CUTSIM - A COMPUTER PROGRAM FOR OPTIMUM CUTTING DRUM DESIGN

Yehuda Amar

A dissertation submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 1988

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

____

(Signature of candidate)

________ day of ______________ 1988

ABSTRACT

To date, manufacturers of coal cutting machines have designed cutter drums without considering the needs of the individual collieries. Different coal seams and product size requirement have in general not been assessed. The use of the CUTSIM program will enable colliery engineers and the manufacturers of continuous miner and longwall shearer to analyse the effect of various pick lacings and select the one most suitable for their cutting conditions. The literature indicates that this approach of simulating and analysing the performance of a cutting drum via the computer has been done previously. However no report is publicly available for converting the first simulating program into a working tool for drum design. This report describes the development of the CUTSIM program and details how the progress was validated successfully against the findings of three different areas of work:

* manual calculations made for the same drum lacing
* previous work performed on the Lee Norse experimental continuous miner in the early 1980's
* results of field testing of pick lacings indicated by CUTSIM.

Various examples of using CUTSIM efficiently in order to obtain a better cutting performance are attached as a demonstration of the potential of CUTSIM.

The program is considered a valuable design tool for the local manufacture of continuous miners and longwall shearer and is currently being used by the coal industry successfully.

It is shown that with the aid of computer simulations of a continuous miner that an inefficient cutting drum laced with 110 picks can be modified to a lacing of only 66 picks, with a significant cutting improvement. The use of CUTSIM for better drum

design or for redesigning of an existing drum is very inexpensive. No additional machinery or instrumentation are required. For comprehensive analysis, the required data input are the geometry of the cutting drum, a sample of coal block and one of the picks which the drum is laced with.

In memory of my mother
Rachel Amar
1929 - 1970

ACKNOWLEDGEMENTS

The Chamber of Mines of South Africa Research Organization has allowed the use of facilities and resources, and permission to publish data, without which this dissertation would not have been possible.

The expert advice of Professor H.R. Phillips has been an inspiration in the completion of this dissertation.

I would like to thank the management and staff at all the collieries visited for their co-operation and help in carrying out the tests.

I wish to express my thanks to Joy Manufacturing for their assistance and to the various pick manufacturers.

The support and understanding of my wife and my daughter during the documentation of this study has played an important part in its completion.

CONTENTS Page

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

LIST OF SYMBOLS

Symbol	Quantity	Unit
DOC	Depth of cut	mm
Fc	Cutting force	kN
Fn	Normal force	kN
Fs	Side force	kN
P1	Cutting parameter	
P2	Cutting parameter	kN/mm
Ft	Total cutting force	kN
ϵ	Attack angle of the pick	degree
Γ	Skew angle of the pick	degree
θ	Angle of pick position	degree
Z	Co-ordinate of pick position along the drum	mm
r	Cutting radius of the pick	mm
X1	Forward drum velocity	m/s
X2	Sideway drum velocity	m/s
X3	Vertical drum velocity	m/s
Z increment	Axial resolution	mm
X1 start value	Initial position of the drum in relation to the coal face	mm
Z range minimum	Initial range along the drum	mm
Z range maximum	Final range along the drum	mm
Fh	Horizontal force	kN
Fv	Vertical force	kN
α	Angle between Ft and Fh	degree
β	Angle between Ft and Fn	degree
K	Linear factor(gradient)	kN/mm
T	Torque	kN·m

LIST OF SYMBOLS

Symbol	Quantity	Unit
Number of rotation	Drum revolutions per minute	r/min
δ	breakout an le	degree
E	Specific energy	MJ/m^3 or MJ/kG

CHAPTER 1 INTRODUCTION

This thesis deals with a method of coal cutting by means of picks on a rotating drum. The technique investigated is the use of a computer program for simulating the coal cutting process and analysis of the related forces and torque. These applications can be used either for assessing the lacing pattern of an existing cutting drum and proposing the changes required or for a new design of a cutting drum. It is vital that production methods are improved and the related cost reduced in view of the present difficult conditions for South Africa in the world market due to:

* The recent drop in coal prices world wide resulting in closing of a number of collieries

* due to the political situation, the South African coal is more than ever before an unwanted product overseas

* increased labour cost makes the coal production too expensive for the collieries.

1.1 General Energy Source Consideration

South Africa is fortunate to have an enormous amount of coal estimated at 51 Gt (51 x 10^9 ton) reserves and 110 Gt of resources as reported in the Petrick report in 1975 and updated in 1981. These findings are also supported by Bright, 1958[1]. The coal (as raw coal or synthesized into liquid fuel at the various SASOL plants) provides an estimated 25 to 50 per cent of the national energy requirements. Since the turn of the century coal production increased gradually to reach 50 million tons in the 1960's. Following a brief stagnation in the late 1960's and early 1970's, the coal production increased at an annual growth rate of about 10 per cent to reach more than 168 million tons in 1986, see Figure 1.1. South Africa is now the 5th largest hard coal producer and the third largest coal exporter in the world, as shown in Table 1.1. Cook, 1987[2].

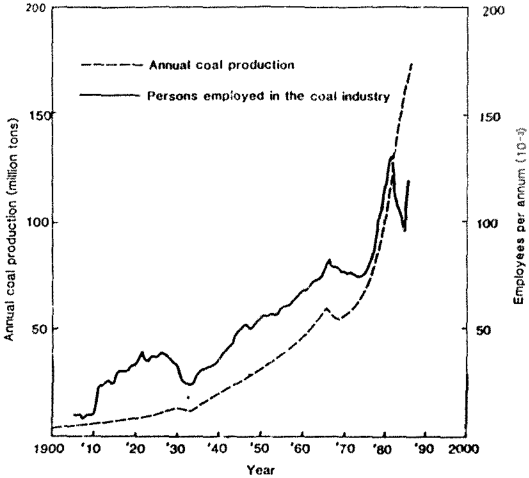


Figure 1.1 Annual coal production and employment for the South African coal industry

Table 1.1 OVERVIEW OF WORLD COAL MINING SITUATION IN 1985

	Production mt	Exports mt	Percentage	Coal Reserves mt	Lite of Coal Reserves at Current Production
China	785,0	7,6	1	+99 000	126 years
USA	743,2	82,9	11	125 353	168
Russia	566,0	23,0	4	108 800	192
Poland	190,0	36,2	19	27 000	141
South Africa	173,1	44,3	26	58 404	337
India	150,0	-	·	19 005	126
Australia	125,0	88,8	71	27 442	219
United Kingdom	94,0	2,5	2	14 000	149
West Germany	88,9	9,1	10	29 919	336
Canada	50,9	27,3	54	1 600	31
Colombia	9,0	2,5	28	1 100	122
Japan	16,4	-	-	1 056	64
France	15,1	1,5	10	574	38

The main reasons for the exceptional growth of the coal mining industry during the past 15 years were a massive increase in electric power generating capacity to meet the longer term needs of the country, the political events in Iran which have threatened the supply of oil to South Africa and the increased world demand for coal following the energy crisis in the late 1970's.

The rapid growth rate of the South African coal industry was facilitated by a well developed infrastructure, an organized and economically-strong mining industry, and most importantly, favourable geological conditions and ample labour resources.

1.2 Mining Methods

Figure 1.2 gives a historical summary of the various mining methods that are in use in South African collieries. Two important trends emerge from this figure. Firstly, the labour intensive hand-loading method of bord and pillar mining which was employed almost exclusively before 1965, has been replaced by the mechanized method of bord and pillar mining where coal is mechanically loaded into shuttlecars and transported to the section belt. More recently the bord and pillar method of mining has been mechanized further by the introduction of drum-type continuous miners (Figure 1.3) which replace drilling and blasting. Secondly, the opencast method of mining has grown in importance since 1970 and by 1986 accounted for about one third of the total coal production. Finally, a number of longwall faces have been installed since 1970 and although this method of mining accounts for less than 10 per cent of the total annual coal production, it is likely to increase in importance.

Figure 1.2 shows also that by mid 1988, the forecasted total coal production obtained by continuous miners (Figure 1.3) and longwall shearers (Figure 1.4) will be about 35 million tons or 20 per cent of the total coal production in South Africa.

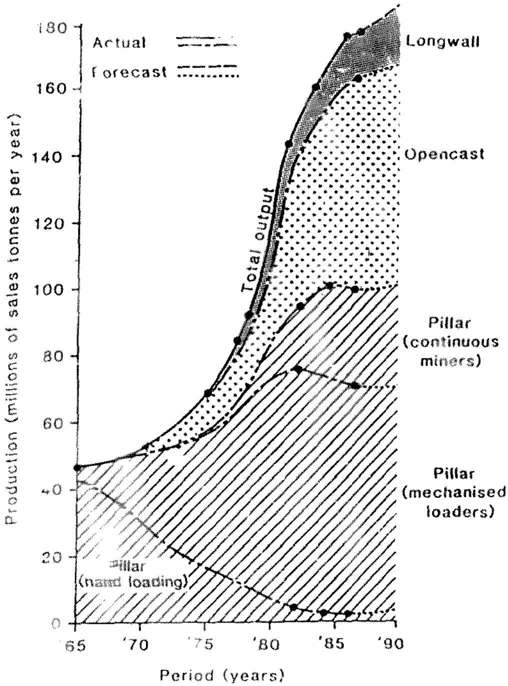


Figure 1.2 Historial summary of mining methods in South Africa

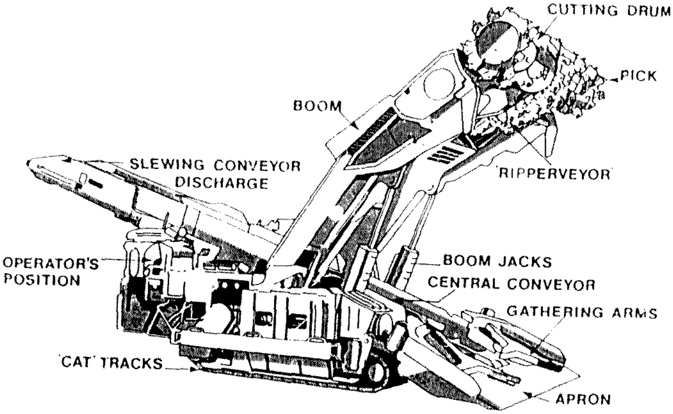


Figure 1.3 Continuous miner, ripperveyor type

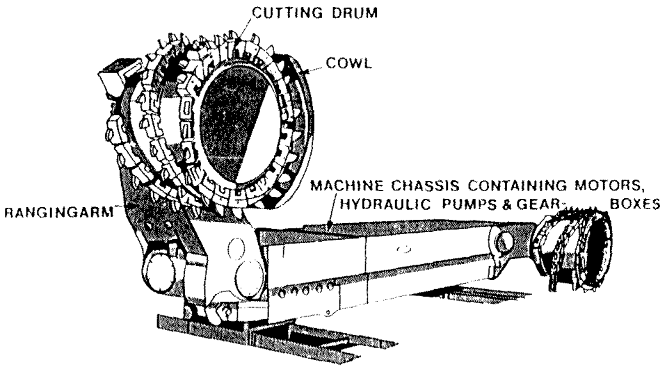


Figure 1.4 Longwall shearer

Table 1.2 shows the 1986 total production figures for South African coal mines. The total coal production obtained by bord and pillar and stooping with continuous miners and longwall shearers was 41.1 million tons, or 24 per cent of the total coal production.

