SORD – a novel underground dredge mining technology

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SYNOPSIS

The SORDMiner is a patented mining principle being developed to exploit mineral and energy resources that current technology can not access. SORDMiner is designed to operate in underground wet, granular, continuously collapsing geological environments such as alluvial and marine deposits. It is somewhat like a cutter suction dredge and should be capable of mining its way through any fine granular material like sand or gravel, pumping the slurry back to the surface. In areas where the target layer is covered, the SORDMiner is inserted below the water table and will tunnel its way to the mineral deposits at depth. This paper describes the development, concept testing and prototype construction of the SORDMiner.

1 INTRODUCTION

The benefits of being able to target underground mineral resources, remotely and with minimal surface environmental impact are substantial and obvious. Decker and Firth [1] outline the external drivers for future mining as:

- Provide better opportunities for an increasing portion of the global population (by increasing total resources available and reducing waste caused by low extraction ratios).
- Tread lightly on the earth for the long term by mining with minimal above ground infrastructure and material movement.
- Remove all workers from exposure to underground hazards.
- Reduce the impact of noise and pollution.

SORDMiner meets all of these criteria as it is able to tunnel into underground deposits leaving the surface environment largely undisturbed. There is no need for costly removal of overburden and it is also remotely controlled from the surface with the ability to target specific localised deposits or mineral strand lines.

SORDMiner consists of a SORD (Subterranean Operated Remote Dredge) head and a Shield (an extendable shield for the umbilical extending back to the surface) and is an approach invented by Sord Technologies Limited in Perth, Australia. Figure 1 shows the basic concept which looks much like a battle tank but with tracks above as well as below.

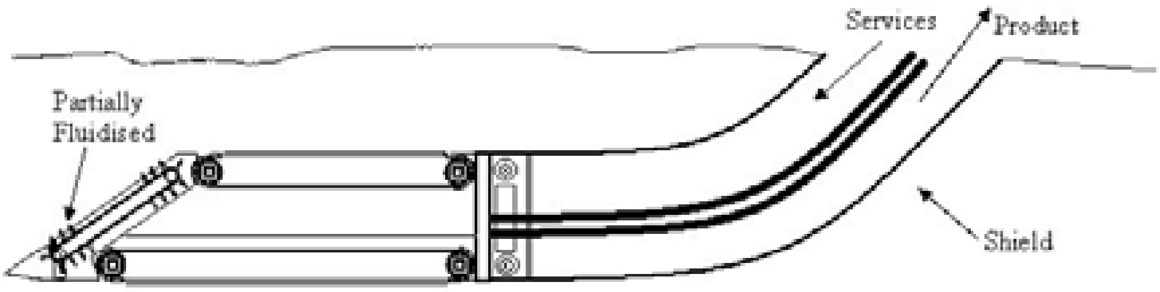

Figure 1 Cross section of SORDMiner and Shield umbilical

When mining, SORDMiner partially fluidises particles on the front face, creating slurry that is pumped to the surface through pipes within the Shield. The front screen is cleared by moving tines. After travelling forward, SORDMiner retraces its path, moving back into the cavity created by the Shield behind. Geophysical and navigational sensors keep the SORDMiner on track. The genius of the system is Shield, which is a self-extending rectangular tube that issues from the rear of the SORDMiner head. As the head moves forward, Shield remains stationary with respect to its surroundings.

2 SUITABLE MINERAL DEPOSITS

SORDMiner technology will allow access to many previously un-mineable continuously collapsing deposits beneath a water table such as oil sands, alluvial gold in deep leads, mineral sands, alluvial diamonds, iron sands, and submerged tailings for retreatment. The most economically significant targets at current commodity prices are the large oil sands deposits in northern Canada and Venezuela where portions of well explored reserves are under water or close to environmentally sensitive large scale river systems.

