REEF MOLE 950 : CLOSE OUT REPORT FOR TRIAL RUNNING FROM JANUARY 2012 TO DECEMBER 2012

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EXECUTIVE SUMMARY

The reef mole 950 (RM950) is an electrically powered, hydraulic, continuous hard rock mining machine, designed to mine at a stoping width of 950 mm. The RM950 follows the RM800, which was installed at Townlands shaft in 2003 and trialed up to 2006. The concept utilizes standard roller cutters similar to tunnel bore / raise bore cutters, mounted on a swinging boom, to cut an opening of 5m wide by 0,95 m high.

Following extensive re-design to address RM800 problem areas and increase cut width from 800mm to 950 mm, the RM950 was built from RM800 parts as well as newly manufactured parts during the period 2008 to 2011.

The RM950 was trialed at Batho Phele shaft during 2012. The project got bogged down in problems, to the extent that, at the end of the trial on 11 December 2012, none of the set objectives or KPI's had even partly been achieved and a total of just less than 6 m advance into rock had been recorded.

The problems encountered fall in the categories mechanical failures, hydraulic problems and problems emanating from a poorly constructed launching cubby.

The positive, to be taken from the trial, is that all of the design solutions on the RM950, implemented to solve problems of the RM800, have proven successful during the limited cutting of the trial. The qualification is that not enough cutting has been done for full evaluation.

New mechanical failures, experienced on the RM950, but not on the RM800, were all either related to parts manufactured not to design specification, or to extra-ordinary loads introduced as a result of the poorly constructed launching cubby. The exceptions are a problem with the design of the steering cylinder porting, which led to failure and cutter bearing retainer loosening. The cause of the latter is still not fully understood at writing of this report and measures taken to counter cutter bearing retainer loosening need to be evaluated during further cutting trials.

No design deficiencies have been identified during the trial, which would require a 'back to the drawing board' approach.

During the period August 2012 to October 2012, underground activities were suspended, following failure of a swing cylinder rod, which required a lengthy repair process. This time was also utilized to properly address all other problems encountered up to that stage. The machine was thus in good mechanical and hydraulic condition, when cutting resumed on 10 December 2012. Only some 600 mm of cutting was done before the cutter bearing retainer loosening problem occurred once more and the trial was ended at that point. This cutting advance finally placed all of the machine grippers on hanging wall and foot wall of machine excavation (solid, smooth rock) and thus should end the problems emanating from the poorly constructed launching cubby.

Since the end of the trial on 11 December 2012, the cutterhead has been removed and all cutters are being re-assembled to new specifications and under stricter control, as measure to solve the cutter bearing retainer loosening problem. An additional vacuum hose tensioning device has been designed and manufactured, for installation on top of the hydraulic reservoir, to alleviate vacuum hose kinking.

The machine should be ready for further trial by July 2013.

As result of work done on the machine during the period of repairs to swing cylinders, the machine is in good condition and ready for further trials, once the cutterhead has been re-installed.

Wear rate of vacuum hoses remains a concern.

1 INTRODUCTION

The reef mole 950 (RM950) is an electrically powered, hydraulic, continuous hard rock mining machine, designed to mine at a stoping width of 950 mm. The RM950 follows the RM800, which was installed at Townlands shaft in 2003 and trialed up to 2006. The concept utilizes standard roller cutters similar to tunnel bore / raise bore cutters, mounted on a swinging boom, to cut an opening of 5m wide by 0,95 m high.

Rock is broken by the reef mole in chips of maximum 60mm x 40mm x 20mm, which are sucked up and transported by vacuum to be dumped directly on a conveyor belt.

The RM950 utilizes three hydraulic grippers to anchor itself inside an excavation during the cutting action. It has to be launched from a pre-constructed cubby, inside which the grippers can be gripped.

Following the trials on the RM800 at Townlands shaft, an extensive re-design phase was gone through to iron out problems experienced and to increase the cutting width from 800 mm to 950 mm. The RM950 was built from RM800 parts and new parts, starting late 2008 and extending up to 2011, when final workshop tests were done.