According to the Government Mining Engineer (1986)[3] there are presently 135 continuous miners in use in mechanized bord and pillar mining, pillar extraction and longwall development. In addition more than 1 000 shuttlecars are in use in underground collieries to transport coal from the working face to the section conveyor belts.

Over the past ten years a total of twelve longwall faces have been introduced in South African collieries. The longwall equipment used in moderately thick coal seams is among the most modern equipment found anywhere in the world. The extremely hard coal has made it necessary to develop extra powerful double drum shearer loaders for local longwall faces. The power rating of these shearers is frequently in excess of 1 000 kW and has set new power ratings records for this type of equipment.

1.3 Common Problems with Existing Equipment

The most common problems experienced by existing cutting drums are:

* Overlaced drum which is unable to penetrate the mineral. The total thrust applied by the cutting machine divided by the number of picks in contact with the coal face is the thrust per pick for that depth of cut. A large number of cutting picks tends to reduce the thrust per pick which will result in a poor penetration rate.

* Uneven sequence of cutting which results in excessive vibration. The designer of a cutting drum should aim for a pick lacing which will result as far as possible in an even force and torque output during one complete revolution of the drum. The pick lacing should result in minimum force and torque cycles for one revolution in order to minimize the vibration acting on the machine.

Table 1.2 Production figures for South African coal mines

Year	Bord and Pillar				Stooping				Longwall	Opencast
	Handgot	Mech	CM	Other	Handgot	Mech	CM	Other		
1977	60 150 079		2 489 393		2 368 548		528 162		2 307 026	15 423 534
1978	11 001 259	55 179 078			2 548 674	605 042			2 042 799	16 011 745
1979										
1980										
1981	4 124 767		13 017 380	69 591 786	1 317 175		1 644 682	1 570 737	5 632 014	44 679 643
1982	2 429 465		16 028 9[illegible]	69 916 666	783 328		1 877 389	1 370 414	6 748 625	38 792 153
1983	1 182 943		19 985 616	66 783 471	1 064 507		5 369 408	1 939 041	10 478 187	51 868 411
1984	1 3[illegible]3 785		21 254 104	76 901 534	506 522		8 269 906	1 450 620	11 028 802	63 252 535
1985	962 263		16 945 022	68 081 294	727 663		10 427 488	1 823 298	12 805 004	59 669 354
1986	1 009 294		16 878 644	65 977 568	407 334		10 887 619	2 047 189	13 340 155	61 328 947

* Coal core generation due to a wide pick spacing between the drum sections. The existing pick lacing used by various continuous miners manufacturers leaves about 130 mm space between the adjacent picks in two drum sections (see Figure 5.15). This results in a build up of coal core which often is not broken by the coal breaker located between the drum sections. This coal core generates much of the vibrations on the cutting machine.

* Small product size which contributes to an increased generation of airborne coal dust and fines production. The overlaced drum which has a poor penetration rate, tends to produce small coal pieces.

1.4 Economical Forecast

The computer simulation and cutting analysis detailed in this thesis can be applied to continuous miners, longwall shearers or any coal cutting machine which cuts with a rotating drum. Assuming that using the recommended pick lacing obtained by this computer simulation will result in 10 per cent increased production of the abovementioned machinery, a significant reduction in cost should result. The present price obtained overseas for South African coal is about U.S. $30 per ton. This means that extra annual income of 123 million U.S. $ could be gained by the coal industry (using the 1986 production figures). No additional investment is required in order to achieve this goal and all indications show that the total benefit could be even greater.

1.5 Potential Benefits

As far as can be determined from the literature, concerning the coal mining industry, computer programs for simulating continuous miner drums have been written previously. However this work is not readily available as no report was written. Therefore there is a need for such research work in order to convert such a program to a working tool for drum design.

The potential benefits which will result from the use of such an assessment are:

1. a faster mining rate of advance

2. reduced operating costs (ie. less pick replacements)

3. extension of the life of the machine due to less vibration during a cutting cycle

4. improved sa[illegible] and health by reducing the amount of respirable coal dust i[illegible]ine atmosphere

5. larger product size.

In the thesis, reference will be made to previous research work done by the Coal Mining Laboratory (CML) of the Chamber of Mines of South Africa and other studies. For example, the cutting profile of a single pick, the relationship between depth of cut and cutting forces and the optimum ratio of depth of cut to pick spacing.

These studies which form the basic rules of the theory of coal cutting are detailed in Section 2.

In order to validate the output of CUTSIM, a number of tests have been carried out at various coal mines together with manual calculations of a 'simple' cutting drum. Details of these tests and other means of validation are presented in sections 6.1, 6.2 and 6.3. The output of CUTSIM has been compared with the forces analyses of the Lee Norse continuous miner[4]. This comparison is detailed in Section 6.2.

CUTSIM is written for the HP 9816 computer with 1 MB RAM and it requires a printer and an Hewlett Packard plotter. This program could also run on HP Bob Cat (HP 300) computer requiring minor changes.

CHAPTER 2 COAL CUTTING THEORY

Study of the action of a single pick cutting coal and the interaction of an array of picks provide the understanding necessary for the efficient design of mining machines.

2.1 The Cutting Process

The amount of energy consumed by a rockbreaking system for excavating a unit volume or mass of rock is called the specific energy (E) and is often quoted as a measure of its efficiency. It has been used to both compare various systems, and also to measure improvements to, or inefficiencies of a given system. A comparison of various methods for rockbreaking systems is reported by Hood, 1985[5]. It is based on the size of the fragments produced by each method and the energy used to break the rock into fragments. The results are shown in Figure 2.1.

The force acting on the top of a pick while cutting is approximated to a single force acting on the tip of the pick. This force can be resolved into three components at 90° to each other to facilitate coal cutting studies. (Figure 2.2).

Unlike cutting metal, which is generally a plastic type of failure, the cutting of coal is invariably performed by inducing a brittle type of failure. This is the only way that most rocks can fail within the commercially viable range of cutting speeds.

This brittle failure of the rock leads to a characteristic cyclic rise and fall in forces with the forward motion of the pick. The increase in cutting forces to a peak is seen to coincide with the formation of a large chip and after such event has occurred forces fall to a low value. (Figure 2.3). The forces will tend to rise again with further forward motion. This cyclic nature of pick force during cutting has been explained by Evans and Pomeroy, 1966[5] and Roxborough and Phillips, 1981[7] amongst others.
As the pick applies the force required to form a large chip, the rock touching the pick is stressed above its failure strength in a triaxially confined manner and it crushes.

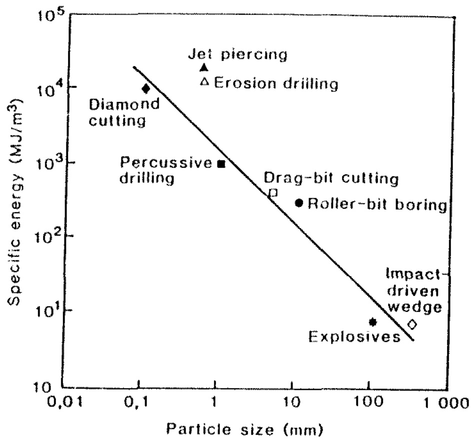


Figure 2.1 The required specific energy for different methods of rock breaking

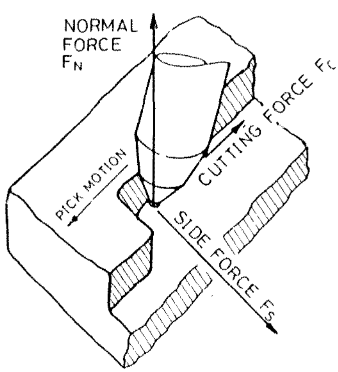


Figure 2.2 Components of active force while cutting mineral

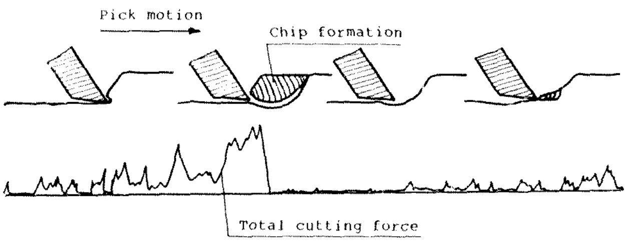


Figure 2.3 Typical cutting forces diagram when cutting coal

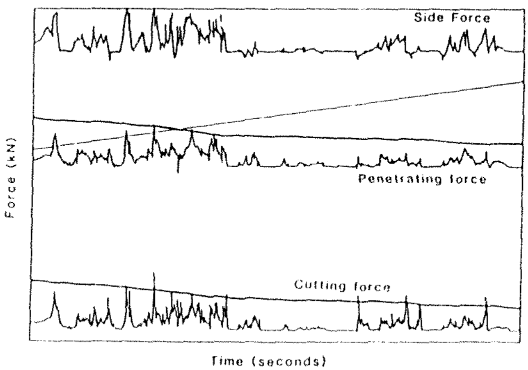


Figure 2.4 Typical analogue traces of tool forces versus distance cut in coal

A typical analogue trace of cutting forces developed by a pick cuttin rock is shown in Figure 2.4 (after Phillips et al. 1983[(. The characteristics shape of the force/time traces will vary with the shape and rigidity of the pick, the rock being cut and the position of the pick in relation to the rock. Pick cutting speed relative to the rock might have an effect on the sequence and magnitude of chipping and crushing events during cutting, but will probably not be great and can be ignored.

