A new underground auger mining system

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Synopsis

This paper describes the research and development programme to develop a prototype underground auger mining system aimed at developing and demonstrating an underground auger mining system able to provide economic access to thinner (<1.8 m) coal reserves of South Africa.

Data concerning the performance of modern coal augers under South African coal mining conditions were gained from a proven surface auger which operated across a range of coal types. These data were analysed and considered in conjunction with historical information regarding previous attempts at building underground augers dating back to the 1950s.

Drawing on these data a prototype underground auger mining system, the BryDet BUA 600 underground coal recovery auger, was designed and manufactured by the BryDet Development Corporation in collaboration with Eskom and Cutting Edge Technology Pty Ltd with support from Anglo Coal and the Ingwe Coal Corporation Ltd.

The prototype BryDet BUA 600 underground coal recovery auger commenced trials in March 2000 at the Matla Mine near Witbank in South Africa. The initial trials were undertaken in an open cut to facilitate the commissioning and training associated with a prototype mining machine. A total of 30 holes was augered in the box cut before the machine moved underground. The prototype BUA 600 first achieved the target penetration depth of 80 m in its third hole.

The prototype BUA 600 is a new underground mining system which has passed early testing with 'flying colours' and could provide access to extensive underground coal reserves unmineable by conventional mining techniques both in South Africa and elsewhere around the world.

Introduction

The potential for underground coal production from drilling or augering machines has been recognized since at least the 1940s. These machines could bore into the virgin coal from stabilized entries and provide access to otherwise sterilized coal reserves. Such operations were held to offer additional advantages beyond improved reserve utilization such as a measurable increase in safety, as all of the excavation would take place in an unmanned area, and the machinery itself would operate from a well supported roadway.

This paper describes the performance of modern surface augers in South Africa and reviews the historical development of underground auger mining technology. It goes on to describe the research and development programme to develop a prototype underground auger mining system aimed at providing economic extraction of otherwise sterilized reserves. This is a collaborative project between the BryDet Development Corporation of the USA, Eskom of South Africa and Cutting Edge Technology Pty Ltd of Australia.

Surface coal augering in South Africa

Surface coal recovery augers are not new and have been around, in one form or another, since before the Second World War. They have proven themselves as reliable mining tools, able to operate under difficult mining conditions and a wide range of ground conditions. However, up until recently they had had limited use in the harder coals of South Africa.

Coal augers have developed incrementally over the last 40 years with auger technology development hitting a plateau in the 1970s and 1980s, see Figure 1. In 1985 the best available surface coal auger had a diesel motor able to produce around 425hp and was only able to penetrate to a maximum hole depth of 50 m and typically produced 450 tonnes per day (single shift), see Figure 1.

Recognizing this plateau in performance the BryDet Development Corporation was formed in 1987 and immediately embarked upon an aggressive coal auger development programme, which has seen auger power rise

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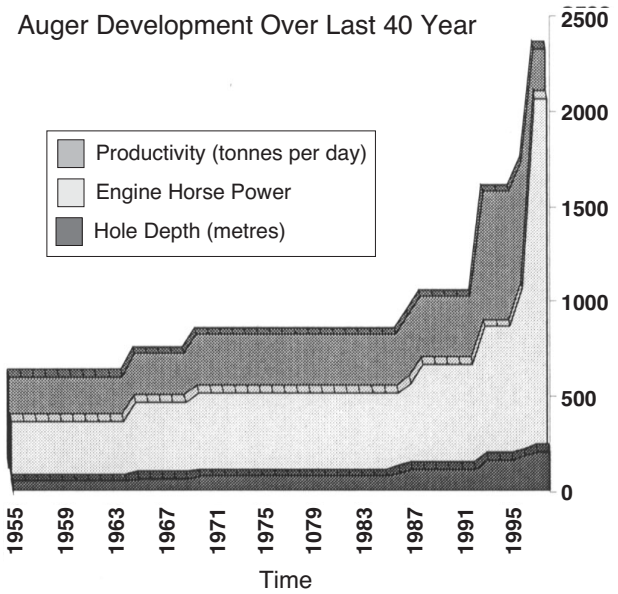

Figure 1—Surface auger mining technology development of last 40 years

to over 2,000hp, hole depth increase to in excess of 200 m and production rates exceed 2,000 tonnes a shift.

The cutting action of an auger differs from other coal cutting machines, such as continuous miners, in that it exploits the lower tensile strength of coal rather than overcoming the comparatively high compressive strength of coal. This makes augers more efficient in terms of the power needed to cut the coal. Note in Figure 2 the size of the cutting surfaces relative to the cutter head diameter. Auger performance is principally governed by two main factors; machine power and cutter head diameter. The greater the power available the deeper the penetration and the higher the mining rate, for the same machine configuration.

