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APPLICATION OF CONTINUOUS DRILLING TECHNOLOGIES IN COAL MINING

Scott Adam¹ and Joel Kok²

ABSTRACT: CRCMining's unique Tight Radius Drilling technology has recently demonstrated highly productive continuous drilling in a Bowen Basin coal formation. The system has been demonstrated to be economically deployable and reliably operable by drilling contractors. A detailed overview of the system is presented, including a summary of the technology status in terms of technical performance, system productivity and stimulation cost. Investigation of the application of continuous drilling technology is currently being extended to underground in-seam (cross panel) drilling and rapid roof bolt hole drilling for long tendon support. An update on these ACARP/CRCMining co-funded research initiatives is presented.

INTRODUCTION

Drilling is a critical element of almost every mining operation. It is interesting that the first rotary drill emerged in 1901, the first roller bit in 1909. Improvements in directional control through advanced borehole assemblies are a more recent innovation, but the fundamental concept of adding screwed sections of jointed drill rods still persists. Inherent constraints associated with the jointed drill string concept have become normalised and an absence of viable alternatives has forced industry to accept the intrinsic limitations, namely:

- Safety hazards associated with intense manual handling and man-machine interactions have persisted despite some attempts to introduce automation of aspects of the drill rod handling process, which are inevitably complex mechanical solutions not readily adaptable to the underground coal environment
- Drilling production inefficiency associated with frequent rod changes, both during drilling and extraction of the drill string
- Compromised formation properties in gas drainage holes due to 'skin effects' generally a result of the cutting action of mechanical drill bits, and the rotary or sliding action of drill pipes in the hole
- Interruption (particularly in horizontal holes) to the wellbore circulation associated with frequent rod changes, resulting in settling of cuttings in the lateral and an increased risk of loss of drill string.
- Limitations in the integration of drilling into other mining processes due to the rigid requirement for a long drilling boom. For example the configuration options for a bolter miner are constrained by the dimensions of the drill mast which generally spans from the roof to the floor of the mining environment.

The inherent and unavoidable high safety risk and low productivity associated with conventional jointed rod drilling systems stand out as an example of hazards that the industry has been forced to accept due to an absence of an acceptable alternative technology. The ubiquitous nature of jointed drilling and its inherent constraints is of itself a barrier to realising alternative concepts which may offer step change performance improvement.

HISTORY OF CONTINUOUS DRILLING WITHIN CRCMINING

In 1994 CRCMining investigated application of high-pressure water jet assisted drilling technology using jointed drill pipes and conventional blade style drill bits. Recognising the benefit of continuous drilling, the CMTE researchers evolved the system into a self-propelled, pure water jet driven drilling tool

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deployed using a reel of flexible hose. In 1997, the water jet drilling technology was deployed into a pre-drilled vertical well to investigate the concept of radial drilling.

Today this expertise includes self-propelled water-jet cutting heads and associated mechanisms that can drill a borehole in a self-regulated manner whilst maintaining effective borehole diameter control. Applications of CRCMining's water jet drilling technology include:

1. **Tight Radius Drilling (TRD)** was developed to enable thick (>2m thickness) coal seams to be safely de-gassed from the surface in advance of the mining process.
2. **High Speed Cross Panel** drilling is an adaptation of the TRD system for underground in-seam application, mainly for the purpose of drilling de-gassing holes. It is also suitable for cross measure drainage holes.
3. **Continuous Cable Bolt Drilling** is being developed for continuous drilling of cable bolt holes for underground long-tendon roof support installation.

TIGHT RADIUS DRILLING

The current TRD deployment system uses a self-propelled, high pressure water drill head to create a radial pattern of horizontal boreholes (laterals) in the target coal seam (Figure 1). The system is deployed into a vertical well, which is prepared with an under-ream zone (1.8 m diameter) at each target horizon to accommodate the deployment whipstock that orientates the drilling tool from vertical to horizontal. Radial lengths in excess of 300 m have been achieved to date, with continuous drilling rates of over 240 m/hr observed in field conditions.