The large chip produced in front of a pick is highly desirable as it indicates an efficient cutting process. However, what is more typical of the cutting process is illustrated by a series of photographs taken of the side view of a tool while cutting rock by Goodrich, 1956[(9)] Two interesting observations emerge from this, the first being that large chips constitute about one half of the total volume of rock cut as shown in Figure 2.5. The other half is shown to be particles removed as fines or dust. The second is that the point of contact between the front or rake face of the pick and the rock surface occurs predominantly very low down the pick face. Goodrich findings comply very closely with those of Tutluoglu 1983[(10)].

2.2 Pick Condition and Geometry

The condition of the pick influences the generation of forces during cutting. If the pick is blunt or of an inefficient design, the forces will tend to be higher at all stages of the chip forming process.

The first workable model of the relationships between pick geometry (Figure 2.6) and forces generated during cutting was developed by Evans 1966[(11)].

The main relationships illustrated in Figure 2.7 were found to hold for all coals (with different magnitudes) and the more important of the fifteen or so attendant principles (Evans and Pomeroy 1966)[(6)] are outlined.

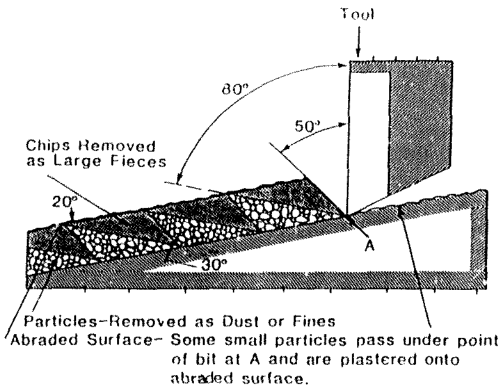


Figure 2.5 Sieve analysis results showing cumulative weight per cent as a function of rock particle size

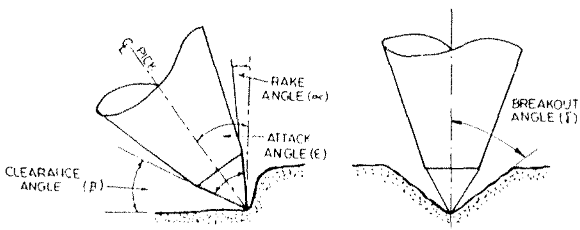


Figure 2.6 Geometry of a pick while cutting mineral

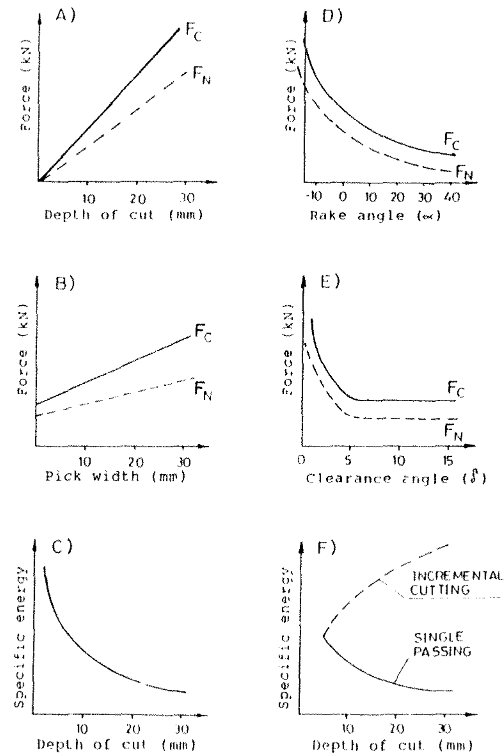


Figure 2.7 The basic relationship for cutting coal with pick

1. All studies and cutting tests show that the total cutting force required to cut coal and its components namely the cutting force Fc, the normal force Fn and the side force Fs increase linearly with the depth of cut. See Figures 2.2 and 2.7A.

2. Picks which approximate the shape of a simple chisel are more efficient than complex shapes. The pencil-point shape is the least efficient. Although it attracts less force than a chisel it also produces less coal and generates more dust.
Due to its geometry this pick is fairly weak and is more vulnareble to rapid wear and failure. THis is still applicable to the more modern picks which have a tungsten carbide insert. A pick with a chisel (or point attack as it is called by various manufacturers) insert which usually have a cutting edge angle of 60° were found to be the more efficient for gouging and crushing action.

3. Large picks are more efficient than small ones. The front rake angle (α in Figure 2.6 and Figure 2.7D) should be made as large as possible but probably no greater than 20°. The back clearance angle (β in Figure 2.6) should be not less than 5° and not more than 10° (see also Figure 2.7E).

4. Specific energy reduces for all shapes of pick as the depth of cut is increased. Shallow cuts are very inefficient (Figure 2.7C).

5. *When cutting deeper the picks in an array can and should be* placed further apart. For maximum cutting efficiency the spacing between picks should be about three times of the intended depth of cut (see Figure 2.8B). As grooves are deepened, breakout angle (δ in Figure 2.6) is inhibited and adjacent picks are prevented from interacting. See also Section 2.3.

6. Typical force and yield curves for pick width are shown in Figure 2.7B. Both are found to intercept on the ordinate. Being at zero pick width, these are the force and yield values wholly attributable to the production of side splay or breakout. The specific energy tends however to remain unaffected with the pick width.

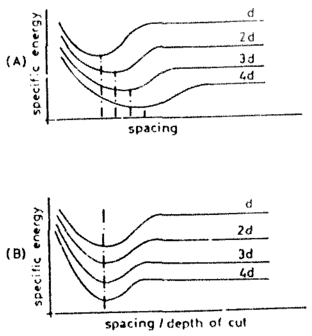


Figure 2.8 Hypothetical relationship between pick spacing and specific energy

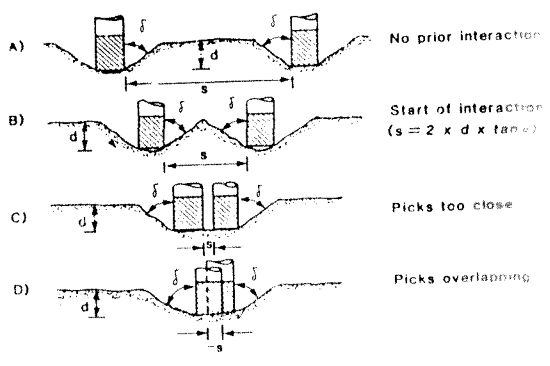


Figure 2.9 Interaction of cutter picks in array

7. Cutting in a corner involves high pick forces and energy. Wherever possible, therefore, an array of picks should provide a cutting sequence that starts with the first pick taking advantage of any available free face and with successive picks progressively extending the free face towards the corner of the excavation. In this way the cutting sequence terminates at the corner. It should never start there. Experiments undertaken by Pomeroy and Brown 1968[12] in coal made use of complex geometry. Their findings show that forces in the corner are two to three times greater than those for the free surface and that corresponding specific energies can be four to five times larger in the corner.

Figure 2.10 illustrates two corner cutting situations using point attack picks. Pomeroy and Brown 1968[12] also show that the cutting forces generated by a skew pick tend to rise with the angle of skewing. For example for a 10 mm wide chisel pick cutting with a rake angle of 10 degrees and at a depth of 3 mm in a sandstone block, the force involved in cutting a corner is about twice that required on a free surface. Also the amount of material cut per pick in a corner reduced and, as a consequence of this and the higher cutting force, the specific energy for cutting in the corner can be as much as three times higher than that for the free surface.

8. Incremental cutting i.e. cutting gradually with relatively shallow cuts till reaching a given depth of cut is very energy consuming. As the groove deepening case, there is no free coal face and this contributes to high cutting forces. (Figure 2.7F).

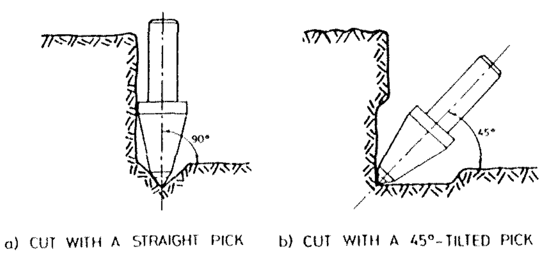


Figure 2.10 Corner cutting pick situations

9. The application of high pressure (about 220 MPa) water jets to pre-slot a block of coal prior to cutting with picks can reduce the pick forces significantly. Second method of water jet assisted cutting is by directing a medium pressure (about 35 MPa) water jet at the coal face just in front of the pick. The effectiveness of a water jet at the pick face in reducing pick force diminishes rapidly with increasing cutting speed. Research work was performed at COMRO by Wojno et al.[13] in 1983 to quantify the reduction in pick forces due to water jet assistance when cutting a typical South African coal. Wojno found that reductions in pick forces of up to 60 per cent resulted from directing a 20 MPa water jet at the pick coal interface during laboratory coal cutting experiments. Due to technical limitations, his work was done at a cutting speed of 152 mm/s in comparison to the cutting speed of 2 500 mm/s used commercially. Figure 2.11 shows the reduction in pick forces when using the jet-at-pick-face (35 MPa) for various cutting speeds and for unassisted coal cutting as found by McVey 1987[14].

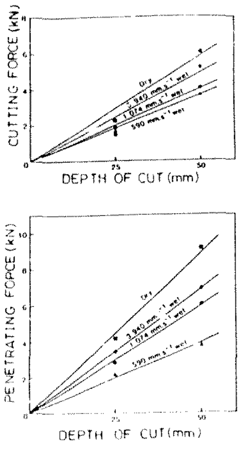


Figure 2.11 Pick force against DOC at various cutting speeds with jet-at-pick-face assistance

2.3 Interaction of Cutter Picks in Array

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 Figure 2.9 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 specific energy will continue to fall but not indefinitely so. Indeed, as the spacing tends to zero, the depth 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. The effect of spacing on specific energy therefore, as shown in Figure 2.8A, indicates a value of spacing at which the specific energy can be expended to be minimized. In fact a group 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 depth of cut, also, that a wider pick spacing is appropriate when the depth of cut is larger.