The larger the diameter of the cutter head the greater the rate of production per metre of hole advance and hence the higher the mining rate.

A collaborative project between Eskom, BryDet Development Corporation, Auger Mining South Africa and Cutting Edge Technology Pty Ltd (CET) saw a BryDet Model 2348-72 Coal Recovery Auger introduced into South Africa in August 1997. Operational performance data, from the BryDet 2348-72, was analysed to quantify the influence of cutter head diameter, coal type and penetration depth upon mining rates. Figure 3 shows a summary of the results of these analyses. The data plotted in Figure 3 is for a 1,000hp BryDet 2348-72 operated by Auger Mining South Africa in South Africa.

There are a number of interesting observations which can be made from the results presented in Figure 3.

- The change from brighter (20% ash) to duller coal (40% ash) moved the graph down for both cutter head diameters, but the relative change was greater for the 1.83m diameter cutter head.
- The gradient of the curve was consistent and contrasting for the two cutter head diameters across the coal types and
- The gradient of the curve was much flatter for the smaller cutter head diameter across all coal types, being controlled ultimately by machine power which was common to all data (i.e. The power draw down curve becomes flatter as diameter decreases for the same available power).

The main performance statistics from a number of operations have been summarized below in Table I for comparison. The data in Table I further illustrate the impact

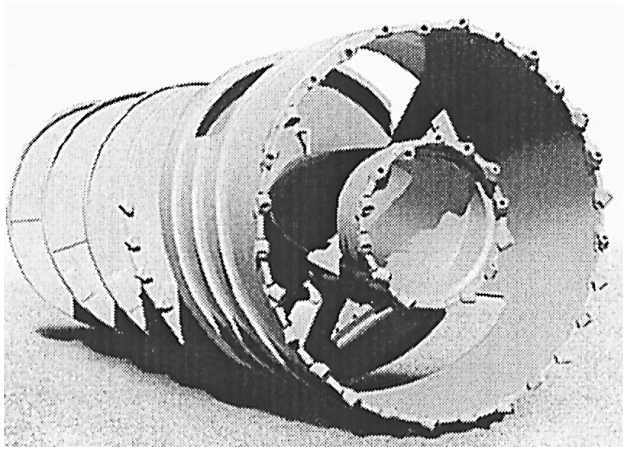

Figure 2—1.83 m diameter auger cutter head

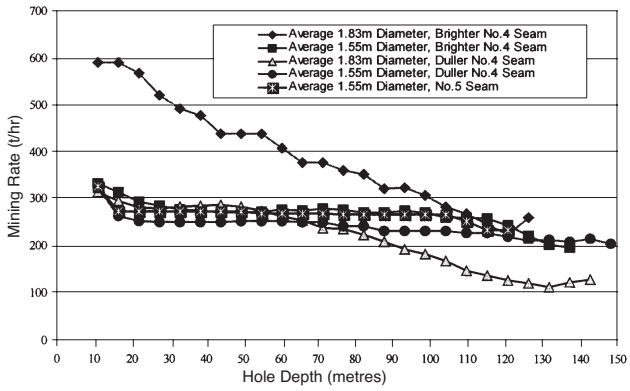

Figure 3—Summary of results from analyses of operational data from surface auger operations in South Africa

Table I

Performance data from a range of surface augering operations in South Africa

	No. 2 Seam[2]	No. 4 Seam[2]	No. 5 Seam[3]
Average hole depth[1]	35.4	101.2	113.6
Average penetration rate (m/hr)[4]	58.4	24.3	42.8
Average mining rate (t/hr)[4]	165.2	68.8	114.1
Average tonnes per pick	37.7	28.3	41.5
Number of auger holes sampled	107	201	38

1-Hole depth varies with application and is limited by geology and mine plans
2-Augered with 1.83m diameter cutter head
3-Augered with 1.52m diameter cutter head
4-Both of these rates are operational averages rather than instantaneous rates

of coal type, hole depth and cutter head diameter. The shorter hole depth in the No. 2 Seam application enabled penetration rate and mining rate to increase significantly as the power draw down effects seen in Figure 3, were reduced.

The comparison between the No. 4 and No. 5 Seam operations is also interesting in that it shows the improvement in penetration rate as the coal seam becomes brighter and 'softens'.

As noted earlier, the cutting action of a coal auger exploits the tensile strength of coal rather than the compressive strength. Therefore as a general rule the brighter the coal seam, i.e. the higher the vitrain content, the better developed the cleat tends to be, this in turn enables the auger to cut more efficiently.

The analysis of the operational data summarized in Table I gave insight into a number of interactions and highlighted the following relationships:

- The penetration depth possible and at what mining rate for a given machine power
- The impact of cutter head diameter upon penetration depth and mining rate
- The impact of coal type upon penetration and mining rates for a range of cutter head diameters
- The impact of coal type upon pick consumption per tonne of coal mined.

