A critical comparison between a compressed air driven rocker arm shovel and a track-bound non-throw loader

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Paper written on project work carried out in partial fulfilment of B.Eng. (Mining)

Synopsis

This report compares the compressed air driven rocker shovel to the newly developed Warthog Non-throw development end loader. The two machines were compared on aspects such as safety, loading potential, energy efficiency and costs. The objectives of the comparison were to determine whether or not the replacement of the rocker shovel with the Warthog will be operationally and financially justifiable.

The results from this study were obtained from underground observations and time studies on the machines, as well as consultations and data collection at the shaft and suppliers.

This paper compares only the Warthog loader to the Trident 215 rocker shovel used at Anglo Platinum's Brakspruit shaft and does not compare the other models of rocker shovels, which are fundamentally the same but will have different loading potentials and specifications. Cleaning times for the rocker shovel are based on underground observations at Brakspruit shaft. These times can be influenced by factors such as blasting practices, compressed air pressure and operator experience and skill. For this reason the times will most likely vary at different shafts. The Warthog cleaning times are based on manufacturer specifications and results from trial stages and therefore further work is required to confirm cleaning times achieved.

The findings from this study indicate that the replacement of the rocker shovel with the Warthog will improve the safety, production, cost and energy efficiency of development end cleaning operations. The Warthog also complements the system of rapid face advance achieved by the Mantis drill rigs, by achieving faster cleaning rates to handle the longer advances and larger volume of rock. In this way the Warthog benefits the overall efficiency of flat end development.

Introduction

For more than 70 years the cleaning of flat development ends in the hard rock mining industry has been done by means of compressed air driven rocker shovels. The use of these machines result in numerous accidents every year due to the inherently unsafe loading action used.

The rocker shovel loads rock as shown in Figure 1. During operation the operator stands next the machine and moves back and forth with it. The controls for the drive motor and the bucket lever are situated on the left-hand side of the machine.

It is a combination of the loading action, position of the operator, and working conditions in the development end that make cleaning with a rocker shovel labour intensive, unsafe and dependent on the skill and experience of the operator.

The mechanization of development ends, such as using the Mantis drill rig at Brakspruit shaft, has been very successful at improving advance rates. The rig has achieved highs of 100 m per month and an average of 60 m per month (Croll, 2006). This is a significant improvement from the 30 m per month advance using conventional drilling. This rapid advance rate, however, has encountered problems with cleaning operations; rocker shovels do not complement higher face development rates due to their loading potential, which is suited to conventional advances. For this reason a faster more efficient development loader is needed.

These factors have resulted in a need for safer, more productive, less labour intensive mining methods and thus the need for mechanization and improvement of machinery has become a major focus. The development and implementation of the Warthog non-throw loader aims to improve production, reduce the labour intensity of conventional loading operations, and reduce the exposure of workers to the hazards of underground rocker shovel cleaning.

The Warthog

The Warthog consists of three main working components: the back actor, front bucket/scoop and the conveyor belt. It operates using the back actor to load the front scoop with rock. It then pushes the rock up the scoop onto the conveyor belt. The conveyor runs

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 Paper received Mar. 2009; revised paper received Mar. 2009.