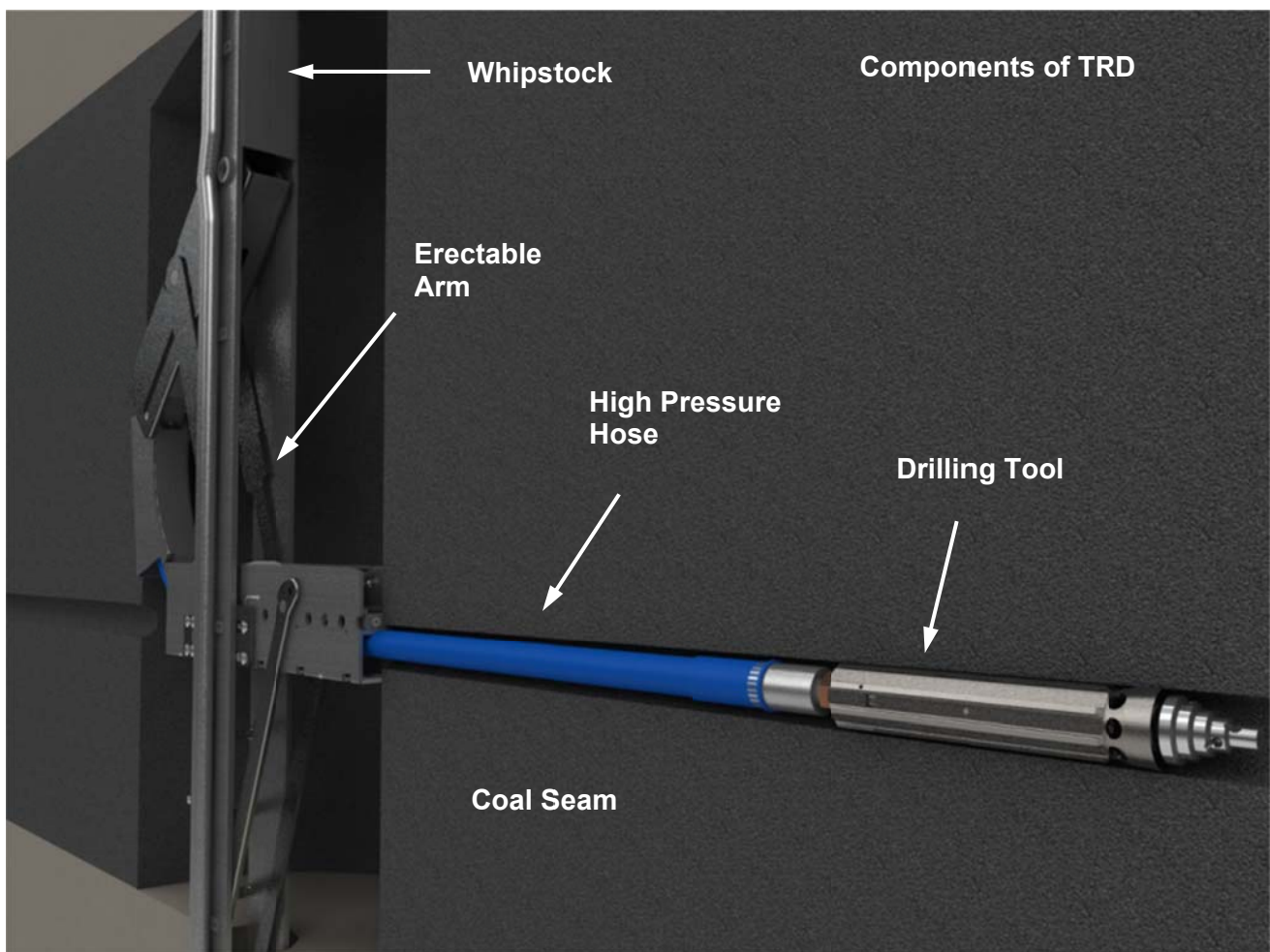


Figure 1: Continuous drilling offers a step change productivity increase and cost reduction to the mining industry. A flexible and continuous conduit is the key enabler