Another economically significant example of a SORDMiner target and one that has been well explored and technically investigated is the deep leads in the mid-north of the state of Victoria, Australia. Containing of the order of 20-30 million ounces of alluvial gold [2] the deposits have been well known for more than 100 years. During the period between 1860 and 1910 in excess of 5 million ounces was taken from the more easily accessible shallow leads in the region. Typical of these deposits, the gold is dispersed in the base of gravel leads (subterranean rivers) up to 100m below the surface. Alluvial gold is concentrated at the base of the lead and in a zone within 0.3 metres of the bedrock interface.

More recent attempts at mining have been thwarted by the large volumes of water flowing through the remaining unmined deep lead areas. CRA (now Rio Tinto) between the late 1970s and the mid 1980s expended at least A$15 million on exploration and research of the major deep lead deposits in Victoria. Drilling of some of the leads was conducted in conjunction with a programme of research and development into various solution mining techniques. No economically feasible mining method was determined.

The SORDMiner's approach to mining the Victorian deep leads is shown diagrammatically in Figure 2. The head would be inserted into the surface material just below the water table, mining through the drift material down into the layer of "wash" gravel just above the bedrock. Mining of the high grade gold bearing gravel would then commence, with the head moving backwards and forwards in the wash material which is from 50m up to 1400m wide.

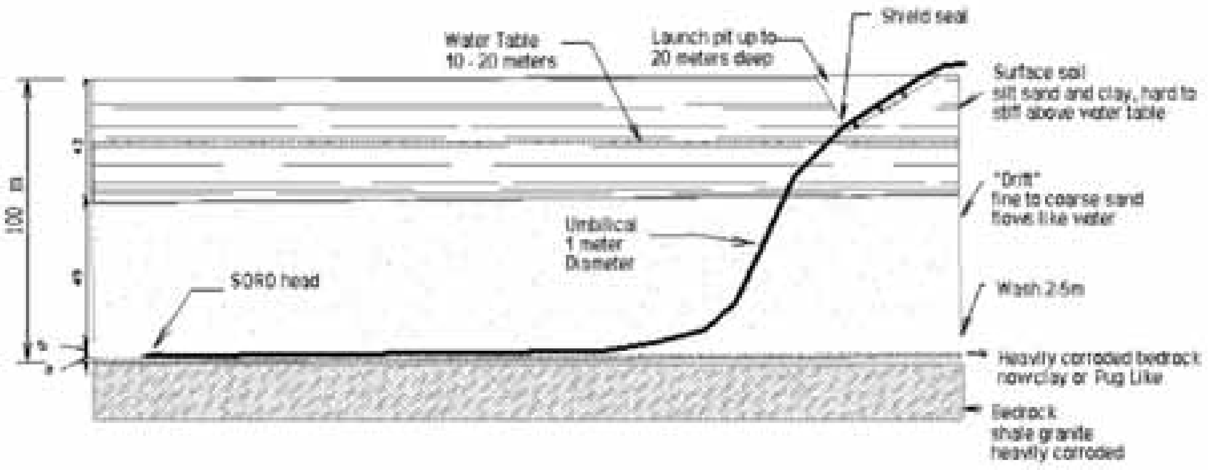

Figure 2 Cross section of SORDMiner in typical Victorian deep leads deposit

3 PRINCIPLE OF OPERATION

3.1 SORD Head

The SORD head combines a number of conventional processes to achieve its functionality. In its simplest form it is a self-propelled screen, with the "grizzly" at the front performing the essential task of separating the coarse material that is too large to be pumped to the surface. In conventional mineral processing plants a grizzly of the proposed aperture would be steeply sloped and material would feed over it so as to achieve size separation. In the SORD head, the critical design requirement is to ensure that oversize material (normally plus 25mm) moves off the screen and does not block the apertures through which undersize material must pass. To achieve this clearing action, there are tines that move between the grizzly apertures, up the screen slope to the top of the head. Instead of normal solid grizzly bars, pipes are used so that water jets onto the facing material, fluidising the smaller particles. The combination of water jets on the surface of the grizzly and a pump below the screen provide the pressure differential to draw undersize material through the grizzly. This is illustrated in Figure 3.