If, as indicated in Figure 2.9B, the interaction starts when adjacent grooves just touch (i.e. $s = 2d.\tan\delta$), the geometrical similarity implicit in the family of curves in Figure 2.8A 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 $2 \tan\delta$, 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.

Figure 2.8B 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.

2.4 Various Mathematical Models of Rock Cutting

The study of the forces produces when cutting rock has led to the determination of the relationships of pick geometry and pick acting forces. Evans 1966[6] developed the first workable model which encompassed the effects on cutting forces of front rake angle, pick width, tensile strength of the material being cut and the depth of cut performed. Evans assumed that the type of failure is tensile in character and his model proved to be applicable to other rock materials.

The mode of the chip formation was not accepted universally as a tensile fracture and this lead to Ernst-Merchant[15] 1945 model of rock failure which claims that the chip is formed by shear failure. The original model was developed for metal cutting and was modified by Potts and Shuttleworth 1959[16] to describe a discontinuous cutting process of shear failure.

Nishimatsu 1972[17] proposed an alternative shear model for rock cutting in which no assumption was made of independence between the shear strength of the rock and compressive stress acting normal to shear plane. This results in higher cutting force production for a given depth of cut in comparison to Evans model[6]. Roxborough 1973[18] made important modifications to Evans' model by adding terms defining the shape of the pick being used, thus extending the practical use of the cutting model in calculating pick forces when cutting coal.

All models mentioned above agree about the following:

* Cutting forces increases linearly with depth of cut (Figure 2.7A).

* Cutting force increases linearly with rock strength.

* Cutting force increases linearly with pick width (Figure 2.7B).

* Cutting force reduces as rake angle increases (Figure 2.7D).

CHAPTER 3 DEFINITION OF PICK CUTTING PROFILE FOR CUTSIM APPLICATION

The cutting profile of a single pick is the shape of the groove cut by the pick on a specific mineral. The cutting profile is affected by the type of pick and by the type of mineral cut.

Each pick may have its own cutting profile. By specifying a set of conditions for a relevant pick, a wide range of cutting profiles can be obtained. For example, the cutting profile of a straight conical pick (90° to the coal face) will be obtained from the coordinates of points A-O-B (Figure 3.1). The breakout profile of a 30° skewed pick is shown in Figure 3.2.

CUTSIM enables the user to define any deliberate breakout profile of the pick. For example the breakout profile of a straight pick could be defined as shown in Figure 3.3 or as in Figure 3.4.

The correct breakout profile for any particular mineral should be determined from laboratory tests.

It is possible that the most suitable breakout profile is typical of the type of pick used in conjunction with the type of mineral cut. Various types of picks may have their individual breakout profile for cutting the same mineral.

The breakout profile shown in Figure 3.1 was found to be the most simple and reliable for simulation purposes, and all cutting analyses detailed in this report were carried out by applying this breakout profile.

3.1 Numerical Model

In order to simulate successfully the cutting process, two significant parameters were established. These parameters will demonstrate the effect of most cutting situations under actual operating conditions, and effectively replace most of the variables involved.

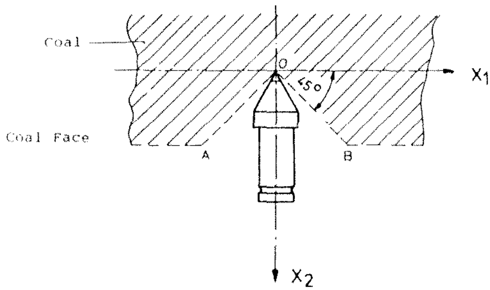


Figure 3.1 *Coal cutting profile with a straight pick*

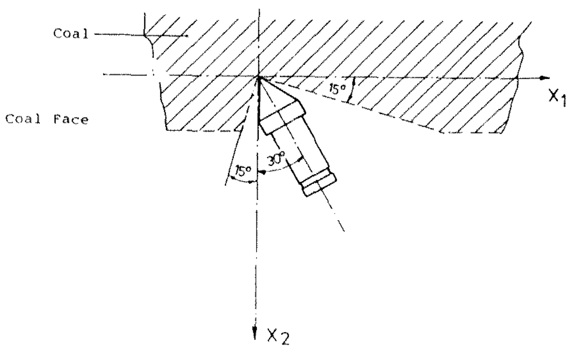


Figure 3.2 Coal cutting profile with a 30 degree skewed pick

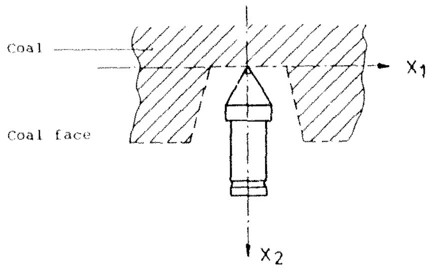


Figure 3.3 Coal cutting profile

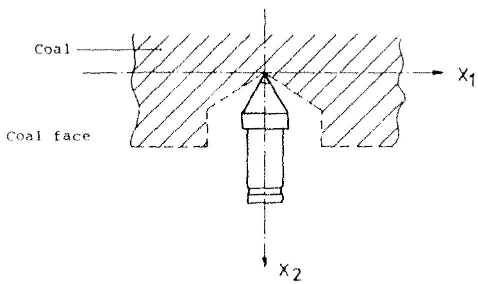


Figure 3.4 Coal cutting profile

3.1.1 Cutting Parameters

For each pick of the pick array on the cutting drum, two cutting parameters, namely P1 and P2, should be defined.

P1 indicates the relationship between the cutting force (Fc) and the normal force (Fn) and is independent of depth of cut (DOC).

P2 is the total force (Ft) in kN required to cut 1 mm DOC in the mineral.

Parameter P2 gives a good indication of the hardness of the mineral. Both parameters depend on the pick attack angle and for a skewed pick, P2 will be higher than for a straight pick.

These parameters are obtained from a number of cutting tests for a single pick in the laboratory, using a linear cutting machine. (See Appendix A for the description of coal sample for cutting tests.)

The laboratory cutting tests are made with a constant pick spacing to depth of cut ratio. By cutting at least twice (for statistical reasons) at various depths of cut, plots of three active forces are obtained. Figure 2.2 shows these three components of the active force on the pick while cutting the mineral. Appendix B details the equipment and technique used for recording the force components.

Plots obtained from the cutting tests (see Figure 2.4), detailed the Normal force - Fn, Cutting force - Fc and the Side force - Fs required to cut the specific mineral for various depths of cut. Appendix D details the cutting test results for various combinations of the relevant variables. These analogue traces of pick forces are converted into the linear components as shown in Figure 3.5. Note that the side force (Fs) is usually negligible in comparison to the other active forces and often is not considered.

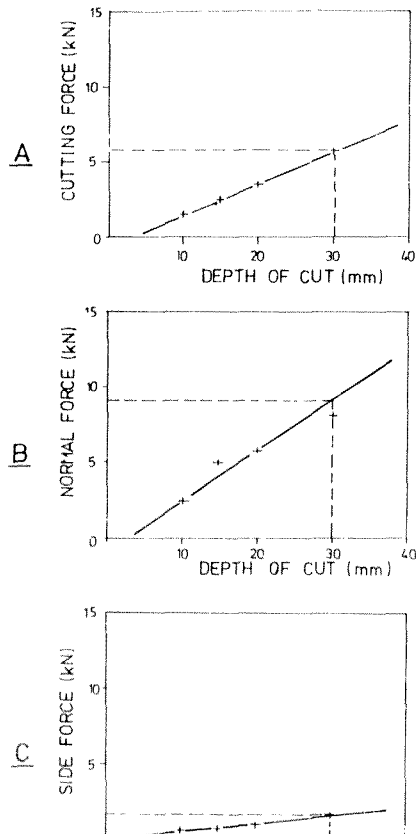


Figure 3.5 Three components of the total cutting force

Figure 3.6 is a vector diagram which shows the resultant force Ft of the three components previously mentioned, for a selected value of DOC.

$$Ft = (Fc^2+Fn^2+Fs^2)^{1/2} \quad (1)$$

The parameter P1 is given by

$$P1 = \frac{Fc}{F_n} \quad (2)$$

and the parameter P2 is given by

$$P2 = \frac{Ft}{DOC} \quad (3)$$

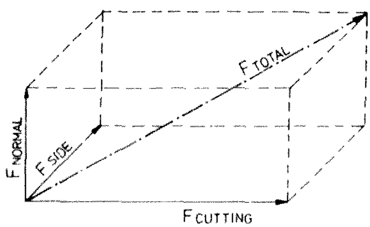


Figure 3.6 Direction of the three components of the total cutting force

Section 5 on the application of the computer model shows how the parameters P1 and P2 play a major role in the flexible use of CUTSIM for most simulating conditions.

3.1.2 *Cutting forces*

For each pick on a cutting drum, CUTSIM assumes a sinusoidal profile of the depth of cut versus the pick angle of contact.

This assumption is valid only for rotational cutting. This means that at 90° arc of contact, the pick reaches its maximum depth of cut. (See Figure 3.7).

For any angle of contact θ

$$DOC(\theta) = Sin\theta.(max\ DOC) \qquad (4)$$

From previous studies it is known that the total cutting force acting on the pick is directly proportional to the depth of cut, as shown in Figure 3.8.

If K is the gradient of the function.

$$Ft(\theta)=K \cdot DOC(\theta) \qquad (5)$$

$$Ft(\theta)=K \cdot Sin\theta \cdot (max\ DOC) \qquad (6)$$

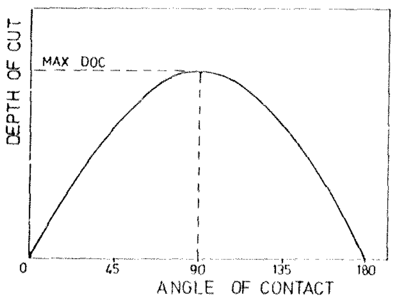


Figure 3.7 The depth of cut as a variable of the angle of contact

Figure 3.9 shows the resolution of the total cutting force into two different sets of components for both the sumping and the shearing modes of a continuous miner. In the sumping mode, the cutting drum of the continuous miner moves horizontally until it reaches a contact arc angle of 180°.