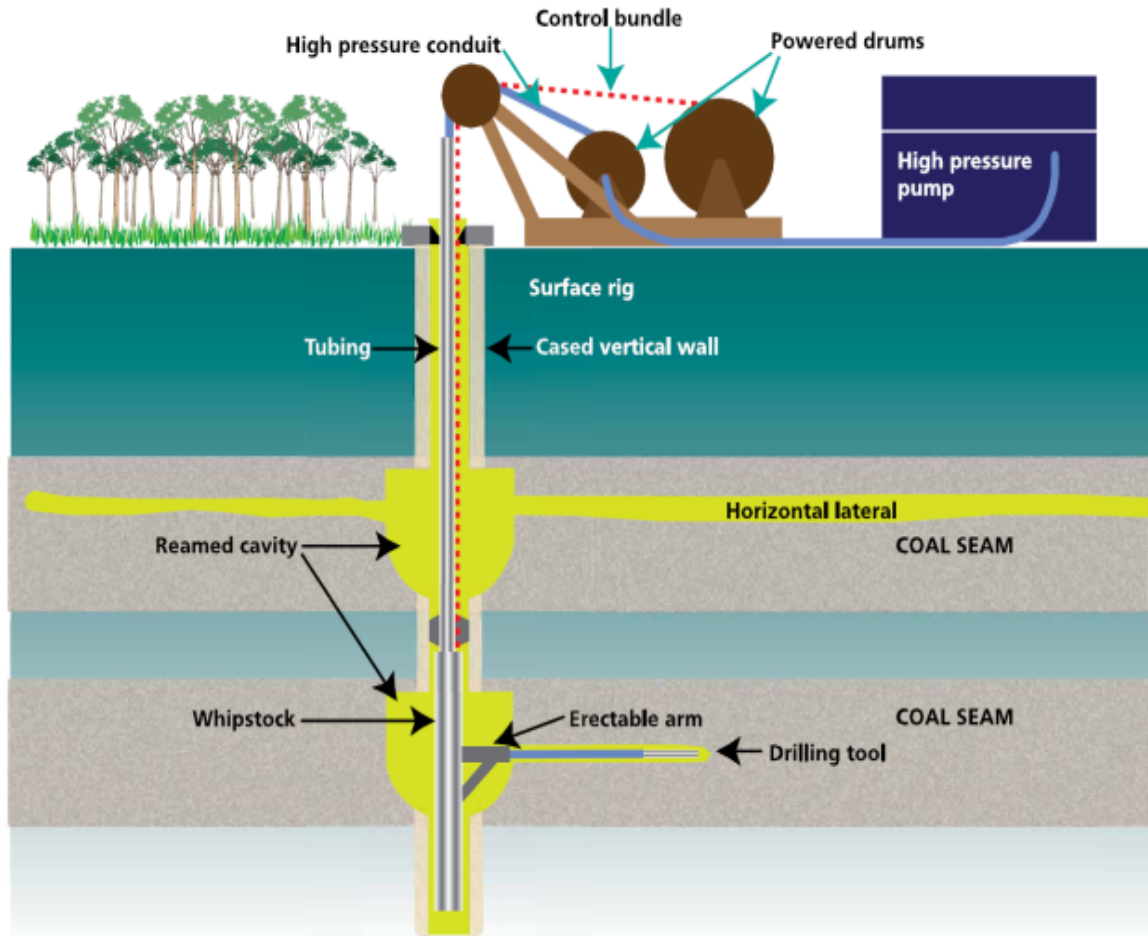


Figure 2: Tight Radius Drilling deploys a continuous water jet drilling tool into the coal seam from a vertical well

CRCMining's water jet drilling technology has evolved to the point that it now reliably and rapidly forms a borehole of constant and regulated borehole diameter, an essential fundamental requirement for reliable drilling. Real time survey electronics in the drilling tool body constantly logs the borehole trajectory and reports the tool position to the surface drill controller in real time. Waterjet drilling systems are inherently remote controllable, with operators able to effectively control the system via computer interfaces. Drill advance is self-regulated and semi-automated. The continuous nature of waterjet drilling is highly compatible with automation and off site remote control of high skill drilling functions.

Seventeen years of development culminated in the first commercial deployment of TRD for the purpose of investigating broad scale degassing of a coal mine. In 2013, TRD was applied at BMC's South Walker Creek mine, proving that water jet drilling can be applied economically.

The system was operated by established service providers, executed under a commercial drilling contract, and achieved high productivity. This work has demonstrated proof of concept for the waterjet drilling method. Extensive patterns of laterals were formed in the coal seam providing a large drainage area. All but three of the laterals were drilled without azimuthal steering.

With a peak productivity of 535 m total laterals drilled in just 6 hours, the vision for a 1000 m per shift drilling technology has been set as a reasonable target. Continuous drilling rates of between 2 and 4m/min were regularly demonstrated during this operation.

During this campaign, the steering concept was trialled briefly in three laterals, with promising results out to approximately 100 m lateral length. It is apparent that improvements in steering control and drilling tool geometry will increase the range, straightness and quality of waterjet drilling systems.