The machine was transported to Batho Phele shaft in fully assembled state and was off-loaded on surface at Batho Phele shaft on 4 October 2011.

Transportation of the machine to underground site was achieved by affixing skids underneath and dragging it with LHD’s. This underground transportation was executed on 8 October 2011.

For the last 35m to the launching cubby, the machine was moved under own power. This action proved challenging and led to some part failures. On 9 January 2012, the machine was inside the launching cubby, in a position where all three of the grippers could be gripped and cutting could start.

The machine was plagued by part failures and other problems, to the extent that, on 11 December 2012, when the trial ended, just less than 6m of advance into rock had been achieved.

2 DESCRIPTION OF SYSTEM

The system consists of three main assemblies :

The **machine assembly** comprises the parts that generate the forces required for cutting action, as depicted below, in figure 2.1.

The roller cutters, with tungsten carbide inserts, are mounted on a cutterhead that swings through an arc of 190°, at a radius of 5 m, rolling the cutters against the face and generating rock chips, to cut an opening of 5 m wide x 0,95 m high.

The cutterhead is mounted at the end of two thrust cylinders, which in turn is mounted on the rotary support housing.

The rotary support housing is driven in rotary motion by the swing cylinders and is swiveled in the delta frame by means of the main bearings.

At the rear end of the delta frame, the gripper carriage, driven by the extension cylinder, can slide forward / aft on two guide tubes.

The integrated rear gripper / steering cylinders are mounted on the gripper carriage.

At the fulcrum of the rotary support housing is the main gripper, which also forms the shaft that connects the rotary support housing to the delta frame, via the main bearings.

Mounted on the cutterhead, is the yaw gripper.

Forward / aft motion of the machine is achieved in one of two modes :

- Gripping the yaw gripper and retracting / extending the thrust cylinders
- Gripping the rear grippers and extending / retracting the extension cylinder

In plane direction change is achieved by gripping the yaw gripper and main gripper and activating the swing cylinders, resulting in rotation of the delta frame about the main gripper.

Out of plane direction changes are achieved by displacement in the steering cylinders.

The **powerpack assembly** is towed behind the machine assembly, by means of the tow cylinder / scissor arrangement. It comprises mainly of the hydraulic oil reservoir, hydraulic pumps and electric motors, solenoid driven hydraulic valves, electric contactors, starting gear and control electronics.

The machine is remote controlled by the operator, from a remote panel, which has a radio link with the control electronics on the power pack.

The **vacuum system assembly** is installed at the conveyor belt dumping site, away from the machine. It consists of two electrically driven vacuum pumps, connected to vacuum pickup nozzles on the cutterhead via vacuum hoses. Each air stream is routed through a cyclone, mounted over the conveyor belt, in which the produced cuttings drop out, onto the belt.