The SORD head contains a number of centrifugal slurry pumps which will deliver the screened material to the surface. Selection of the pumps to pass the desired particle size and to develop the required head and flow is relatively straight forward and not dissimilar to typical dredge mining applications. As the pumped material has a wide size and density distribution it is important to ensure that velocities in the head and the discharge line are sufficient to prevent settling.

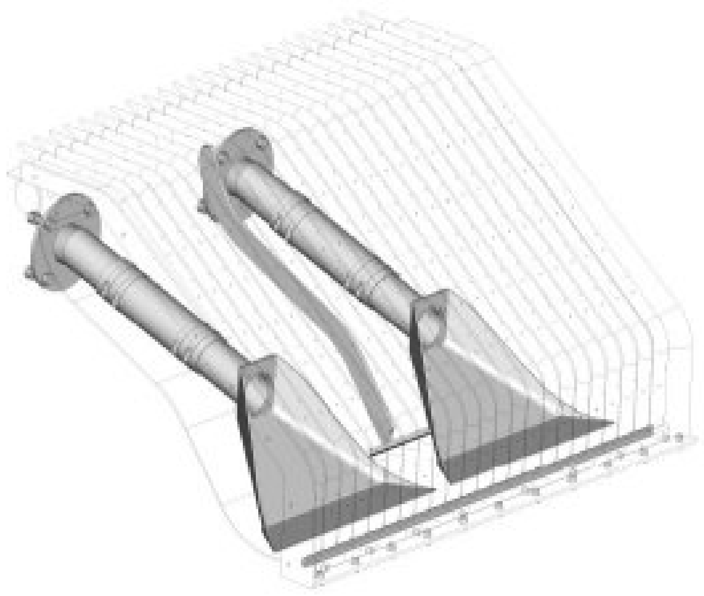

Figure 3 Slurry pump inlets and grizzly screen with water jets at the front of SORDMiner

The use of water jets in the cutting and delivery of the solids to the pump inlet combined with the surrounding water dictates that the suspension entering the pump has a relatively low concentration, say less than 30% by volume. Such suspensions are inherently unstable and care needs to be exercised to ensure their successful transportation, in particular on re-starting the line in the event of an unscheduled shutdown. Horizontal hydraulic conveying of such suspensions with material that have size and density ranges similar to those expected are quite common and vertical hoisting of run of mine (ROM) and spoil products are an established technology [3]. However, in the case of the SORDMiner everything that is harvested by the miner must be pumped to the surface without modification and through pipelines that will have varying grades or angles of inclination from horizontal to vertical. As such, high discharge velocities (of typically around 4m/s) are proposed to ensure that all the material is transported to the surface regardless of pipe orientation.

The head also contains the electric motors and hydraulic pumps and motors necessary to power the tines, drive tracks and the slurry pumps. Also within the SORD head there will be a navigation system which will be critical to ensure the head can be steered through the mineral bearing horizon and to avoid previously mined areas. Lastly, at the rear of the head is the Shield deployment apparatus.

3.2 Drive thrust

The SORD head is driven by rubber faced tracks coupled to chain conveyors on the top and bottom surfaces. The tines in the grizzly also assist with propulsion as a result of the actions of the tines in moving material backwards over the top of the head.

To assess if the drive-thrust of the tracks and tines exert sufficient force onto the surrounding strata to overcome drag, extensive modelling work was undertaken by the CSIRO [4]. The calculations for this were based on a lower bound solution for the maximum pressure of the collapsing, water saturated frictional soil stratum. The driving capacity of the tracks for a number of different ground conditions was calculated.

In a granular environment such as mineral sands the resulting angle of contact friction of the tracks (averaged over the total contact area) is close to the internal angle of friction for sand (25-30 degrees). Based on a full scale model with a total drive track area of $18m^2$, a conservative estimate of the thrust is about 150kN. Because of the back-sloping grizzly, in general the thrust provided by the top drive track is smaller than the thrust from the bottom drive. This results in a net clockwise moment favouring upward movement of the head which needs to be counteracted by the "dive" planes.