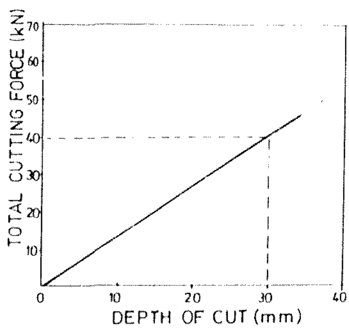


Figure 3.8 The total cutting force as a linear force

After completing the sumping operation, the cutting drum performs the shearing operation in which it moves vertically to the floor level while cutting with an arc of contact of approximately 90°.

During the shearing mode the following forces act on each pick:

(i) F vertical = $Ft(\theta) * Sin(\theta+\beta)$ (7)

(ii) F horizontal = $Ft(\theta) * Cos(\theta+\beta)$ (8)

(iii) Torque = F cutting * r = $Ft(\theta) * Sin\beta * r$ (9)

r - the cutting radius of the pick tip

Integration of these components on all picks placed on the drum for all possible angles of contact will give the total vertical forces, horizontal forces and torque acting on the drum for one complete cycle.

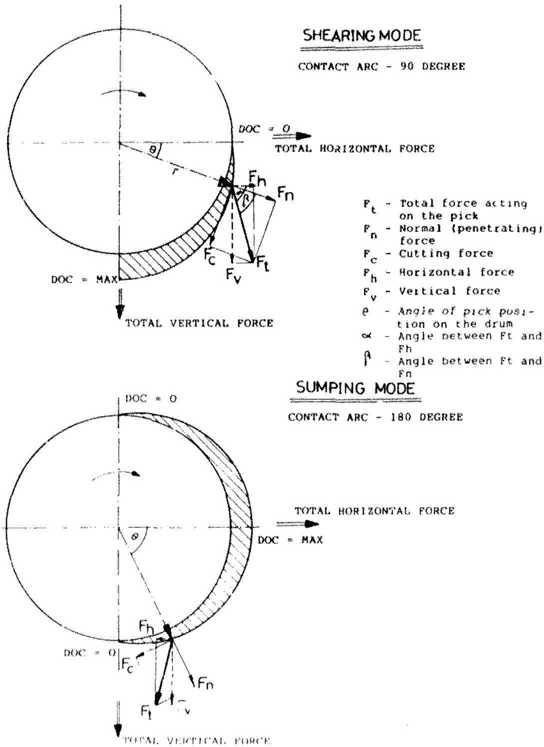


Figure 3.9 Resolution of total cutting force into two different sets of components

For a cutting drum with n picks

$$F\ total\ vertical = \sum_{i=1}^{i=n} (F\ vertical)_i \quad (10)$$

$$F\ total\ horizontal = \sum_{i=n}^{i=n} (F\ horitonzal)_i \quad (11)$$

$$Torque\ total = \sum_{i=1}^{i=n} (Torque)_i \quad (12)$$

The gradient K is determined by linear cutting tests. See Figure 3.8.

From equation (3) $K = \frac{Ft(\theta)}{DOC(\theta)}$

This means that the factor K is identical to the parameter P2

Hence K or P2 indicates the total force in kN required to cut at a depth of 1 mm in the mineral. This parameter is a good indication of the coal hardness. Note that K is obtained by cutting the mineral with a straight pick.

The angle β between Ft and Fn is also closely related to parameter P1.

From equation (2) P1 = Fc/Fn

$$\tan \beta = Fc/Fn \text{ (See Figure 14)} \quad (13)$$

Hence: $P1 = \tan \beta$

$$\beta = \tan^{-1} P1 \quad (14)$$

The total torque of all picks indicates the required torque of the cutting machine in order to cut the relevant mineral with the specified number of picks at that specific depth of cut.

The total torque of the machine specified by the manufacturer should always exceed the maximum total torque calculated by CUTSIM.

The three calculations of horizontal force, vertical force and torque depend on the arc of contact of the drum. The smaller the arc, the fewer the number of picks cutting simultaneously.

The total thrust of the continuous miner divided by the number of picks in the coal face gives the thrust per pick. For an overlaced drum, the thrust per pick is low, due to the large number of picks. Therefore, a reduction in the number of picks laced on the drum will increase the thrust per pick and facilitate a better pick penetration.

CHAPTER 4 COMPUTER MODEL

In order to simulate the cutting process of a rotating drum with relative ease and enable numerical forces and torque analysis to follow, a computer program was written.

4.1 Advantages of a Simulated Numerical Model

It is extremely difficult to optimize drum design under normal operating conditions because:

* adverse environmental conditions limit the use of sophisticated instrumentation and data acquisition systems

* the nature of the cutting operation is complex so that a large number of picks can be generating both static and dynamic effects on a continuous miner

* production demands limit the availability of the machine for test purposes.

An alternative method of optimizing the design of a continuous miner is through the use of a modelling technique. Very good results can be obtained using a numerical model validated against experimental data obtained in the laboratory. Apart from making an analysis possible, a carefully designed numerical model offers the following advantages:

* Reduction of the variables. The engineer can reduce the number of variables dramatically by a sensible definition of a physical situation. It is often found that a large portion of the variables have only a secondary effect on results. By placing restrictions on the model, these secondary parameters can be eliminated. A typical example is sideways or axial movement of the continuous miner. By ensuring that the conditions under which the model is used are within the restrictions, accurate results can be obtained.

* Economical analysis. Valid results can be obtained by using a computer program and experimental laboratory data, resulting in a significantly lower cost in comparison to the field tests using expensive equipment. It is however very important that results obtained from the model be correlated with some form of experimental data from time to time.

* Larger scope. The time required to analyse a particular situation is much less than that required for an experimental program. The net effect of this is that results are obtained faster and a much larger scope of the effects and situations can be studied.

* Independent variables. It is often much easier to vary only a single parameter in a numerical model. This will enable the engineer to make a detailed study of the effect of various elements of the model.

4.2 Description of the Model Used

A numerical model is determined by two factors:

* the physical situation to be analysed

* the experimental data available for a particular simulation

The objective is to find the best possible model for the situation to be analysed, subject to the limitation of the experimental data.

In order to simulate a cutting situation, the following data is required:

* the specific cutting profile of each type of pick

* the lacing pattern of the picks on the drum

* the mineral cutting parameters (P1 and P2)

* the cutting conditions (see Section 5.3) of the continuous miner.

The following assumptions were made in order to make the cutting simulation possible:

* the condition of the pick remains the same throughout the cutting analysis

* the mineral properties are homogeneous in all directions

* the cutting drum is always parallel to the coal face and to the floor

* the movement of the cutting drum while shearing down is vertical only

4.3 Drum Layout

The cylindrical nature of the continuous miner drum resulted in the selection of a right handed cylindrical coordinate system. This system was selected for the handling of the drum data as shown in Figure 4.1.

A right handed orthogonal cartesian co-ordinate system was selected to be used as the global frame of reference for the system.

This system is used to specify the following:

* the mineral properties in 'blocks' or 'layers' within space

* the actual drum position in relation to the mineral

* the rotational velocity of the drum

* certain control parameters (ie. displacement of the drum during the period in which the analysis is made).

The origin of the cylindrical coordinate system is positioned in the global frame and it is assumed that the Z axis is parallel to the global X2 axis.

The position of each pick on the cutting drum is specified by its own cylindrical co-ordinate system positioned on the drum. For example the location of pick A in Figure 4.1 is determined by the parameters: radius - r, angle - θ (measured from the vertical line OB) and distance Z along the drum.

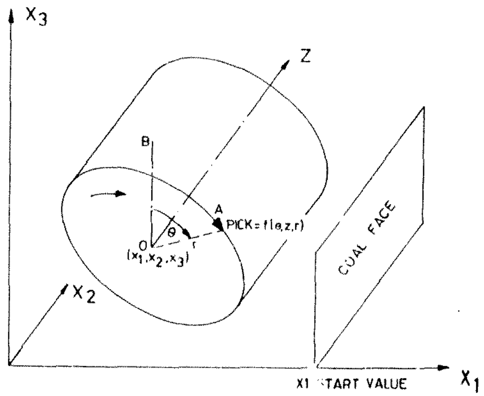


Figure 4.1 The cylindrical system of the drum and the global frame system

4.4 Mineral Properties

The mineral properties are specified in the global co-ordinate system. Blocks of mineral are specified (zones on all three axes), each with unique parameters that can influence the cutting mechanism (see Figure 4.2).

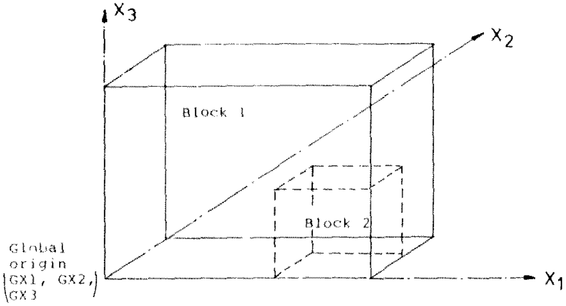


Figure 4.2 Block of mineral in a global co-ordinated system

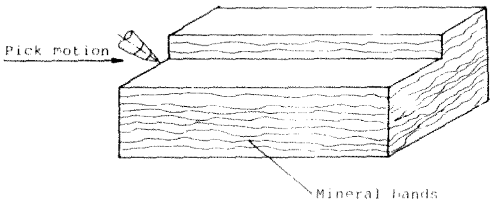


Figure 4.3 Direction of cutting in mineral with a large number of bands

CUTSIM uses the parameters P1 and P2 instead of an internationally agreed standard measure of mineral hardness such as Brinell or Vickers. This results in a more flexible use of CUTSIM and eliminates the use of expensive measuring instruments for defining the mineral hardness.

CUTSIM assumes that the mineral properties are homogeneous, that is, identical in all directions. However, in order to obtain precise and unified characteristics of the mineral, the cutting tests for deriving the parameters P1 and P2 should be performed in a standard way, ie. for minerals which comprise large numbers of bands (ie. coal), the cutting test should be made along and on the surface of the bands as shown in Figure 4.3.

CHAPTER 5 APPLICATION OF THE COMPUTER MODEL

This section includes data and instructions which are required to run CUTSIM for specific applications. However, in order to demonstrate the flexible use of CUTSIM and the way various cutting situations should be simulated, this information is included.