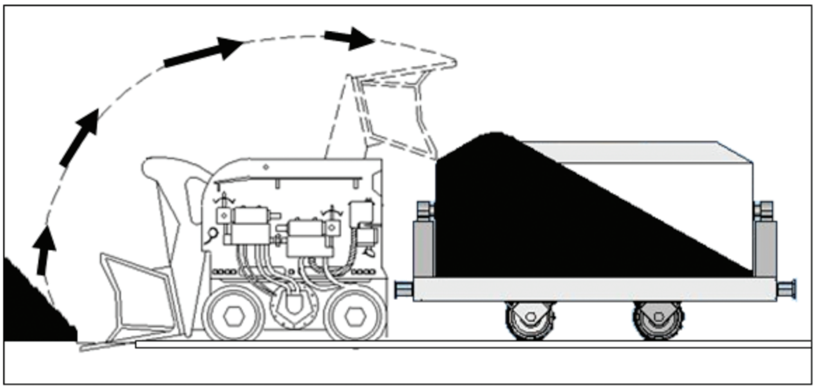

Figure 1—Rocker shovel loading action

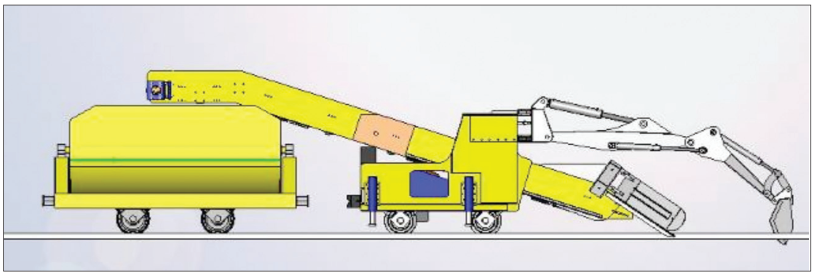

Figure 2—Side view of Warthog

continuously, transporting the rock to the hopper directly behind it. Figure 2 illustrates the side view of the Warthog with the hopper directly behind it.

During loading, the body of the Warthog remains stationary, stabilized by four hydraulic props. In this way only the back actor and conveyor move, ensuring that the portion where the operator stands is stable and stationary. The loader is self-propelled and can be driven forward when necessary. The side flaps of the scoop can be adjusted with the hydraulic cylinders to assist with loading and to adjust the width of the machine to the haulage width.

Results

Safety

Operator position

The position of the operator, with relation to the moving components of the machine as well as the development end, determines the risks and hazards which to they are exposed.

When loading with a rocker shovel, the operator stands next to the machine and walks back and forth with it. In the case of a derailment severe injuries can occur to the operator due to the loader riding over his feet or toppling over and pinning him against the sidewall.

The throwing action of the loaders bucket results in the full bucket getting thrown over the machine, directly in front of the operator. The operator's close proximity to the bucket during the throwing motion makes him/her susceptible to injury from large rocks or foreign objects such as wire sticking out of the bucket.

When cleaning the development end, the Warthog is stabilized by four hydraulic props and the operator stands on a platform, which remains stationary during operation. This eliminates the risks of slipping and falling while operating the machine and reduces the chances of derailments because the wheels are stabilized and motionless.

Figure 3 illustrates the position of the different operators during loading. The black shaded area represents the front 3.5 m of the development end that has recently been blasted and is therefore completely unsupported. This is also the area where the majority of the broken rock lies, and therefore where the operator spends the majority of the time cleaning. When cleaning in this area the operator is exposed to the risks of falls of ground and rolling rock.

The Warthog's reach allows the operator to clean an entire end from a safe and supported area. The distance from which the operator works also reduces the risk of rockfall incidents or accidents. The reach obtained by the back actor reduces the amount of time that the machine spends on the sliding rails, which are unstable and can result in derailments.

Derailments

The derailments and the consequent re-railing of track-bound machinery is an industry wide problem, particularly with heavy machinery. Because of the confined space of development tunnels, derailments pose a major risk to underground mine employees who can be severely injured by the machine. The most common and dangerous derailment injuries are from machines falling against people, crushing them against the sidewall, and from the wheels coming off the tracks and riding over their feet and legs.

The safe re-railing of the rocker shovel is a problem that the mining industry has been faced with since the machine was first introduced 70 years ago. There is as yet no effective re-railing method that can be considered safe and efficient.

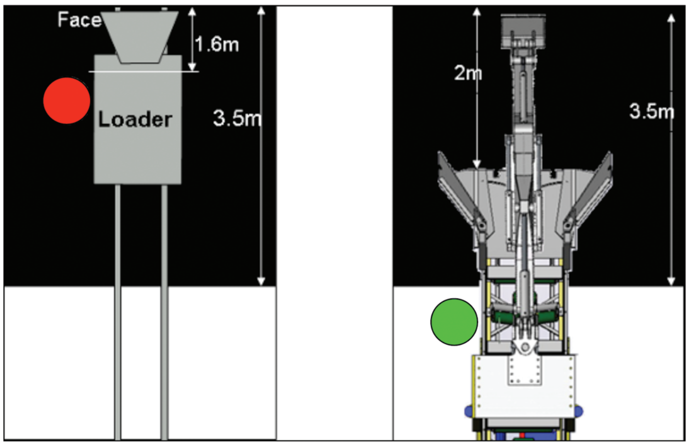

Figure 3—Operator position during loading

While loading with the Warthog, it is stabilized and remains stationary. It also has a very controlled loading motion. This makes it less susceptible to derailments while loading. If a derailment does occur it will likely happen in a more controlled manner and will be noticed and corrected before injury occurs.

