MACHINES FOR THE DEVELOPMENT AND EXPLOITATION OF MINES

MADENCİLİKTE HAZIRLIK VE ÜRETİM MAKİNALARI

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ABSTRACT

A well planned development programme is a pre-requisite of any mining system. Where longwall systems have been adopted the ability of the development programme to ensure that there is a continuity of production is of prime importance to the success of mining operations

The reasons for choosing a specific machine which is suitable to its task should be based upon laid down parameters. These parameters determine the machine specification The methods and reasons for determining these values require careful and thorough consideration.

Tunelling machines are continuously being tried in harder material. Designers and manufacturers are responding by innovation in all areas. These areas of innovation are to enable the machine to perform safely, efficiently and cost effectively.

It is felt that the present designs of development machines gives the mine operator in the right conditions a safe reliable and economic alternative to drill and blast methods.

ÖZET

İyi bir şekilde planlanmış hazırlık programı her turkt madencilik sisteminin bir on gereksınmesidir Uzunayak uygulamalarında, hazırlık programları madencilik operasyonlarının başarılı bir şekilde yapılabilmesi, üretimde sürekliliğin sağlanabilmesi y önünden çohonemlidir

Amaca uygun, belli bir makinanm seçimi için gerekli sebepler birtakım parametrelere bağlı olmalıdır. Bu parametreler seçilecek makinanm Özelliklerini, değerlerini belirler. Bu özellikleri, değerleri belirlemede uygulanan yöntemler ve nedenler dikkatli, detaylı bir çalışmayı gerektirir.

Tünel açma makinaları devamlı daha sert kayaçlarda kullanılmaya çalışılmaktadır. Tasarımcılar ve üreticiler de bütün alanlarda yenilikler ile karşı karşıyadtrlar. Bu değişik alanlardaki yenilikler makinalann daha emniyetli, daha randımanlı ve düşük maliyetli bir duruma getirilmelerini sağlar.

Bir gerçektir ki günümüz hazırlık makinalarıntn tasarımı maden idaresine delme ve patlatma yöntemlerine karşı (uygun şartlarda kullanıldıklarında) emniyetli güvenilir ve ekonomin bit alternatif sağlamaktadır.

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1. INTRODUCTION

In the quest for ever increasing productivity in Mining with consequent reductions in costs, the trend has been towards concentration of effort into high production units. This has resulted in a need for higher rates of development in order to match these increases in production and the development of a wide range of equipment to mechanize roadway drivage.

Manufacturers can now offer a wide range of machines designed for the variable conditions found in Mining, from Continuous Miners for development in coal and other stratified deposits to Heavy Duty Roadheaders for major drivages in hard rock.

2. SELECTION OF MACHINE

The choice of the most suitable machine is of crucial importance to the success of a mechanized drivage, the use of a machine of insufficient power or cutting ability will result in increased downtime, increased spares usage, increased maintenance and consequently higher operating costs. Moreover a poor development performance can affect overall mine production such that the consequential losses are many times greater than the cost of purchase of the correct machine in the first place.

There are various parameters which influence the selection of the most appropriate machine:

— Type of strata
— Roadway shape
— Roadway support system
— Gradient
— Ventilation
— Dust suppression

2.1. Type of Strata

There are several factors to be examined when considering cuttabilitv.

2.1.1. Compressive Strength

As a generality rocks can be conveniently classified according to compressive strength. However, alone it has little bearing on machine performance.

2.1.2. Tensile Strength

Materials exist with low compressive strength but high tensile strength and are consequently difficult to cut (for example Gypsum)

Where the compressive strength of the material suggests it is cuttable and the tensile strength is less than 10 % of the compressive strength then this rock should be a good cutting proposition. If the tensile strength İs greater than 10 % of the compressive figure more tests are advisable.

2.1.3. Specific Energy of the Rock

This is the work done to remove a unit volume of rock and is a measure of cutting efficiency.

Minimum specific energy represents maximum cutting efficiency and also maximum potential excavation rate of a given power input.

Specific energy is directly proportional to the mean cutting force for a given depth and spacing of cut.

Manufacturers have available standard laboratory test for specific energy which when compared with the wide operational experience with machines, give very accurate estimates of the cutting rate to be expected in various materials.

2.1.4. Abrasivity

Several factors, quartz content, grain size and crystalline structure, cause a material to be abrasive affecting tool wear and dust production with a resultant increase in the specific energy value.

In abrasive conditions a reduction in the tool speed would be advantageous requiring the use of heavier duty machines if the rate of production is to be maintained.