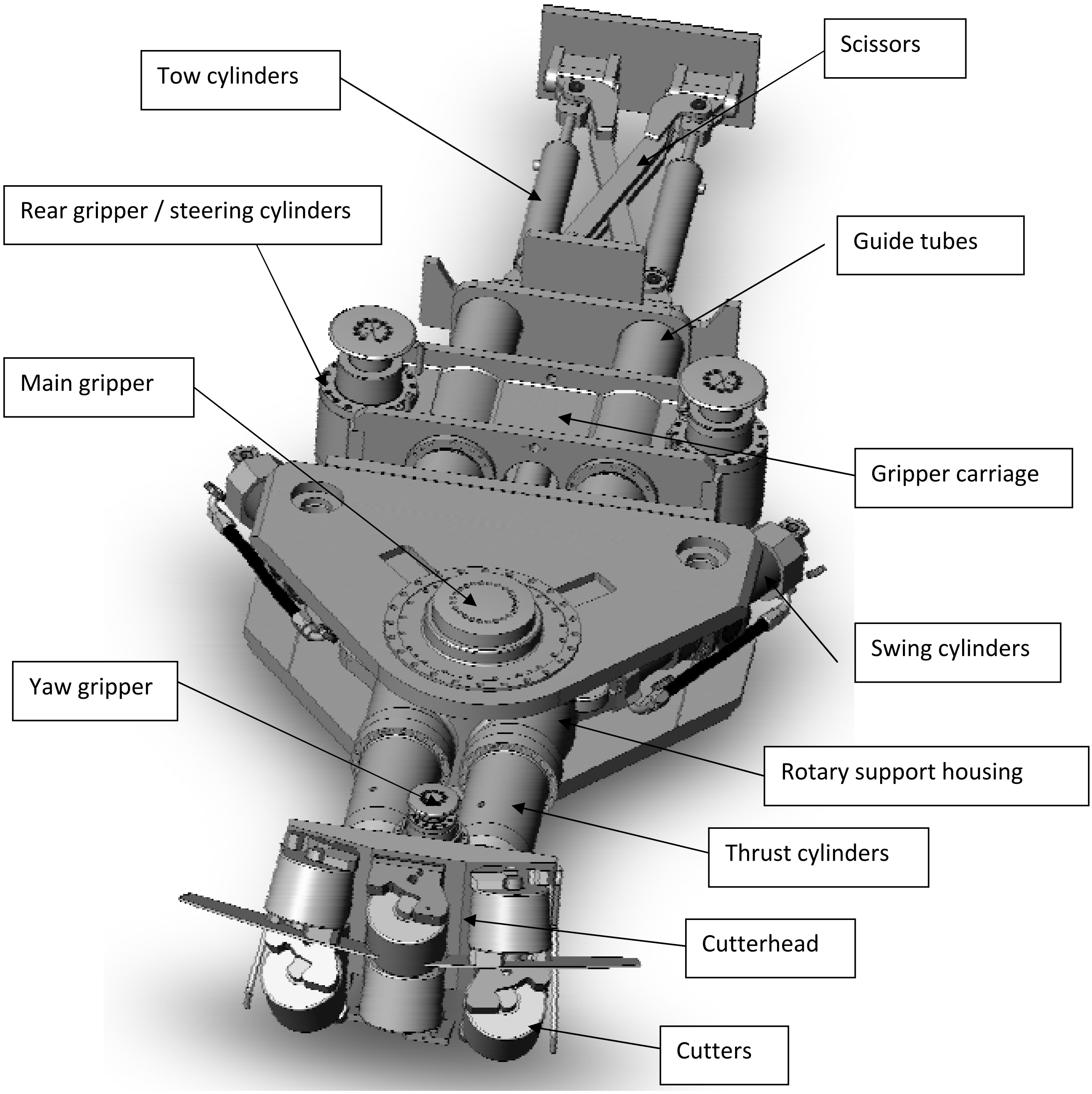

Figure 2.1 : Machine assembly

3 PERCEIVED ADVANTAGES OF REEF MOLE SYSTEM

The following are the main advantages above conventional mining, perceived for the RM950 as a mining system :

Less dilution

No blast disturbance of rock

Less support of hanging wall required

Reduced manpower

Reduced energy per ton of rock mined

Remote control – increased safety

4 OBJECTIVES

Following the trial of the RM800 at Townlands shaft, the objectives for the trial at Batho Phele were set as follows :

- Establish power levels for sustained, reliable operation
- Establish crew procedures for extension of power, vacuum, water and air
- Establish best maintenance and safety practices to maintain continuous operation
- Demonstrate that the KPI's as per PEMS document can sustainably be met.

5 PROBLEMS ENCOUNTERED DURING COURSE OF TRIAL

The project became bogged down with problems, to the extent that, at the end of the trial on 11 December 2012, none of the objectives had even partly been achieved. The remainder of this paragraph will deal with the problems encountered and steps taken to rectify the problems.