Noise

Noise-induced hearing loss (NIHL) is a major problem in mining, costing the South African mining industry millions of rand each year. In addition to this, the quality of life of the person with the hearing impairment is greatly reduced (Clark, 2005). According to Clark (2005) some of the many effects of noise on people are: annoyance, decrease in productivity, physiological distress, and physiological changes. The frequency and severity of accidents also tend to be higher in noisy working environments.

Rocker shovel operators have the most severe mean hearing losses compared to other underground employees. The operators are exposed to noise levels of 111.4 dBA (Edwards, 2001). This is substantially higher than the 85 dBA legal limit and results in NIHL.

The Warthog emits less than the 85 dBA noise limit and therefore poses no risk to the hearing of the operator, (Sachse 2008).

Power source

The rocker shovel is powered entirely by compressed air. When a compressed air hose is opened without being securely fastened to the loader, or when it breaks loose from the machine that it is powering, severe damages can occur. The high pressure of the air that it supplies causes the hose to fling around uncontrollably with a great deal of force, injuring people in the vicinity.

The Warthog is powered by electro-hydraulics. The lubricant oils used in underground machinery have flashpoints that are three times higher than petroleum and can be ignited if there is a leak. This creates the risk of fire. For this reason the machine has a fire extinguisher installed and operators must be trained to extinguish fires. The trailing cable, used to supply electricity to the machine, has the risk of being driven over by the loco or hoppers passing it. This can cut the cable, damaging the power supply and can electrocute nearby employees. These factors can pose major risks if not monitored and controlled effectively.

Productivity

The throwing action of the rocker shovel generally results in the hopper being filled to only approximately 60 per cent of its maximum capacity, this is because the throw of the rock does not reach the back of the hopper (Figure 1).

The Warthog uses a conveyor belt system that discharges the rock directly above the hopper. The hopper moves forwards or backwards to ensure that it is being effectively filled. In this way the hopper is loaded to its maximum capacity and a load factor of 100 per cent is achieved.

From these load factors and results from underground observations it was found that the rocker shovel requires 22 hoppers and the Warthog requires 16 in order to clean a 2.5 m advance.

The time taken to clean an end is shown in Table I. The hopper tramming times recorded during the cleaning shift are based on time measurements made on level 11 west. The tramming distance from the face to the tips is approximately 2.5km. Therefore the tramming times will vary on different levels, depending on the distance required to tram and the amount of traffic along the haulage. By comparing the results obtained from the time study we can see that the Warthog can clean up to 2 hours 22 minutes faster than the rocker shovel.

This faster loading time can be utilized by cleaning two ends per shift. This can be achieved by blasting two ends on day shift or by using one Warthog to replace two rocker shovels on one half level. Each half level uses two rocker shovels, one for flat end development cleaning and one for cleaning at the base of travelling ways and boxholes.

Blasting two faces in one shift is possible with the Mantis drill rigs; however, cleaning constraints with the rocker shovel has limited it. With the higher loading potential of the Warthog it should be possible to clean two ends on night shift.

Blasting two faces every day will likely encounter equipping constraints, therefore a better option may be to blast one flat end on one day and two every second day. In this way the Warthog can clean two flat ends on one day, and one flat end and the bottom of a travelling way or boxhole every second day.

Table I

Results from time study

	Rocker shovel	Warthog	Variance
Hoppers required	22	16	11
Loading time	6 x 22 = 132 min	5 x 16 = 80 min	52 min
Shunting time	5 x 22 = 110 min	5 x 16 = 80 min	30 min
Tramming time	120 min	60 min	60 min
Total cleaning time	6 hours 2 min	3 hours 40 min	2 hours 22 min

By utilizing the Warthog in this way it can replace two rocker shovels and the monthly call can be increased from 55 m to 80 m.