2.1.5. Fracturing

In-situ conditions such as bedding planes, thickness of strata and degree of fracturing all have an important bearing on the potential excavation rate.

If the rock İs laminated or fractured, this will assist cutting, if the rock is massive and homogenous this will probably reduce the cutting rate.

2.2. Roadway Shape

In-seam drivages are often rectangular and as such are ideally suited to all types of heading machine though the fastest rates of advance will probably be achieved by Continuous Miners.

However, where extra strength is required from the roadway support, in deep workings or where weak or highly pressured ground is encountered, arched profile supports are used. The use of an arch will generally necessitate the use of a boom machine due to its ability to accurately produce a variety of profiles.

2.3. Support System

Where the strata is self supporting, then this is obviously the most desirable situation. However, where it is necessary to add additional support, the machine must be suitably equipped and must be able to excavate in a manner suitable for the system of support required.

Where this is to be roof bolts, the machine should be equipped with power take-offs to power the bolters which may be machine mounted or independent depending upon the application.

If steel arches or square work steel supports are to be used, the machine must be able to accurately profile and clean-up for the legs to be set. Moreover, the machine should be equipped, wherever possible, with attachments to assist in the lifting of the roof beam thus reducing the manual work involved in setting supports leading to increased development rates as well as greater safety.

2.4. Gradient

The available machines are capable of operating on different gradients. Track engine power and growser bar design must be carefully considered if in-line gradients over 14° or cross-gradients in excess of 8° are contemplated.

23. Ventilation

In applications where the dust production is likely to be a problem the ventilation system must be carefully considered.

As a generality the dust production from any tunnelling machine is such that simple forcing ventilation is unlikely to prove acceptable since the loss of visibility leads to diminished control of the machine as well as poor working conditions.

Exhaust ventilation overcomes these problems since the dust is removed from the roadway as it is produced. However, where explosive gases are a problem or where high ambient temperatures preclude the use of exhaust ventilation alone, then an overlapping system of ventilation is recommended.

This should take the form of a main forcing system delivering clean, cool air to within around 50 m of the face of the heading overlapped by a secondary exhausting system equipped with a dust filter which is maintained to the face of the heading thus keeping the working environment clear.

2.6. Dust Suppression

In general, water used for machine cooling purposes is then applied through sprays for suppressing dust.

It has become common practice with roadheaders to apply the water through the cutting head so that the dust is suppressed at source. Whilst considerable improvements in dust production are achieved, it has still been necessary to utilize overlapping ventilation to comply with the very stringent dust regulations.

However experience with high pressure water applied to the cutting head has so reduced the dust production in certain applications forcing ventilation alone has proved adequate (Figure 1).

With continuous miners high pressure water jets applied to the picks are not possible, but the machines can be equipped with machine mounted dust scrubber systems which extract much of the dust after it is produced thereby protecting the operator from excessive dust.

In some applications such as potash mining, it is not acceptable to contaminate the product with water and in these applications the cooling water is contained in a closed circuit with a heat exchanger. In these cases the ventilation system must be designed to deal with the dust produced. /