5.1 Numerical Simulation of Various Mining Conditions

CUTSIM simulates all cutting conditions irrespective of mineral hardness or pick bluntness. The parameters P1 and P2 represent the complete cutting configuration and can change with any of the following conditions:

* degree of sharpness (bluntness) of the pick (or pick mass loss). (See Appendix D)

* mineral type

* pick shape

* water jet assisted cutting

* skew angle of the pick (See Figure 5.1)

* pick spacing

The effect that the above factors have on the values of parameters P1 and P2 is illustrated in Tables E1 to E5 with further explanations provided in Appendix E.

From Appendix E it is shown that for the most coal cutting conditions, the parameter P1 is the range of 0,5 to 6,8. The parameter P2 can vary in the range of 0,07 to 1,22 kN/mm for most cutting conditions.

Figure 5.1 shows the definitions of the pick skew angle and attack angle.

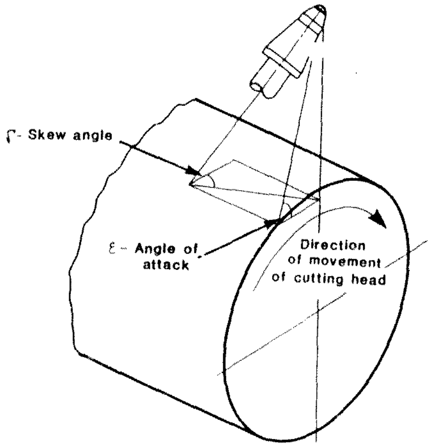


Figure 5.1 Definitions of the pick skew angle and angle of attack

5.2 Pick Lacing of the Drum

Figure 5.2 shows a typical lacing layout of a continuous miner drum. The line of θ=0 indicates that the picks adjacent to this line will cut the mineral first (picks 1,33 and 40) followed by the adjacent picks (picks 10 and 48) and so on. The picks with maximum θ angle will cut last followed by the second revolution of the drum. Each number on the drum layout indicates the location of a single pick.

For convenience, the relevant data of the pick geometry is best prepared in the form of a table as shown in Table 5.1. This data is entered into CUTSIM and results in the drum layout of Figure 5.2.

Table 5.1 Tabulation of pick patterns

Pick Group	Pick Detail	No. of Picks	Pick Code	Skew Angle	Cutting Radius	θ min	θ max	Z min	Z max
1	pick A	1	AO	0	559	0	0	429	429
2	pick B	2	-10	-10	559	36	216	353	353
3	pick C	2	-30	-30	549	72	252	353	353
4	pick D	2	-45	-45	445	108	288	318	318
5	pick E	2	-45	-45	521	144	324	318	318
10	13-18	6	AO	0	559	15	165	505	885
47	7-10	4	AO	0	559	195	285	2982	2754

For simplicity this table details only some of the picks used in the drum layout shown in Figure 5.2.

Note that each pick group (minimum two) has a definite geometrical order and can be entered as one pick group in the above table. For example the picks in group No. 47 (Figure 5.2) have the same spacing along the Theta axis and the same spacing in the Z axis-hence they share one entry in Table 5.1.

From the above Table it is seen that pick groups 2, 3, 4 and 5 have different skew angles, and usually the cutting radius of these picks is also different.

The values of Theta minimum and Z minimum of a group of picks should match respectively. This means that Theta minimum is related to z minimum and vice versa. If they do not, the pick group may have an incorrect geometrical orientation.

The pick code is the name given to a specific group of picks in the pick file and is used for documentation only. All the geometrical data of the pick patterns should be entered on the drum file. (See Appendix K).

5.3 Cutting Conditions

Once the cutting profile for each pick with and the parameters P1 and P2 have been defined, the full lacing pattern should be entered

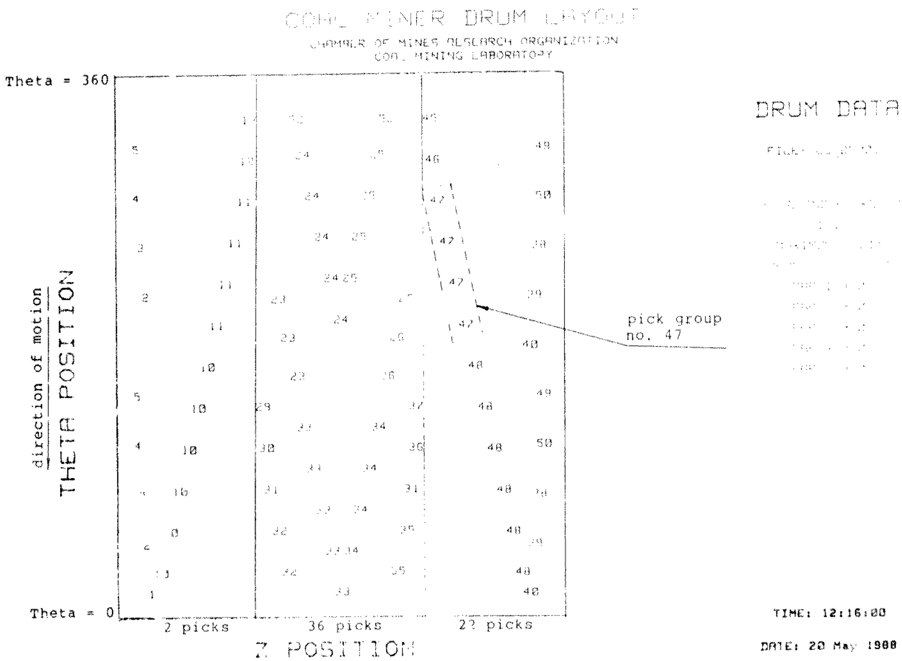


Figure 5.2 Pick lacing on solid drum : Joy 14CM 9

on the data disk of CUTSIM. An analysis of the breakout profile resulting from the lacing pattern of the cutting head can then be obtained (see Figure 5.3). The analysis requires a set of input data to define the cutting conditions. (See Table 5.2).

Only relevant data should be entered. Normally, many entries will be left as zero, because provision has been made in the program for the future inclusion of various types of machinery.

Table 5.2 Cutting condition for analysis

Cutting Conditions	
X1 Drum velocity [m/s]	: ,03
X3 Drum velocity [m/s]	: 0,00
Drum rotation [rpm]	:60
Time increment [s]	:10,000
Drum Z increment [mm]	:10
Drum X1 start value [mm]	: -250
Drum X2 start value [mm]	: 0
Drum X3 start value [mm]	: 0
Maximum analysis time [s]	: 10
Maximum analysis theta [0]	: 0
Maximum analysis X1 [mm]	: 0
Maximum analysis X2 [mm]	: 0
Z range minimum [mm]	: -200
Z range maximum [mm]	: 1500

X1 drum velocity [m/s] - The forward drum velocity in m/s. (See Figure 4.1). This is equivalent to the forward velocity of the continuous miner or the linear velocity of the longwall shearer.

X3 drum velocity [m/s] - The vertical drum velocity in m/s. (See Figure 4.1). Used only when simulating vertical cutting of continuous miner, shear mode or complex mining in vertical and horizontal axes simultaneously.

Drum rotation - The number of drum revolutions per minute (see Figure 4.1).

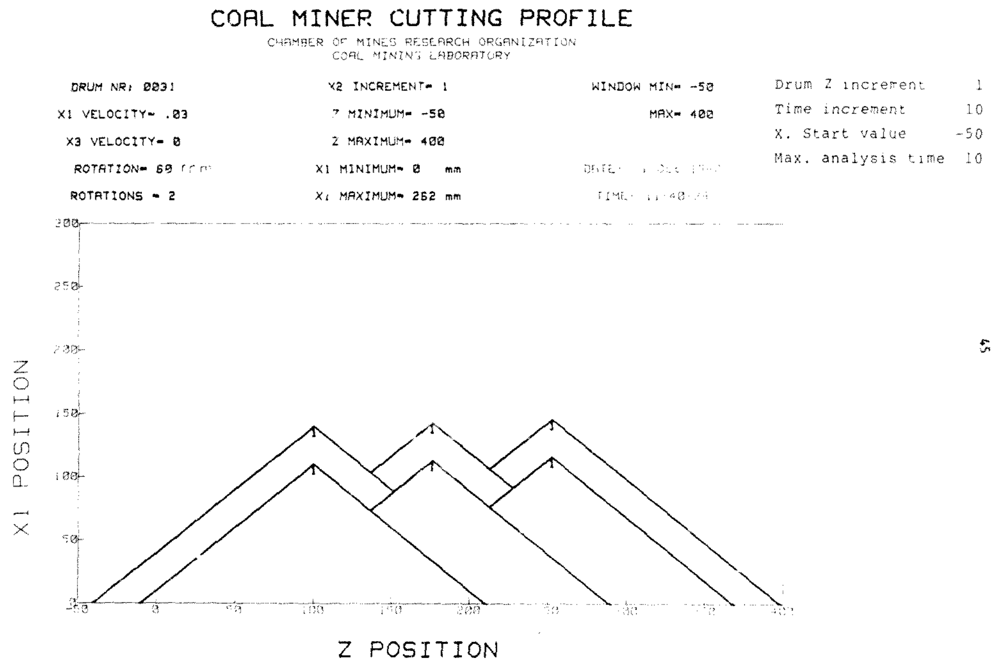


Figure 5.3 The breakout profile obtained by using Z increment = 1

Time increment - [illegible] time interval in CUTSIM is used as an alternati[illegible] [illegible]r to theta (the angle of contact - see Figure 3.[illegible] [illegible]ing the drum rotational velocity and the drum [illegible]try, the time increment indicates the location of each pick at any moment. In the data entry for the cutting conditions, the time increment and the maximum analysis time can be different. However, for the regular use of CUTSIM, enter these two parameters as 10 seconds.

Drum Z increment - This indicates the axial resolution to be used in mm.

