Tests on the cutting performance of a continuous miner

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SYNOPSIS

This paper describes tests on the performance of a continuous miner in cutting South African coal. Although coal cutting has been investigated extensively overseas, the results have not led to significant changes in machine design because these machines find little difficulty in cutting the softer overseas coals at a fast rate.

In general, the results of the tests show that cutting efficiency improves markedly as the depth of cut per revolution of the drum increases, and that the best spacing of picks on the drum is twice the depth of cut. Pick shape is of secondary importance in terms of cutting efficiency, only small differences having been found between the performances of conical- and chisel-shaped tools.

SAMEVATTING

Hierdie referaat beskryf toetse in verband met die werkverrigting van 'n deurlopende myner vir die sny van Suid-Afrikaanse steenkool. Hoewel die sny van steenkool op groot skaal in die buiteland ondersoek is, het die resultate nie tot beduidende veranderinge in die ontwerp van die masjien gelei nie omdat hierdie masjiene dit nie moeilik vind om die sagter oorsese steenkool teen 'n vinnige tempo te sny nie.

Die resultate van hierdie toetse toon oor die algemeen dat die snyrendement merkbaar verbeter namate die diepte van die sny per omwenteling van die trommel toeneem, en dat die beste spasiëring van die pikke aan die trommel twee maal die diepte van die sny is. Die vorm van die pikke is van sekondêre belang wat die snyrendement betref, aangesien daar net geringe verskille tussen die werkverrigting van keëlvormige en beitelvormige pikke gevind is.

Introduction

One feature common to all mechanical methods of coal winning, whether involving a hand pick, a coal drill, or a cutting machine, is that each depends for its action on the penetration of a wedge of some shape or form into the coal face. In the case of a hand pick, it is a single wedge being repeatedly struck at the face, the force, frequency, and position of the blow being left to the experience and judgement of the mineworker. The intelligence of the miner and his inherent physical flexibility provided him with additional variables in the use of his wedge. It is certain that no mining machine is as efficient as a man in terms of the coal produced per unit of work done[1].

However, mining machines can concentrate vastly more power in the confines of a coal face than can be obtained from manpower. A machine can deploy a large number of high-powered, fast-moving wedges to attack the coal, cutting prodigiously, but doing so in a 'non-thinking' repetitive fashion unresponsive to the type of opportunity for ease of extraction that could so ably be recognized and exploited by a coal hewer.

From the earliest intoduction of coal-cutting machines, their efficiency has left considerable room for improvement. However, this was not highlighted until efforts were made to broaden the application of the first mechanized longwall installations in Europe by the use of machines such as ploughs and shearers. In particular, the introduction of the German-invented coal plough into British mines after World War II revealed serious inadequacies in its ability to handle the generally stronger British coals.[2]

Reports on the coal-cutting and associated work undertaken by the Mining Research Establishment of the National Coal Board (N.C.B.) have been published widely over the years. Perhaps the most important single account of the research is the monograph by Evans and Pomeroy[3]. However, there are several other key publications, each of which represents a significant contribution to our knowledge of the mechanics of coal breakage by pick. Evans's model of wedge penetration into coal provides a good theoretical understanding of the effects of coal strength, depth of cut, and pick geometry on the forces required to cut[4], and the results of Pomeroy's laboratory coal-cutting experiments established certain principles that are claimed to be fundamental to the design of an efficient coal-cutting system[5,6].

Despite the widespread availability of such useful information, surprisingly little practical use has been made of it. The N.C.B. designed a large pick drum for longwall shearers based on these principles[7], but it had only limited application and success. Similarly, parallel work undertaken at The University of Newcastle-upon-Tyne in England[8] led to the development of a novel type of longwall plough[9], which also had limited but, in this case fairly successful, application[10].

The main, but by no means only, reason for the limited application of known principles is that modern longwall machines, particularly the shearer, have been made progressively more powerful and have thereby found little difficulty in cutting coal, even if inefficiently, at a much faster rate than can be loaded onto and carried away by the conveyor. Cutting has therefore become of secondary importance to the loading function of the machine. Since the drum of a shearer has the dual and simultaneous roles of cutting and loading,

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designs have tended to concentrate on loading efficiency, which has requirements that are, from several standpoints, in conflict with the maximization of cutting efficiency. This dichotomy remains largely unresolved. The increasing levels of output and production rate required from expensive longwall installations, being achieved by an increase in the size and power of the equipment rather than by an improvement in its efficiency, are often at the expense of high coal degradation and unacceptably high airborne dust levels at the face.

In South Africa, progress in the application of fully mechanized continuous mining systems will depend on their ability to cut at maximum efficiency. Here, the high strength and abrasiveness of the coals are major factors inhibiting the use of full face extraction by machine. Equipment designed overseas, principally for use in the U.S.A. and Europe, where coal seams are generally much weaker than here, is usually technically and economically inferior, in terms of productivity, to conventional South African working methods, which make use of explosives to break the coal.

In the medium term at least, the continuous miner is one of the most appropriate machines for South Africa's predominantly bord-and-pillar coal mines, since it does not involve any major change in the traditional method of mining. The conventional cyclic operation of drill, cut, blast, and load is replaced by the continuous miner, which is able to undertake the equivalent of all of these functions simultaneously. To be able to deal with hard coal, however, and to improve significantly on the performance of conventional methods, the continuous miner has to be used to its maximum potential. In this context, one of the most important considerations is to establish, in the field as well as in the laboratory, criteria for the design of cutting drums so that the available power of the machine is directed towards achieving the maximum possible cutting and production rate consistent with minimum downtime and machine maintenance requirements.

Experience with the 34 continuous miners operating in South Africa in December 1978 showed that, on average, 40 per cent of the total downtime for these machines was due to mechanical failures associated with cutting[11]. This is double the figure for continuous miners in the U.S.A.[12]. In addition, the instantaneous cutting rate for the South African machines was appreciably lower than that found either in the U.S.A. or Australia. These facts bear testimony to the difficult cutting conditions

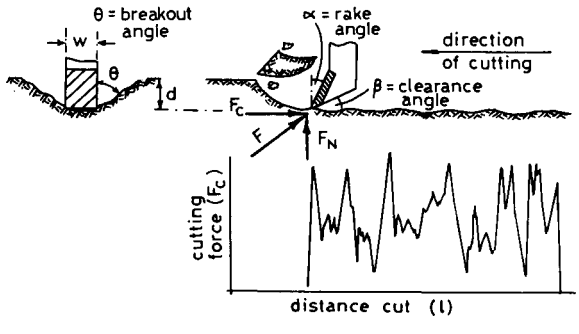

Fig. 1—Notation and definitions for coal cutting by pick

prevailing in South African coal mines, and emphasize the urgency of finding ways of improving the applicability, performance, and reliability of continuous miners in this country.

To achieve this general objective, the Chamber of Mines Research Organisation has embarked on a major research programme on the assessment of coal cutting and the cuttability of coal seams. One of the major components of this programme is the evaluation, in the mine and using an actual continuous miningm achine, of those principles determined mainly in the laboratory by Evans, Pomeroy, and others[4–6]. As far as is known, this is the first time that a full-scale controlled field investigation of the principal variables involved in the design and application of a machine cutting drum has been undertaken. The project was much encouraged by the experience with a similar experimental continuous miner in the U.S.A. that was used in an assessment of the validity of the deep-cut principle[13] — one of the concepts originally proposed by Pomeroy.

BASIC MECHANICS OF COAL CUTTING

When a pick cuts across the surface of a block of coal, it is seen always to produce a groove that is much wider than the width of the pick. Also, the depth of the groove is sometimes greater than the depth of the pick. As illustrated by Fig. 1, the excess lateral breakage occurs as sidesplay and, although its surfaces are usually irregular, it can be represented by an equivalent angle of inclination to the vertical. This is termed the 'breakout angle', and for a given coal it remains fairly constant for all depths of cut. The production of excess coal is variable and depends mainly on the direction of cutting in relation to the cleat and bedding of the coal, pick shape also being of some significance in this context.

The cutting of coal is characterized by a rapid linear increase in the force acting on the pick as it penetrates. Eventually this force exceeds the strength of the coal, and a coal fragment or chip is produced with an attendant and instantaneous reduction of pick force. The coal chip extends ahead of the pick, the latter then advancing under zero or negligible force until it re-engages a fresh coal surface, after which the chip-formation process is repeated. This leads to a typical saw-tooth shape of force–distance diagram for a pick, as shown in Fig. 1, with peaks that are irregular in magnitude and frequency owing to the heterogeneous nature of coal. Although coal is known to have time-dependent stress–strain properties, these are of no practical significance when cutting, even at the slowest speeds. From this standpoint, coal can be regarded as a brittle material. Evans's model provides a valuable analytical insight into the mechanics of coal-chip formation by a wedge[4].

The recognition that breakout angle θ remains constant with depth of cut is significant, since it leads to what is probably the most important fundamental principle of coal cutting. Evans's theory, which is fully consistent with laboratory experience, shows that the cutting force acting on a pick is linearly proportional to the depth of cut. A low specific energy (i.e., the work done or energy consumed to produce unit volume or mass of coal) implies a high efficiency. Also, as shown

in Fig. 1, the generalized cutting force F acting on a pick can be resolved into two mutually perpendicular components: F_C the cutting force that acts in the direction of cutting, and F_N the normal force acting perpendicular to the direction of cutting. The mean cutting force F_C multiplied by the distance cut gives the amount of work done. The normal force, F_N, is the force required to maintain the pick at a constant depth of cut. It has zero or negligible displacement in its direction of action, and does not contribute to the work done in cutting the coal. Depending on pick shape and some other factors, a sideways or lateral force can sometimes be generated. When it does exist, it is always of low magnitude and can therefore safely be ignored at this stage.

The effect of cutting depth on the work done to cut coal, and its relationship to the quantity of coal produced, are as follows.

$$\text{Work done to cut coal} = F_C.l = K_1.d.l, \quad . \quad . \quad . \ (1)$$

where F_C = mean cutting force
d = depth of cut
l = distance cut
K_1 = a constant (depending on the shape of the pick and the coal strength).

$$\text{Volume of coal cut} = (W.d+d^2.\tan\theta)l, \quad . \quad . \ (2)$$

where θ = breakout angle
W = pick width.

