Integrated design of an XLP dozer

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Underground mining imposes very rigid constraints on mobile equipment design. The choice of a particular mining ‘method’—i.e. the specific mix of techniques for excavation, ground support, and materials handling—is greatly influenced by the nature of the orebody being exploited. Mining methods tend to be fairly conservative, relying upon well-established and proven equipment designs. In order to improve worker safety and productivity, South African platinum mines have increasingly turned to mechanization. An added benefit of these mechanization efforts is that the nature of the mining can be modified based on the feasible equipment designs. These efforts have resulted in changes to the mining methods employed in South Africa’s narrow-reef platinum group metal (PGM) orebodies, as well as the development of a suite of mobile equipment which enables implementation of the new production processes. This paper focuses on the design and development of one of these machines—a narrow-reed bulldozer suited to selective mining. The resulting machine is a miniature unmanned bulldozer and multipurpose crawler platform designed for narrow-vein mining applications, with integrated mechatronics and remote control capabilities. This paper will discuss the development of the machine and the applications for which it was designed.

Introduction

For several years mechanization has had a tremendous impact on the underground mining industry. Successful development of new mechanized mining systems requires long-term collaborative partnerships between many parties, including mining companies, equipment suppliers and academic institutions [Robbins (2000)]. As a specific case, underground narrow-reef platinum mining in South Africa has driven innovation in increasingly sophisticated mining methods with advanced machinery. The aim of such innovation in mechanization has been primarily concerned with increasing productivity and improving safety. A general discussion of the issues regarding the introduction of mechanization in an underground narrow reef mine is presented in Willis et al. (2004). Among the criteria identified for successful introduction of mechanization, an overall ‘holistic’ integrated approach is deemed essential. This includes concurrent consideration of mine design and equipment selection. Thus, the design and development of a new machine (or suite of machines) simultaneously with the development of a new mining method has the potential to achieve significant symbiotic benefits.

Mechanized mining methods utilizing specialized extra low profile (XLP) machines for narrow-seam platinum mining are currently in various stages of development in South Africa. A comparison of traditional mining methods with XLP mechanized mining of UG2 in the Bushveld Complex shows that XLP mining had the lowest waste dilution, highest production rates, lowest overall costs and the best head grade [Egerton (2004)]. A detailed account of XLP mechanized breast mining at Anglo Platinum can be found in Harrison (2006). The results of trials from various mine layouts in different locations are described. When benchmarked against conventional mining and low profile room and pillar methods, it was shown that XLP mechanized breast mining has the ‘potential to add more value’. Another account of the development and implementation of mechanized breast mining by a collaboration between Lonmin Platinum and Sandvik is presented in Pickering and Moxham (2007). Details are provided of the development process of the XLP suite of trackless mining equipment consisting of a drill-rig, roof bolter and loader.

The focus of this paper is to discuss the development of one particular machine, the Sandvik LZ100L dozer, designed to perform a specialized task within the overall mining method of XLP mechanized breast mining in South Africa. This will include a description of the machine and its function with respect to its operating environment and the overall mining method. Also, certain aspects of the design process will be highlighted along with specific design issues. Finally, some other novel applications will be discussed for which the machine is well suited outside of its intended design function.

The LZ100L dozer—an overview

The Sandvik LZ100L dozer, shown in Figure 1, is an extra low profile (XLP), remote-controlled underground bulldozer designed to operate in low-back (ceiling) work areas. With its compact body design, crawler tracks, and hydrostatic drive system, the machine is highly maneuverable and responsive, allowing users to quickly and safely move material throughout the mine.

The base machine dimensions are 850 mm (h) × 1 600 mm (l) × 2 750 mm (w) and the weight is 5 700 kg. It is powered by a four cylinder, indirect injection diesel engine.
with turbocharger. An on-board electric fill pump and filtration system is used for replenishing hydraulic oil. Each crawler track is driven by a variable hydraulic motor and the blade is driven by two hydraulic cylinders. Among the safety features is a fire suppression system with manual actuators located at two locations on the machine frame.

The drive configuration consists of an open-loop hydrostatic circuit comprised of a single variable displacement pump, flow dividing valve, and two variable displacement hydraulic motors integrated with double-reduction track drives. The machine steers by stalling the track on one side while driving the opposing track. Blade function is limited to blade lift and lower on the standard machine.

The LZ100L dozer was designed exclusively for remote radio control operation with a hand-held controller. A 900 MHz CAN-bus radio transceiver was custom-designed for the machine in collaboration with a well-known supplier of underground mobile equipment radios. The radio transmitter is slightly larger than a modern video game controller, as shown in Figure 2.

The controller has several built-in safety features that include dead man buttons on the upper edge of the controller that halts machine movement if the buttons are released, a tilt sensor that halts machine movement if the controller is tilted past a certain angle, a display screen to send prompts to the operator, an emergency stop button, and a built in access code. Through an onboard embedded CAN control, the LZ100L dozer is instrumented to gather data from sensors and send control signals to the actuators.