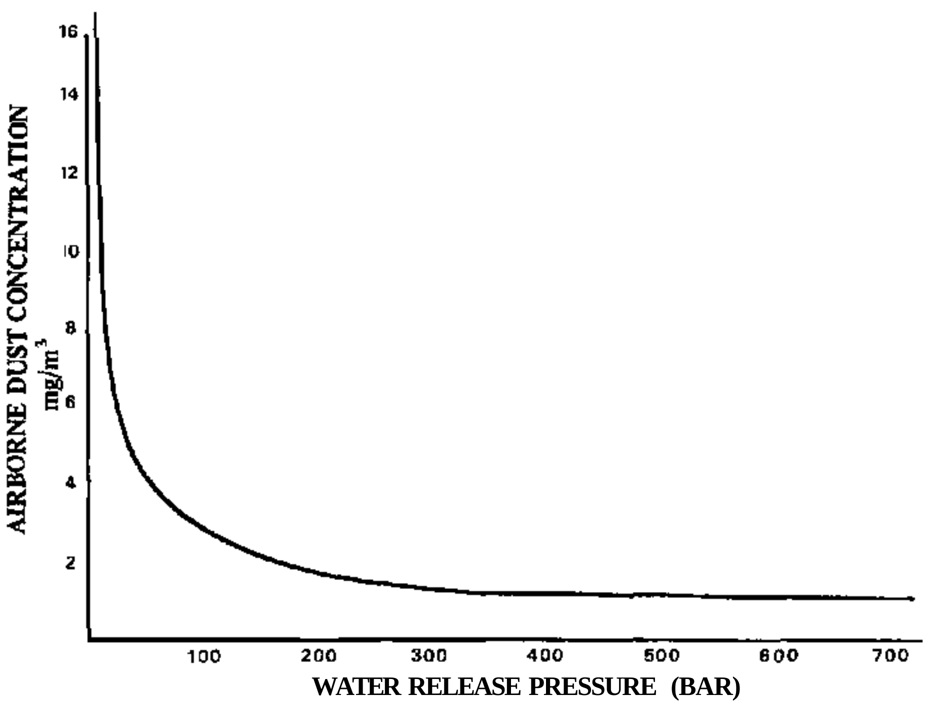


Figure 1. Results of dust suppression tests.

3. EQUIPMENT AVAILABLE

The available equipment falls into two broad categories:

1) Development Machines:
   Boom type machines
   Continuous chain cutting machines

2) Production Machines:
   Boom type machines
   Drum type machines

3.1. Development Machines

3.1.1. Boom Type Machines

These machines are based on the cutting boom principle which originated in Hungary after the Second World War. The original machines were light duty (less than 13 tonnes in weight) and used for developing galleries in coal or soft rock. The potential for this type of machine was quickly recognised and a range of machines was developed by several manufacturers, but whilst these machines were largely successful, more powerful machines were later developed to cut harder strata, and increase performance and reliability.

Boom type tunnelling machines can generally be split into four main groups:

— Utility Roadheaders
— Medium Duty Roadheaders
— Heavy Duty Roadheaders
— Cutting Booms within Circular Shields

3.1.1.1. Utility Roadheaders

The term Yoadheader' is used to describe boom type track-mounted machines which both cut and load material. Machines of the utility group are normally under 30 tonnes in weight with low power cutting booms, where the cutter motor is often a lood carrying structural member of the boom. Typical machines of this group are the Dosco MK2A and Alpine AM50 (Figure 2).

3.1.1.2. Medium Duty Roadheaders

This group of machines have higher power available to the cutting boom - up to twice that available to the utility machine. The cutter motors do not form a structural part of the boom but are protected inside the lifting arm structure. Arcing and lifting forces are generally 2 to 3 times the forces available to the utility mac-

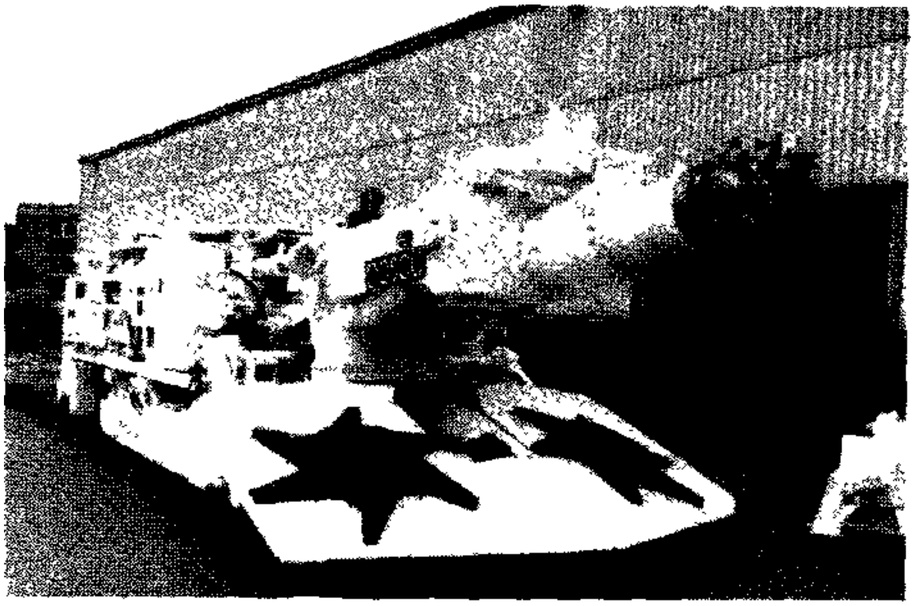


Figure 2. Boom type machine.

hines, with machine weights normally in the range 30-50 tonnes. Typical machines of this group are Dosco MK2B, SU 20 (narrow width machine), LH 1300 (low height machine), Alpine AM75 and Paurat E169.

3.1.13. Heavy Duty Roadheaders

As the need to cut hard strata more cost effectively continued, this range of machines was developed with weights 65-110 tonnes for use in long drivages. Cutter motors up to 300 kW are available with arcing and lifting forces 5 times that of the utility machines. Typical machines of this group are Dosco MK3, Alpine AM100 and Paurat E200.