History of underground auger development

A summary of the development of underground auger technology, as far as has been able to be determined from available records, is outlined below, Follington *et al.*[1].

Compton Augers (Compton), a US company based in West Virginia, did their first underground auger test in 1949/1950. It was a simple carriage on a frame that was dragged into position. It had a cutter head diameter of approximately 0.76 m with 0.91 m long auger flights.

Compton re-designed their underground auger in the early 1950s. In re-designed form it had walking skids, could drill both left and right from the roadway, had a 56kW electric motor, 0.91 m diameter cutter head, 1.22 m long auger flights and a conveyor against the face designed to load shuttle cars, see Figure 4.

The Salem Tool Company (Salem), another US company but based in Ohio, made its first underground auger some time in the mid-50s. In the late-50s Salem built a two-unit auger (drilling unit and power unit) powered by a 37kW electric motor driving hydraulic pumps. It had a 0.91 m diameter cutter head with 1.52 m long auger flights.

Also, in the late 50s Salem built an underground coal auger to drill 0.61 m diameter ventilation holes at a 45 degree angle for the anthracite mines in eastern Pennsylvania. It was powered by a 45kW electric motor, with 0.91 m long auger flights.

In 1964 Salem designed and built the Model UCA-201 underground auger, see Figure 5. It was powered by two 37kW electric motors, had a 0.91 m diameter cutter head and 1.83 m long auger flights. The machine drilled successfully, but the concept was not supported by the mine personnel so it did not become a commercial success.

During the late 60s and early 70s three more of this style of machine were made for use in the Ruhr Valley in Germany. They were operating in high roadways and a monorail system was used to handle auger flights. The major problem was the extreme pressure due to the depth (over 600 m) which caused the cutter head and auger flights to be squeezed. To try to overcome this problem the next machine (Model UCA-400) was designed with more power (about 112kW) and the machine after that (UCA-1000) with 350kW. They continued to have problems from the extreme pressure and the resultant hole closure. The UCA-1000 is currently displayed in a museum in Bochum, Germany.

In 1972, Badger Manufacturing Company (Badger), a US company, revived the idea of underground augering with a machine they called the Coalbadger. Aware of the failings of earlier auger machines, Badger improved upon the prior art in a series of prototype machines, ultimately resulting in the inclusion of the following features:

- A 112kW main drive designed to drill a 0.91 m diameter hole to a depth of at least 30 m
- A system of hydraulic jacks which were capable of levelling the machine on uneven ground so that auger trajectory could be better controlled and
- A unique sliding frame arrangement which allowed the drill frame to move from borehole to borehole storing and retrieving drill sections from the adjacent hole, thereby eliminating most of the tedious hand loading of augers.

In 1974 Badger previewed their Coalbadger auger miner to the mining industry. A company named FMC Corporation (FMC), a US company based in California, visited Badger and reviewed the machine specifications and operating procedure with Badger personnel. Badger had solved many of the problems which had plagued prior augers, however certain

Figure 4—Early Compton underground auger, circa 1950

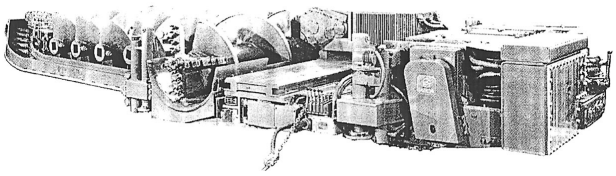

Figure 5—Salem UCA-21 underground auger, circa 1964

other problems remained unresolved. In a 1977 report by the FMC, Baldwin *et al.*[2], some of the more important reasons why earlier underground augers had failed were noted as follows:

- Lack of sufficient power to drill a large diameter hole deep enough
- Lack of a method of steering the cutter head to avoid cutting roof and floor
- Lack of an effective method of loading, unloading and storing auger flights while drilling
- Lack of a haulage system to remove the cut coal from the throat of the borehole and keep the machine from becoming coal bound.

The FMC-modified Coalbadger was demonstrated underground for 6 months. Three panels of coal developed for the demonstration were mined. The test operations were thereby significant as one of the first underground auger mining efforts which yielded a substantial tonnage of coal. The auger mine tests further identified additional improvements that would heighten the production potential of underground auger mining.

The following innovations appeared particularly beneficial:

- Shortening of cycle time through the addition of an auger-flight extractor mechanism to operate independently of the auger, removing flights from the augered hole and transferring them to the auger drive head
- Improvement of the tramming system to provide increased manoeuverability and ease of machine alignment with the seam and ribs
- Incorporation of a frame levelling device to facilitate alignment with the coal seam
- Improvement of operator's station and controls
- General upgrading of system to improve the total system reliability.