Since, for a given situation, pick width, W, and breakout angle, $\tan\theta$, are both constants (say K_2 and K_3 respectively), the combination of equations (1) and (2) gives

$$\text{Specific energy} = \frac{F_C.l}{(W.d+d^2.\tan\theta)l} = \frac{K_1.d}{d(K_2+K_3.d)} = \frac{K}{K+d_0} \quad . \ . \ . \ . \ . \ . \ . \ . \ (3)$$

where $K_0 = K_1/K_2$
and $K = K_3/K_2$.

Equation (3) indicates that specific energy decreases (i.e., the efficiency improves) as the depth of cut increases. It also shows that as d tends to zero, the specific energy approaches a maximum finite value of K_0/K.

These considerations relate to a single pick cutting unrelieved; a mining machine uses an array of picks disposed on some form of cutter head, drum, or jib in which the picks are required to interact. The effect of spacing between picks on their cutting efficiency is important.

If two adjacent picks in the array shown in Fig. 2 are placed a large distance apart, s, they cannot interact, and, effectively operating as unrelieved cutters, they will each require the same specific energy. If the picks are now brought closer together, a position will be reached at which they start to interact, the groove cut by the leading pick providing relief for the following pick. It is found that such relief will cause a reduction in the specific energy requirements for the following pick. If the spacing between picks is further reduced, the

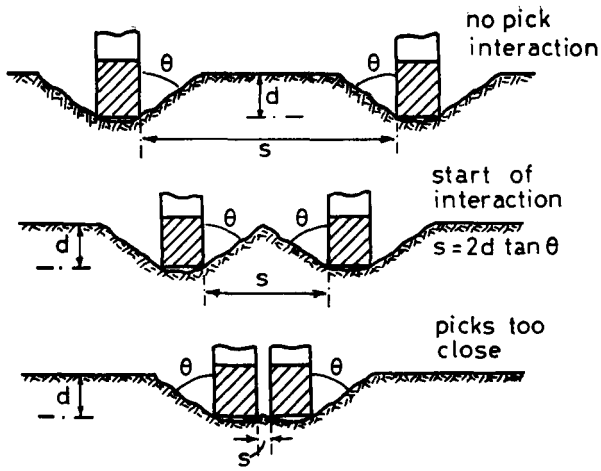

Fig. 2—Interaction of cutter picks in array

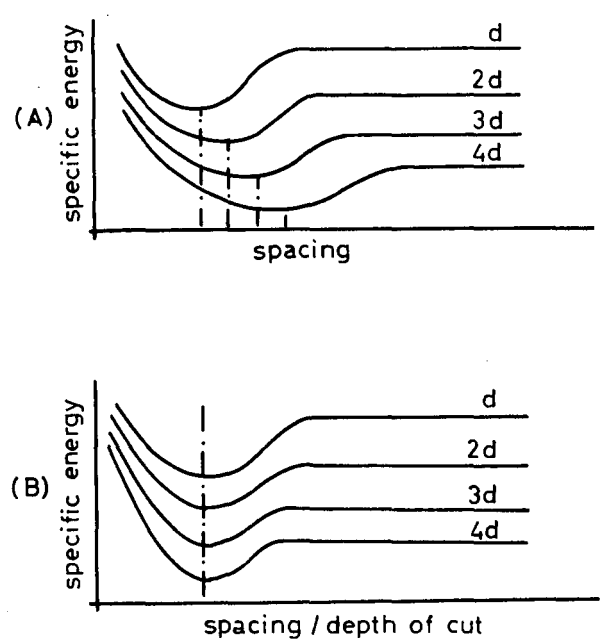

Fig. 3—Hypothetical relationship between pick spacing and specific energy

specific energy will continue to fall but not indefinitely so. Indeed, as the spacing tends to zero, the depth of cut of the following pick tends to zero since it is then cutting exactly in the 'shadow' of the leading pick. At that position, the specific energy is at a maximum, as indicated by equation (3). The effect of spacing on specific energy therefore, as shown in Fig. 3A, indicates a value of spacing at which the specific energy can be expected to be minimized. In fact, a family of curves can be drawn, each showing a minimum specific energy for a different depth of cut and consistent with the general level of specific energy, being lower at the high depths of cut; also, that a wider pick spacing is appropriate when the depth of cut is larger.

If, as indicated in Fig. 2, the interaction starts when adjacent grooves just touch (i.e., $s = 2d.\tan\theta$), the geometrical similarity implicit in the family of curves

in Fig. 3A can be normalized if the spacing, s, is divided by the depth of cut, d. Now, on the basis of spacing expressed as a multiple of cutting depth, interaction between the grooves will occur at 2 $\tan\theta$, which is the same for all depths of cut. Similarly, if geometrical similarity persists, the s/d ratio at which the specific energy is minimized will be the same for all depths of cut. Fig. 3B shows how specific energy is expected to vary with s/d ratio, the value of the minimum specific energy reducing at the higher cutting depths.

THE EXPERIMENTAL CONTINUOUS MINER

Since the continuous miner has a drum that is used exclusively for cutting, it is probably the most suitable of all production machines to feature in coal-cutting experiments. For the same reason, it is the machine whose performance is likely to be most influenced by changes in the design of its cutting system.

The following objectives were chosen for the experimental work conducted by the Chamber of Mines:

(i) the establishment of the cutting principles that can be incorporated into current machine designs without need for major modification,

(ii) the evaluation, under practical operating conditions, of the benefits that will accrue from the application of those principles,

(iii) a determination of whether any improvement that follows can be sustained in practice and be of sufficient magnitude to significantly improve the performance of the present generation of continuous miners in South Africa,

(iv) the provision of field data and other appropriate information relevant to the design of future machines and components for South African conditions,

(v) the establishment of a yardstick of performance against which associated laboratory cutting tests can be related and compared, and the provision of a similar link with techniques being developed concurrently for the assessment of seam cuttability.

For these controlled field experiments, the Chamber of Mines purchased a Lee-Norse HH 456 (Fig. 4), which is an adaptation of the conventional HH 455 production model. The selection was influenced by the performance of the HH 456 in the U.S.A., where it was used successfully for research on the generation of airborne dust during cutting and on the deep-cut principle in this context[13].

Several modifications were made to the machine, which is shown schematically in Fig. 5.

(i) *Provision of higher and variable sumping force.* This was achieved by an integrated hydraulic 'goalpost' anchor structure at the rear of the machine. When jacked between roof and floor, the machine can be thrust forward from it by the use of two hydraulic rams. These provide a much greater sumping force than can be obtained from the crawlers, which are now allowed to

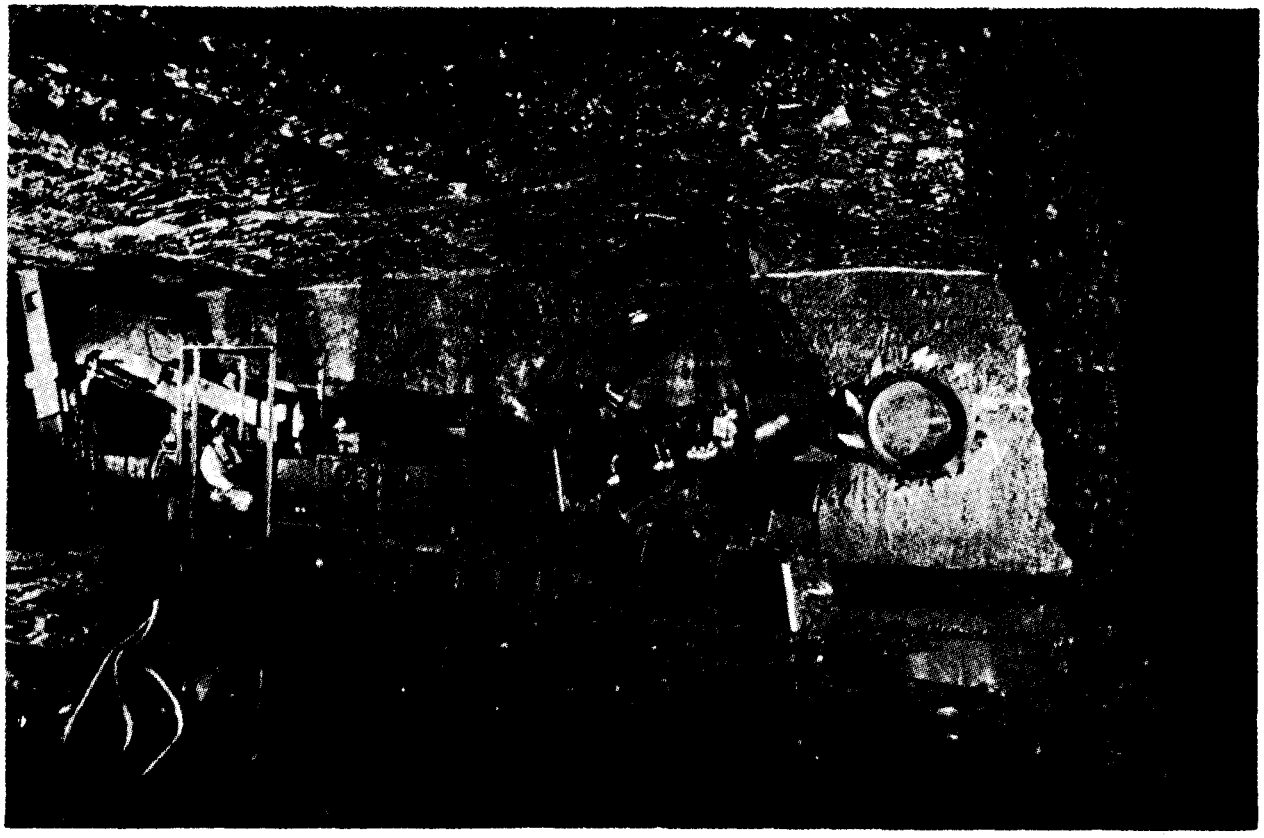

Fig. 4—A general view of the HH 456

'free-wheel'. A wide range of sumping forces can be generated by variation of the hydraulic supply to the rams, and this enables the sumping rate andc orresponding depth of pick penetration per drum revolution to be controlled and varied.

(ii) *Enhanced shearing force.* After generating the required depth of sumping, which is normally done at roof level, a conventional production machine shears the face by hydraulic rams pulling the cutting boom down. To increase the magnitude of the available shearing force, a shear-assist assembly was mounted above the boom, consisting of a heavy cantilevered arm connected to the boom by a double-acting hydraulic ram. When activated, the ram forces the arm to the roof and thereafter provides a downward force on the boom additional to the normal arrangement. Hydraulic flow and pressure to the total system are controlled so that varying rates of shearing and depth of cut per drum revolution can be achieved.