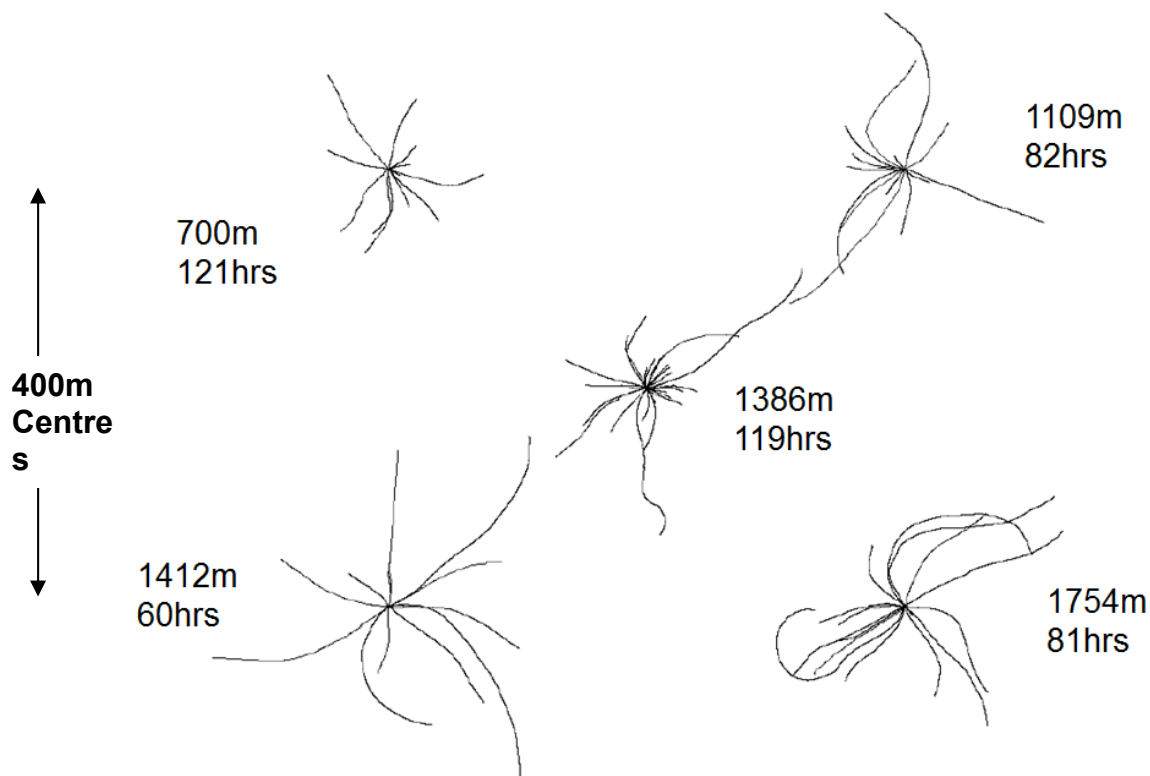


Figure 3: A five well pilot at BMC's South Walker Creek demonstrated commercial system performance

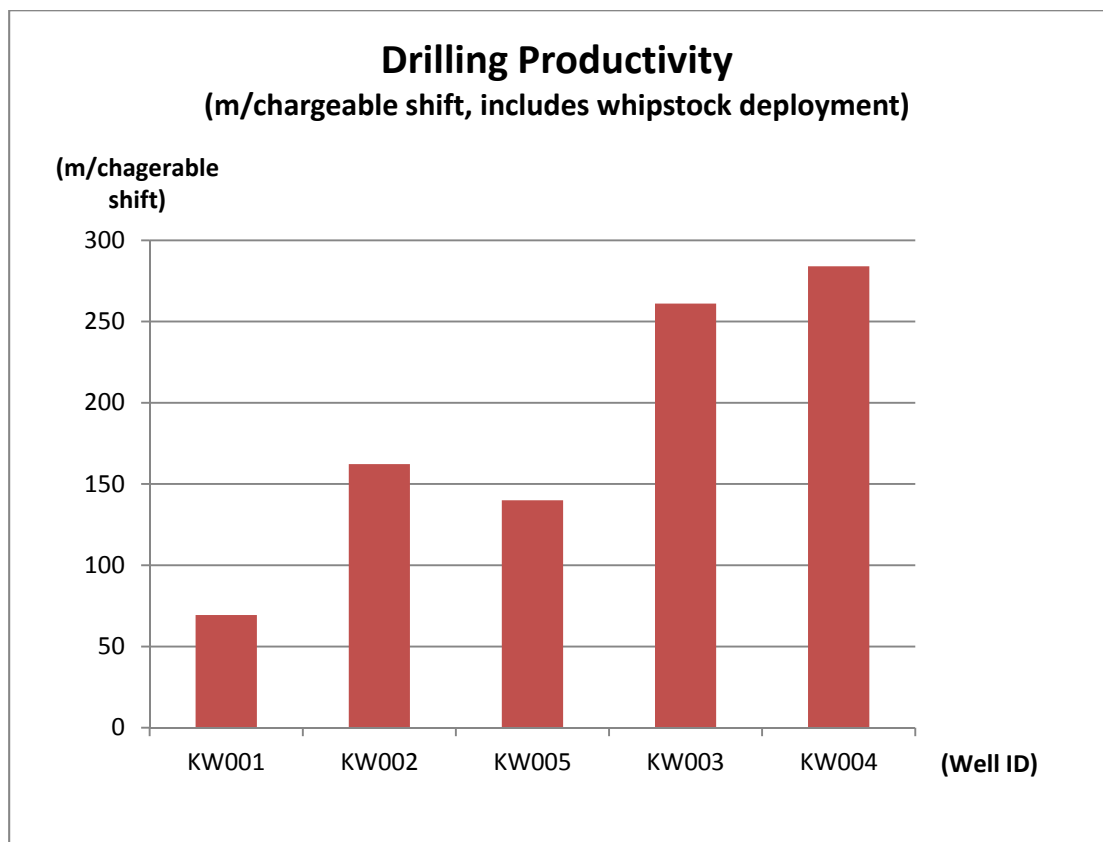


Figure 4: Drilling Productivity at South Walker Creek (in chronological order from left to right)