In 1987 the Vryheid (Natal) Railway, Coal and Iron Co. Ltd, a South African based company, undertook to design and fabricate an underground auger at their Hlobane Colliery, Collins[5]. The machine was designed to penetrate up to 70 m with a 0.5 to 0.7 m diameter cutter head using 2 m long auger flights, see Figure 6. The machine had a total installed electrical power of 147kW. The machine was trialled on the surface and underground at Hlobane Colliery in 1988. The

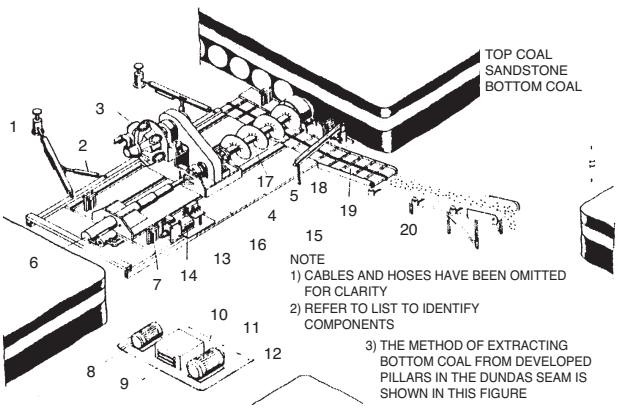

Figure 6—Illustration of the underground auger built at Hlobane Colliery, circa 1988

results of the underground trials were not sufficiently encouraging to warrant further development.

In 1993 Horizontal Boring Pty Ltd, an Australian based company, was approached by a coal mining company to convert an existing surface augering machine from diesel to an electric drive for use in underground coal mines. The initial trials generated interest from a number of collieries and Coal Augering Pty Ltd (Coal Augering) was formed to pursue the development of an underground auger mining system, McKinnon[3]. The equipment passed through multiple generations each improving on the last. Coal Augering demonstrated the feasibility of drilling 1.8 m diameter auger holes and achieved penetration depths of 50 m, Coffey[4].

In 1998 the BryDet Development Corporation, Eskom and Cutting Edge Technology embarked on a project to design and build an underground auger mining system. The project was conducted with the technical support of both Anglo Coal and Ingwe Coal Corporation Ltd staff. The development of the BryDet underground auger mining system is outlined in detail in the next section.

Development of the BryDet underground coal recovery auger

The main aim of the collaborative project between BryDet, Eskom and CET was to develop and demonstrate an underground auger mining system able to provide economic access to the thinner (<1.8 m) coal reserves of South Africa.

A comprehensive review of previous underground auger mining systems was undertaken, given in the last section. This review provided a starting point for the development of the concept for the BryDet underground auger mining system. Particular attention was paid to the issues of flight handling in confined spaces, lateral and vertical control of the system, coal clearance systems and operator safety.

A series of detailed analyses were then conducted to test this concept using data gained from the operation of a surface auger under a range of conditions in South Africa. The impact of a number of key design parameters was modelled numerically using the operational data gained in South Africa. These parameters included; cutter head diameter, auger flight length, penetration rate and hole depth, see Figure 7.

The numerical modelling revealed a strong relationship between flight length, penetration rate and productivity, see Figure 7. However, the flight length was predicted to have a greater influence upon productivity, particularly at larger cutter head diameters. The effect of hole depth was also studied but was predicted to have a lesser influence upon productivity and its influence increased with cutter head diameter. The machine power was kept constant throughout all models to assist in the ready comparison of parameters on a common basis.

The numerical simulations were used as a guide in determining the main design parameters for the prototype underground auger mining system including cutter head diameter, machine power and auger flight length.

Other key design guidelines were agreed through consultation with mine staff. These mainly concerned roadway dimensions and operational requirements.

Consultation with Eskom and mine staff set the main design parameters for the project as follows:

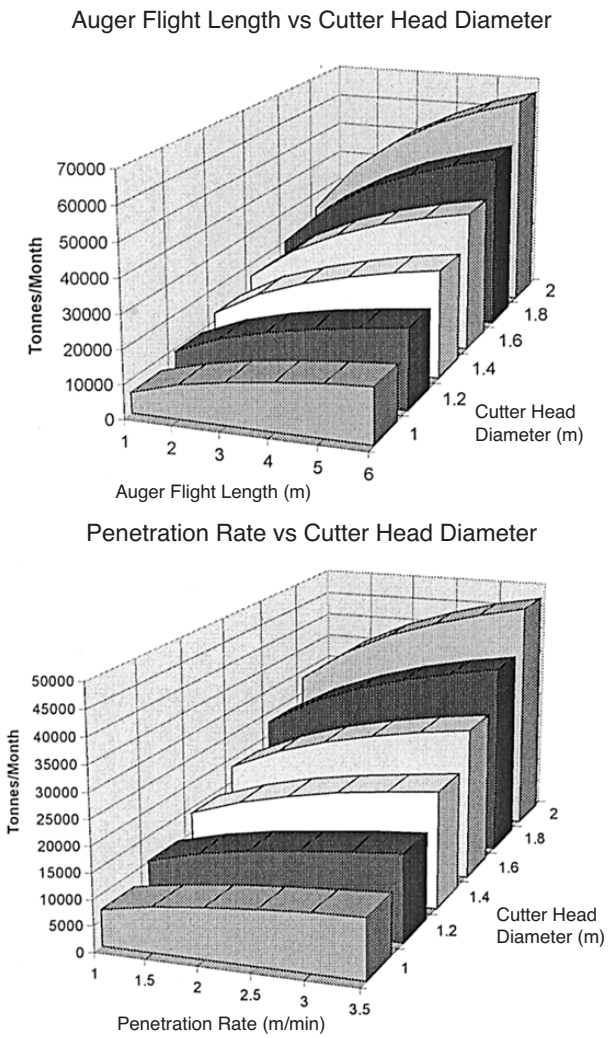

Figure 7—Results of modelled interactions between design parameters based on data from surface augering operations in South Africa

- Target seam thickness 1.0 to 1.8 m
- Maximum penetration depth of 80 m
- Ability to operate in a roadway 1.8 m high to 6.0 m wide
- Adequate ventilation for safe operation
- Effective dust suppression systems onboard
- Ability to operate singled sided in a twin roadway layout
- Ability to take auger flights from previous auger hole to minimize flight storage in the roadway
- Machine must be able to negotiate intersections
- Machine must be able to be dismantled to fit down mine shaft
- Machine must be able to be serviced and have major assemblies replaced within the roadway
- Machine must be powered by 3.3kV
- Ability to tolerate soft floor conditions
- Ability to vary centre to centre spacing of holes from 0.55 m up to 2.0 m.

The BryDet underground auger mining system was designed in line with the guidelines listed above. In order to facilitate the re-use of auger flights between auger holes the system was designed with two main modules; a Drill Unit and a Retrieval Unit, see Figure 8. The basic specifications for the prototype BryDet BUA 600 underground coal auger mining system are summarized in Table II.

The prototype BryDet BUA 600 underground coal recovery auger was built with an on-board storage capacity of three flights while leaving the staging area free and allow normal operation of the system, see Figures 9 and 10. The retrieval unit has a chain rack system to move auger flights towards and away from the staging area as required.

The prototype system also has remotely operated auger flight latch and de-latch mechanisms. These were considered

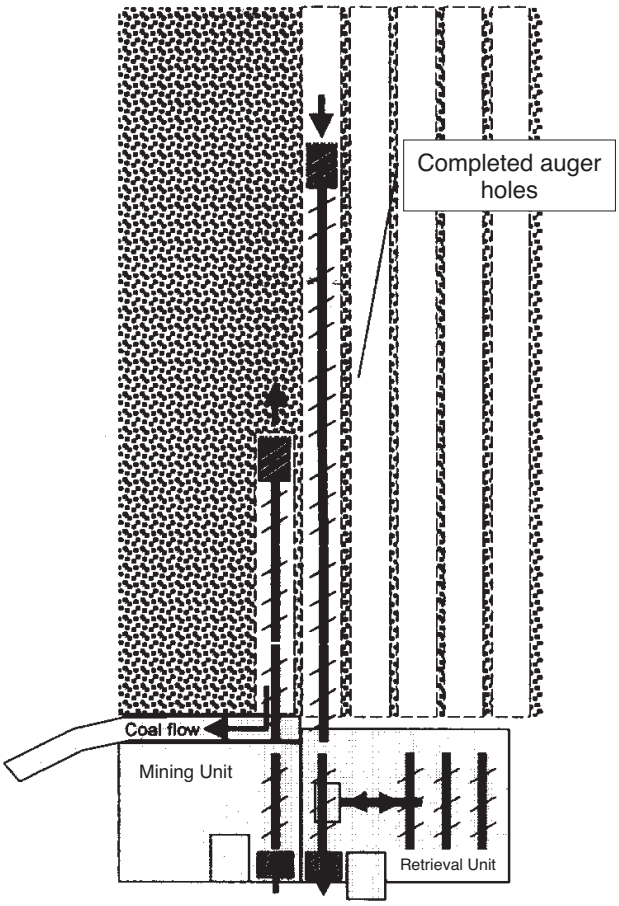

Figure 8—Schematic of basic BUA 600 concept and operation

Table II

Summary of technical specifications for prototype BryDet BUA 600 underground coal recovery auger mining system