(iii) *Variation of cutting-drum speed.* The rotational speed of the cutting drum can be varied by the changing of gear boxes. Each of the two drive trains between the motor and the cutting drum includes four gear boxes, three of which can be interchanged or replaced to provide different gear ratios. In addition to the normal production speed of 66 r/min, four other speeds of approximately 42, 35, 15, and 7 r/min are available.

(iv) *Pick spacing pattern.* A specially modified drum makes provision for variations in the lateral and radial spacing of picks in the cutting array. The position and number of detachable pick boxes can be changed to give 4 levels of lateral spacing (50, 100, 150, and 200 mm) using picks of either chisel or conical profile. The centre line of a pick box makes an angle of 36,5° with the drum radius at the pick tip. The type and location of gauge cutters were not varied but remained the same as for a normal production machine. The role of the gauge cutter is somewhat different from that of the line cutter. Because they account for not more than 9 per cent of the coal cut by the drum, it was considered preferable to maintain constant gauge-cutting energy and vary only the main pick array, rather than to attempt an assessment of the effects of different types and dispositions of gauge picks.

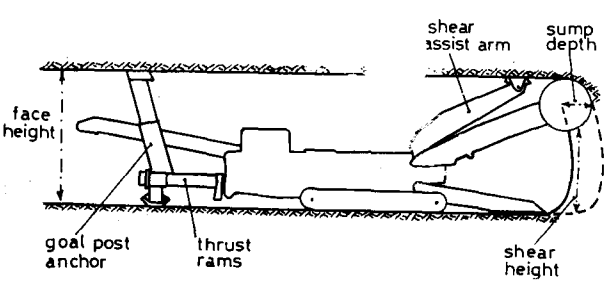

Fig. 5—Schematic diagram of the experimental continuous miner

The machine, a frontal view of which is shown in Fig. 6, has the following general specifications:

Mass, kg	55 600
Maximum/minimum cutting height, m	3,48/2,12
Cutting drum width, m	3,15
Cutting drum diameter, m	1,13
Maximum drum torque, Nm	162 700
Nominal drum speed (production), r/min	66,0
Nominal drum speeds (experimental), r/min	41,7
	34,5
	14,7
	7,0
Nominal pick tip speeds (experimental), m/s	2,47
	2,04
	0,87
	0,41
Line pick spacings, mm	50
	100
	150
	200
Cutter motors, kW	2×224
Pump motor, kW	224
Ground pressure, kN/m²	248

INSTRUMENTATION AND DATA RECORDING

An initial 'shake-down' period, during which the HH 456 was used as a normal production machine, proved to be invaluable in indicating the type of instrumentation and the method of data recording to be used, and in the planning of the experimental programme.

As a consequence of such experience, the machine was placed in a dedicated heading under strictly controlled operating conditions, so that the effects of a change in any one variable at a time could be evaluated with a good degree of confidence.

Continuous Remote Recording

Electrical signals from various instruments placed on the machine were fed to chart recorders located in a remote recording station. Several quantities were measured and recorded for control purposes; those providing information on machine performance were as follows.

(i) Cutting-drum revolutions – from a tachometer giving a voltage output proportional to the drum speed.

(ii) Thrust and shearing velocity – from a tachometer activated by a wire attached to the shear-assist arm via the cutting boom.

(iii) Cutting-drum power – from a power transducer giving an analogue trace at the recording station.

(iv) Thrust pressure – by remote recording, from the output of a pressure transducer, of the pressure in the cylinders thrusting from the goal-post anchor frame.

(v) Shear pressure – from a pressure transducer with output fed to the remote station for recording the pressure in the shear-assist cylinder and the normal boom cylinders (which were the same during shearing).

Direct-reading Instrumentation

Several instruments were placed on the machine to provide the operator with immediate control and operational information for spot checks. These included motor ammeters on the cutting head, a voltmeter, an hour meter on the cutting head, an inclinometer on the body, and pressure gauges on all the main hydraulic circuits.

Adjustable relief valves enabled pressures in the hydraulic circuits to be pre-set to provide the required forces for each test.

External Measurements

In addition to the several readings and recordings obtained from the various instruments, the following manual measurements were made: seam height, final sumping depth achieved, shearing distance, machine tilt angle (by use of the inclinometer), angle of thrust mechanism (goal-post thruster rams), horizontal distance between machine and nearest survey peg, time taken to sump, and time taken to shear.

In addition to these measurements, note was also taken during each test of the cutting-head operating hours, the quantity of dust-suppression water consumed, and the extent of wear on the cutting picks. In addition, samples of coal were taken from selected cuts for determinations of size distribution and calculations of the degree of coal fragmentation based on the coarseness index[14]. Since local variations might occur in the coal lithology and strength over the distance covered by a series of tests, samples representing the main vertical subdivisions of the seam were recovered at regular intervals for the monitoring of such changes.

Calibration and Resolution of Machine Forces

The pressure transducers were calibrated to provide a direct reading of absolute thrust and shear forces by the use of a hydraulic jack and load cell. For thrust calibration, the jack and cell were placed between the face and the cutter drum to provide a known and incrementally increasing horizontal force, and thereby a corresponding readout on the thrust-ram transducers. Similarly, a known vertical force was applied in increasing increments to the drum and the response on the shear-pressure transducer was measured.

A complete analysis was also made of the distribution of the forces acting on the machine. When cutting in sump or in shear, a continuous miner is subject to a number of external forces, and their distribution, direction, and magnitude influence the performance and stability of the machine. In addition, internal forces and moments are generated during its operation, and their nature and relationships must be determined to provide a basis for the analysis and interpretation of experimental data. This analysis, which is too lengthy to include here, was found to agree fairly well with the resolved components of force measured during calibration[15].

The shear-assist assembly is shown in Fig. 6.

Other quantities, such as sumping and shearing rates, cutting-head power, speed, and torque, were measurable

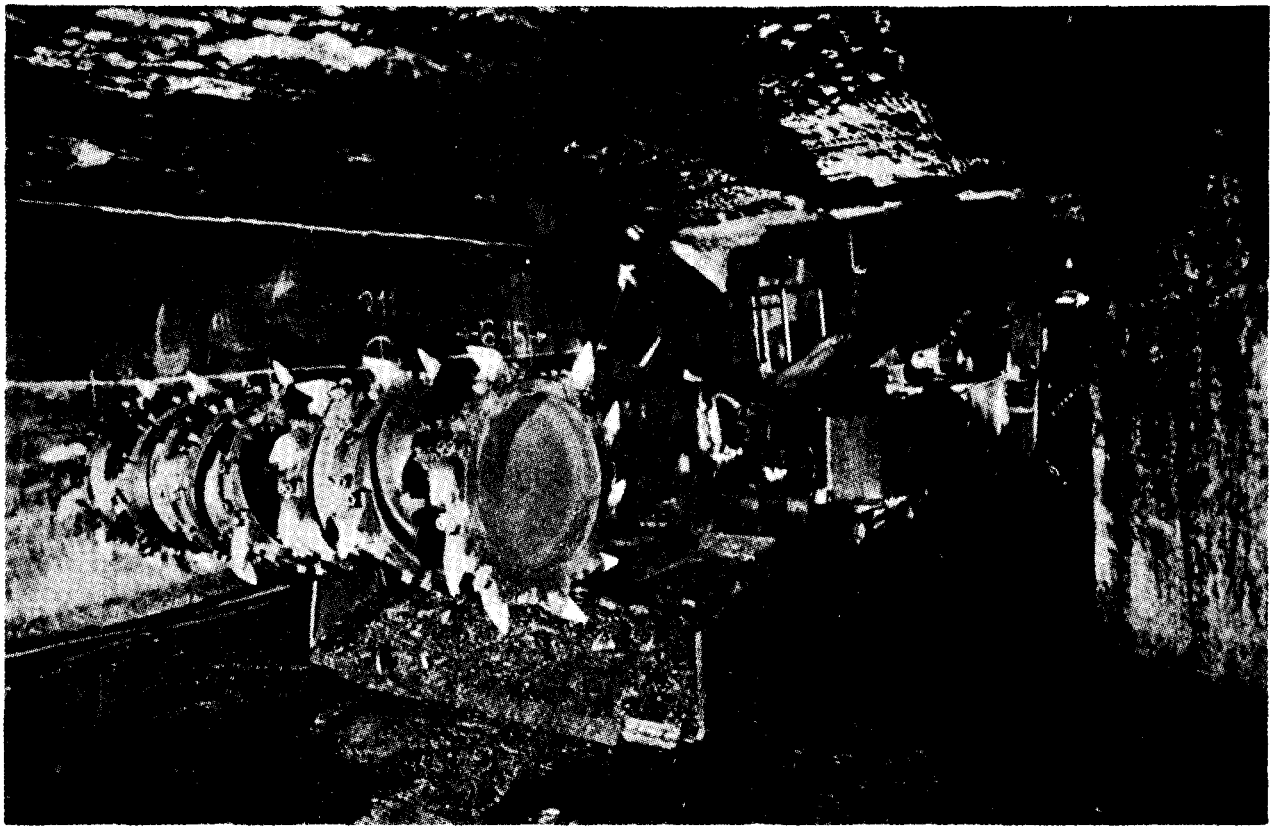

Fig. 6 Shear-assist assembly showing relationship to cutter-head boom

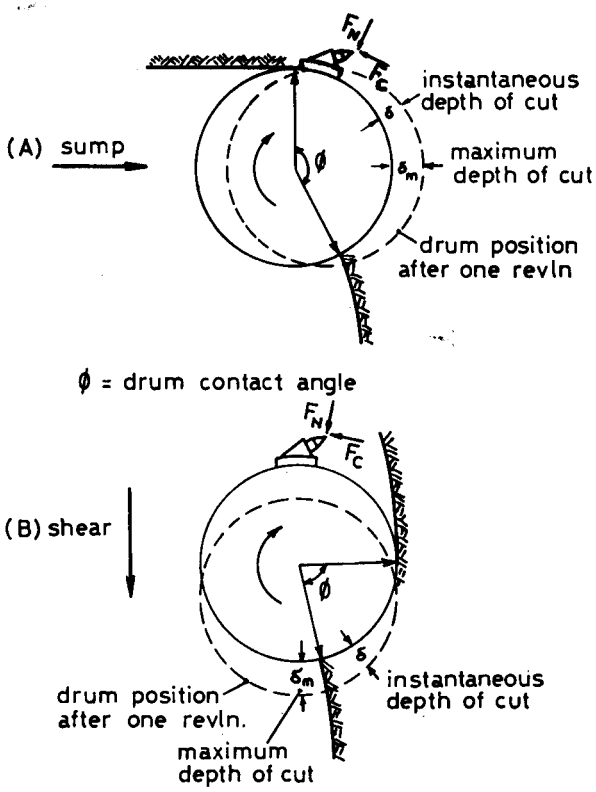

Fig. 7—Configuration of depth of cut and contact arc for sumping and shearing

to a high level of accuracy. By use of the characteristic curves for the motors, in conjunction with the recorded data, the power absorbed and the total work performed by the head motors could be determined.