The problems encountered that prevented progress, fall mainly in three categories : mechanical failures, hydraulic problems and problems emanating from a poorly constructed launching cubby.

5.1 MECHANICAL FAILURES

5.1.1 REAR GRIPPER CYLINDER BARRELS BLOWN UP

Shortly after starting the machine to move it towards the launching cubby, movement of the steer cylinders became jerky. The cylinders were removed and taken to the manufacturer, stripped and assessed. The problem was identified as that the steer cylinder rods, which are also the rear gripper cylinder barrels, were blown up.

The cause was eventually traced to an error in the design of the porting of the rear gripper cylinders. The problem was rectified and was not encountered again. It needs to be mentioned that, when the cylinders were returned to site, seals were leaking and the cylinders had to be removed and taken to the manufacturer again. The result was that the delay because of the blown gripper cylinder barrels was unnecessarily extended.

5.1.2 FAILURE OF ANTI-ROTATION RODS ON STEER CYLINDERS

During movement of the machine towards the starting cubby, the anti-rotation rods of the steer cylinders failed and consequentially the steering displacement transducers were destroyed. This was a direct result of the uneven concrete on approach to the launching cubby, resulting in forces being exerted on the rods, in excess of the design forces.

The rods were increased in diameter, made of stronger material and two rods instead of one were mounted on each cylinder. The problem was not experienced again.

5.1.3 FAILURE OF YAW GRIPPER BRACKET BOLTS

Still during movement of the machine towards the launching cubby, the yaw gripper mounting bracket bolts broke, also as direct consequence of the uneven concrete on approach to the launching cubby, resulting in forces being exerted on the bolts, in excess of the design forces.

The bolts were inaccessible and the bracket was temporarily welded. It lasted until the machine was in the launching cubby. When the cutterhead was later removed, the bolts became accessible and were replaced and the bracket was also properly welded. The bracket failure problem was not encountered again.

5.1.4 DEFORMATION OF REAR GRIPPER SHOES

Shortly after gripping the rear grippers for the first time, the upper shoes were deformed to the extent that oil ports started leaking. This was to some extent caused by uneven hanging wall of the starting cubby, but mainly by the fact that the gripper shoes were made of material not to specification. New shoes were made to specification by the cylinder manufacturer and installed on site. The problem did not occur again, despite gripping on very uneven hanging wall.

5.1.5 CUTTER BEARING REATINER LOCKING TABS BREAKING OFF / CUTTER BEARING FAILURE

Shortly after cutting commenced, cutter bearing retainer locking tabs broke off on three of the cutters and retainers unscrewed. As a result of this, the lower bearing of the right hand lower gage cutter also failed.

This could only be rectified by taking the cutterhead off and taking it to a workshop, which caused a lengthy delay. Only the cutters with failed retainers were re-built. Eventually, the root cause of the cutter bearing problem was named as incorrect procedure during original assembly of the cutters, resulting in too low pre-load on the bearings. At the time of writing this report, this was still not established beyond all doubt.

5.1.6 THRUST CYLINDER BOLT FAILURE

At one occasion, a number of thrust cylinder bolts failed. The problem was traced to a hydraulic circuit error, which caused the thrust cylinders to be over pressurized. The circuit error was corrected and all of the bolts (not only the failed ones) were replaced. The problem did not occur again.

5.1.7 SWING CYLINDER ROD FAILURE

On one of the swing cylinders, the rod failed just behind the rod eye. Metallurgical investigation revealed extensive welding on the hardened alloy steel in the area of failure during original manufacture of the rod, which was grossly in violation of manufacturing specifications.

New rods were manufactured under warranty by the cylinder manufacturer, both cylinders were rebuilt and re-installed on the machine.

This was a major failure that caused a delay of more than 3 months.