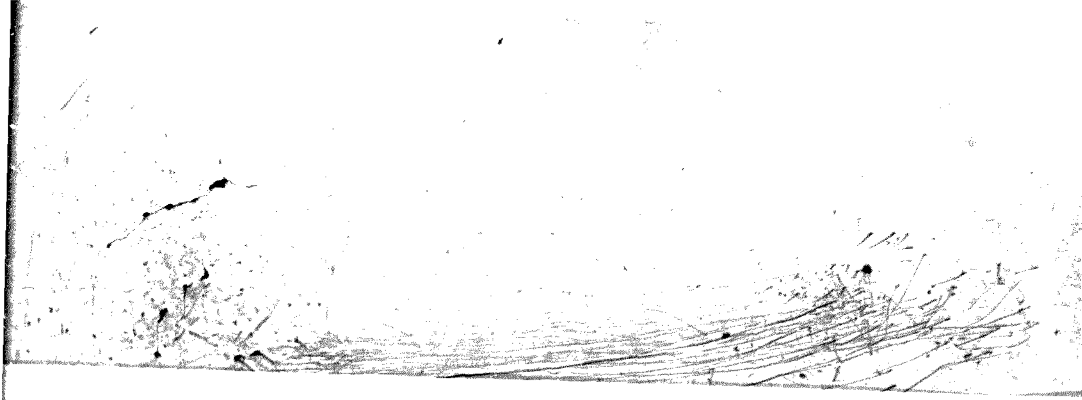
The minimum required value is 1 mm. For regular use of CUTSIM, enter Drum Z increment as 10 mm. The greater the Z increment, the less accurate will be the breakout profile but the program will run considerably faster.
Figures 5.3 - 5.5 show the effect of various drum Z increments. The breakout profile in Figure 5.3 is calculated for 1 mm resolution. Hence the profile is unified and very accurate. Figures 5.4 and 5.5 show the same breakout profile calculated for 10 mm and 30 mm axial resolution respectively, hence the obtained profile is considerably less accurate.

Drum X1 start value [mm] - This indicates the initial position of the drum in relation to the coal face. From Figure 4.1 it can be seen that this entry will always be negative in sign.

Drum X2 start value [mm] - not applicable, reserved for future use.

Drum X3 start value [mm] - not applicable, reserved for future use.

Maximum analysis time [sec] - not applicable, normally enter 10, as was explained previously when discussing the time increments.



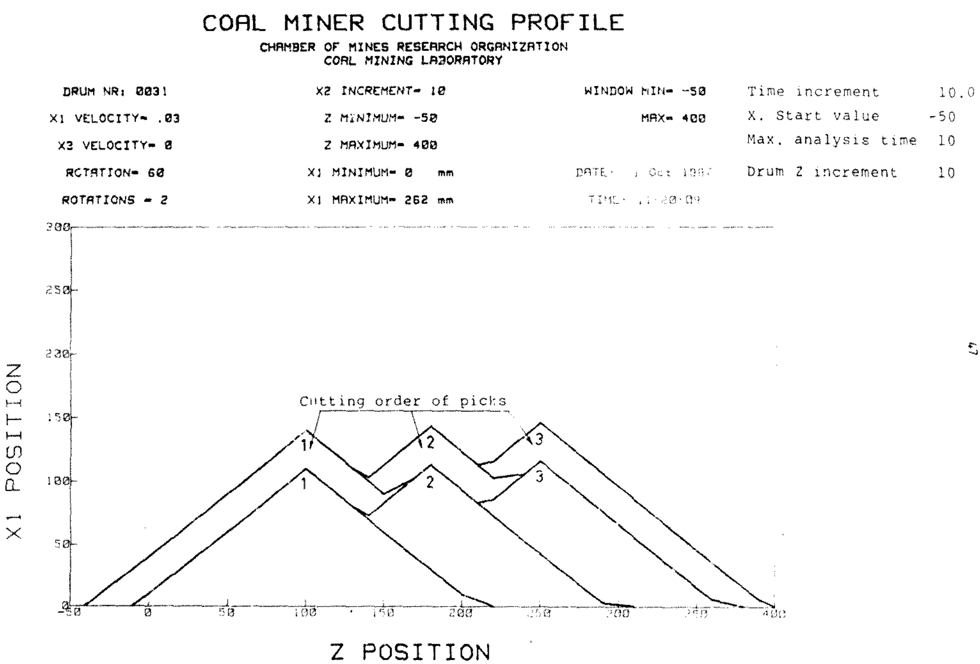


Figure 5.4 The breakout profile obtained by using Z increment = 10

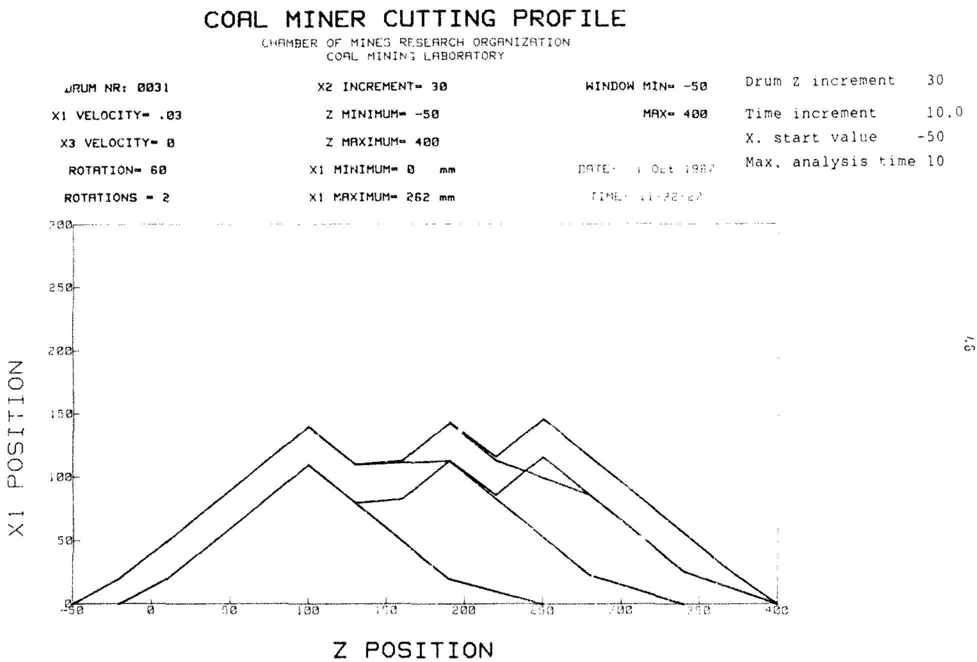


Figure 5.5 The breakout profile obtained by using Z increment = 30

Maximum analysis theta [θ] - not applicable, reserved for future use.

Maximum analysis X1 [mm] - not applicable, reserved for future use.

Maximum analysis X2 [mm] - not applicable, reserved for future use.

Z range min/max [mm] - The range to be analysed in the axial direction of the drum. Normally the minimum Z range will be less than the actual minimum Z in order to include the drum edge. It is recommended that the whole range of the drum is analysed and later, the user can zoom to the relevant part of the drum.

5.4 Cutting Profile of the Drum

Once all cutting conditions have been specified, CUTSIM is ready to analyse the breakout profile of the whole drum. See Appendix K for an activity flowchart. Table 5.3 details the additional required data input for the display of the breakout profile.

Table 5.3 The required data for the breakout profile of a drum

Cutting Profile Analysis	
Number of rotation	2
X1 drum velocity [m/s]	0,03
Plotter address	3
Window minimum [mm]	-50
Window maximum [mm]	500
Save dynamic data [Y/N]	Y
Quick plot [Y/N]	N
Plot group number [Y/N]	Y
Plot without numbers [Y/N]	N

Note that in case of contradictory data (for example 'Plot group number : Y' and 'Plot without numbers : Y'), a system error will occur.

Number of rotations: The user of CUTSIM can enter any required number of drum rotations. Normally, two are sufficient to cover all aspects. The greater the number of drum rotations, the more time needed for processing and plotting.

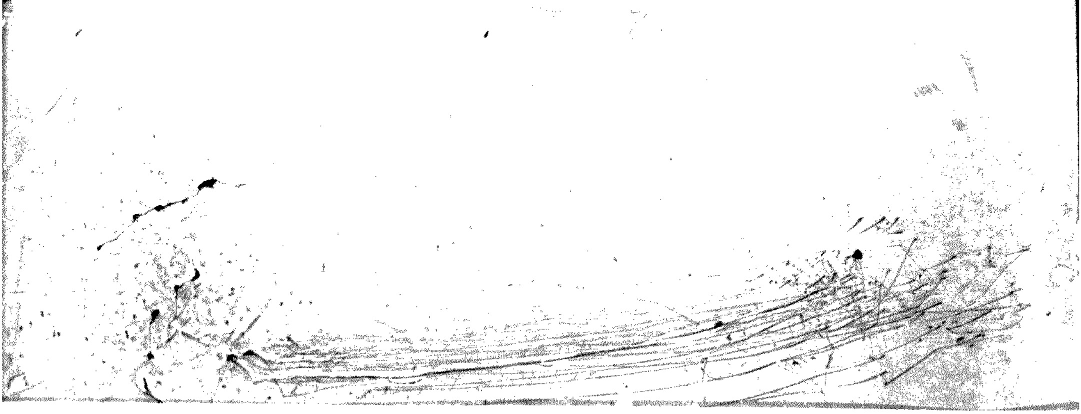
X1 drum velocity [m/s]: This is the same X1 drum velocity which was required in the cutting conditions.

Plotter address: Enter 3 for plotting on the computer screen (CRT). Enter 705 for the Hewlett Packard plotter. Alternatively press dump graphics for a hard copy from the printer after plotting on the CRT.

Window min/max.: CUTSIM enables the user to determine a breakout profile for any spectra zone of the drum. This is done by specifying the required zone by entering 'Window minimum' and 'Window maximum'. Note that without exception *'Window minimum' > z minimum and 'Window maximum' < z maximum.* A contradictory range of Window or Z will result in a system error. Figure 5.6 shows an example of zone selection for the breakout profile shown in Figure 5.5.

Save dynamic data [Y/N]: Enter 'Y' if you have made any changes in the cutting conditions since the last processing data stage. (See Appendix K for an activity flowchart). For the safe use of CUTSIM it is good practice to re-save the dynamic data file by specifying 'Y' before proceeding further.

Quick plot [Y/N]: The response 'Y', will result in the breakout profile detailed in Figure 5.7. All the descriptive data will be missing. Use this utility for a quick draft only. For the final and full plot, enter 'N'.