EXPERIMENTAL PROGRAMME

Although the experimental continuous miner is able to operate at a number of different head rotational speeds, the experiments described here were all undertaken at a head speed of 41,7 r/min. The results of tests made at other speeds will be reported elsewhere.

Drum Design and Operational Variables

The main variables and the levels at which each was investigated in the experiment were as follows:

Variable	*No. of levels*	*Levels*
Pick type	2	Chisel : Conical
Pick spacing	4	50mm, 100mm, 150mm, 200mm
Depth of cut	*	Range 0 to 120 mm

*The depth of cut taken by the machine cannot be predetermined since its value depends on the hydraulic pressure and supply to the thrust and shear rams. It can be set to provide a rough depth, but a precise value for the average depth of cut must be calculated. In this context, it has to be recognized also that the depth of cut taken by a pick varies along its arc of contact with the coal face as illustrated by Fig. 7.

The pick geometry and the numbers used at each of the levels of spacing were as follows:

Pick type	*Width*	*Tip angle*	*Rake angle*	*Clearance angle*
Chisel	29 mm	60°	10°	20°
Conical	—	60°	6,5°	23,5°

The rake and clearance angles presented to the face by each of the above pick types depends on the angle of the pick box, which throughout these experiments was fixed at 36,5°.

Spacing mm	*Number of picks* *Face picks*	*Gauge picks*	*Total*
50	51	24	75
100	26	24	50
150	18	24	42
200	14	24	38

The number and disposition of face picks was the same for both the chisel and the conical types at any given level of spacing. The position of the gauge cutters, which were always of conical shape, was not varied.

Because the continuous miner cuts with a rotating drum, a pick does not take a constant depth of cut as it passes through coal. When sumping, as shown in Fig. 7A, the pick enters the coal tangentially at a shallow cut near the roof, gradually increasing its depth as it rotates, achieving a maximum at about mid-drum level. After that the depth of cut diminishes until the pick leaves the coal tangentially again at a shallow cut. In shear, illustrated in Fig. 7B, the pick also enters the face tangentially at about mid-drum height. Its depth then increases to a maximum as the pick leaves the coal face.

Values of depth of cut, calculated from the rotational speed of the head and from the sumping and shearing rates, are therefore maximum or near-maximum values in shear, but are average values of the mid-drum depth in sump, since, as the sump deepens, so the arc of cutting contact lengthens and the depth of cut decreases.

The depth of cut could not be predetermined with any precision, but a required high, medium, or low value could be arranged by variation of the pressure and flow to the appropriate sumping and shearing circuits. The following pressures were available to the machine operator:

System	*Pressure* MPa	*Applied force* kN	*Resultant force at drum* kN
Sump	20 (max.)	995	872 (along boom)
	4 (min.)	199	96 (along boom)
Shear	20 (max.)	1224	338 (normal to boom)
	3 (min.)	184	137 (normal to boom)

Machine Performance Criteria

To give as complete and useful a basis as was possible for a comparison of the effects of changes in the principal variables, the following performance criteria were used.

Force along the boom. This is the total force acting along the cutter boom required to cause the drum to sump into the coal face. It is a measure of the aggregate forward force acting on all the cutter picks as they are made to penetrate the coal face (i.e., ΣF_N in Fig. 7A).

Force perpendicular to the boom. The aggregate normal force acting on all the active picks as they are made to penetrate the coal face during the shearing operation (i.e., ΣF_N in Fig. 7B).

Cutting-head torque. The torque required for the cutting head to cut the coal face in either the sumping or shearing operations. It is an aggregate of the cutting force acting on each of the active picks (i.e., ΣF_C in Fig. 7).

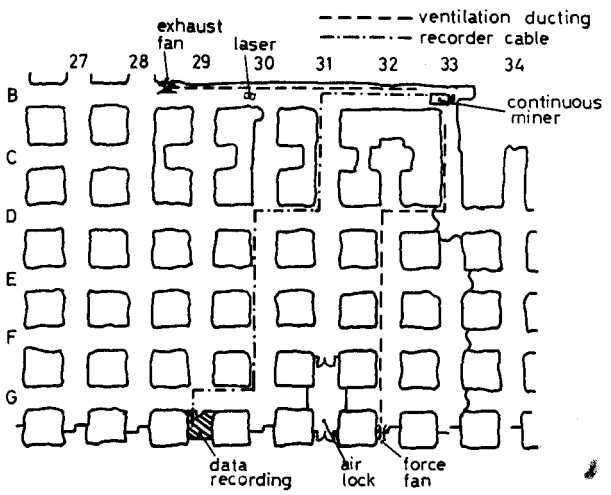

Fig. 8—Layout of test site

Specific energy. The amount of work expended in cutting unit mass (kJ/t) or unit volume (MJ/m^3) of coal. It is computed from the cutting-head torque, the cutting speed, and the quantity of coal cut in a given time. Specific energy is the most widely accepted criterion of cutting efficiency, a lower specific energy indicating a higher efficiency.

Coarseness index. This is a dimensionless number on an arbitrary scale that reflects the size distribution of cut coal. It is a summation of the cumulative mass percentages obtained from a conventional size analysis[14].

It should be noted that, when the machine is operating, only a proportion of the picks on the drum are actually cutting. In sump, at any instant, the number of picks engaging the coal is rarely more than half the total number. In shear, the number is usually between one quarter and one third of the total.

Data Reduction and Analysis

An elaborate procedure was used in the treatment of the data obtained from the experiments. This included digitizing of the strip-chart traces and subsequent computer analysis of these and other information from the data sheets. Certain standards and other scientific criteria were laid down for the acceptance or rejection of data.

Owing to factors like coal heterogeneity, variations in friction coefficients, and lack of precise control in the cutting depth, it was inevitable that the final results should show an appreciable amount of scatter. It was therefore an essential aspect of the data analysis that the experimental results should be subjected to various rigorous statistical treatments so that they would show the required empirical relationships and so that the statistical level of confidence could be established.

THE TEST SITE

The experiments were undertaken in the No. 4 Seam at Anglo Power Collieries (Kriel Division), which is situated in the Witbank Coalfield approximately 160 km to the east of Johannesburg.

The test site, which is shown in Fig. 8, was at a depth of 50 m in a fully reserved area remote from other mining activity. Since it had been developed exclusively by continuous miner, it was free of the possibly disrupting effects of blasting. The seam at this location is nearly horizontal and well clear of faults and dykes. A parting in the seam provided a good natural roof, giving a face height of 3,5 m. Rooms were driven 6,5 m wide, leaving 9,5 m square pillars and giving a factor of safety of 2. There was no significant spalling or other indication of high roof pressure, and no roof supports were required or set. All the tests were undertaken in heading B to avoid possible effects from changes in the direction of mining.

At Kriel, the No. 4 Seam (Table I) has an average thickness of 4,5 m, although only the lower 3,5 m is extracted. The seam roof is composed of shale, and the immediate floor is sandstone. The stratification of the seam is regular and, although it is relatively cleat free and compact, there is evidence of bedding with the coal subsections showing significant variations in strength between roof and floor. However, there seems to be little tendency for the seam to part along the bedding planes, except at the distinctive horizon 3,5 m above the floor.

TABLE I

LITHOLOGY AND STRENGTH PROPERTIES OF THE NO. 4 SEAM AT THE TEST SITE

Subsection and thickness m	Description	Impact Strength Index	Hardgrove Grindability Index	Uniaxial compressive strength MPa	Specific Energy MJ/t
1—0,25	Dull lustrous	57	69	15	11
2—0,17	Mainly bright	72	44	20	20
3—0,43	Dull lustrous	64	74	18	11
4—0,15	Mainly bright	67	77	17	12
5—0,55	Mainly dull	72	58	30	24
6—0,30	Mixed	76	57	23	25
7—0,30	Mainly dull	69	59	15	8
8—0,20	Mainly dull	70	62	12	14
9—0,20	Mainly dull	69	60	21	15
10—0,35	Mainly bright	74	55	18	14
11—0,60	Dull lustrous	63	92	11	9
TOTAL —3,50					

The weighted average values are as follows for the various coal-strength parameters:

	Impact Strength Index	Hardgrove Grind-ability Index	Uniaxial com-pressive strength MPa	Specific energy MJ/t
Sumping section	65	69	18	13
Shearing section	72	58	25	19

The values of uniaxial compressive strength were determined from cylindrical specimens, 45 mm in diameter and 90 mm in length, cut axially and loaded perpendicular to the bedding. The values of specific energy were obtained by use of the Chamber of Mine's coal-face penetrometer, which is designed for use in the field. The results from this instrument are not expected to equate with those from an actual mining machine because of differences due to scale and cutting confinement. However, the information it provides on hardness, strength, and cuttability gives a useful qualitative assessment of the strength of the seam and its subsections.

EXPERIMENTAL RESULTS

Early experience showed that no meaningful data would be obtained for chisel picks operating at spacings of 50 and 200 mm. A 29 mm-wide chisel spaced at 50 mm leaves a gap of only 21 mm between picks, thus requiring very little breakthrough of coal between adjacent picks. Conversely, the very high stresses imposed on chisels at a spacing of 200 mm caused unacceptable damage to picks and pick boxes, and this part of the test programme proved to be unpractical.

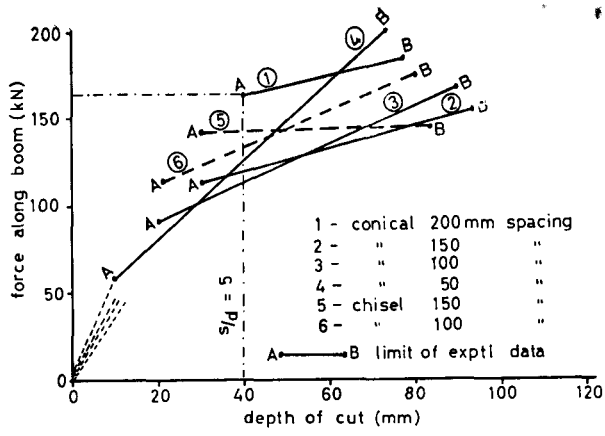

Fig. 9—Force along the boom during sumping

Performance during Sumping

The maximum forward advance of the machine during sumping was 0,635 m, which gave a total sumping depth of the same value providing no slip occurred at the goal-post anchor. The actual sumping depth achieved was always measured and, if it fell below 0,57 m, the test was abandoned. To avoid end-effect problems, the data obtained over the first 50 mm of sumping were discarded, and all the results given here relate to a sumping interval between 50 mm and at least 570 mm or at most 635 mm.