The potential production benefits on one half level associated with increasing the call to 80 m/month over one year are shown in Table II.

The production benefit on one half level that is using a Mantis drill rig and Warthog would result in an additional R84 311 493 worth of proven ore reserves being made available for further development after one year.

Cleaning applications

The Trident 216 rocker shovel can clean a span of only 2.36 m, in a 3 m wide development end; this results in about 64 cm width of fly rock being left along the sidewalls. When cleaning the bucket is filled by pushing it forwards into the rock pile. This becomes troublesome when the rock pile is small and when there is no solid face to push against, making it difficult and more time consuming to clean. This rock will need to be hand lashed by the day shift.

The Warthog can clean a span of about 6.3 m. It can therefore clean right up to the sidewalls of the development end and can also be used for cleaning cubbies and cross-cut breakaways. The back actor also allows it to clean right to the footwall when necessary. It therefore has the advantage of reducing the need for hand lashing, thereby reducing the labour intensity of development mining operations on both night and day shifts.

Power supply comparison

The rocker shovel is powered by a 50 mm compressed air hose, It consumes approximately 850 m^3/h of air at a pressure of about 400 kPa. The compressed air pressure supplied at the face and resultant consumption is less than what the manufacture specifies, this results in less throwing power and possibly decreased productivity rate. Higher pressure would, however, result in greater throwing force and likely increase the possibility of injuries associated with the throwing action and derailments.

The Warthog is powered by a 525 V electrical supply. This is the same supply that powers the Mantis drill rig, and therefore no additional installation is required. It uses a 2.5 kW motor to power the conveyors drive pulley and a 15 kW motor to power the hydraulics.

Energy efficiency

The energy efficiency of energy delivery media is shown in Table III. The energy efficiency of electro-hydraulics is significantly better than that of compressed air. This results in the Warthog consuming far less energy to operate than the rocker shovel (Sachse, 2008).

The comparison between electrical power and compressed air is difficult as both of these power sources have significant benefits over the other. Compressed air has advantages such as reliability and safety benefits, as it eliminates the risk of electrocution in the wet underground working conditions. Problems with using compressed air are the inefficiencies due to excessive air losses as a result of leaking air columns, poor maintenance, and equipment efficiency.

Electricity is a more efficient source of power with generally lower running costs. There is, however, risks of electrocution. These risks have become less as technology and safety devices have been improving. There is also the problem of power failures, during which time machinery stands.

The realization that electricity supply in South Africa is at risk and the significant price increases that will be applied, has resulted in mines applying stringent power saving strategies. Compressed air is very inefficient and is one of the largest electricity consumers in hard rock mines. To improve the energy efficiency of mines replacing compressed air with other more efficient systems is therefore essential.

According to Petit (2006) compressed air operated machinery is being challenged in favour of more energy efficient alternatives and the likelihood is a shift towards full electric mining. If drilling is done with electric or hydropower drills, replacing the rocker shovel with the Warthog would mean a non-pneumatic mine is possible. The Warthog is therefore a more prospective option for future mining operations that may phase out the extensive use of compressed air.

Table II

Production benefits on one half level

	Rocker shovel	Warthog	Variance
Call per month	55 m	80 m	25 m
Total meters after 1 year	660 m	960 m	300 m
Replacement factor	48.6 m^2/m= 200 ton/m	48.6 m^2/m = 200 ton/m	
m^2	32 076 m2	46 656 m^2	14 580 m^2
Ore reserves	132 000 tons	192 000 tons	60 000 tons
Grade	4.12g/t	4.12g/t	
Ounces (28 g/oz)	19 423 oz	28 251 oz	8 828oz
Value of proven reserves ore available after 1 year (R 9 550 /oz): prices (20/01/2008)	R 185 489 650	R 269 801 143	R 84 311 493

Table IIII

Efficiency of energy delivery media (Sachse, 2008)

	Generation efficiency	Reticulation pressure drop	Energy after leaks	Efficiency of end use equipment	Overall efficiency
Compressed air	50% x	64% x	18% x	33% =	1.9%
Oil electro-hydraulic	80% x	80% x	100% x	42% =	27%

Costs

The running costs are determined using a 23-day month and the time the loader spends loading during the shift (including shunting time but excluding tramming time). The unit costs of compressed air and electricity are based on the average of the last 3 months of 2007 at Brakspruit shaft. Labour costs were not included in this comparison as these amounts could not be released by the contracting company due to confidentiality.