5.1.8 STEER CYLINDER ATTACHMENT BOLT FAILURE

Some steer cylinder attachment bolts were stripped out of their tapped holes on the gripper carriage. This was a direct consequence of the concrete footwall crumbling during gripping and causing loads on the bolt connection, which it was not designed for. As the remaining bolts were sufficient to carry the cutting loads, this failure did not cause significant delays. This failure was rectified during the delay, caused by the swing cylinder failure, by deeper drilling and tapping and additional welding. The control program was modified to prevent moment loading on the cylinders in the case of footwall yielding.

5.2 HYDRAULIC PROBLEMS

5.2.1 HYDRAULIC LEAKS AS RESULT OF POOR WORKMANSHIP DURING ASSEMBLY

Several leaks occurred, mainly on the swing manifold assembly, due to poor workmanship during assembly of the powerpack. Leaks were causing frequent stoppages.

During the three month outage of the machine due to swing cylinder failure, the swing manifold assembly was taken out to workshop and re-built, with specific attention to experienced seal failures.

5.2.2 SWING MOTION HYDRAULIC CHANGE-OVER

The swing motion change-over was jerky from the start and caused swing pressure spikes. During the three month outage of the machine due to swing cylinder failure, the swing manifolds with hydraulic circuitry was taken to a workshop and the swing change-over circuit was simulated on a test bench at the works of the supplier of the hydraulic control system. The hydraulic circuit was modified to rectify the jerky change-over.

5.2.3 PLUMBING FAILURES

At one point, two welded steel fittings sprung leaks and the head of a swing hose was blown off, on the swing cylinder circuit. The problem was traced to an orifice come loose, which caused pressure intensification and resultant over pressurization of the plumbing. This was rectified when the swing change-over was addressed, during the delay caused by swing cylinder failure. Additional relief valves were introduced to prevent the consequential damage of such mal-function.

5.3 PROBLEMS EMANATING FROM POORLY CONSTRUCTED LAUNCHING CUBBY

The poorly constructed launching cubby led to significant lost time and mechanical failures.

5.3.1 MECHANICAL FAILURES AS RESULT OF POOR STARTING CUBBY

The following mechanical failures, already mentioned, were as direct consequence of the poorly constructed launching cubby and approach to the cubby:

Steer cylinder anti-rotation rod failure

Yaw gripper bracket bolt failure

Stripping of steer cylinder attachment bolts

5.3.2 FURTHER DELAYS CAUSED BY POORLY CONSTRUCTED LAUNCHING CUBBY

The foot wall of the launching cubby was of cast concrete, while the hanging wall was rock, as exposed during blasting of the cubby, just above the parting layer.

Crumbling of concrete

The concrete was found to be very weak, with result that it crumbled under load and the main gripper embedded itself in the concrete during gripping and kept working itself deeper into the concrete during cutting. This caused much delay :

Extension per pass had to be limited because of unsure gripping integrity

After each thrust excavation, the main gripper had to be maneuvered out of the hole, pressed in the concrete and the hole had to be filled before gripping and a new excavation could be attempted.

Continuous embedding of the main gripper during an extension caused much difficulty at the start of a new extension, to get the machine lined up with the previous excavation.

When the rear grippers arrived at the crumbled concrete section, similar problems were experienced.

Hole in hanging wall

A hole had erroneously been blasted into the hanging wall during construction of the cubby. When grippers were gripped near the hole, the rock crumbled. The entire machine had to be maneuvered to get the grippers round the hole, or steel packs had to be suspended in the hole, for the grippers to contact on. This caused much delay.

6 ACHIEVEMENTS

As mentioned before, virtually no achievements can be recorded against the set objectives for the trial. Achievements lie in the successful solutions applied to problems of recurring nature experienced on the RM800. The following paragraphs list the RM800 problems, which appear to have been successfully addressed on the RM950.

6.1 LOSS OF TUNGSTEN CARBIDE INSERTS FROM CUTTERS

On the RM800, tungsten carbide inserts were regularly lost from the gage row of the lower gage cutter. For the RM950, the non-cogging, non-skidding, non-skewing cutter was designed.

At the end of the 2012 trial, no tungsten carbide inserts had been lost – the design change appears to have been successful.