Force along the Boom during Sumping

The variation in force acting along the boom as the

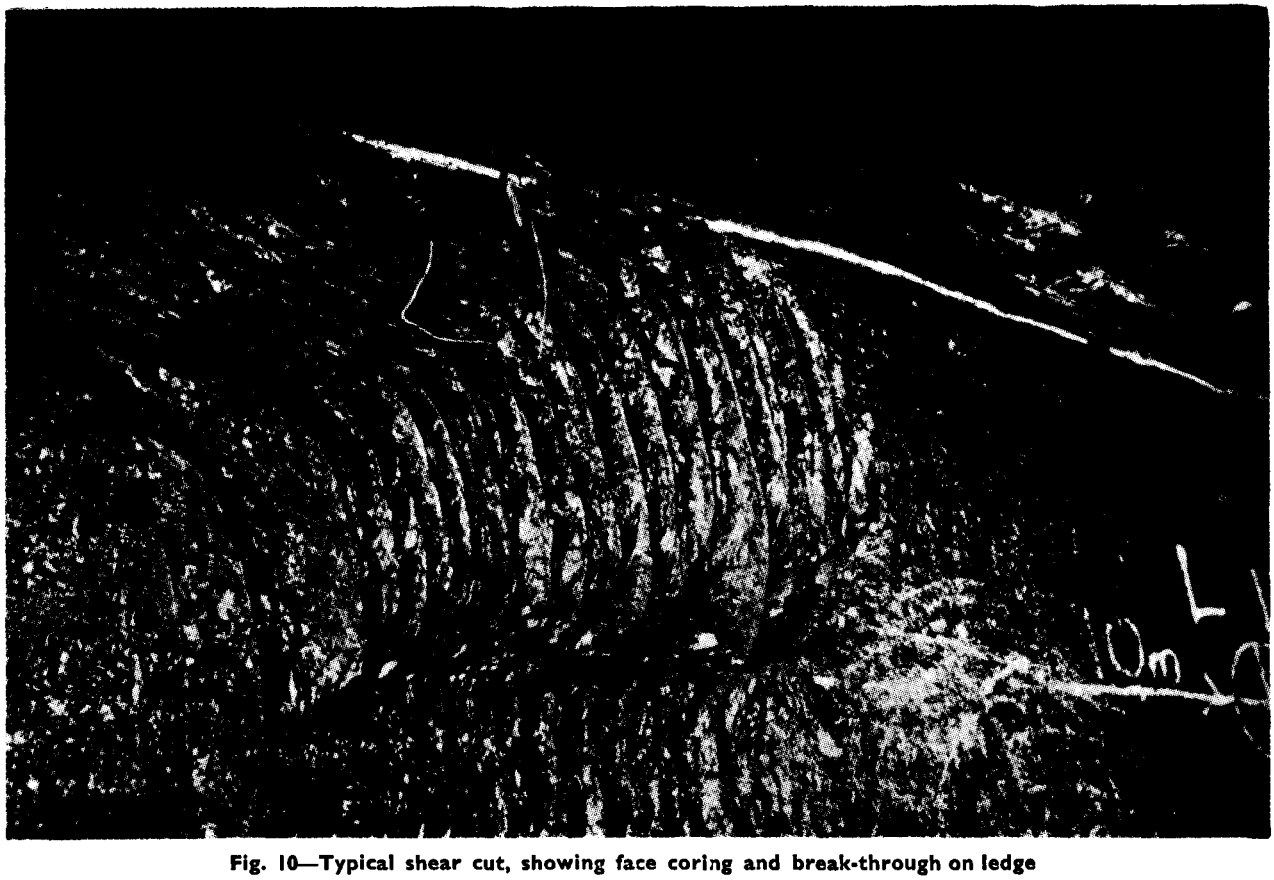

Fig. 10—Typical shear cut, showing face coring and break-through on ledge

depth of cut was increased is shown in Fig. 9 for the two types of pick at their respective levels of spacing. In each case, the A–B region is the range to which the experimental data apply.

Three significant factors emerge from these results.

(i) There is, in all cases, a linear increase in sumping force with depth of cut.

(ii) The gradient (rate of increase of force with depth) is lower when the pick spacing is higher.

(iii) Interaction between picks in the array occurs only in the A–B region. In each case a cutting depth below that appropriate to point A is unpractical since the picks in the array are then cutting too shallow to interact.

The taking of successive shallow cuts at a high spacing does not cumulatively lead to a breakage pattern equivalent to a large single cut. A series of shallow superimposed cuts produces deep narrow channels in the coal face, inhibiting lateral breakout. If this 'coring' of the coal occurs, it prevents the machine from advancing when the depth of core exceeds the reach of the pick. Such coring is often seen at the roof during sumping, and at the face during shearing, owing to the shallow depth of cut as the picks enter the coal tangentially. Fig. 10 shows this clearly for shearing, but it should also be noted that coring is absent on the shelf of the shear, at which point the picks are taking their full depth of cut and thereby producing good lateral breakout.

It is significant to note (for the reasons outlined above) that no experimental data could be expected when the depth of cut was less than that appropriate to point A on each of the graphs of Fig. 9. The position of point A is in each case equivalent to an s/d ratio of 5, the implication being that interaction between the grooves ceases when the s/d exceeds 5. Such was indeed found in practice, with minimal operation data showing at s/d values greater than about 5. As an adjunct to these observations, a series of laboratory pilot-cutting experiments was undertaken at various cutting depths up to 30 mm, and it was confirmed that interaction between adjacent grooves in a block of No. 4 seam coal ceased when the s/d exceeded about 5.

Based on the foregoing considerations, and the knowledge that pick forces are linearly proportional to cutting depth, it is reasonable to propose that, in each case, point A should be linearly connected to the origin. Being equivalent to unrelieved cutting, this O–A section provides, by inference, data on the performance of a set of single unrelieved picks. The average normal force per pick, F_N, can be determined if the ordinate value is taken at the point A for each graph, which is the limit of unrelieved cutting, and is related to the s/d ratio via the depth of cut (abscissa) and the known value of spacing for the graph, and if the average number of picks cutting at any one time throughout the sumping operation is calculated. Data derived in this way for conical picks are given in Table II.

When plotted, as in Fig. 11, the normal force per pick is seen to be linearly proportional, through the origin, to the depth of cut. This result is wholly consistent with the results obtained from unrelieved cutting tests in the laboratory on a wide range of coals throughout the world.

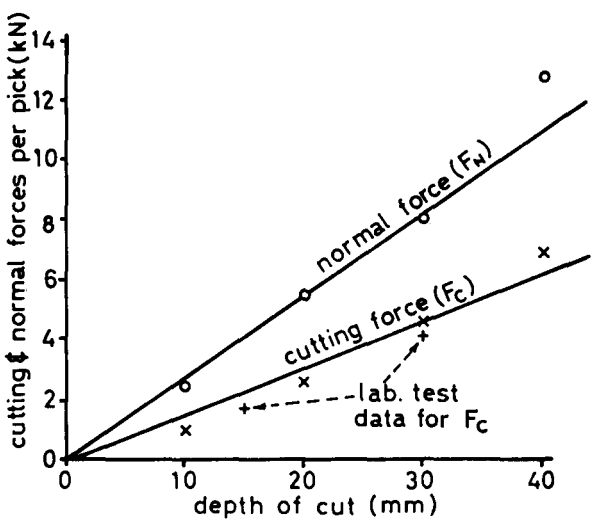

Fig. 11—Average normal and cutting forces per pick for an s/d of 5 (limit of relief) during sumping

Torque during Sumping

Whereas the force acting along the boom is related to the normal force acting on the picks, the torque is a measure of the pick cutting force. It is torque that supplies the work to cut the coal.

The torque–penetration curves for conical and chisel picks are shown in Fig. 12. The data available for each graph, as in Fig. 9, are restricted to a depth-of-cut range A–B over which interaction between the picks was occurring. Again, the A–B section is substantially linear, with the gradient generally decreasing with increased spacing. However, there is one departure from this trend: the 150 mm spacing gradient is somewhat lower than for 200 mm spacing. Statistically, a decreasing gradient with spacing relationship is still possible for the 200 and 150 mm spacings without transgressing an acceptable estimated standard error of their difference.

TABLE II

AVERAGE NORMAL FORCE FOR PICKS CUTTING UNRELIEVED IN SUMP

Spacing mm	Depth of cut at A, mm	Boom force at A, kN	No. of picks	Av. no. of picks cutting	Normal force per pick, kN
200	40	163	38	12,7	12,8
150	30	112	42	14,0	8,0
100	20	91	50	16,7	5,5
50	10	58	75	25,0	2,3

The general argument presented in the section on force along the boom on the interaction ceasing at point A, and the several reasons for this and its implications, are precisely the same for torque. Values for the average unrelieved cutting force for conical picks were determined on a similar basis and are presented in Table III. These values, also plotted in Fig. 11, show a linear increase of cutting force with depth of cut.

Some preliminary laboratory experiments with an instrumented cutting rig on Kriel No. 4 seam coal provided some average cutting force values for cutting depths of 15 mm and 30 mm using a conical pick of similar geometry to those on the continuous miner. The average values obtained of 1,7 kN and 4,1 kN respectively are shown superimposed on Fig. 11. However, the angle of attack of the pick to the coal in the laboratory tests was 45°, as opposed to the 36,5° pick-box angle used on the continuous miner. In the laboratory this would produce a front rake angle 8,5° larger, resulting in somewhat lower cutting forces. Despite this, the laboratory values show excellent agreement with the unrelieved cutting data abstracted from the torque–penetration graphs, and adds considerably to the confidence and practical significance that can be attached to coal-cutting data obtained in the laboratory.

Variation in Specific Energy with Depth of Cut during Sumping

It must be emphasized, in the context of these results, that depth of cut refers to the advance per revolution of the cutting drum and *not* to the total depth of sump achieved.

