, leading to less falls of ground and less scaling.

• Rigs are operated by one man, who is removed from the face (where most Falls of Ground (FOG) occur), and the rockdrill itself (avoiding noise and vibration induced illnesses). The operator thus suffers less fatigue.

• The water powered loader is silent and more rapid than its compressed air counterpart.

• Water energy is virtually free, or cheap, with the help of gravity to build up required operating pressures.

What is also true, but less common, are the pitfalls of hydropower:

• Hydropower pipes are expensive. The larger bore pipes are imported, and the Rand fluctuations make this risky. Long lag times from order to receipt also occur.

• Equipment is considerably more expensive than its air counterpart. It is also normally heavier. This means parts are more costly too. Hoses particularly, are an expensive consumable.

• Hydropower equipment is a more advanced technology than pneumatics. This means less internal tolerances. Water needs to be of a good quality, treatment needs to be careful (machines do not take well to the 'hammer repair' method) and procedures need to be followed. As this does not easily happen overnight, initially maintenance and repair of equipment is costly.

• Drilling at double the rate is certainly adventitious, but if hydropower is not implemented to take advantage of this, all that has been put in place is an expensive way of letting the crews “knock-off” early.

Many of these challenges can be overcome through good management and procedures.

THE 3 SHAFT SYSTEM

The shallow depth of 3 shaft meant a hydropower system with a surface booster pump was the preferred option. The rest of the system is relatively simple, and consists of one 300mm Nominal Bore (NB) pipe leading down the shaft, to a narrowing string of pipes on each level. Final pipe dimensions, in the stopes and development ends, are 50mm NB.

The system serves six levels from 1 092m to 1 342m deep. Surface pumps generate 6.5 MPa of pressure. The system, with pressure regulating valve (PRV) stations on the lower levels, gives a constant and reliable 17 – 18 MPa to the face equipment.

An important thrust at 3 shaft is to make hydropower the sole means of mechanical energy on the shaft, with one exception: compressed air to supply refuge bays which is required by law. To date, hydropower driven areas still have some air operated equipment, as no effective solution has been found for cases such as charging up with ANFO and the desludging of blast holes. Current solutions involve water driven air compressors feeding modified air equipment. Initial indications are that the equipment will need improvement to match its air counterparts.
CURRENT DEVELOPMENT

3 Shaft development is still close to the station, with two levels developed sufficiently to allow ore flow from stoping. All main development comprises of 3,5m x 4,0m haulage and RAW ends. Initial cross-cut spacing is 120m – which will be extended to 150m once grade behaviour is better understood and stoping has got under way (Figure 1).

The work is being completed through the use of an array of equipment. Part of one level is being developed through the use of electro-hydraulic equipment (this will not be further detailed). Over the last few months, work with pneumatic equipment is being phased out; the balance of the developing is being done by Mantis drill rigs, HPE drill rigs, handheld machines and the Monorail Raise Climber.

![Figure 1](image)

Until recently, triple shifts were run on some of the equipment, but this has been reduced out to conventional single shift blasting and to double shift blasting of raises.

- The Mantis drill rigs (Figure 2) are used by contract miners. The tyre-mounted rig is self-propelled using a diesel engine to move it from end to end. When at the end it is connected to the electrical supply to drive a motor and pump which supplies the rig with hydraulic power to operate the twin booms. The rockdrills are normal hydropower drills mounted onto the booms. The rig drills the support as well as the face. Cleaning is done by diesel LHD which tips into hoppers.

The rigs are operated on two shifts. Each shift blasts two 3,3m rounds. Advances of 160m per rig per month are being achieved.

The contractor supplies all of his own labour which includes (per shift):
- One Master Operator who drills
- One fitter who maintains the machinery and drives the LHD
- Four equipping and charging labourers
- Two locomotive drivers

The development layout was changed to accommodate LHD cleaning. Connecting cross-cuts are spaced 60m apart instead of 120m and are broken away at 90 degrees.
Track installation is done up to the second last connecting cross-cut. This is done by another contractor.