3.1,1.4. Cutting Booms Within Circular Shields

Tunnelling Shields were primarily used in soft ground applications in conjunction with cast iron or concrete segmental linings. In order to excavate mixed rock tunnels of a circular profile, the cutting boom and pedestal from the utility roadheader were built onto a sliding base to provide the forward sumping movement and installed in a circular shield. Debris is loaded onto the conveyor by the action of the cutter boom, a flipper under the boom, or a backhoe in larger diameter tunnels.

Cutting booms from the medium and heavy duty machines were later installed in shields to cut larger diameters, harder strata and increase performance and reliability. Single boom versions can excavate from 1.8-7 m diameter tunnels, but multi-boom applications have used up to 4 booms excavating 11.5 m diameter *tunnels.*

3.12. Continuous Chain Cutting Machines

As the need for mechanization of roadway drivage became apparent in the immediate post war years, development of suitable equipment took place along two separate lines in Europe and in the USA. In Europe the requirement to cut both coal and stone led to the devetopment of the roadheaders, whereas in the USA the requirement for high speed drivages and production in room and pillar situations led to the development of the continuous miner - originally employing cutting chains.

3.1.2.1. Dintheader

The continuous miners from the USA were tried in the UK coal mines during the 1960's, but were found to be unreliable when cutting the shales generally associated with the thinner seams. Thus the Dintheader was developed by the NCB for roadway in coal and shale sections.

The Dintheader machine weights 16 tonnes, cutting the strata by means of cutting chains around a cutting jib which also loads the cut material into a central scraper conveyor.

The cutting action of the Dintheader, being used on radially rotating picks limits its application to coals and rock of less than 600 kg/cm' compressive strength.

3.12.2. In Seam Miner

The original hyrdaulically driven ISM designed by the British Research and Development Establishment (BRDE) and manufactured by Dosco was introduced İn 1971 as a thin seam stable hole machine.

Today electrically driven machines have successfully operated in various applications such as:

a) Face openings
b) In-seam roadway drivages
c) As production machines
— on s hortwall faces
— for partial extraction systems

Machine heights range from 0.86 m to 1.73 m and machine widths from 4.3 m to 13.4 m.

The ISM consists of a cutter jib, base frame, control panel, power pack and conveyor.

The cutter picks are mounted on carrier plates attached to a chain driven by two electric motors. Loading buckets are attached to this chain and these buckets pick up the cut material and discharge it into a chute and then onto the conveyor system.

The jib can be pivoted on the base frame hydraulically to adjust the cutting horizon thus steering the machine up or down. Side steering is achieved by hydraulically operated pads at each end of the machine.

The whole machine is advanced by pushing rams anchored to twin leg staker units, and advance of 1 to 3 m can be achieved before repositioning of the staker is required.

Two bar setting devices are incorporated into the jib assembly.

All hydraulic and electric functions are operated from the control panel and the hydraulic power pack is towed from behind the machine.

The ISM has been particularly successful in Australia where the roadway development is difficult and costly because of poor roadway stability. Indeed by using the ISM single entry drivages for the development of longwall panels have been possible because the stability of the roadway driven by other machines.

Continuous operation with the ISM is possible because the roof support can be set close to the face at the same time that cutting and loading operations are carried out. In Australia this has resulted in advance rates in excess of those rates achieved by other development machines, i.e. up to 18 m/shift.

Because of the ISM's success as an in-seam roadway drivage machine, machines 2 and 3 m high have now been developed and are currently undergoing trials in Australia.

3.2. Production Machines

This section can be split into two main sections:

— Twin Boom Continuous Miners
— Drum Type Continuous Miners

3.2.1. Twin Boom Miners

The first Twin Boom Miner was introduced in 1976 as a production machine in harder materials beyond the range of conventional Continuous Miners. The pro-