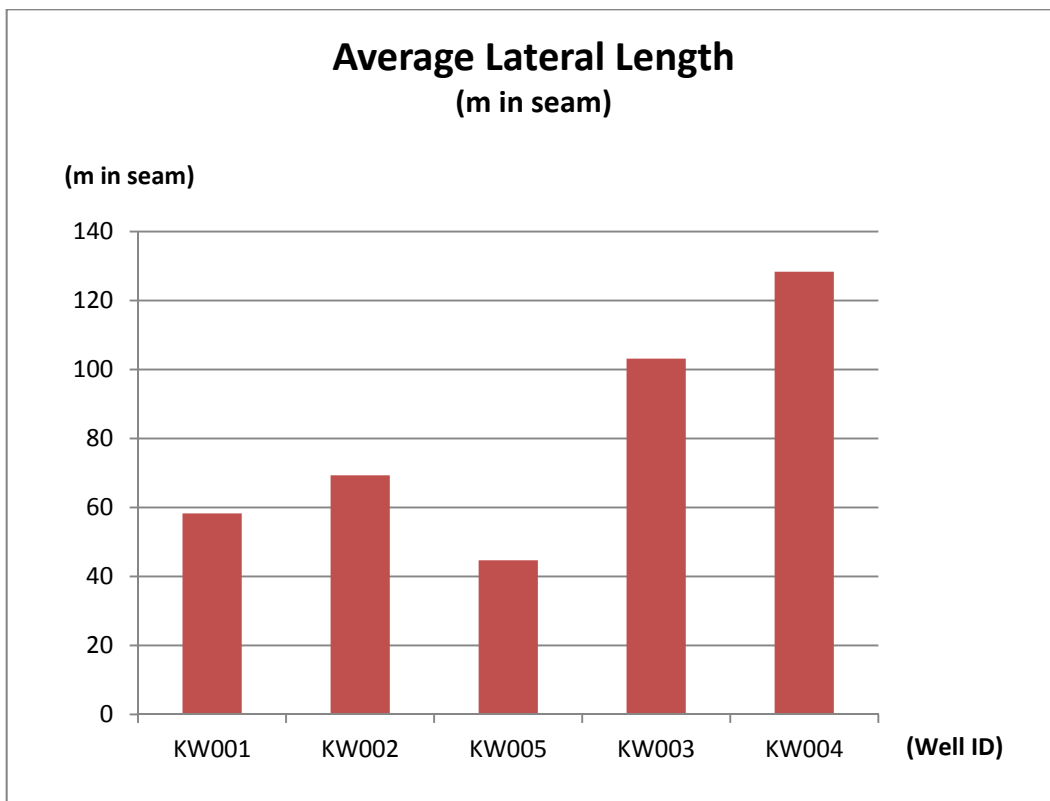


Figure 5: Average lateral length by well (in chronological order from left to right)