The drag force acting against the progress of the head is the sum of the drag across the external surfaces and protrusions of the head. This drag is determined by the angle of friction of the metal-sand or gravel interface relative to the face of the head. The front screen area can be removed from the calculation as it should be operating as a fluidised bed with the slurry being drawn from this face by the slurry pumps "sucking" the head forward.

Again using the mineral sands as an example, drag is mostly from the sides of the head (area about 12 m^2) plus some non-track areas top and bottom, as well as the Shield deployment tool. Using a head weight for a production machine of approximately 20 tonnes, a conservative estimate for total drag should be in the range 20-60kN. This means the driving force should be ample to propel the head forward.

Further insight into issues such as the balance between pumping action and forward movement, effectiveness of "dive" planes for directional control, drive traction and drag was obtained by Mullhaus et. al. [5] using a 3D discrete element computational method (DEM). Using novel panel elements with both geometrical constraints for the motion of the surrounding soil and the ground water, each panel element sensed the resulting force and moment from the local pore pressures and the particles in contact with the panel. The effect of wall friction was also considered. The SORDMiner head was modelled using 8000 panel elements, with each tine made-up from 6 panels and drive belts on the top and bottom consisting of about 600 panels each. Each kinematic component had its own mass centre whereby the mass centres of the tines and the drives are continuously moving relative to the resulting mass centre of the head. The tines and grizzly model with water jets is shown in Figure 4. The computer modelling supported the simple analysis of SORDMiner motion underground.

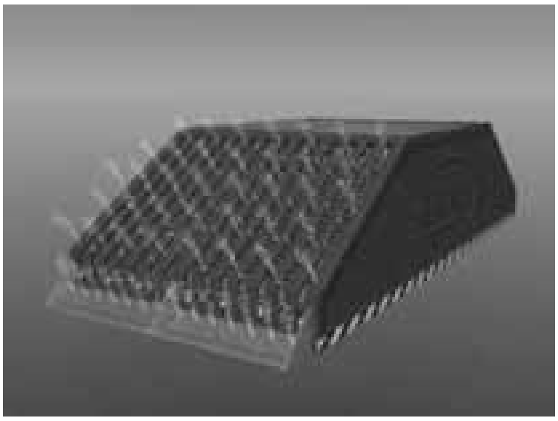

Figure 4 DEM computer model of SORDMiner head showing tines and water jets [5]

3.3 Shield umbilical

The Shield is a fluid inflatable cloth tunnel deployed from the rear of the SORDMiner head and designed to protect the umbilical within from rock collapse. The umbilical connecting the head to the surface supplies electrical power, sensor and control system cables, high pressure water lines as well as the slurry pipes carrying the ore back up. The umbilical floats within the Shield which in turn is filled with water or suitable density non-settling slurry (eg. drilling mud) to ensure the correct pressurisation balance to resist the force from the surrounding strata.

The polymer cloth outer of the Shield is initially stored flat in a roll at the surface rig. When it is deployed it is drawn down through the inside of the outer shell around a set of rollers in the deployment tool at the back of the head before being “zipped” together to form the new outer shell. As such, once deployed, the outer cloth remains stationary to the surrounding strata allowing the extension or retraction of the cloth back up inside the Shield depending on the direction of movement of the head. The area around the outer lip of the deployment tool is continuously flushed to prevent particles clogging the zip during operation. Figure 5 shows a simple circular Shield with two zippers. The square Shield uses 4 zippers, one just around from each corner. A detailed description of the operation of Shield is given in the core patent of Graham [6].