6.2 REPEATED SEAL FAILURE ON THRUST CYLINDER GLANDS

Recurring failure of the thrust cylinder gland seals on the RM800 was addressed on the RM950 by elimination of the removable gland. At the end of the 2012 trial, this problem had not been experienced again – the design change appears to have been successful.

6.3 REPEATED MAIN GRIPPER GLAND SEAL FAILURE

Recurring failure of the main gripper gland seals on the RM800 was addressed on the RM950 by elimination of the removable glands. At the end of the 2012 trial, this problem had not been experienced again – the design change appears to have been successful.

6.4 REPEATED CUTTERHEAD GRIPPER GLAND SEAL FAILURE

Recurring failure of the cutterhead gripper gland seals on the RM800 was addressed on the RM950 by introduction of a different seal type and a spherical bearing for the cylinder to swivel about. At the end of the 2012 trial, this problem had not been experienced again on the yaw gripper – the design change appears to have been successful.

6.5 STEERING CYLINDER HEADS BREAKING OFF

The recurring problem of steering cylinder heads breaking off on the RM800, was addressed on the RM950 by introduction of a new, different steering cylinder concept.

At the end of the 2012 trial, this design change appears to have been successful – the failures experienced on steering cylinders have been related to extra-ordinary forces, caused by uneven concrete, while moving the machine towards the launching cubby. No failures have been experienced during the cutting operation.

6.6 INSUFFICIENT GAGE ROW CLEANING / VACUUM PICKUP

Insufficient gage row cleaning / vacuum pickup on the RM800 was addressed by changing the design of the cutterhead, vacuum nozzles and air nozzles on the RM950. The design changes appear to be reasonably successful.

7 SUMMARY OF WORK DONE ON MACHINE BEFORE CUTTING OF DECEMBER 2012

During the three month delay, caused by the main gripper failure, a program was launched to rectify problems on the machine that were encountered earlier, but could not be fixed properly at the time, without major stripping and taking assemblies to a workshop. This program resulted in the machine being in excellent condition when cutting started again. Cutting commenced again on 10 December 2012 and went well for about 600 mm of advance. On 11 December 2012, it was discovered that the locking tabs of the bearing retainer on the right hand bottom gage cutter were broken off again and cutting was stopped, ending the 2012 trial. The following table summarizes actions performed during the outage due to the main gripper failure.

FAILURE/RISK IDENTIFIED	ACTION TAKEN DURING PERIOD 23/7/12 TO 24/10/12
Some steer cylinder attachment tapped holes stripped.	Holes in gripper carriage drilled and tapped deeper. Cylinder flanges welded to gripper carriage
Swing cylinder failure	Swing cylinders removed & delivered to supplier New swing cylinder rods manufactured and assembled, pressure test on cylinders Swing cylinders fitted on machine
Swing cylinder rod eye pin failing as consequence of rod failure	New pins manufactured of harder material plus new rod-eye bearings installed
Left hand gage cutters not cutting.	Left hand gage cutters shimmed
Main hydraulic pump sometimes draws air due to slope of powerpack.	Jacking system implemented to skid pan to level power pack
Steer cylinder sensors not implemented	Laser sensors and steering algorithm implemented in the control program.
Steer cylinder laser sensors vulnerable to falling rock.	Designed, manufactured and installed protection
Vacuum hoses and air/water hoses subject to jamming, kinking and breaking.	Installed new slurry hoses. Replaced damaged vacuum nozzle. Installed guide