Table IV illustrates capital and annual running costs. It can be seen that the energy efficiency of the warthog results in lower power costs than the rocker shovel. The maintenance costs of the warthog however are likely to be higher than that of the rocker shovel.

The total ownership cost (TOC) of each machine over a 5-year period is shown in Table V. The present value (PV) of the running and maintenance costs is calculated using an interest rate of 10%. The present value (PV) factor of 3.791 was calculated for 5 years at 10%.

The total expenses of the Warthog will be about R 350 000 more than the rocker shovel. This cost is almost twice that of the rocker shovel. If the Warthog can replace two rocker shovels, as mentioned, then the costs and expenses of the Warthog will become slightly less than those of the two rocker shovels that it replaces. By including the potential revenue of the proven ore reserves available for further development, the PV of the total cost shows that the Warthog is the more feasible option. The additional 319 million rand worth of proven ore reserve that can be made available sooner therefore justifies the use of the Warthog.

Conclusions

Safety

The operational safety of the Warthog far surpasses that of the rocker shovel. The Health and Wellbeing of development end machine operators are also made better by the lower noise levels and less strenuous working conditions to which they are exposed.

Table IV

Capital and annual running costs

	Rocker shovel	Warthog
Capital cost	R205 000	R 400 000
Maintainance cost	R36 000/ year	R 96 000/year
Power cost	R 20 021/year	R 2 211/year

Table V

Total ownership costs (TOC)

	Rocker shovel	Warthog	Variance
Capital cost	R205 000	R400 000	R195 000
Running cost (PV)	R75 900	R8 381	R67 519
Maintenance cost(PV)	R136 476	R363 936	R227 460
PV of cost to mine (5 years)	R417 376	R 772 317	R354 941
Present value of proven ore reserves made available	+ R703 191 263	+ R1 022 816 133	R319 624 870
Total owning cost (TOC) over 5 years	+ R702 773 887	+ R1 022 043 816	R319 269 929

Production

The Warthog can clean a development end approximately 2½ hours faster than the rocker shovel. If this time can be utilized efficiently it should be possible for the Warthog to replace two rocker shovels on a half level. The monthly call on one Mantis drill rig can also be increased to 80 m, resulting in an additional R84 million worth of ore reserves being made available each year per half level. The Warthog can therefore complement the systems of rapid face advance in development ends which the Mantis drill rigs can achieve.

Power supply

Compressed air and electricity which powers the rocker shovel and Warthog respectively both have significant benefits over one another. In terms of reliability, compressed air operated machinery is generally better than electrically run machines. The efficiency of compressed air is significantly worse than electro-hydraulics. With the current energy concerns in Southern Africa the need for energy efficient operations has become of great importance. The Warthog therefore offers a more energy efficient development end cleaning solution.

Costs

The present value of the cost to mine of one Warthog is close to double that of one rocker shovel. If utilized to its full potential the Warthog can replace two rocker shovels on each half level, thereby making the cost neutral. The total owning cost of the Warthog indicates revenue of 319 million Rand more than the rocker shovel when taking into account the value of proven ore reserves that can be made available after 5 years. This justifies the use of the Warthog.

Ultimately the rocker shovel is a very difficult machine to replace because of its simple, robust and reliable design, which is well suited to the mining industry. However, in order to improve the safety of mining operations, workers need to be removed from hazardous working conditions. Mechanization such as the Warthog aims to improve safety by allowing workers to operate machines from a safer position as well as to reduce the manual labour intensity of operations.

Acknowledgements

The contributions, support and guidance from Dr Ronny Webber-Youngman is greatly appreciated. Mr Udo Sachse from New Mining Technologies, Anglo Platinum, as well as the personnel at Brakspruit shaft are thanked for their contribution and support.

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