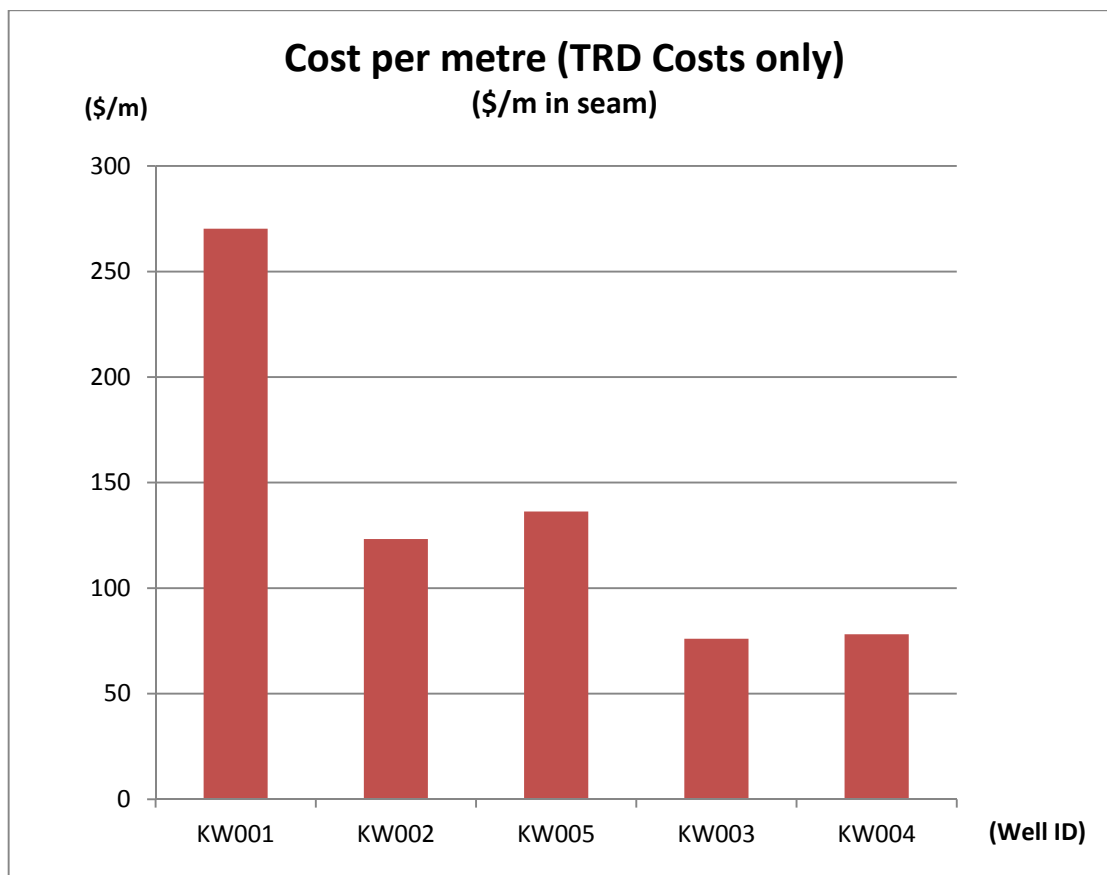


Figure 6: Cost per metre, per well (in chronological order from left to right)

HIGH SPEED CROSS PANEL (HSXP) DRILLING

Underground In-seam (UIS) drilling is carried out for three purposes in Australian coal mining: geological exploration, degasification of workings for mine safety, and greenhouse gas capture. Drilling across coal panels for the purpose of pre-mine gas drainage forms the bulk of UIS drilling activities. A survey of UIS drilling practises was recently completed by CRCMining for ACARP Project C17017ⁱ (Adam, *et al.*, 2013) and it was revealed that for the applications of cross panel and cross measure drilling, significant opportunity exists to improve the following:

- *Safety, by addressing inherent manual handling hazards associated with UIS drill rigs*
- *Rig utilisation productivity; by addressing inherent inefficiencies of UIS drill rigs, such as frequent rod changes, slow pipe tripping cycles, slow average drilling rates. Current productivity is around 70-100m/shift. Currently, to drill a typical cross panel borehole drilling techniques take 4-6 shifts with two men crews*
- *Reliability of borehole installation, through adoption of continuous drilling practises (eliminating the need to stop circulation for the addition of jointed pipe.)*

CRCMining's waterjet drilling technology has the potential to revolutionise drilling in coal mining applications. Rapid and continuous drilling eliminates man-machine manual handling hazards associated with conventional drilling, and will dramatically increase drilling productivity. The intrinsic simplicity of continuous drilling will enable future automation of the drilling cycle. In combination the advantages of continuous in-seam drilling will slash cost of pre-mine gas drainage whilst transforming the safety and productivity of the drilling function.

Development of a water jet drilling system for cross panel (UIS) applications was initiated in 1998, with ACARP funding. The results of this work are documented in ACARP Project Reports C7024ⁱⁱ (Dunn, *et al.*, 1999), and C8023ⁱⁱⁱ (Dunn *et al.*, 2001). This early work was aimed at the development of technical concepts and designs for a cross panel drilling system, and the manufacture and testing of such a system through a series of highwall drilling trials. In summary, specific technology development areas from this early work included:

- Demonstrating the concept of a continuous waterjet drill as a means of drilling horizontal in-seam drainage holes, with high penetration rates and with some long holes achieved.
- Preliminary investigations and development work on a suitable survey technology to track borehole trajectory.
- Investigations and development of concepts for effecting trajectory control (steering) of the drilling tool and
- Successful development of a prototype compact rig format with potential for underground application. The prototype rig carried 350 m of high pressure hose (Figure).



Figure 7: CRCMining's prototype HSXP rig with 350m hose capacity (2005)

The most recent HSXP trial was completed in 2005. The high speed cross panel system shared the same water-jet drilling technology as the TRD system. The drilling tools are the same. Improvements to the drill head technology including the cutting mechanism, survey electronics, wireless communications and steering techniques, have been successfully shared.

The 2005 trial showed that despite the successful development of a prototype drilling system, drill head cutting technology had at that time not yet matured sufficiently to provide reliable drilling performance. As a direct result, the drilling distance and quality were observed to be generally poor. The key observations from this project included (extract of a post-trial presentation):

From 2005; *"A means of strictly regulating hole diameter at all times is yet to be achieved*

- *Boreholes were calliper logged as consistently oversize (90 mm to 150 mm diameter)*
- *Inadequate flow rate for cuttings to stay entrained in flow due to large borehole diameter*
- *Build-up of cuttings in borehole increases the likelihood of 'boggy' drilling*
- *Appeared that bogging of hose due to accumulation of cuttings substantially increased friction on the hose and was ultimately a limiting factor for drilling depth and*
- *Drilling rate was erratic during testing (ranged from 0 to 5 m/min)"*

From this extract above, the key problem identified with the waterjet tools used in 2005 was their inability to regulate borehole diameter, from which a series of undesirable drilling conditions cascade. However, the lessons and the successful outcomes of the HSXP program did feed into the TRD project.