Mining unit		Retrieval unit	
Length (m)	5.86	Length (m)	6.48
Width (m)	5.10	Width (m)	4.67
Height (m)	1.52	Height (m)	1.52
Weight (t)	28.93	Weight (t)	30.39
Carriage thrust (t)	15.42	Carriage thrust (t)	15.42
Electrical power (kW)	450	Electrical Power (kW)	110
Rotation speed (rpm)	0–45	Rotation speed (rpm)	0–19

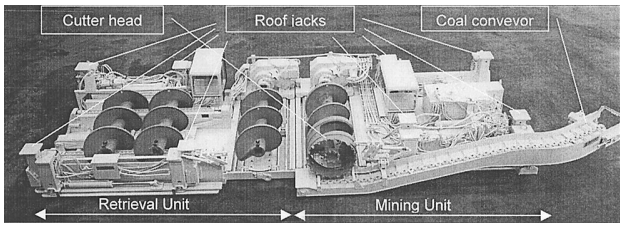

Figure 9—Prototype BryDet BUA 600 underground coal recovery auger

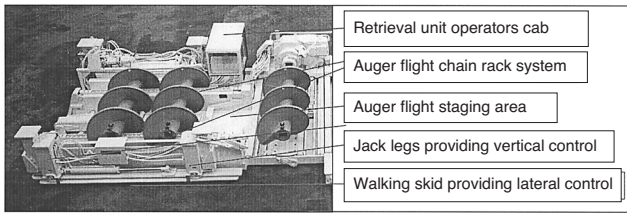

Figure 10—Detailed view of retrieval unit

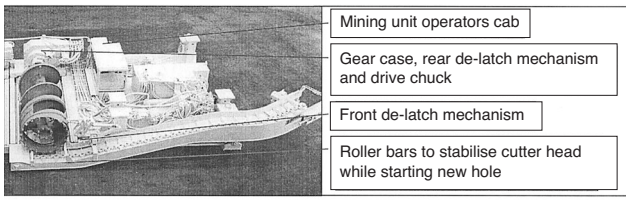

Figure 11—Detailed view of drill unit

to be important as this latch/de-latching process would otherwise require operators to leave their reinforced operator cabs and undertake hazardous operations in limited space, see Figure 11.

The prototype BryDet BUA 600 underground coal recovery auger offers a major increase in capability over previous underground auger technology. Figure 12 charts the development of underground auger technology. The BUA 600 significantly increases the power available and target hole depth.

Performance to date

The prototype BryDet BUA 600 underground coal recovery auger commenced trials in March 2000 at the Matla Mine near Witbank in South Africa. The initial trials were undertaken in an open cut to better facilitate the commissioning and training associated with a prototype mining machine. A box cut was excavated down to the No. 5 Seam horizon and the exposed highwall was prepared for auger mining. A total of 30 holes were augered in the box cut before the machine moved underground, see Figure 13.

The third hole drilled reached the target depth of 80 m. The first two holes stopped short due to the cutter head passing out of the seam horizon. This problem was addressed in the way the cutter head was laced with picks. The relatively short cutter head, 3.1 m compared with a 5.4 m for surface machine, made the auger string even more sensitive to pick lacing and operator controls.

The operating crew were being trained at the same time and had limited experience in the operation of coal augers. Figure 14 shows a plan of part of the box cut at Matla Mine.

Detailed records were kept of the prototype BUA 600's performance during the commissioning period. Particular attention was paid to rotation speed, rotation pressures,