System monitoring and diagnostic capabilities are implemented through onboard instrumentation, such as pressure transducers, temperature transducers and electronic fluid level gauges, and allow the machine to respond quickly to events such as overheating, blocked filters or an overloaded pump. An effective troubleshooting tool was developed to identify the type and location of a problem and in some cases, provide a possible solution to assist operators and service personnel.

**Development process**

Sandvik Mining and Construction follows a well-defined Offering Development Process (ODP). The five phases of the ODP are: (1) collecting and screening, (2) business pre-study, (3) product development, (4) piloting, and (5) lifecycle management. In the discussion that follows, the focus is on phase (3) product development in the context of the LZ100L dozer.

The product development phase of the LZ100L dozer project began with the creation of a User Requirements Specification (URS) document in May 2004. The URS is a high-level document that does not detail specific features of a machine itself, but rather the functional requirements and operating conditions necessary for the system to accomplish its tasks without a predetermined solution in mind. The end goal of the URS was the development of a specification for a panel-cleaning machine or machines for use in an XLP mining capacity such that the machines meet the functional, maintainability, serviceability, cost and schedule requirements of the end user.

The next step in the process was to develop an implementation plan for the project. The objective of this part of the process was to build the project team, establish the project timeline, milestones and deliverables, and cost targets.

The initial concept design of the LZ100L dozer commenced in the second quarter of 2004. After just over a year, a fully operational prototype entered service at Lonmin’s Karee 1B mine in the third quarter of 2005. A series of extensive field trials were performed, followed by design improvements over the next eight months. Approximately 30 design improvements were made during this period. The following areas were identified for improvement:

- Track assembly mounting
- Track shoe configuration
- Hydraulic oil cooling
- Vehicle ground clearance
- Engine control
- Blade design.

Upon completion of design improvements, the LZ100L dozer entered service at Karee 1B in the first quarter of 2006, with full production beginning in the third quarter of 2006.

**Target application**

The LZ100L dozer was designed to be used as part of an extra-low profile mining operation. The first step in the overall ore extraction process is blasting of the face with explosives. The blast is designed to throw as much material as possible into the gully area. The resulting blasted
material that fills the panel is a coarse mix of ore and waste rock with an uneven distribution of sizes and shapes. Approximately 40% of material blasted from the face is thrown into the gully. A bulldozer then removes the excavation material from the very restricted space of the panel to the gully. The gully is a larger, more open space where an LHD (load haul dump) vehicle collects the material for transport to a conveyor hopper. This process is illustrated in Figure 3. The panel dimensions typically measure 4 metres wide, 21 metres along the face and as little as 1 metre high from the floor to the roof.

The use of a radio-controlled bulldozer to accomplish the panel clearance operation is a relatively new technique. The standard method to clear that panel is with large cable mounted buckets that are assembled and fixed to the walls within the panel. These buckets are operated to continuously drag the excavation material into the gully. This is very dangerous due to the likelihood of cables snapping. It is also very time-consuming to set up and reconfigure the infrastructure for the cable system. Moreover, the operator must be located further away from the panel. Therefore, the clearance operation cannot be monitored as closely, so much of the excavation material is left behind to be cleaned up manually.

On a historical note, early attempts have been made at introducing miniature ‘remote’ bulldozers for material removal tasks in underground mining. One such machine designed in the 1960s is described in Anon (1962) as weighing 1 746 kg and having dimensions of 0.75 m high, 1.5 m long and 1 m wide. The crawler track motors and...
blade positioning cylinder are actuated pneumatically though a handheld control box. The purpose of this machine is to move broken ore into the paths of scrapers.

The overall extra-low profile mechanized breast mining method in which the panel clearance task is performed, is shown schematically in Figure 4.

The orebody (or reef) is typically only 1.1 metres high, so breast mining is used to minimize dilution of the ore. The first step in this method is to develop the gully. The mining cycle of drilling with an XLP drill rig, blasting, bulldozing and roof support with an XLP bolt then ensues. Ground conditions are generally quite good so no pillars are required along the face. It is generally sufficient to screen and bolt the back, with grout packs installed as required.

### Design challenges

The harsh underground mining environment and restricted operating space presented a number of unique design challenges. The major design issues are as follows:

- **Traction:** The steel tracks operating on friable bedrock experience reduced traction and are subject to high abrasion.
- **Cooling:** The confined nature of XLP mining can make ventilation challenging.
- **Impact damage:** The frame is prone to frequent collisions with the roof due to 1.1 m stopping width.
- **Vibration:** Steel tracks on bedrock lead to vibration transmitted through machine structure, affecting electrical and hydraulic connections.
- **Serviceability:** The physical dimensions of the vehicle constrain component layout and accessibility.

As mentioned previously, the design of the machine commenced in Q2 2004. Approximately six weeks were spent evaluating sketches, CAD proposals and system specifications (hydraulics and electrical) prior to the commencement of detailed design. Important design constraints (apart from cost) were: machine dimensions (particularly the height), ambient operating temperature, power-to-weight ratio, traction and gradeability. The machine layout was largely determined by dimensional constraints, together with the necessity to have the radiator at the rear of the machine, so as to find room for the large radiator fan shroud. A preliminary layout of major machine components at week six is shown in Figure 5.