The Shield is a new concept within the mining industry though a similar principle is used in pile boring through unstable and permeable layers which would otherwise collapse and flow into the hole. In pile boring, mud is pumped into the hole and forms an impermeable coating on the material in the unstable strata. A positive pressure is then maintained within the hole which prevents the surrounding material flowing into the hole. The pressure differential at the interface is typically limited by the depth of the water table and possible density of the mud used. Differentials of the order of 5 m equivalent of water are reported to be common. It is proposed to operate the Shield with a differential head of approximately 2 to 4m water.

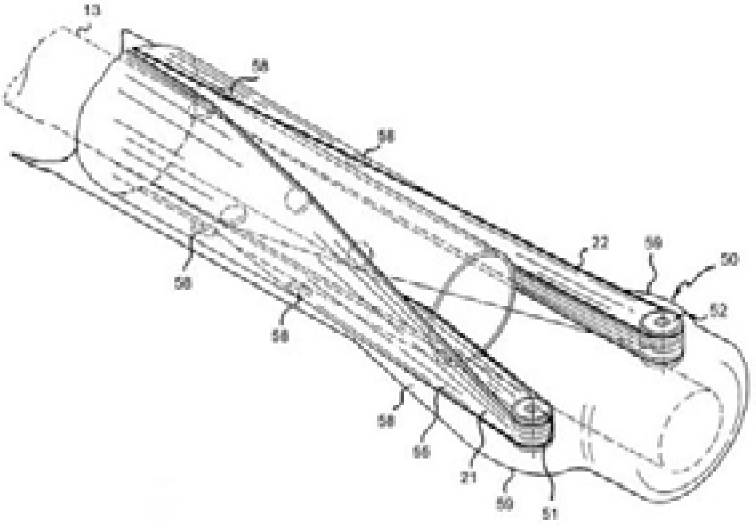

Figure 5 A circular Shield deployment tool sketch from the original patent [6]

The drag to draw the umbilical down through the Shield should be relatively minimal. The electrical cables and polyethylene slurry and water pipes will have relatively neutral buoyancy depending on the solids concentration and density of the chosen inflation slurry and low friction coefficient against the cloth.

The design of the zipper to close and seal the Shield as it is deployed has been carefully studied with both FEM stress analysis and prototype testing to optimise geometry. A proprietary ZipSeal design has been developed which provides a very strong push-in type seal that is relatively low cost. Separating loads of up 4 tonnes per lineal meter have been applied to the prototype zip seal without failure. The typical ZipSeal profile is shown in Figure 6.

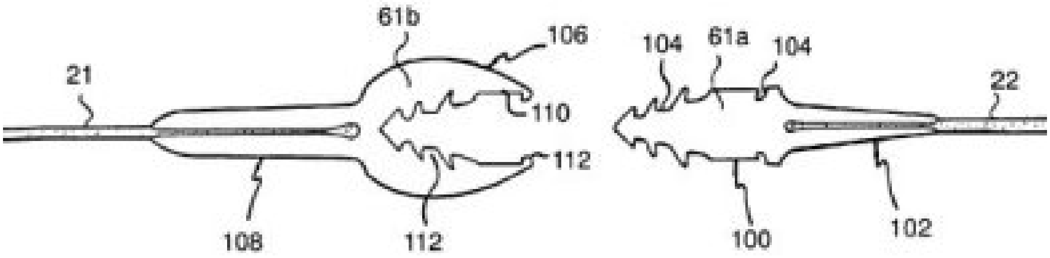

Figure 6 ZipSeal sketch showing the “pine tree” branch design [6]

In-principle simulation of the Shield has been undertaken in a small scale sand tank designed to test deployment, flushing and the ability of the cloth to support (relatively shallow) sand loads. The test tank was 15m long and 1m deep and is shown in Figure 7. The pressure data confirmed the support characteristics of both the circular and square profile Shields in settled sand.

Figure 7 Deploying the model Shield in the slurry test tank

4 PROTOTYPE TESTING

As with many new technologies, the simulations and concept testing can only provide answers up to a point beyond which a prototype of sufficient scale is required to prove the overall design. A prototype size of 5m long x 1.6m wide x 1m high was chosen as the smallest size where all the equipment selection and design could be economically tested. Design was based on mining sand up to a distance of 50-100m from the surface rig and at a depth of up to 10m. Nominal sand mining rate is 100t/h.