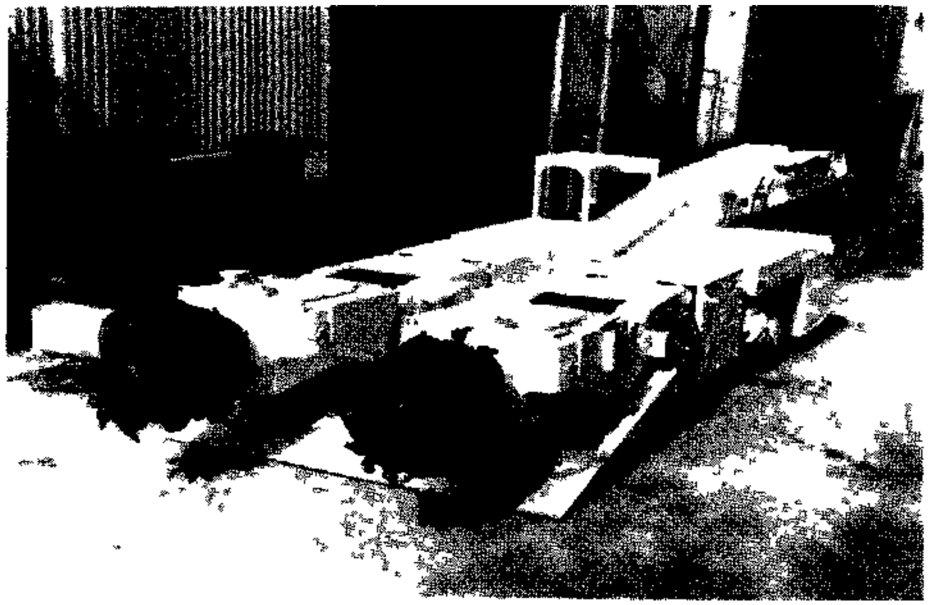


Figure 3. Twin boom miner.

to type was tested in an iron ore mine in Britain where the production rate of over 100 tonnes per hour was enough to encourage British Steel to order two machines for production.

The utilization of contra-rotating cutting heads means that reactive forces are opposed and negated which allows very high slewing forces to be applied to the booms.

The original twin boom machines weighed 70 tonnes and have been successfully used in Potash, Rock-Salt, Borate, Iron-Ore and Coal where production rates in excess of 400 tonnes per hour were achieved. One TB600 in a coal mine averaged production rates of 47,000 tonnes per month with availabilities of over 90 %.

As a result of these successes a range of Twin Boom Miners has been developed from the smallest TB2000 at 70 tonnes, to the TB3000 weighing over 120 tonnes. It is this latter machine, working in a Bauxite Mine in Australia, which is producing over 600 tonnes per hour from a hard bauxite material of over 800 kg/cm^2 in compressive strength (Figure 3).

3.2.2. Dram Type Miners

The basic configuration of the modern continuous miner İs a steel main frame supporting crawler tracks, gathering head, cutting head and conveyor. The drum type rotary auger sumps in at roof level and cuts downward to the floor with assistance from hydraulic cylinders, but material is loaded onto a central chain conveyor by gathering arms (Figure 4).

Factors such as design of crawler tracks, forward centre of gravity and rear hydraulic stabilization allow a high proportion of machine weight to be transformed into sumping and downward cut forces provided stability during cutting operations.

The latest continuous miners are all electric with 6 motors. Drive is to each crawler track via a 3-speed reduction gearbow is from a DC motor. 2 electric motors with a power availability up to 314 kW drive the main cutting head.

Machines in this all electric range can extract height ranges from 0.9 m up to 3.7 m and total installed power up to 448 kW is available.

Continuous miners can be operated by radio or remote cable control as well as the manual system. According to the application requirements, scrubber systems for dust extraction, closed loop cooling systems and roof bolting units can all be fitted.

4. COST EFFECTIVENESS

Cost effectiveness of a particular system or machine is a measurement of the performance achieved in terms of output against the costs of achieving that perfor-

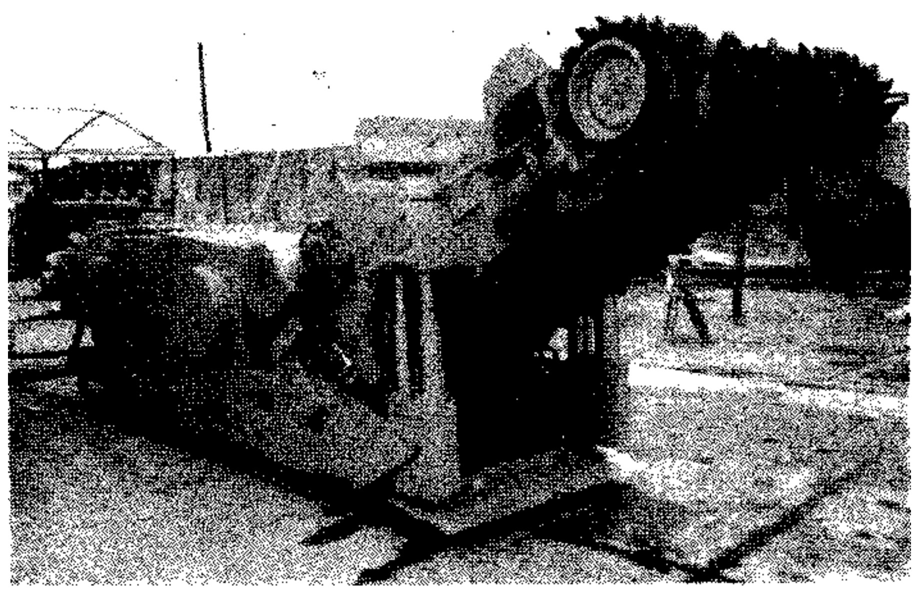


Figure4. Drum type miner.