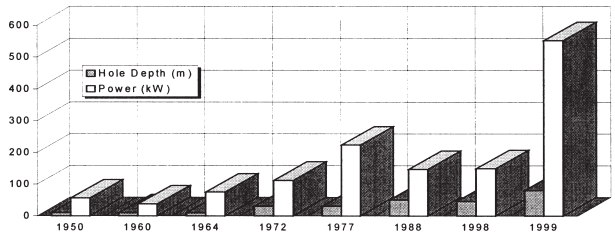

Figure 12—Underground auger technology development over the last 50 years

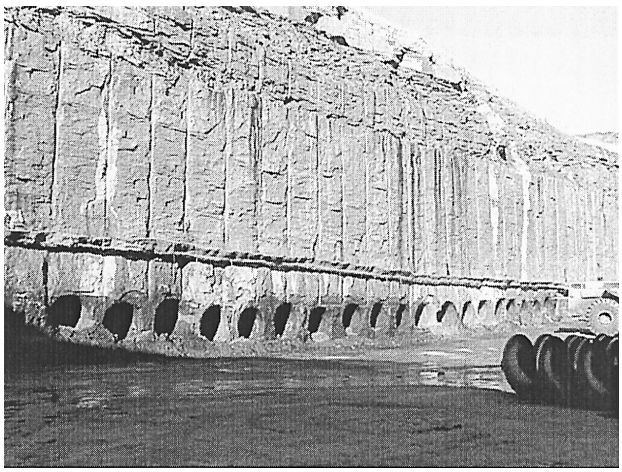

Figure 13—First 19 auger holes in the box cut at Matla Mine

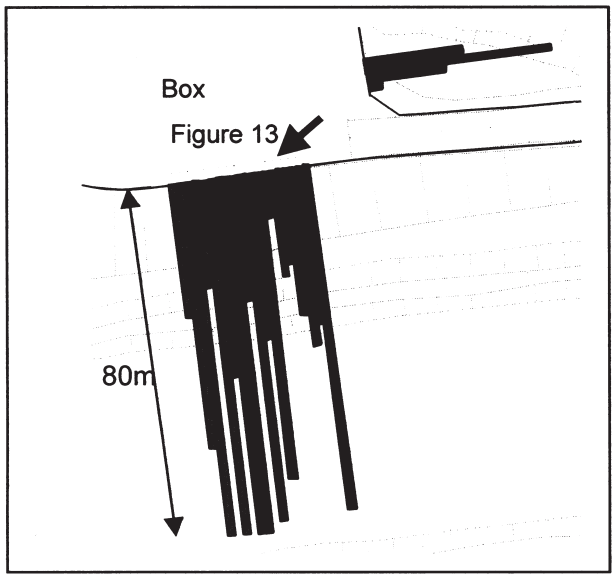

Figure 14—Plan of some of the auger holes drilled in box cut at Matla Mine

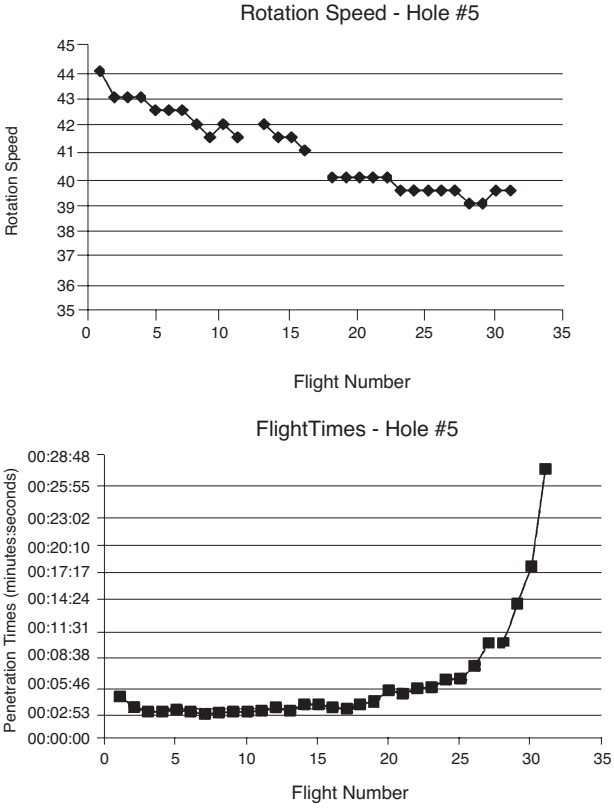

Figure 15—Graphs of flight times and rotation speed variations over hole depth for Hole #5

crowd pressures, penetration rates, motor temperatures and electric motor currents.

The graphs shown in Figure 15 illustrate the steep decline in penetration rate as an abrupt power draw down effect was encountered at a depth of approximately 25 auger flights (approx. 65 m). The flight time is the time taken to drill in an auger flight length (2.6 m). This same effect is seen in the rotation speed except at a depth of approximately 15 flights (approx. 39 m) the crowd pressure (carriage thrust) was backed off to preserve the rotation speed. This effect is shown graphically in Figure 16a, where crowd pressure and rotation pressure are plotted for Hole #5.

In an attempt to overcome this limitation the hydraulic pressures on the mining unit were raised, this displaced the power draw down effect to around 30 flights (approx. 78 m). This was close to the target depth of 80 m and greatly improved the penetration rate over the last 5 auger flights, see Figure 16b.

The pressure settings on the mining unit were only made after the 25th flight to see the effect of raising the pressures while the system was under heavy load. The significant reduction in flight times is evident from the two plots in Figure 17. The elevated hydraulic pressures also increased the product fragment size significantly, particularly at the start of the auger hole. The flight times reduced at the start of the hole with times as low as 2 minutes recorded.

A flight time of 2 minutes per flight equates to approximately 1.3 m/minute. Based on the experience with the surface machine that is an average penetration rate, still below the best achieved by the surface machine.

One of the traditional problems affecting the No. 5 Seam in South Africa is its soft floor material. This did not prove to be a problem for the prototype BUA 600 either in terms of an operating surface or to the performance of the cutter head.

The proving trials for the prototype unit continue, but target penetration depths and rates were achieved early in the commissioning period.