The effect of depth of cut on specific energy for the 4 levels of conical-pick spacing and the 2 levels of chisel-pick spacing is shown in Fig. 13. From these results the following general observations can be made.

(i) In all cases, the specific energy was seen to fall sharply as the depth of cut was increased. This emphatic trend and the general shape of the curves obtained are generally consistent with the theoretical model advanced earlier that led to equation (3).

(ii) There seems to be little difference in the performance and efficiency of chisel- and conical-shaped picks except at high penetration, when conical picks appear to have a slight advantage.

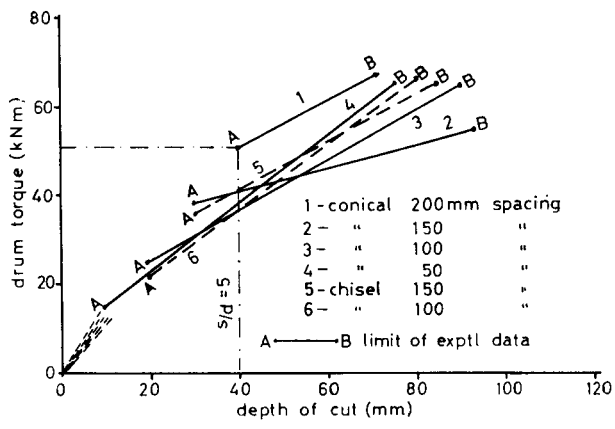

Fig. 12—Torque during sumping

TABLE III

AVERAGE PICK FORCE CUTTING UNRELIEVED IN SUMP

Spacing mm	Depth of cut at A mm	Torque/drum radius at A kN	Av. no. of picks cutting	Cutting force per pick kN
200	40	89,9	12,7	7,1
150	30	67,3	14,0	4,8
100	20	43,3	16,7	2,6
50	10	26,0	25,0	1,0

The respective curves at 100 mm spacing are effectively the same. Although laboratory work consistently shows the chisel pick to be a more efficient tool than a pick of any other shape, it is evident that such differences as may exist are of secondary importance, and that the dominant variable in terms of cutting efficiency is depth of cut. Indeed, because of the high concentrations of stress at its tip, the conical pick can achieve a larger depth of cut for a given level of force than a chisel pick.

(iii) It could not be expected that the curves in Fig. 13, which are for relieved cutting, would exactly follow the shape prescribed by equation (3), which relates to unrelieved cutting. Consequently, the curves for the two narrower spacings of 50 and 100 mm reach a minimum specific energy, which then increases. This means that, for these spacings, the picks are cutting too deeply, resulting in an s/d ratio that is below the optimum (i.e., operating on the left side of the minimum in Fig. 3). Similarly, the largest depth of cut achieved in the experiment was not sufficiently high for the 150 and 200 mm spacing to approach the minimum specific energy.

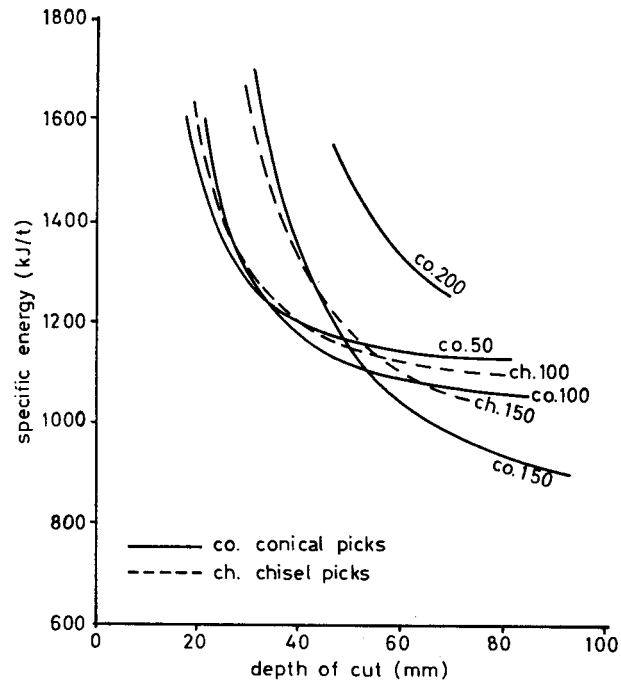

Fig. 13—Effect of depth of cut on specific energy during sumping

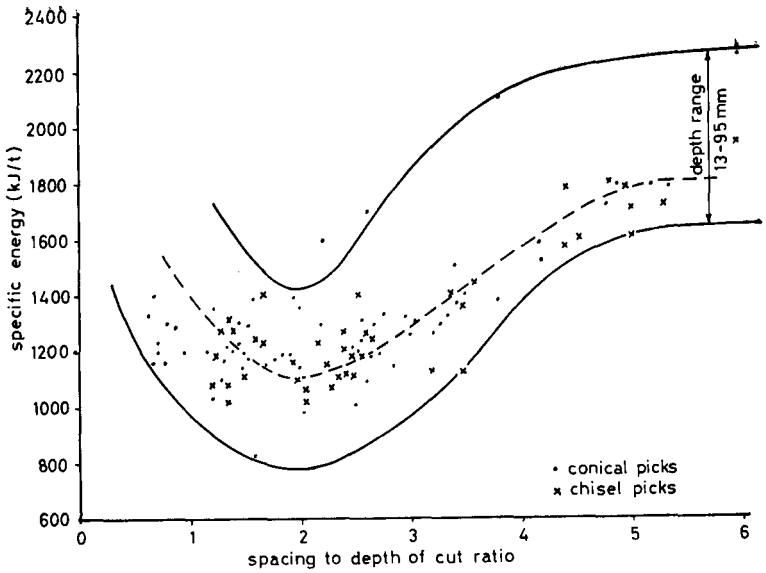

Fig. 14—Variation in specific energy with ratio of spacing to depth during sumping (all data combined)

(iv) At a spacing of 150 mm and more, few results were found for depths less than about 30 mm and, at a spacing of 100 mm, there are no data below a cutting depth of 20 mm. This is consistent with the observation made elsewhere that interaction does not occur when the s/d ratio exceeds 5.

(v) In general, Fig. 13 shows that deep-cutting, wide-spaced picks produce a considerable improvement in cutting efficiency. Comparison of the extremes shows that a shallow-cutting, narrow-spaced array of picks required a specific energy in the region 1600 to 1700 kJ/t, whereas a wider-spaced, deeper-cutting combination required about 900 kJ/t. This represents almost a halving of specific energy, with strong indications that there would be a further significant improvement in efficiency at even greater depths of cut.

Variation in Specific Energy with Pick Spacing during Sumping

Because there was not precise control over the depth of cut with the continuous miner, it was not possible for a series of curves to be constructed to show how specific energy varies with the s/d ratio at different depths of cut. Comparisons with the hypothetical curves in Fig. 3, which were verified in principle by laboratory cutting tests, cannot therefore be made.

It is logical, nevertheless, for all the results to be combined, irrespective of depth of cut, and to be presented graphically on the premise that the collective data should define an envelope similar to that bounded by the curves for smallest and largest depth of cut shown in Fig. 3B, and from which an optimum s/d ratio might be seen. As the evidence indicated that pick shape is of secondary significance in terms of cutting efficiency, the results for conical and chisel picks were plotted together.

The results (Fig. 14) give a strong indication that the optimum ratio between pick spacing and depth of cut for maximum cutting efficiency is 2. When the median was used, the highest specific energy was found to be about 1800 kJ/t, which improved to a best value of approximately 1100 kJ/t when the s/d ratio was 2.

An alternative method used in the analysis of these experimental data is based on the now reasonably well-authenticated hypothesis that the optimum s/d ratio is the same for all depths of cut. A mathematical model is proposed that describes the part of the curve that applies to relieved cutting, this being the region to which the data on the continuous miner apply. The equation is as follows:

$$\text{S.E.} = a_0 + a_1 s^2 + \frac{(b_0 + b_1 s^4)}{d^2}, \quad . \quad . \quad . \quad . (4)$$

where $S.E.$ = specific energy (kJ/t)
s = pick spacing (mm)
d = depth of cut
a_0, a_1, b_0, b_1 = constants.

When this model is used, contours of equal specific energy can be constructed for different pick spacings and depths of cut. The constants determined from an analysis of the experimental data are as follows:

	Conical picks	*Chisel picks*
a_0 =	1 140	1 176
a_1 =	0,01116	−0,01116
b_0 =	154 245	103 571
b_1 =	0,00118	0,00118

If these values are substituted in equation (4), differentiating with respect to s and equating to zero show that the minimum specific energy occurs, for all depths of cut, at an s/d ratio of 2,17. This is very close to the value of 2, which was assessed direct from Fig. 14.

Performance during Shearing

Shearing tests were undertaken immediately after sumping had been completed. Sumping was, in all cases, done at the same horizon immediately beneath the coal roof. The total depth of sumping achieved before

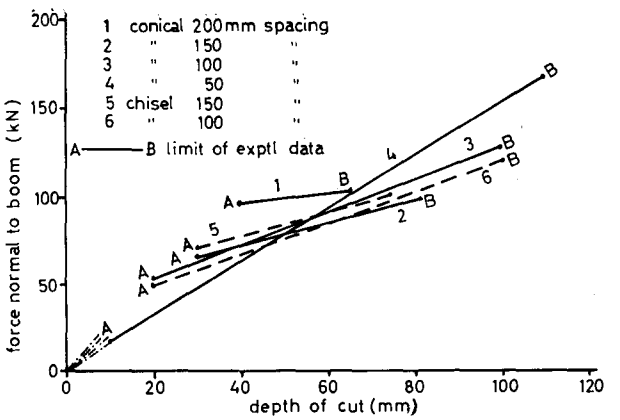

Fig. 15—Force normal to the boom during shearing

shearing commenced was consistently in the narrow range 0,570 to 0,635 m, giving a shearing thickness of the same amount.

Force Normal to the Boom during Shearing

The force required to move the boom down the face and shear the coal is shown in Fig. 15. This includes data for the conical picks at four levels of spacing, and for the chisel picks at two levels of spacing. The downward force on the boom during shearing is seen in all cases to increase linearly with depth of cut. The graphs are very similar, in shape and order of sequence in terms of pick spacing, to those for sumping, which are shown in Fig. 9. The rate of increase in force is again found to depend on pick spacing, with the rate decreasing as the pick space increases.