mance, when compared with other available systems or machines as alternative methods of work. In relation to tunnelling machines it can be best measured in terms of cost per unit volume extracted or as cost per unit distance of tunnel advance.

There is no yardstick of an acceptable cost per metre advance of tunnel, as each different situation will have its own relevant criteria, e.g., geological condition, cost of labour, availability of equipment, etc. It is always difficult to estimate the costs due to production losses incurred if the tunnel is not completed in the time estimated - hence the least cost effective method per metre advance may turn out to be most cost effective overall, due to an earlier completion date minimising future production losses.

When determining cots per meter advance, certain costs remain fixed irrespective of drivage method or machine, e.g., supports, lining, transportation, etc. However, the following variables apply :

— Capital costs of equipment ,
— Spare parts consumed
— Consumable items (cutting tools, oils, greases)
— Operational labour requirements
— Maintenance labour during operation
— Labour requirements for overhaul

Machine performances depend upon many factors with both manufacturer and end user having responsibilities and a part to play in ensuring the best performance is achieved.

The following factors affect performance:

— Suitability of machine for conditions
— Machine reliability
— Standard maintenance
— Availability of spare parts
— Appropriate support system
— Adequate debris disposal and material supply systems
— Suitable environmental conditions
— Adequate training in operation and maintenance
— Appropriate motivation of workforce

5. LATEST DEVELOPMENTS IN TUNNELLING MACHINES

5.1. Cutting Head design

Boom type tunnelling machines are continually being tried in harder rocks, and designers have responded by introducing larger, heavier, and more powerful machines in order to meet this task. However, until recently, very little design work has been done on the cutting head.

On the heavy duty machines it has been generally accepted that point attack cutting tools are a necessity to enable cutting tool consumption to be kept to an acceptable level. However, on Medium Duty and Light Duty machines it is necessary to look at each individual application before deciding on the choice of type of cutting tool (point attack, forward attack or radial) (Figure 5).

Research into cutting tool desing is continuing to enable boom type machines cut harder strata more economically. Substitutes for Tungsten Carbide tips have been tried with very little success. However very recently a West German Pick Manufacturer has claimed that their new sintering process means that a new grade or tip exhibits greater toughness and is less prone to fracture and will last up to three times longer in abrasive rock. If so, then this will be a significant development.

Work has been carried out at the NCB Mines Research Establishment in developing 'Computer Aided Design of Cutting Heads'. Programmes are now available to aid the design of cutting heads. Basic cutting head specifications are determined manually from past experience for a particular application, and inputed into the computer. The computer then assists the designer by means of a visual display unit, to formulate the best cutting head design possible to the basic parameters which have been manually inputed. Precision manufacture will then ensure an effective cutting head.

Experience to date has indicated a definite improvement in cutting performance in hard rock applications when using cutting heads aided in design by computer.