Since the last HSXP trial (2005), wherein the drilling results were poor due to immature drill head design, subsequent water jet drill technology improvements have resulted in drilling performance breakthroughs during the TRD trials at Broadmeadow Mine in 2010 and South Walker Creek in 2013 (These vastly improved drilling tools are yet to be trialed for HSXP).

The TRD breakthroughs described above have mitigated several key technical risks identified in the 2005 HSXP trials. A more recent technical risk review has identified the remaining key technical risks of;

- DRILLING RANGE - Reliably achieving 500 m long laterals to develop a cross panel fan pattern will require an improvement to the drilling system thrust/friction ratio.
- STEERING CONTROL and ACCURACY – Although survey electronics and the real-time wireless communications technology is established and proven from TRD, an improvement in steering control and survey accuracy is required to equal or exceed current UIS survey performance.
- BOREHOLE QUALITY - The drill head will require some tuning to match it to the UIS application to ensure high quality borehole creation is maintained at high penetration rates, in a variety of coal conditions, particularly friable, 'soft' coals.

An ACARP project is currently underway which seeks to address these remaining HSXP technical risks through a program of targeted, laboratory-based research, and a field validation trial at Peabody's Wambo underground mine in mid-2015.

This program of work aims to mitigate the remaining key technical risks, such that an investment in developing a commercial variant of the system would be a lower risk proposition for a commercializing entity.

CONTINUOUS CABLE BOLT DRILLING

Cable bolt or long tendon installations for roof support is considered to be a hazardous and highly unproductive (though necessary) geotechnical exercise, and presents a major bottleneck in the roadway development system in underground coal mining. Rock bolt drills themselves are considered to be higher risk equipment with operational risk mostly associated with rock falls, manual handling injuries, and incorrect operation of bolting machines (Burgess-Limerick 2010)^{iv}. The evidence provides support for an improved and safer technique for cable bolt (6-8 m) drilling and installation systems so as to improve safety and productivity.

CRCMining is currently investigating a continuous cable bolt drilling system. The envisioned drilling system will use a high-pressure water jet cutting head deployed at the end of a flexible hose for

continuous drilling of holes of varying lengths. This essentially negates the need for manually adding / removing drill rods as part of the cable bolt installation process, reducing hazards associated with manual handling and poor productivity. The final embodiment of this technology is expected to have a small operational foot print. This technology is expected to provide a safer and more productive approach for this element of rapid roadway development.

The "Water-jet Cable Bolt Drill Investigation" project (ACARP C21018, Tadik *et al.*, 2013) showed promising potential for CRC Mining's water-jet technology in drilling to cable-bolt hole quality requirements (namely in the areas of diameter control, straightness, hole depth, and borehole quality).



Figure 8: Current cable bolt drilling practice is manual-handling intensive

Key questions that this investigative project sought to answer included:

1. **Can water jets rapidly drill straight and smooth holes?** Drilling tests in 1.5 m long homogenous sandstone resulted in straight and consistent holes with tight diameter control. Penetration rates of 1.8 m/min were achieved at 90 MPa of water pressure.
2. **Can diameter control be maintained through bedding planes and spudding sections?** Drilling tests demonstrated that the water jet head was susceptible to produce slightly irregular diameter when the rock being encountered was inhomogeneous (i.e. of variable hardness such as that encountered when drilling through bedding layers). To achieve stricter diameter control in such instances, a modification to the drilling apparatus was made, and proved successful in providing good diameter control in inhomogeneous sandstone and also tested to be effective in preventing loss of control when spudding (during which the cutting head is susceptible to stalling).
3. **Can the tool drill up to 8 m by pushing the drilling tool with a hose?** Drill propulsion by transmission of thrust force via the flexible high-pressure supply hose itself was investigated. (TRD drilling tools use rear-ward facing jets that give it propulsion). This thrust force transmission method and potential issues with longer holes (i.e. high friction, hose spiralling causing lock-up) was investigated and assessed to be effective,
4. **How much water is required?** During the course of the experimental program, highest drilling rates were achieved with an injection pressure of 90MPa (max capacity of CRC Mining's high-pressure pump unit), with maximum water usage at approximately 100 litres/min. It is recognized that such consumption levels are at the high end of the range typical of current commercial rigs (generally below 50 litres per minute). Optimisation of the cutting head geometry and nozzle configuration has the potential to increase cutting efficiency (less water pressure / flow-rate required) while maintaining hole quality and productivity.