There are currently two rigs in operation as of January 2004 with two more planned in the next two months. The purpose of the rigs is to rapidly access a block of ground on four levels.

- Three hydropower HPE drill rigs (Figure 3) are in use. The blasting cycle is simple. Subsequent to cleaning with a hydropower loader (Figure 4), the support rig (Figure 5) is trammed in, and tendons installed. This is removed, and the drill rig pushed in. Finally, after drilling, the rig is removed and charging up takes place.
While the rig has many advantages, such as:

- The operator is removed from face
- Fast drilling with three booms
- Low physical effort
- 3m long rounds
- Single operator

Figure 4

Figure 5
The following problems were encountered:

- The tramming of the various rigs/units is time consuming. A dedicated locomotive was implemented.
- Drill steel was damaged through the excessive application of force by the operators. Damage was in the form of sheared shanks and steel bent beyond recovery from the hole.
- Parts, in particular chains, broke regularly. The operators have been trained on part replacement and best practices, so that downtime is minimized and drill steel and chains are not damaged. The rigs are now reliable.
- Initially the ends advanced poorly. This was rectified by proper desludging and charging methods.

Advances of 80m per rig in a month (haulage and RAW together) have been achieved, with over 70m advances achieved on consecutive months.

- Flat end development crews are made up of five Hydropower Operators who drill, blast and equip the end. One locomotive driver is used on day shift for shunting and material transport to the section. Three people work on night shift to clean with a hydropower loader and battery locomotive. They normally clean two ends per shift, depending on the advance rate of the end.

  Crews average 35m per month. Although this is a conventional type of mining with hydropower energy it is very flexible.

- Subsequent to discussion with Hydropower Engineering (HPE), it was decided to test a monorail mounted raise climber (Figure 6) in a new raise line.

  The machine is hydropower driven, and comprises of four segments that run on a toothed track hung closely to the hanging wall. The front segment is a single boom hydropower rig which is used to drill the face with a 2,1m round. The second segment is the operator’s cab, followed by a hose reeler which manages the hydropower hose as the climber moves. The last component is a load carrying tray, for the equipment necessary to work.

  The climber has proven to be reliable and largely problem free. The development of the raise is done by a four man crew, who perform all the operations, equipping and cleaning. Subsequent to the entry examination, roofbolt support is drilled by a hydropower hand machine and installed. The necessary rail segments are installed by attaching them to the eyebolts secured in the hangingwall. The segments can be installed at a range of gradients to accommodate the changing reef behaviour. Subsequent to installation, the rig is moved forward and drilling begins. The rockdrill operator (RDO) remains at the face while the others extend the pipes. Charging up with ANFO is done with compressed air, and the round is fired using a shot exploder.

  Current face advances are 35m to 40m per month. Only one unit is on trial at present however this project has huge future potential.

  The monorail is utilized during the ledging and equipping phase of the raise. The rails can be left in place as they are ‘blast-on’ rails. The boom is swung to the side and the initial ledging round drilled. The load tray, which HPE claims is able to carry a winch, can be used for exactly that as well as other equipment. As current ledging and equipping costs are high, and the duration long, the monorail should go a long way to streamlining the process.

  The labour saving and extra advance generated through hydropower is critical to future production on 3 shaft.

  Development has begun to show returns; with the “Meter per In Development Worker” running at 5,0 and the “meter per Total Costed Employee being 3,2. The costs have come off a high of R18 290 per meter to current levels of R7 065 per meter and the trends are favorable for further cost reductions.
CURRENT STOPING

The stoping operations at 3 shaft got off to a bumpy start – the mining of the reef in the immediate vicinity of the shaft required special precautions. During sinking, the inner pillar was removed. The outer pillar was recently completed. Faulting in the shaft area allowed water from the stopes to enter the shaft orepasses. This lead to the stope converting back to pneumatics in order to reduce the amount of water entering the passes.