With the same line of reasoning as advanced for force along the boom, and with the experimental data again being confined to the A–B section of each graph, a similar analysis can be undertaken to show the average normal force acting on the picks. As found previously, point A in all cases occurs at the spacing-to-depth ratio of 5, which has been shown to be the limiting value for interaction between picks and the value above which it is unpractical for the machine to function.

The data for pick normal forces at the depths of cut appropriate to point A are given in Table IV. These data are plotted in Fig. 16, which shows a reasonably good linear correlation of force with depth of cut. In this case, the values for normal force are somewhat lower than those found during sumping. This is to be expected since, when shearing, the picks are cutting to a free face, which is not available during the sumping operation.

Torque during Shearing

The relationship between torque and depth of cut for the two types of pick at the different spacings is shown in Fig. 17. The linear increase in torque with depth of cut is evident once again, the effect of spacing on gradient and the range of experimental data confined to the A–B section of each graph being as persistent as those found in Figs. 9, 12, and 15. Point A once more represents an s/d pick interaction limit of 5 in the case of each graph.

The torque, appropriate to point A in each case, was measured on the ordinate, and is tabulated with other relevant data in Table V.

The results for cutting force per pick that are plotted against depth of cut alongside the normal force values in Fig. 16 are of similar magnitude and gradient to the corresponding relationship for sumping, which is shown in Fig. 11.

It might be expected that both the cutting and the normal forces for a pick operating in shear would be appreciably less than for a pick operating in sump, owing to the lower arc of drum contact in shear and the presence of an additional free face to assist breakage. It should be noted, however, that the strength of the section of the coal seam at the test site in which the shearing experiments were undertaken is significantly higher than the strength of the coal section where sumping was carried out. (The relevant data on seam strength are given in Table I.)

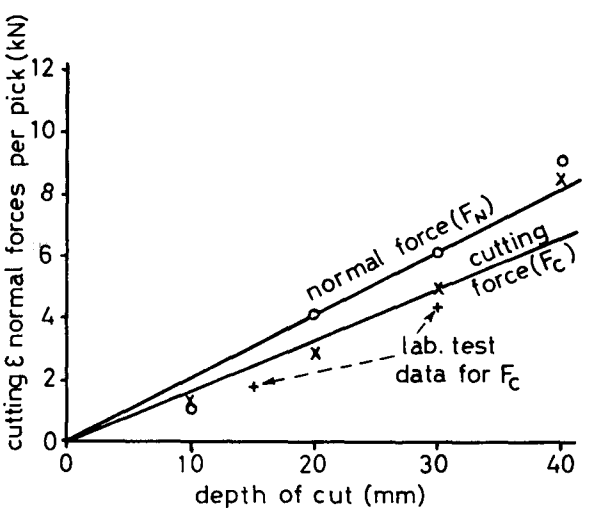

Fig. 16—Average normal and cutting forces per pick for an s/d value of 5 (limit of relief) during shearing

TABLE IV

AVERAGE NORMAL FORCE FOR PICKS CUTTING UNRELIEVED IN SHEAR

Spacing m	Depth of cut at A, mm	Boom force at A,kN	Total no. of picks	Estim. no. of picks cutting	Av. normal force per pick kN
200	40	85,1	38	9,5	9,0
150	30	62,5	42	10,5	6,0
100	20	50,1	50	12,5	4,0
50	10	17,8	75	18,8	0,9

Variation in Specific Energy with Depth of Cut during Shearing

The effect of depth of cut on specific energy during shearing is shown in Fig. 18 for both types of pick at their various spacings. The conclusions drawn from these shearing results are virtually identical to those found in sump.

(i) For each type and spacing of pick, the specific energy reduces rapidly as the depth of cut is increased. The shape of the curves obtained conforms well with that prescribed by the theoretical predictions of equation (3). Because of interaction effects, the results for both 50 and 100 mm spacings (Fig. 18) approach minimum values of specific energy. This was also observed during sumping, and the reasons outlined earlier are equally valid here. The data for the curves at 150 and 200 mm spacing in Fig. 18 do not extend to a sufficient depth of cut for the minimum specific energy to be reached.

(ii) The effect of pick shape on cutting efficiency is subordinate to the effect of cutting depth. Despite theoretical and laboratory experimental evidence to the contrary, the conical pick was found in practice to perform at least equally as well as the chisel pick. The intrinsically better penetration of the conical pick, which enables it to achieve a given depth of cut with less force than the chisel pick, is evidently of overriding significance in this context. Having achieved such penetration with less force, the almost optimally spaced array of conical picks would produce a coal yield similar to that produced by chisel picks. This observation on the relative performance of conical and chisel picks in array at depth is not necessarily in conflict with the basic theoretical and laboratory conclusions, which strongly favour the chisel pick.

(iii) As with sumping, the results in shear show the benefit to the cutting efficiency that can be derived from the use of deep-cutting, wide-spaced picks. A comparison of Figs. 13 and 18 shows that the general levels of specific energy for shearing are not very different from those required for sumping.

TABLE V

AVERAGE CUTTING FORCE FOR PICKS CUTTING UNRELIEVED IN SHEAR

Spacing mm	Depth of cut at A mm	Torque/drum radius at A kN	Estim. no. of picks cutting	Av. cutting force per pick kN
200	40	80,0	9,5	8,4
150	30	52,0	10,5	4,9
100	20	35,0	12,5	2,8
50	10	21,4	18,8	1,1

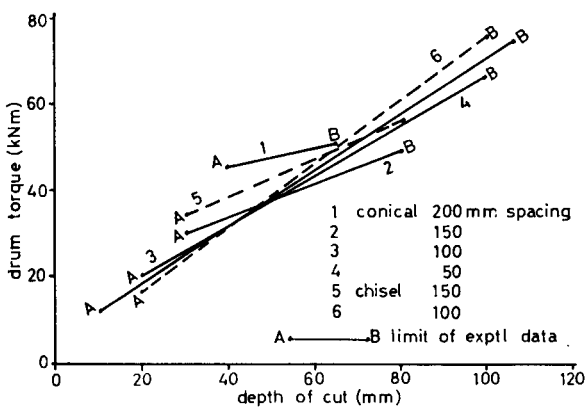

Fig. 17—Torque during shearing

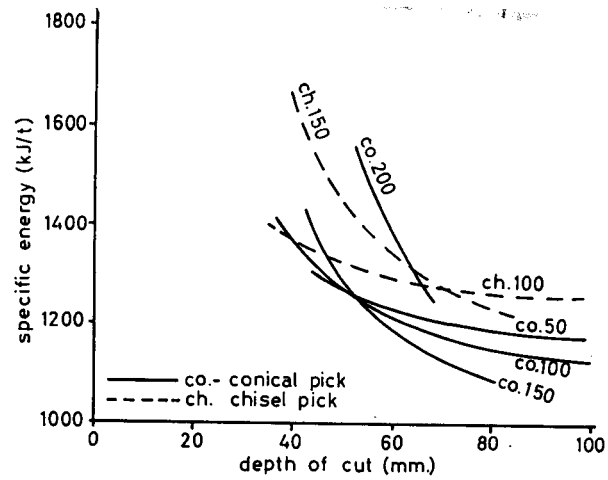

Fig. 18—Effect of depth of cut on specific energy during shearing

Comparison of Specific Energy with That during Sumping

Data for a depth of cut of 80 mm abstracted from Figs. 13 and 18 gives the values listed in Table VI. For each type of pick, the specific energy during shear is higher than during sump. This is contrary to the expectation that the shearing operation would be able to exploit the free face produced by sumping. It appears also to be in conflict with the results of earlier experiments with an instrumented continuous miner in the U.S.A., which indicate a 40 per cent reduction in specific energy requirements during shearing as opposed to sumping[13].

The reason for this discrepancy almost certainly lies in the fact that the strength of the coal at the Kriel test site is significantly less over a thickness of about 1 m adjacent to the roof than it is over the remainder of the seam section (Table I). Since sumping is carried out wholly in the top 1 m of the seam, the specific energy requirement would be appropriately lower at that horizon. Some average measures of coal strength over the sumping and shearing sections of the face are given in Table VII.

As a low Hardgrove Grindability Index corresponds to a high coal strength, Table VII shows, in all cases, a significantly lower cuttability of coal at the sump-in section. In fact, the values for penetrometer specific energy and average grooving force (obtained from the same instrument) reflect the difference in cutting resistance probably more accurately than the other test methods, since they are measured *in situ* and involve actual cutting of the coal. The tests for Hardgrove

TABLE VI

SPECIFIC ENERGY OF CONICAL AND CHISEL PICKS

Type of pick	Spacing mm	Specific energy, kJ/t	
		Sumping	Shearing
Conical	50	1 130	1 190
	100	1 060	1 150
	150	940	1 090
Chisel	100	1 100	1 270
	150	1 040	1 230

TABLE VII

RELATIVE STRENGTH OF SUMPING AND SHEARING SECTIONS OF NO. 4 SEAM

Measure of coal strength	Sumping section	Shearing section	Degree of higher strength of shearing section %
Hardgrove Grindability Index	69	58	16
Impact Strength Index	65	72	11
Penetrometer, J/g	13	19	46
Av. grooving force, kN	12	17	42
Unconfined compression strength, MPa	18	25	39

Grindability Index and Impact Strength Index are both indirect methods, which are carried out on coal fragments in the laboratory.

Of interest and obvious significance is the 46 per cent and 42 per cent higher cutting resistance in the shearing section with the specific energy found in the U.S. experiments, which is 40 per cent lower in the shearing than in the sumping section.

Effect of Pick Spacing on Specific Energy during Shearing

The lack of precise control over the depth of cut was the same in the shearing as in the sumping experiments. The experimental data were therefore again combined and, because of further supporting evidence found during shearing that pick shape is of secondary significance, the results for conical and chisel picks were plotted together (Fig. 19). The magnitude and trend of the results are very similar to those found for the sumping tests, as shown by a comparison of Figs. 14 and 19.

Specific energy reaches a minimum when the ratio of spacing to depth of cut is approximately 2. The depth-of-cut range over which the experimental data span is 39 to 110 mm compares with the depth-of-cut range during sumping, which was between 13 and 95 mm.

Although the family of curves lying within the envelope defined by the upper and lower boundary curves cannot be drawn, a median curve was constructed as was done for the sumping data. This gives a maximum specific energy of about 1550 kJ/t, falling to approximately 1150 kJ/t at a spacing-to-depth ratio of 2. The corresponding values during sumping were 1800 kJ/t and 1100 kJ/t.