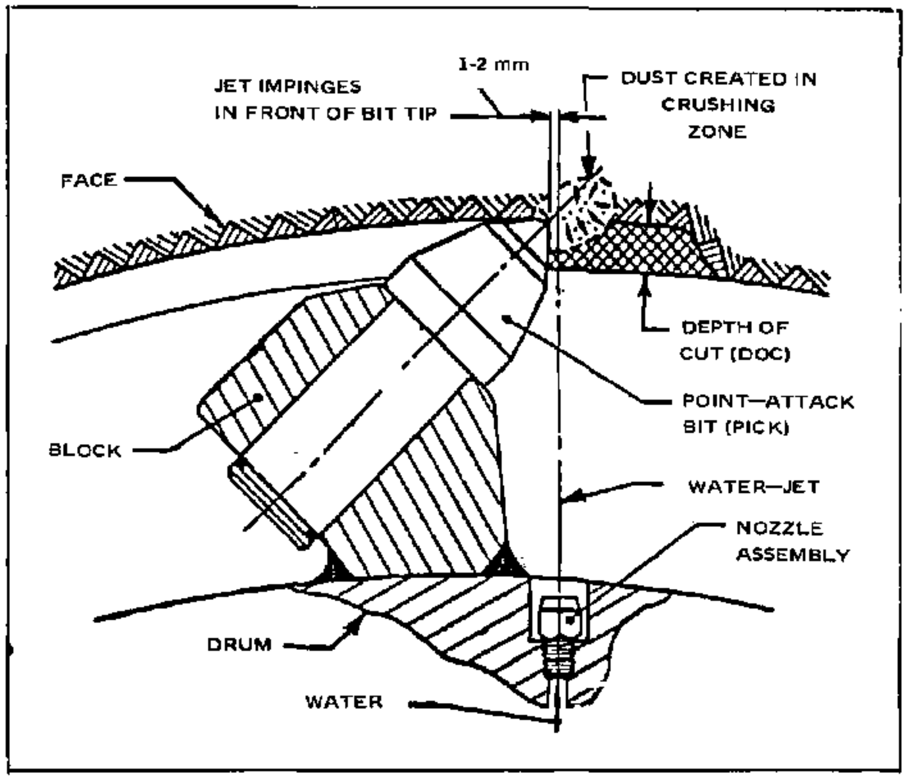
5.2. High Pressure Water Jet Assisted Cutting

Research was initiated into the alternative method of improving roadheader performance by assisting the cutting of these machines by high pressure water jets.

The development was split into two phases:

— The design, manufacture and field testing of a 700 bar system.
— Similar exercise for 2 000 bar system.

Although initial investigations had shown that the reduction in cutting forces required reached a maximum of 35 % at 1 750 bar, it was decided to concentrate on using a water pressure upto 10 000 psi (700 bar).



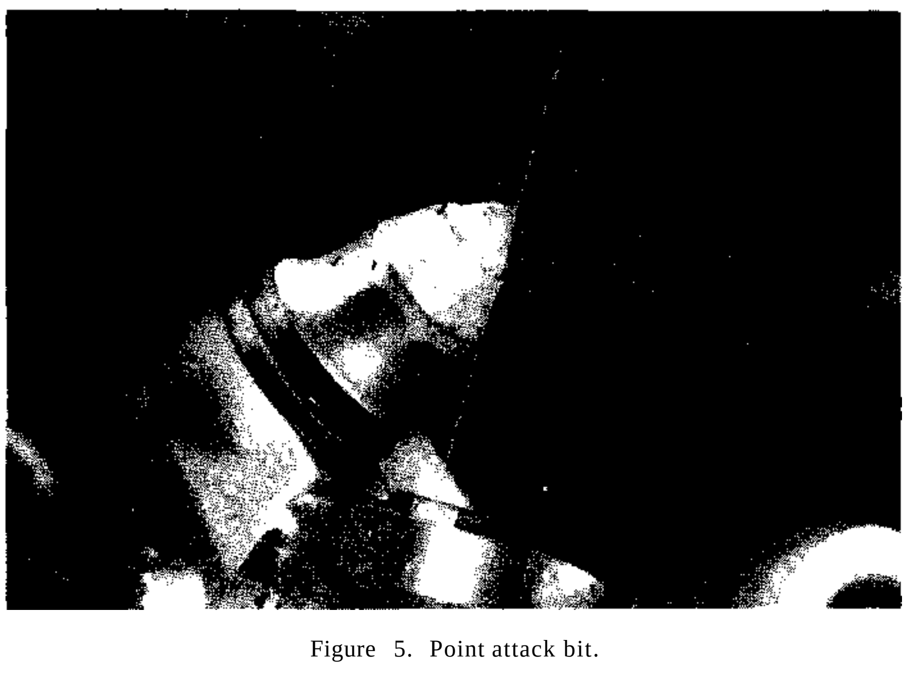


Figure 5. Point attack bit.

Field trials with the Water Assisted Cutting from 100 to 700 bar have shown that there is:

— Greater machine stability.
— Reduction in airborne dust - better visibility, better working conditions.
— Reduction in frictional sparking.
— Increased pick life.

What has not been proven is that water pressure up to 700 bar significantly assist the cutting. It would also appear that each particular rock type may have an optimum pressure requirement for High Pressure Water Assisted Cutting to function.

Manufacturer« have still not committed themselves to the second stage of develoment, i.e. machines witfi systems up to 2 000 bar, because of the length of time it has taken to develop reliable equipment to operate up to 700 bar. Operational problems have also been experienced when operating at 700 bar.

— Dust is replaced by a mist of water which reduces visibility and saturates operators.