Aside from this, excess water in the shaft pillar meant that hydropower stoping was stopped for some time. Reverting back to hydropower is almost complete, with all new raise lines on full hydropower systems. Currently three-quarters of production is generated by hydropower crews. Other areas have a hybrid system namely: compressed air drilling and hydropower cleaning.

The balance of the operation will move to hydropower when crew training is complete.

Stoping layouts are similar to most narrow reef metalliferous mines. From drives, cross-cuts are developed to reach just below the reef plane. Here raises are developed with attacking points, from which up and down-dip ledging to 15m either side of the original raise is done. Breast panels are then established. 50m Interlevel spacing is due to the shallow dip of the reef.

The stope panels vary in size from 15m to 4m. This is due to various rock mechanics considerations related to the proximity of the shaft and increased depth. On average, however, a panel is 25m long. A strike pillar, three meters wide, is left on the up dip side of each panel, with two meter wide holings every ten meters. (Figure 7)

Many changes have occurred to the stope layouts in order to optimize the use of the equipment and counter problems experienced in the past.

Stope panels are 25m long and operate much like 1 and 2 shaft: pneumatic or hydropower drilling of holes (using a stope jig (Figure 8) or hand-held), capped fuse detonation and face scraper cleaning with the mini-cannon assisting (Figure 9). Stope crews are nine people on day shift and three people on night shift.

With regard to hydropower itself, various aspects are apparent.
Very few intrinsic design failures have been noted, and the supply of spares is good enough to not be problematic. The crews enjoy the hydropower equipment – particularly the cleanliness of it. Hydropower is also supported by the stopers and the production supervisors.

The expected efficiencies have not yet been realised at 3 shaft. However, they are steadily climbing as techniques and modifications have improved. The main problem encountered is the flat dip of the reef. This means pure hydropower water jet cleaning is not feasible. Through a hybrid system (face scraper and mini-cannon) much has improved.
The high cost of maintenance warrants mentioning. Beatrix 3 shaft, as is recommended in various papers, from the hydropower equipment suppliers, outsourced the maintenance of its equipment to the suppliers. Initially, problems were encountered with mechanical reliability and spare parts, but this was to be expected under the circumstances of a new shaft with untrained crews. The HPE rig and loader reliabilities were low, and maintenance cost for drills was high with a long turnaround time, as the drills had to be sent off site to be serviced and repaired.

Hydropower equipment is also considerably more expensive than air equipment, so a new part is costly. This is however offset by the longer life of the product and results in lower operating cost than pneumatics.

Good water quality required for hydropower at 3 shaft is difficult to achieve. The reason for this is the highly corrosive fissure water which is pumped from the shaft. The water is filtered and treated so that it meets the high standards necessary for hydropower. If the water is not properly treated it can lead to internal component corrosion and wear.

The operators have not yet truly appreciated the sensitivity of the equipment to dirt and rough handling. Initially, maintenance was characterized by rockdrills that had been damaged by being struck or left lying in water and mud pools, or connected up to dirty hose ends.

Costs during this period led the shaft to build its own repair stations on site, managed and operated by the suppliers. They carry their own supply of parts. The workshops include drill repair shops, equipment to cut and repair hydropower hoses to the required length and a valve test station. Existing workshops have helped reduce costs by sixty percent and reduced the turnaround time of items they repair.

Maintenance costs have fallen considerably since the implementation of on site repairs, but this trend is also due to other factors. Personnel have improved their treatment of the equipment, and poor handling now constitutes about half of the maintenance work. The correct storage of equipment would save fifty percent of the shaft’s maintenance cost. A peculiar finding is the number of fully operational rockdrills that are sent to the surface for maintenance. This is due to poor fault finding procedures – once again a training issue.
Large valves have been reliable, with only three repairs needed to date. Some unusual problems have occurred – gloves or rocks found in the valve.

Maintenance of equipment is logged and a feedback system is in place, so that suppliers can monitor the performance of their equipment and make modifications if necessary. Suppliers also have their own full-time personnel visiting areas underground to look at improving equipment use and life.