Conclusions

There are a number of key conclusions which can be drawn from the work presented in this paper. These include the following:

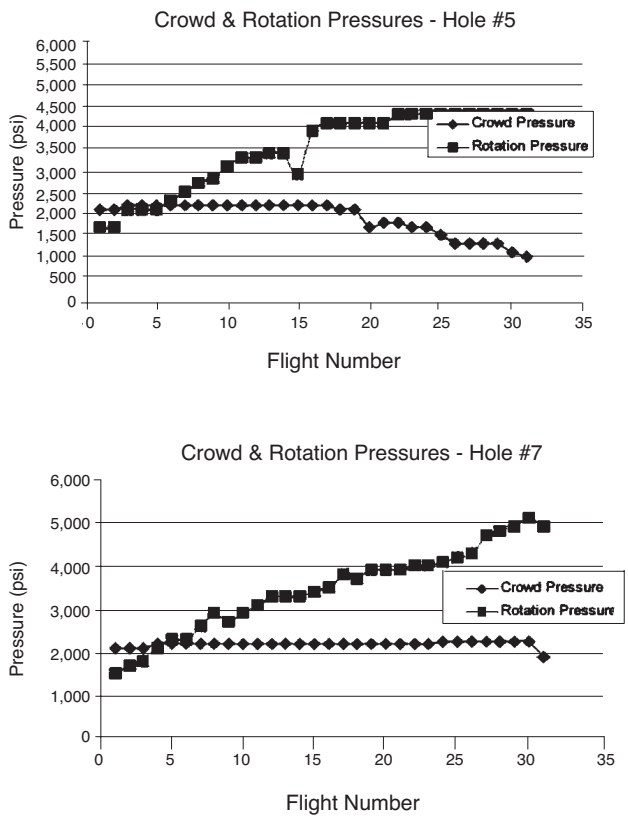

Figure 16—Crowd and rotation pressures for Hole #5 and for Hole #7

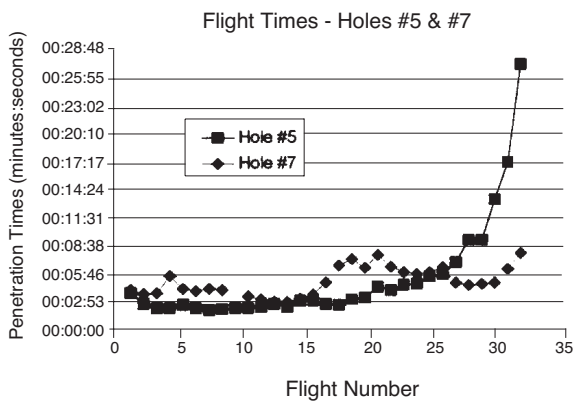

Figure 17—Comparative plots of flight times for Holes #5 and #7

- Modern coal augers have proven themselves capable of operating effectively in the hard coals of South Africa
- The key parameters controlling surface auger performance were found to be cutter head diameter, available power, penetration depth and coal type
- There have been multiple attempts at designing and building underground coal augers over the last 50 years, of which few have been successful
- The practicality of drilling large diameter (1.8 m) auger holes in an underground coal mine has been demonstrated
- A design concept was developed for the prototype BUA 600 drawing on past projects, surface augering experience in South Africa and elsewhere and from consultation with Eskom and mine staff
- Main design parameters for a machine to suit South Africa's coal mining conditions were derived from consultation with Eskom, Ingwe and Amcoal
- The prototype BUA 600 embarked on trials in March 2000 and achieved target depth in its 3rd hole
- Raising the hydraulic pressures on the mining unit moved the power draw down effects out to the target depth and significantly improved flight times for the last 5 flights
- The prototype BUA 600 proved itself capable of operating on the known soft floor conditions of the No. 5 Seam
- The shorter cutter head was found to be very responsive to changes on crowd and rotation pressures as well as pick lacing.

The prototype BUA 600 is a new underground mining system which has passed early testing with 'flying colours' and could provide access to extensive underground coal reserves unmineable by conventional mining techniques both in South Africa and elsewhere around the world.

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Spotlight

SAIMM council member appointed Centennial Professor of Rock Engineering at Wits

SRK Consulting (South Africa) has announced that Dr Dick Stacey, who has been Chairman of SRK Board of Directors for the past four years has left SRK to take up the position of Centennial Professor of Rock Engineering at the University of the Witwatersrand's Mining Engineering Department. A move fully supported by SRK.

SRK is very proud of Dick's appointment and fully support the view that he will make a major contribution to rock engineering in the country through his new position. They would like to acknowledge, with thanks, the contribution Dick has made to the development of SRK over the past 24 years. He will continue to play a role in SRK's future as an Associate Consultant.

The SRK Board announces the appointment of Mr Peter Terbrugge as Chairman of SRK (South Africa). Peter has been with SRK for 21 years and is well known to the mining industry. ◆