The overall internal layout of the head is shown in the 3D model in Figure 8. Starting at the front there is the grizzly with tine drive motors on either side. In the middle are the drive track hydraulic motors and then the two slurry pumps and piping. Towards the rear is the hydraulic oil tank and pump and lastly at the tail are the rollers of the Shield deployment tool.

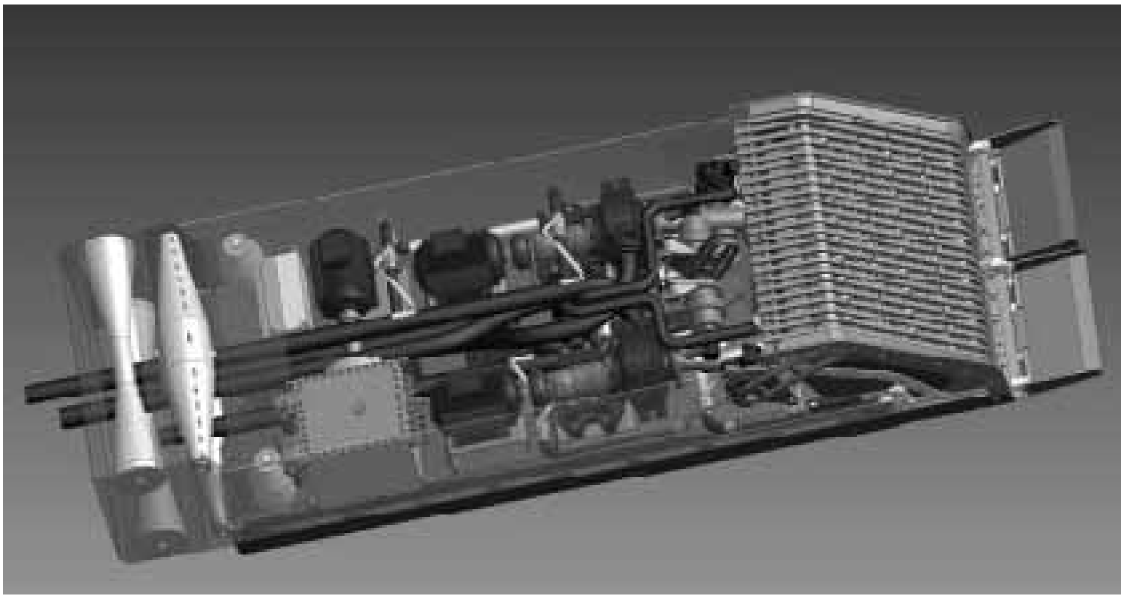

Figure 8 Internal equipment layout of the prototype SORDMiner head

4.1 Slurry pumping and water circuits

The slurry pumping circuit consists of two parallel centrifugal pumps feeding separate discharge lines. The slurry pumps are 4/3AHE Warman®[1] with 55kW specially designed liquid filled electric motors that are direct coupled to the pump. The motors operate via variable frequency inverters giving a pump speed range of 0-2200RPM. The discharge pipes will extend from 50-200m long and at a flowrate of 40l/s and nominal 30% by weight slurry, each line will deliver approximately 50t/h. The discharge line velocity is about 6m/s in the 100mm HDPE pipe at this duty. This compares to the calculated settled bed velocity of approximately 2m/s for sand slurry with a d_{50} particle of 300 μm.

The separate process water circuit is pressurised by a 700kPa centrifugal pump feeding 3x100mm nominal HDPE pipes down to the head. There are a number of water jets around

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[1] New technology (post 1991) Warman® slurry pumps from Weir Minerals are sold as Envirotech® pumps in Africa

the grizzly for fluidising the face as well as flushing points in the head (for clearing chain sprockets and cleats). Specifically, there are 600 holes in the grizzly pipes for the forward facing fluidising jets, there are seven jets on each of the side skirts of the grizzly protecting the chain ways for the tine drive and seven lift jets from a header at the base of the grizzly spraying out over the dive planes. As well as these essentially fluidising jets, there are two large 50mm diameter angled jets from a separate header feed into the suction of each of the pumps to provide for start-up and shut-down flushing or dilution should it be required.