The compliment of engineering personnel is important. Hydropower is a more technically advanced system, and while it may reduce the labour complement on the face, it requires an increase in the engineering and support complement. Qualified engineering personnel are needed to maintain the system. Initial steps did not include this which led to long waits before repairs were undertaken. This has been rectified and standing time has been dropping as the reliability of equipment goes up and the training and experience of the users improves. The supply companies operate on a maintenance contract.

**SAFETY**

Over the last 18 months, only five accidents directly related to hydropower have been recorded. Two of these were treat and returns, one lost day injury and two serious injuries – a fractured toe and a fractured finger. These injuries were caused by operators not adhering to safety precautions.

The low accident rates indicate the inherently safe nature of hydropower. Of the few accidents which occurred, only one was related to water – a treat and return, the others were more ‘cause neutral’ – generally pinching by moving equipment.

What has been noted by its ‘non-existence’, are FOG incidents on rig operations. While rigs do create a more stable hangingwall due to accurate drilling, they also remove the operator from the high risk zone and stop hand collaring. Mechanization reduces finger, back & lifting injuries. Safety devices are built into the reticulation system to automatically shut off the water in case of a rupture.

There is consensus on 3 shaft that the hydropower equipment is definitely superior when it comes to noise, atmosphere, cleanliness and ambient temperatures. The value of this is not easily determined, but what is noticeable is a ‘mood’ improvement across the shaft. Along with the new infrastructure, cemented cross-cuts (to prevent gold losses) and professional trackwork (to minimize derailments), hydropower helps generate a modern and professional feel to the operation.

**HUMAN RESOURCES**

There is a shortfall in trained and experienced hydropower crews as a higher level of skill is required. This has delayed the stoping switchover to hydropower. The lack of experience has led to some bad habits, such as the poor treatment of equipment, which is expensive. In order to combat this, training is done over six weeks – where workers are multi-skilled, trained in safe use of equipment and fault-finding procedures. A team building week is scheduled on completion of formal training. The team exercise, termed ‘Bompodi’, also helps to generate a holistic process to stope work, which, among other benefits, will lead to the support of the hydropower process by smaller, more productive crews.

As in all new shafts it takes time for the new crews to establish themselves, adjust to the new technology and work together effectively. Experienced operators have been selected to work with the inexperienced crews and train them in best practices.
FUTURE PROJECTS

Plans to address the current problems and future work expansion are in place. Some of the highlights are listed below:

- New stoping layouts, which will not differ drastically from present layouts, are being looked at. This will be used to optimize the use of hydropower. Double shift blasting is being considered.
- The fleet of drill jigs in use is being expanded.
- Development end rounds are going to be examined to help generate a more effective blast.
- Training will be continued.
- Rockdrill allocation will be monitored more closely.
- A HPE drop-raise rig (Fig 10) is being tested with excellent results.
- A hydropower ANFO loader is in operation and is effective; however the weight of the unit is an issue.
- Emulsion units are being investigated for development ends.
- Hydropower grout gun is being designed.
- Hydropower fans will be installed in Methane areas.

Figure 10

- Water control is always an issue and innovative solutions are required to solve this problem.
CONCLUSION

The start-up of a new shaft is crucial to its success or failure. In order for hydropower to be successful it must be correctly implemented. Correct implementation depends on putting the right procedures in place, focusing on training and the necessary support to backup the system.

Hydropower has many advantages including improved safety, reduced physical effort, increased productivity and reduced cost. Pumping and compressed air costs are not seen as a direct cost to the mining core business as a per unit cost, thus the perception that conventional mining is still more cost effective that hydropower. Electrical energy cost in pumping and compressed air was in the region of 50% of the total energy costs to GFL in F2003. The end user will never realize these costs until such time that effective energy allocation can be channeled to the end user. All these elements make hydropower a viable technology at shallow depth, provided it is seen as a holistic system and correctly implemented.

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