— Small particles of cut material can be blasted back from causing injury to operators unless protected.

— Floor conditions, particular if the machine is working to decline, can be adversely affected because of the quantity of water used.

There is still a lack of information regarding the effect of water release pressure on dust dispersion under constant flow conditions. As more and more machines are introduced with high pressure water systems the effect is being studied. It would appear that the most significant reductions in dust dispersion etc are found up to 200 bar with a continuing but greatly reducing improvement up to 700 bar and there is now doubt whether the improvement in dust control etc, obtained by using pressures in excess of 200 bar - up to 700 bar - justify the extra cost and complexity involved.

As a result of the above, the cheaper, simpler medium pressure system of up to 200 bar is becoming a standard feature of medium and heavy duty machines. In both systems the medium high pressure water is supplied from the pump through high pressure hoses to the trunk shaft. The water then flows through the trunk shaft via a special trunk shaft seal to the jets on a special high pressure cutting head.

5 _3. Automatic Control and Profile Guidance

In the construction of tunnels with boom type roadheaders, there is a need for a control system that enables the X Section, especially the profile to be cut more accurately, quickly and more economically than the present method of relying totally on operator skill. Unnecessary extra work and costs can arise from either recutting the profile due to undercutting, or packing or infilling around the roadway supports due to overcutting.

In the drilling field, fully automated computer control of Drill Jumbos was achieved İn 1978-79 with three levels of control possible; fully automatic drilling using pre-programmed plan, manual operation through the computer, manual control without computer assistance but with display on a Visual Display Unit (VDU).

The NCB Mining Research and Development Establishment are currently testing Automatic Control Systems from two separate suppliers on roadheaders. The results of these trials will determine the future design of Automatic Control Systems for the National Coal Board.

The two units undergoing trial have the following features:

- Have facility for fully automatic, manual operation through computer and manual control.

- The Hydraulic Circuit operating boom lift and slew will be controlled, the speed being regulated by the load on the cutter motor.

- Laser beam datum for determining displacement of machine from centre line.

- Error induced by equipment will be no more than + 5 cm at the cutting head.

- The equipment can be utilized for both single and twin boom machines.

The profile guidance part of this system has already been fitted to a circular tunnelling machine İn a civil engineering tunnel, and has proved very successful in maintaining an accurate profile effecting considerable savings in concrete requirements.

5.4. Health Monitoring

During the last few years, rapid strides have been made in instrumentation and data processing which have been developed to aid engineers to maintain tunnelling machines (as well as other production equipment) underground, instead of relying only on the planned maintenance scheme. Mechanical, electrical and hydraulic units can be tested on a routine basis as a means of regularly checking machine condition and performance against set standards.

Testing of hydraulic circuits of tunnelling machines are carried out in many NCB mines using orifice test units.

Computer analysis of these tests show up any deteriorating trends in the hydraulic performance, and allow faults which are developing to be rectified at an early stage.

However, a stage further is to utilize a variety of analogue pressure transducers used in selected positions on the machine to pick up the hydraulic performance, and allow faults which are developing to be rectified at an early stage.

However, a stage further is to utilize a variety of analogue pressure transducers used in selected positions on the machine to pick up critical pressure in the hydaulic circuit, with instruments for measuring electric power levels, and temperature measuring devices in the hydraulic oil and in the vicinity of the cutter gearbox. These instruments feed data through a microprocessor to a VDU close to the machine operator, or to another station underground or on the surface.

The aim is to provide the engineer with as much up to date correct information as possible regarding the health of the machine, to help improve maintenance, which will in turn improve the reliability and performance of the machine.

6. CONCLUSIONS

The paper has discussed the large range of tunnelling machines now available throughout the world for most applications in coal mine development and production operations.

It is difficult to lay down exact parameters as to an acceptable cost per metre advance of tunnel as each application will differ in many respects. However, tunnelling machines have been used cost effectively in various mining development and production roles - often producing minerals in sufficient quantities at the right cost levels to be considered as production systems themselves.

In recent years, research and development has moved away from the design of heavier and more powerful machines to concentrate on aspects which can improve the performance of the tunnelling machine and make it more reliable. Great emphasis İs now placed in design on reliability of components by the use of special hardwearing materials where possible. Maintenance has also been made as simple as possible by utilizing lubrîcated-for-ltfe components, and by centralized or automated lubrication systems.

The present designs of medium/heavy duty machines gives the mine operator an economic alternative to drill and blast in rocks that would have been previously considered too hard for mechanized drivage. Moreover the introduction of high pressure water has reduced the high tool costs often associate with this strata.