Automated valving allows flow to individual jetting systems to be varied as required to modify concentration or clear blockages.

The slurry pumps are shown assembled into the head in Figure 9.

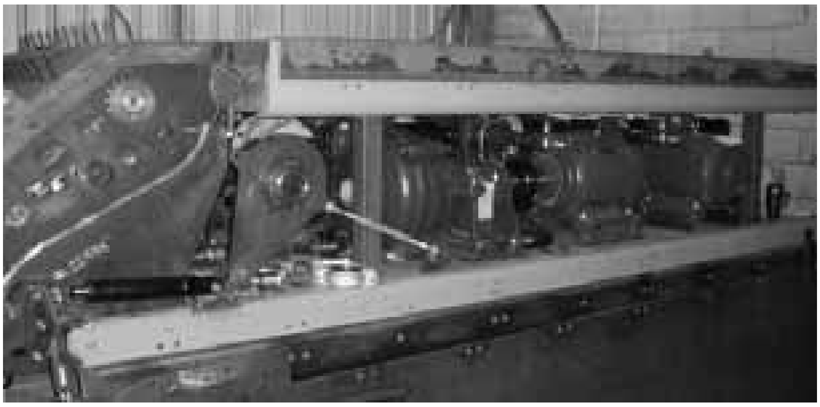

Figure 9 Partially constructed prototype SORDMiner head with tine drive sprockets and Warman® pumps in position

4.2 Tine and track drives

The tines are driven by two 15kW hydraulic piston motors capable of generating a tine speed of up to 5m/s. As with many equipment choices for the head, the tine drive motor was chosen conservatively to ensure worst case ground conditions and soil types could be handled. The grizzly screen gap width is 25mm. The tines drive sprocket, side skirts and grizzly are shown in Figure 10.

Figure 10 Front grizzly screen and tines in partially constructed prototype SORDMiner head

There are 2 drive tracks on the top and bottom surfaces of the head as shown in Figure 11. Two drives on each surface are required to enable some directional steering (like a skid-steer tractor). Four 10kW hydraulic motors provide up to 80kN of thrust from the tracks with linear speeds up to 40m/h underground for the 8 tonne head.