	plates over gripper box. Improved method of binding of water/air hoses to vacuum hoses. Improved attachment of vacuum hose tensioner to vacuum hoses. Eliminated all protruding bolt ends on vacuum hoses.
Gage cleaning **between** bottom gage cutters inadequate	Re-connected air nozzles to inside of gage cutters
Hydraulic fittings and – hoses failing, o-rings failing	Checked all hoses and fittings for tightness. Checked all bolts for correct length and tightened Removed modified swivel blocks, machined out suspect welds and re-welded. Checked / replaced o-rings on high pressure inlet ports to manifold. Checked all orifices are correct size and tight.
Over- pressurization of swing cylinder return lines due to orifice coming loose	Fit check valves and relief valve so all A- and B-lines see relief valve
Jerky switch over on swing cylinders causes swing pressure spikes	Removed swing manifolds and set up in workshop test bench simulation. Fault finding and modified change-over circuitry.
Accidental over pressurization of parts of machine, through incorrect plumbing	Checked all pressure settings and locked. Checked plumbing
Re-grip during thrust and rear extension excavation not tested.	Reviewed re-grip algorithms in control program.
Problems in data retrieved from the data logging function of the PLC	Analyzed existing data files to determine discontinuities in data. Optimized data processing software. Expanded the PLC parameters exported via OPC.
Steer alarms not available on control panel	Implemented steer alarms on control panel.

8 ADDRESSING OF REMAINING PROBLEMS

On 10 December and 11 December, some 600 mm cutting was done, before the bearing retainer on the right hand lower gage cutter was found to be loose again.

From this cutting, two remaining problems were identified :

- Cutter bearing retainer loosening
- Vacuum hose kinking

The cutter bearing retainer loosening problem was unexpected on the RM950, since the cutter bearing design and installation procedure were identical to that of the last, successful iteration of the RM800 cutter. All investigations performed lead to no more than a strong suspicion that errors were made during the original assembly of the cutter bearings, when the cutters were manufactured.

Since the end of the 2012 trial, the cutterhead has been removed and taken to a workshop. Cutters have been stripped and it has been found that, on all other cutters, apart from the right hand lower gage cutter, there are no problems and the bearings are undamaged. On the right hand lower gage cutter, the lower bearing has been destroyed and there is once again so much secondary damage that a watertight conclusion about the root cause of the failure could not be drawn.

The cutter bearing assembly procedure was modified in effort to prevent the possibility of errors. Measurement of certain control parameters during assembly has been built into the procedure. Cutters are all being re-assembled to the new procedure and under strict control.

The vacuum hose kinking problem was a new problem, introduced during the last cutting of December 2012, by using slurry hose as replacement for the previously used hose, in attempt to increase the wear life of the hose. Since the end of the 2012 trial, this problem has been addressed by designing an additional vacuum hose tensioner, which will be mounted to the rear of the current vacuum hose tensioner, on top of the oil reservoir of the powerpack.

9 CONCLUSIONS

During the 2012 trial, the project got bogged down with problems, to the extent that virtually no progress was made with regards to the objectives and KPI's set for the machine. The problems entailed mechanical failures, hydraulic problems and problems related to poor construction of the launching cubby.

Progress was achieved in the sense that the major problems of the RM800, addressed with design modifications on the RM950, did not occur during cutting of the 2012 trial. Also, no problems were identified that would require 'back to the drawing board' design changes. The bearing retainer loosening problem on the cutters was still not fully understood at the end of the trial and may be the one exception to the previous statement. The mechanical and hydraulic failures that occurred were the consequences of not-to-specification manufacturing of parts and poor workmanship during assembly of the powerpack.

The cutter retainer loosening problem was unexpected, since there was no change in the bearing design or assembly procedure from the last, successful RM800 cutter design.

As result of work done during the period August to October, when the machine was out of action due to swing cylinder rod failure, the machine was in good condition for the December cutting and remains so for further trials.

Since the end of the trial, the cutterhead has been removed and taken to a workshop. Cutter bearings are being re-assembled into the cutters to different specifications in order to prevent the bearing retainer loosening problems. The different specifications have left the design unchanged, but focus on elimination of errors that can occur during assembly of the cutter bearings. Efficiency of these measures can only be evaluated during further cutting.

Manipulation of vacuum hoses during cutting is being addressed by implementation of a second hose tensioner, mounted on the powerpack. Wear of vacuum hoses remains a concern.