A second phase of this project is currently underway in which a field prototype will be developed and deployed to Wambo coal mine for field trials in 2015.

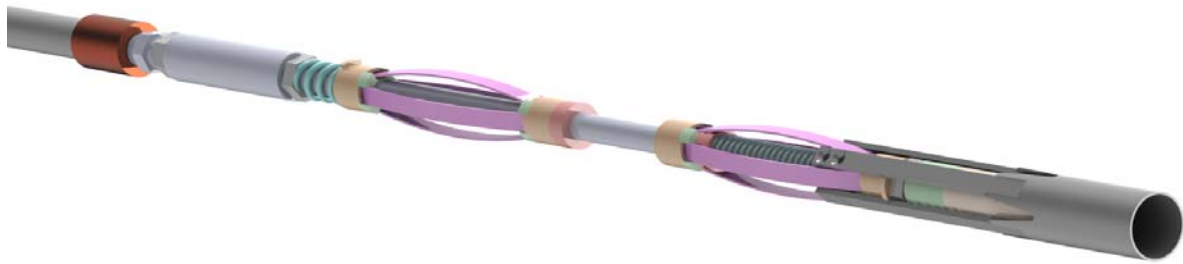


Figure 9: Prototype water jet cable bolt drill currently in development by CRCMining

The specific objectives of the second phase are:

1. Develop a field-deployable drilling tool prototype that embodies the key functionalities to meet hole quality requirements set by cable-bolt drilling application.
2. Optimise the cutting head design to improve drilling productivity and energy/water efficiency.
3. Field trial demonstration in a mine portal that assesses drilling tool's capability in drilling a minimum of 6 m – 8 m long holes in vertical-up and sub-vertical trajectories.
4. Assess and document issues related to water jet drilling in a mining environment.
5. If field trials are successful, proceed to OEM(s) engagement to initiate technology transfer.

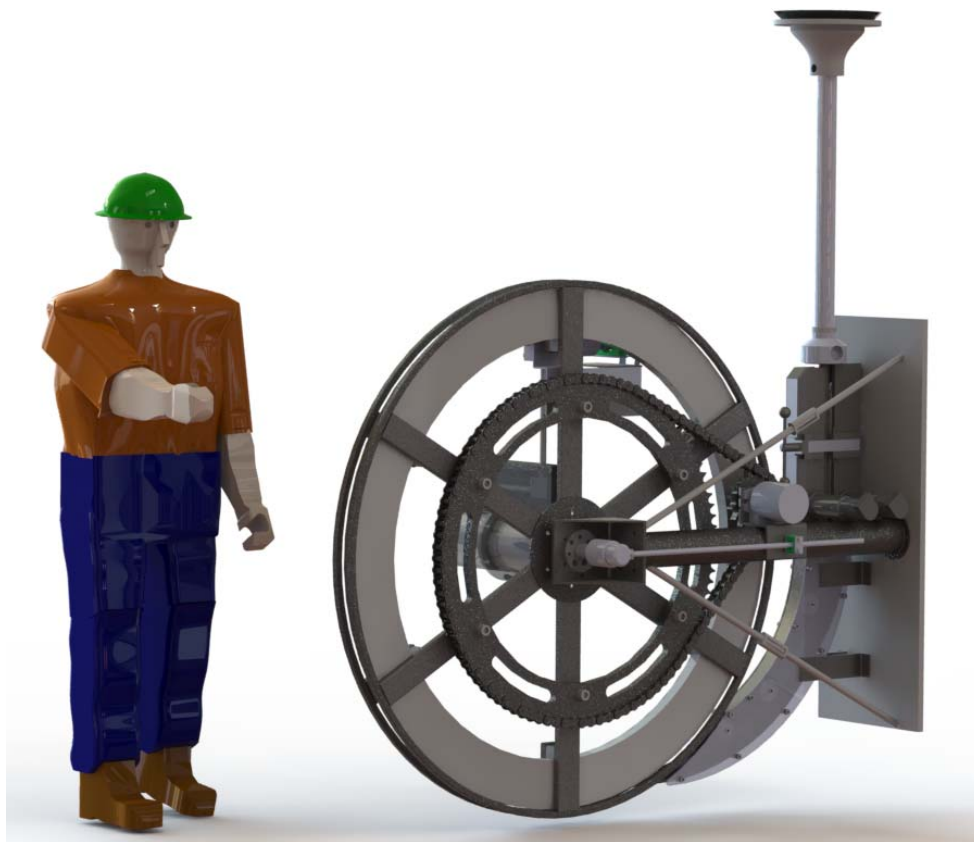


Figure 10: Concept deployment rig for the cable bolt drill tool

CONCLUSIONS

Continuous drilling techniques have been shown to be effective and further work is being planned.

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