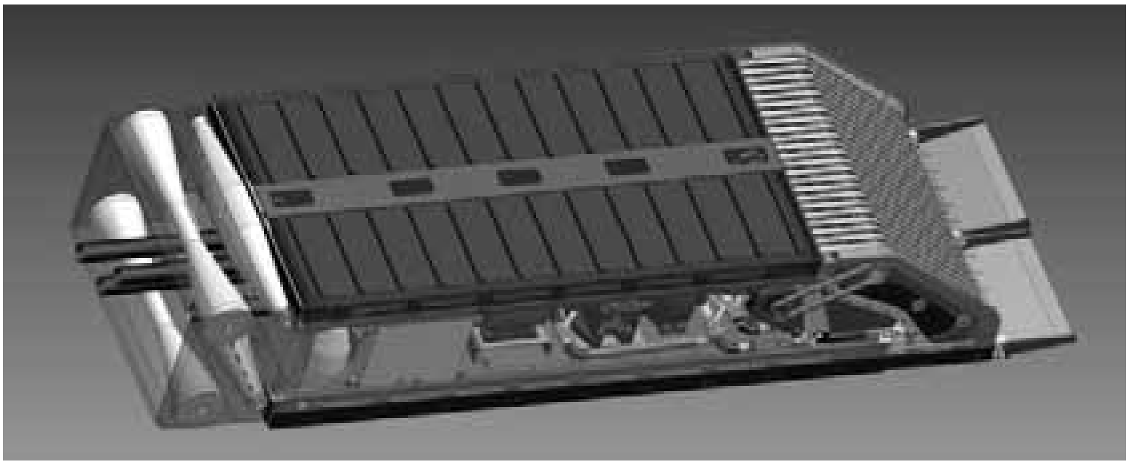

Figure 11 Dual track drives on the top surface of the SORDMiner head model

The track surface is conveyor belting that is held in place by metal cleats bolted to brackets on the chain drive. Figure 12 shows the construction of the tracks with end rollers, bearing plates and drive sprockets and chain for the rubber faced tracks.

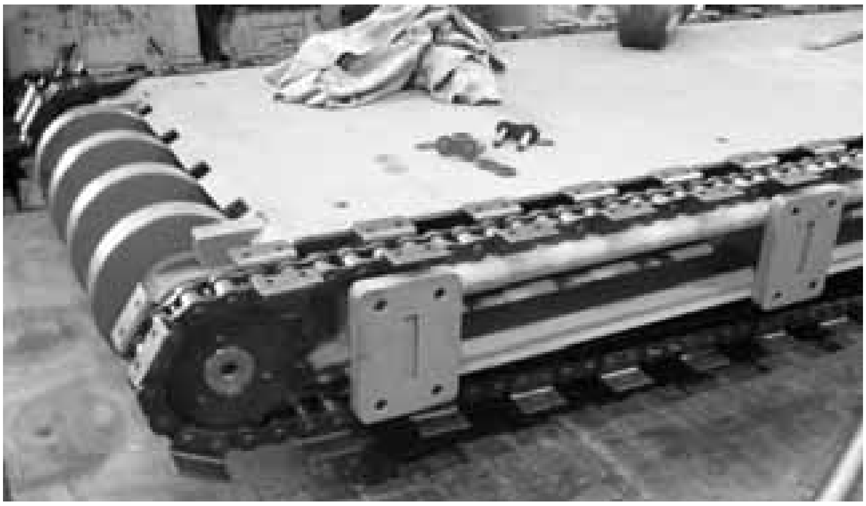

Figure 12 Track drive chains and bearing plate of partially constructed prototype SORDMiner head

The sealing of the drive track ends is important to prevent a build-up of carry-over material in the body of the head. A hydraulically operated slide seal is used to scrape the face of the track retracting out of the way of each passing cleat. Any excess sand is flushed out of the end zones by water jets. Side sealing of the track is via a thick flexible rubber skirt running against a metal side plate.

4.3 Instrumentation

The instrumentation philosophy for the prototype is based on relatively simple measurement of key parameters.

- Hydraulic pump: pressure, temperature, tank level.
- Slurry pump: inlet and outlet pressure, flow, power input, speed, solids concentration.
- Water pump: outlet pressure, flow.
- Jets: pressure and flow.
- Dive plane: inclination angle.
- Front tines: speed, hydraulic pressure.
- Drive tracks: speed, hydraulic pressure, distance, actuation monitor, load cell.
- Head: inclinometer, magnetic compass, accelerometer.
- Deployment tool: speed, load, video, pressure, deflection angle, pressure.

5 SUMMARY AND CONCLUSION

SORDMiner is a novel technology for extracting valuable minerals from wet, granular, underground, environmentally sensitive deposits. As part of the capital raising activities of the company, various industry experts have been involved in providing commentary to the viability of SORDMiner. While recognising the high risk attached to the development of the technology, most [4], [7] believe that SORDMiner is viable if the myriad engineering details can be worked through to a reasonable level of reliability. As the next step in bringing this technology to commercial application, prototype construction is underway and plans for future in-ground trials are well advanced. These trials will be important to understanding potential operational issues and validating the proposed mining system.

Once prototype testing is completed it is planned to design larger units that will go into production. It is estimated that scale-up of the SORDMiner to handle production rates of 1000t/h or more will be possible.

6 REFERENCES

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