The blade linkage arrangement dictated the front of the chassis. A straight blade was chosen for the following reasons: 1) Simplicity; 2) Higher kW/m3 and kW/m ratios than a U-blade; 3) Low cost; 4) Higher production than an angle blade.

Using an industry-accepted drivetrain sizing and selection procedure, computations were made in order to size the diesel engine, hydrostatic drive pump and motors. The results were then checked empirically against other dozers on the market. For example, the power-to-weight ratio is approximately 8.2 kW/ton. This is in the middle range for a selected number of popular dozers used in the construction industry. A regression of engine flywheel power on weight for this sample of dozers yielded a predicted required engine power of 46.6 kW, slightly more than the 44.7 kW engine selected for the machine. However, it is also known that the highest power consumption on a tracked vehicle is when the machine is turning. Construction dozers must turn in all types of conditions such as clayve loam, which has very high cohesion. In contrast, the LZ100L dozer operates on dry, sandy material, bedrock and the occasional pile of small boulders. These conditions, combined with the fact that machine has comparatively high pushing power per cubic metre of blade volume, and per metre length of blade, indicated that the engine selected was suitable for the job.

The crawler tracks were custom designed for the application. Although there are many readily available dozer crawler tracks assemblies available for purchase from aftermarket suppliers, none of the ones examined that was suitable for the rugged application underground, were small enough to fit on the machine. Thus, a crawler assembly design project was initiated with the supplier.

As with all other underground equipment design criteria, reliability and serviceability of components were both extremely important. However, in the development of the LZ100L dozer, these considerations warranted increased attention. This is because the project not only entailed development of a machine, but was part of a much larger project, the development of an entirely new mining method, in which operating conditions are severe, and skilled service technicians are scarce. Design features such as automatic fire suppression, an on-board electric filling pump for the hydraulic tank, and a radiator with self-cleaning features were purpose-designed for the application.

### Field trial support

Proper field trial support is critical to overall product development, as illustrated in Figure 6. Throughout the LZ100L dozer field trials, feedback was transmitted back to the factory by onsite South Africa personnel, visits by factory personnel and a MAXIMO database. MAXIMO is a maintenance management information system that has been deployed to gather component reliability information as well as machine performance information. It documents key events with the machine such as repairs done to the machine, time the problem occurred, and the total downtime resulting from it.

Design reviews were conducted frequently throughout the 12-month trial, based on field trial feedback. Some aspects of the prototype design were improved and implemented as the trial progressed, such as blade design, crawler track shoes and radio control. This process was repeated until the targeted KPIs (e.g. reliability, availability and operating cost) were achieved, signaling an end to the trial.
Design improvements were made to certain aspects of the vehicle as more detailed knowledge about the operating conditions was gained. Some specific design improvements are as follows:

- The size of electrical panel was increased and mounted on sliders to facilitate connector access and serviceability.
- The fan shroud was mounted at the rear of the machine to facilitate wheel motor fitting access.
- The top covers and support structure were redesigned for easier removal to facilitate access to internal mechanical components.
- Extreme-abrasion hydraulic hoses were introduced to reduce hose jacket chafing due to the vibration of the machine.
- Wear components were incorporated into blade to extend blade life.

Future developments—leveraging the design to other applications

In addition to XLP mining, there is excellent potential for the LZ100L dozer in other mining and construction applications. One particular application was demonstrated at an opencast tar sands mine in Western Canada. The LZ100L dozer was shown to be able to effectively clean piles of tar sand accumulated under ore preparation plant feed conveyors. This is currently accomplished with front-end loaders. The benefits of using the LZ100L dozer for this task are as follows:

- The machine operator may be located at a safe distance away from the dangerous area directly beneath the ore conveyors.
- The machine operator may sit comfortably in the cab of a pickup truck, rather than being exposed to temperatures lower than -40°C that are possible throughout the winter.
- The machine itself is capable of moving more material, more quickly than current means due to greater power and traction.
- Since the machine has such a low profile, feed conveyors may be built lower to the ground, thus reducing infrastructure cost.

Furthermore, the LZ100L dozer has tremendous potential for research and development of robotics applications. A collaborative project is currently underway with the University of British Columbia, Queen’s University and Sandvik Mining and Construction to investigate an automated XLP panel clearance system. The onboard mobile computer control system, along with various onboard sensors such as pressure transducers and track speed sensors are well suited for developing and implementing innovative capabilities. Ongoing research is focused on the development of traction control to reduce track shoe wear, modelling of machine-terrain interaction, control algorithms incorporating the coupled effects of the actuators and autonomous task execution.

Conclusions

An extra low profile remote operated bulldozer has been developed and is currently being employed in mechanized platinum reef mining operations in South Africa. This machine, as a component of an XLP suite of machinery, has made a valuable contribution to an innovative new approach to mechanized platinum mining. Unique design challenges were overcome and new applications were discovered to make use of the capabilities of the LZ100L Dozer.

References


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