The same mathematical model that describes the relieved cutting section of the curve, which is expressed by equation (4), was applied to the shearing data. When the following constants were used, it was found to provide an excellent fit with the contours of equal specific energy constructed from the experimental data when the depth of cut was used as the vertical axis and spacing as the abscissa:

	Conical pick	*Chisel pick*
a_0	1 173	1 316
a_1	−0,00930	−0,00930
b_0	260 413	193 286
b_1	0,001140	0,001140

The substitution of these constants in equation (4), differentiating with respect to s, and equating to zero show that specific energy is minimized when the ratio of spacing to cutting depth is 2,02. This agrees well with the value of 2,17 found from the same equation based on sumping data. Similarly, both these calculated values show good agreement with the optimum ratio of spacing to depth of cut of approximately 2, which was obtained direct from the experimental data for sumping and shearing and is shown in Figs. 14 and 19 respectively.

Size Distribution of Coal

Controlled laboratory cutting experiments invariably show a clear relationship between size distribution of the cut material (coal or any other rock material) and the specific energy. Generally, the experimental variables that lead to a minimum specific energy also produce the maximum size distribution and *vice versa*. The curve for coarseness index is usually found to be the inverse of the curve for specific energy. This is quite understandable since it can reasonably be argued that an excess of energy over the minimum required to cut the material is absorbed in the production of a greater degree of coal fragmentation. From this thesis it would be expected that inefficient coal cutting would lead to the production of small coal and a large amount of dust.

Measurements of airborne dust were not made during these experiments for several technical reasons but mainly because experiments in the U.S.A. with a similar

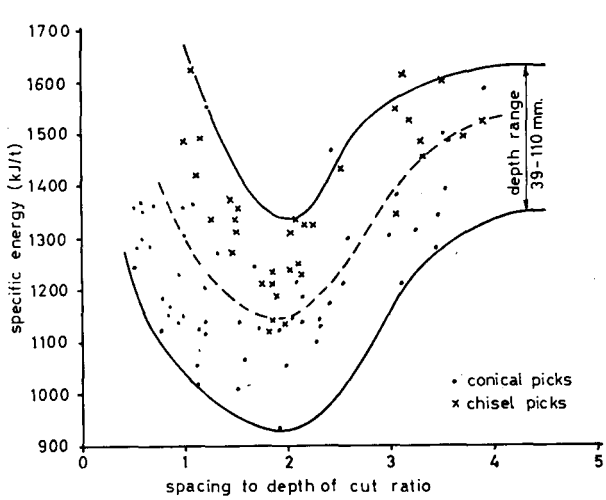

Fig. 19—Variation in specific energy with ratio of spacing to depth during shearing (all data combined)

machine had shown that the production of dust is indeed closely related to cutting efficiency[13]. However, samples of coal taken during the present experiments were analysed to provide a coarseness index, which was determined by a summation of the cumulative mass percentages of five size fractions: plus 50 mm, 25 to 12,5 mm, 12,5 to 6 mm, 6 to 3 mm, and minus 3 mm. The coarseness index ranged from 600 to 100, the upper limit being appropriate to all the material larger than 50 mm, and the lower limit to all the material smaller than 3 mm.

Unfortunately, considerable problems were experienced in the finding of a reliable sampling technique, and values of coarseness index proved to be very inconsistent. Disappointingly little use could therefore be made of the data, and no conclusive trends could be established. Fig. 20, which shows coarseness index plotted against pick spacing for all the depths of cut, gives some indication of the wide scatter of the data. However, it provides some evidence, although tenuous, that coal size increases as pick spacing is increased.

The use of the size distribution data proved to be somewhat more revealing than the use of coarseness index. This involved the expression of the minus 6 mm material as a percentage of the total coal cut during a test. In Fig. 21, which shows this plotted against pick spacing, there is a fairly strong indication that the percentage of small coal decreases significantly as the pick spacing increases.

Continuous miners in South Africa typically produce almost double the percentage of minus 6 mm coal than was produced on average by the experimental machine. A likely explanation for this is that most production penetration rates are substantially less than those in the experimental programme, an observation that lends support to the belief that coal size improves with cutting efficiency.

Conclusions

Specific conclusions on how pick forces and cutting energies are influenced by pick shape and spacing, and by depth of cut, have been drawn throughout this paper, and only the major conclusions are listed here on a more general basis.

(i) For maximum cutting efficiency, the spacing between adjacent picks in an array should be approximately twice the pick penetration per revolution of the drum (i.e., depth of cut).

(ii) The depth of cut per revolution is the dominant variable in terms of cutting efficiency.

(iii) Provided that a large depth of cut is achieved, the effect of pick shape on cutting efficiency is of little significance.

(iv) At comparatively great depths of cut (92 to 103 mm) in what is by any standards a very hard coal, the torque availability of the HH 456 was well in excess of requirements.

(v) The sump force along the boom to produce the greatest depth of cut exceeded 200 kN or approximately 20 t.

(vi) The downward force on the boom to give the greatest depth of cut in shear was more than 150 kN (approximately 15 t).

(vii) The maximum nominal instantaneous cutting rates occurred at the highest depth of cut and the widest pick spacing.

(viii) Although the experimental results in this programme are far from conclusive, there is some evidence to support the laboratory and field conclusions of other workers that the size distribution of coal improves with cutting efficiency.

(ix) There is some good evidence to suggest that carefully designed and controlled cutting experiments undertaken in the laboratory can provide data that are both qualitatively and quantitatively relevant to machine-cutting operations in a mine.

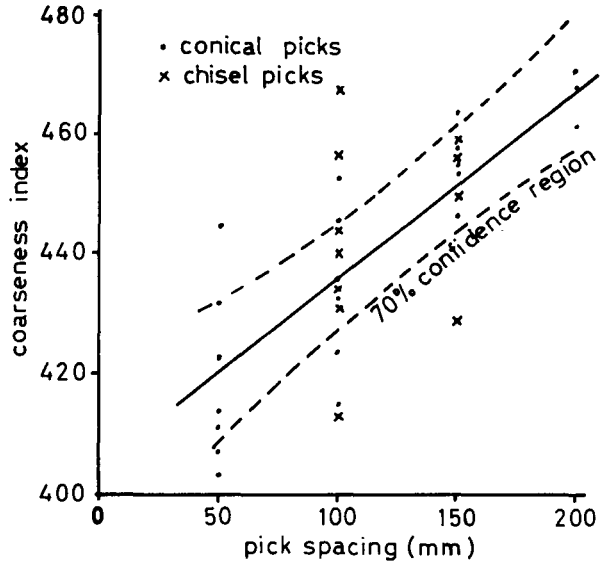

Fig. 20—Effect of pick spacing on coarseness index

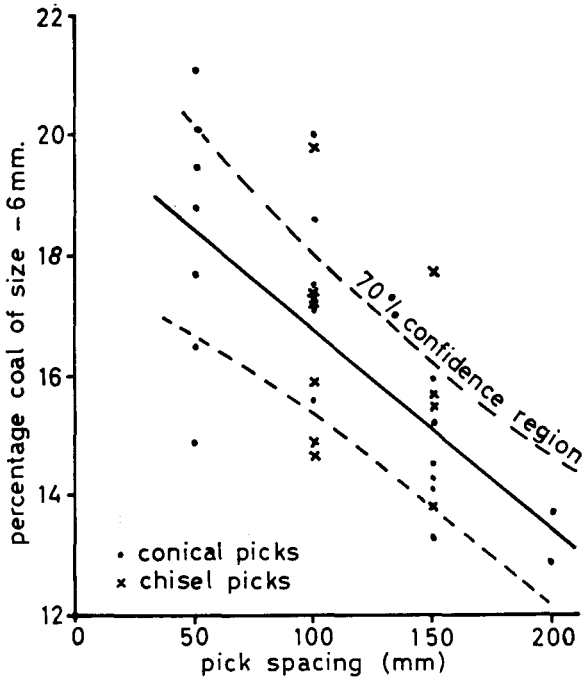

Fig. 21—Effect of pick spacing on the production of small coal

(x) The general principles for efficient coal cutting that have been established through systematic laboratory investigation and theoretical study were shown, by and large, to be valid in practice.

It needs to be stressed that the results presented here and the conclusions reached are based exclusively on a fixed drum speed of 41,7 r/min. This paper is therefore a progress report: the project is intended to include a study of the performance of the same machine in the same seam at drum speeds of 34,5 r/min, 14,7 r/min, and 7,0 r/min. It is not expected that the results obtained during further experiments will lead to conclusions that are different from or in conflict with those presented here, but the further work will quantify the effects of cutting speed on pick forces, cutting energies, and productivity rates.

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International mining, Germany

Bergbau 81, the world's largest mining fair, to be held at Düsseldorf, West Germany, from 11th to 17th June, 1981, will provide the most complete coverage of mining equipment, services, related products, and technology ever presented at one location. In addition to the hundreds of exhibits, Bergbau 81 will be the scene of three international conferences.

International Mining Congress

During this five-day Congress, developments and trends in mining and their economic and environmental implications will be discussed. Specifically, the newly-emerging importance of the world's coal resources will receive a major emphasis in the Congress programme. Bergbau 81 participants will be able to attend numerous seminars on the overall role of the mining industry in national economies and the international community, on environmental aspects of mining, and on management and operation of mines. Technological advances that will result in more economical mining methods will be presented. Additionally, future educational and training requirements for mining engineers will be outlined.

Interocean 81

The International Congress for Ocean Mining will be held on 15th June, 1981, at the Düsseldorf Fairgrounds' Exposition Congress Centre. Interocean 81 is sponsored by the German Committee for Marine Research and Technology e.V. and the Association for Industrial Marine Technology e.V. The topics will cover all important technical and economic aspects of ocean mining, including specific scientific and industrial activities in the exploration and exploitation of marine minerals. The programme will cover prospecting, mining, and processing methods and technology for

- manganese nodules containing manganese, copper, nickel and cobalt;
- hydrothermal muds with high zinc, copper, and silver contents;
- phosphorite nodules known to contain 22 to 29 per cent phosphorite;
- mineral sands consisting of cassiterite, titanium, and monazite.

Tunnel 81

A special conference on tunnel construction, Tunnel 81, will offer seminars on innovative tunnel construction methods, technology, and new research findings specifically related to transportation and sewage-disposal projects in urban areas. This three-day conference, 11th to 13th June, 1981, will be of particular interest to transportation and civil engineers and to planning consultants.

More information about Bergbau 81 and the related conferences can be obtained by contacting the S.A. German Chamber of Trade and Industry in Johannesburg.