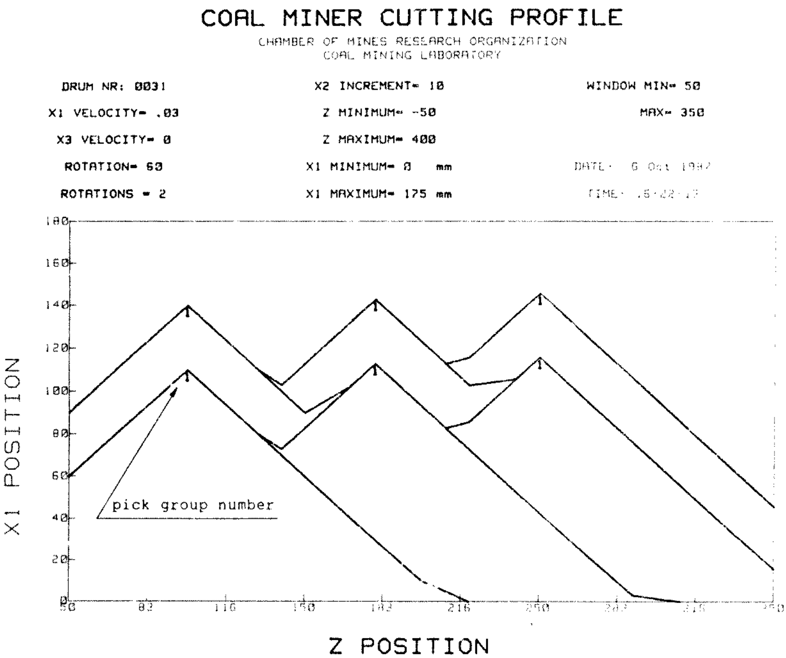
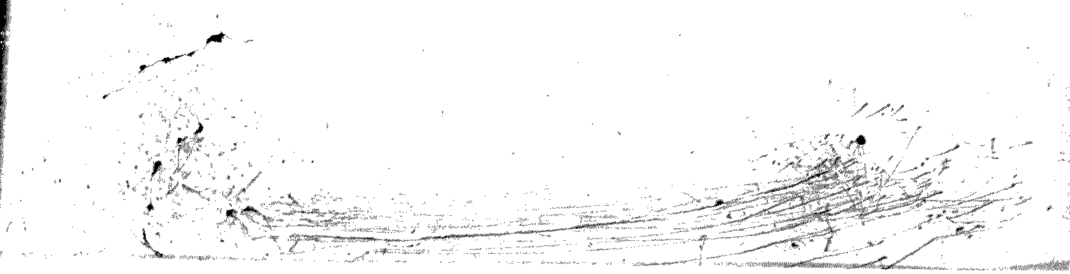


Figure 5.6 Zooming the breakout profile



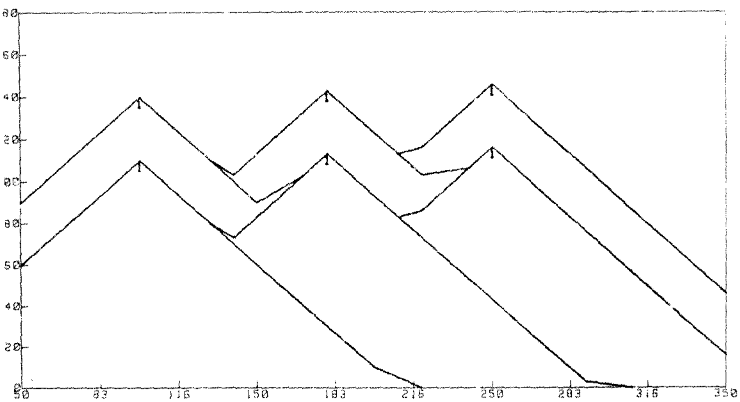


Figure 5.7 The breakout profile obtained by using 'quick plot'

Plot group number [Y/N]: The group number is as entered into the drum file (See Table 6.1). Enter 'Y' if you want to see the group number of the pick as it is shown in Figure 5.6. This will enable the user of CUTSIM to identify any certain pick on the breakout profile.

Plot without numbers [Y/N]: Enter 'Y' if you want the breakout profile plotted without any numbers (pick group numbers or the order of cutting). To be used normally for the breakout profile of the whole drum, where there is not enough space for the numbers (see Figure 5.8). Enter 'N', and the output will be as shown in Figure 5.4. These numbers show the order in which the picks enter the coal during one revolution. This feature could be used for designing a cutting drum for tracing the cutting order.

5.5 Analysis of Continuous Miner Forces and Torque

CUTSIM resolves the total force acting on each pick for each degree of contact (or for every five degrees of contact, used for quick calculation) into two mean components, namely vertical force and horizontal force. (See Figure 3.9). The program then integrates all the vertical components into a total vertical force. The same procedure takes place with the horizontal components. The calculation of the torque is performed as indicated previously by applying the equations 9 and 12.

Normally for general use of CUTSIM, the force analysis will be done for two typical arcs of contact, namely 90° for shearing mode and 180° for sumping mode as shown in Figure 3.9. However CUTSIM c. also perform the force analysis for any arc of contact. Note tha. in certain circumstances, due to the nature of rotating component it is possible to obtain lower forces while cutting with a larger arc of contact.

CUTSIM will determine the following factors which can be used fc comparing drum designs.

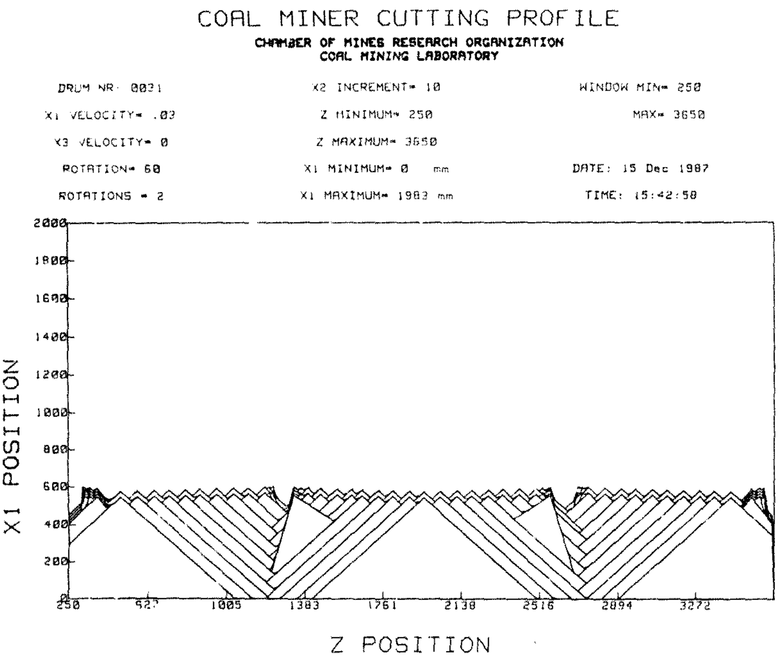


Figure 5.8 The breakout profile plotted without any marking numbers

* magnitude of vertical forces

* magnitude of horizontal forces

* amplitude and frequency of vertical forces

* amplitude and frequency of horizontal forces

* magnitude of the required torque

* amplitude and frequency of the required torque

* number of picks on the cutting drum

* average product size

* presence of idle or non productive picks

* analysis of the performance of the gauge picks

* generation of mineral cores between drum segments (continuous miner only).

* calculation of average specific energy for one drum rotation

* the possibility that the gauge cutters will release the broken mineral.

Some examples of how the above criteria can be applied, will be provided in Chapter 6.

5.6 Corner Cutting Drum Design

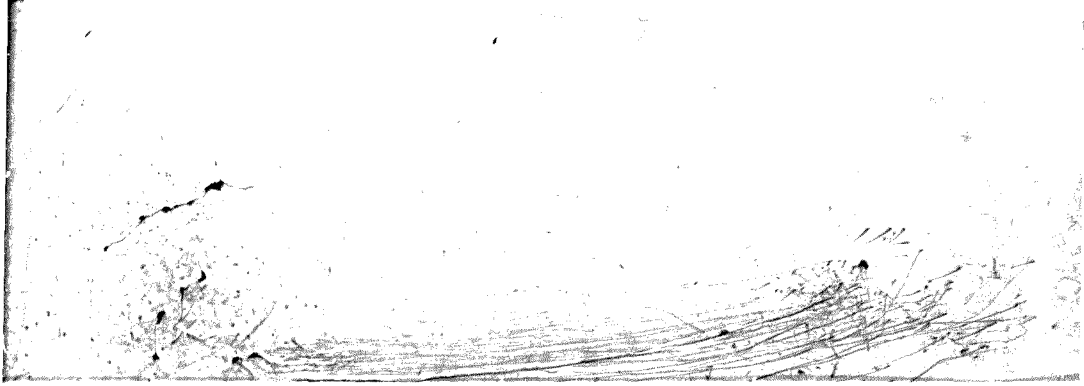
In every excavation there is at least one corner which defines the boundary of the cut volume and in which the cutting process is likely to be impeded because of the constraint imposed by the corner. A corner cutting situation may develop where the sequence of picks becomes discontinuous e.g. at the hub spaces between the drum sections where a coal core tends to be generated.

On most of the Joy cutting heads there are 10 gauge picks at each edge of the drum. For an average lacing of 65 picks, these gauge cutters form about 31 per cent of the total picks used. Therefore it is very important to understand the behaviour of gauge cutters and to be in a position to improve or optimize the design of corner-cutting arrays.

Figure 2.10 illustrates two corner cutting situations using point attack picks. The straight pick disposition is not common in practice because of the clearance difficulties. However, some longwall shearer drums and coal ploughs still use corner cutting picks approximating to it. Skewing the pick to provide clearance for itself and its holder is the more usual practice. Skewed picks are also used on the continuous miner drum in order to cover the hub spaces and prevent generation of a coal core.

The increased duty of the gauge cutters is manifested by the high incident of damage to these picks and pick boxes. This problem is generally overcome by using two or three sequences of picks to cut the corner of the excavation instead of one sequence as is used for the line cutters. In this way, corner cutting picks operate at only one half or one third of the depth of cut to which line cutters penetrate.

A close analysis of the breakout profile of the Joy 14CM 9 continuous miner (Figure 5.9) shows that the corner cutters at each edge of the drum tend to deepen a groove in advance of the line cutters. Enlargement of the left hand section of the drum for 30 mm per cycle forward drum velocity (Figures 5.2 and 5.10), shows that the gauge cutters have generated a groove which is about 22 mm in advance of the line cutters. In order to optimize the performance of this drum and overcome the adverse cutting effect of both corners, a new lacing geometry was suggested. If the curved broken line (Figure 5.10) is the new coal face, this will result in



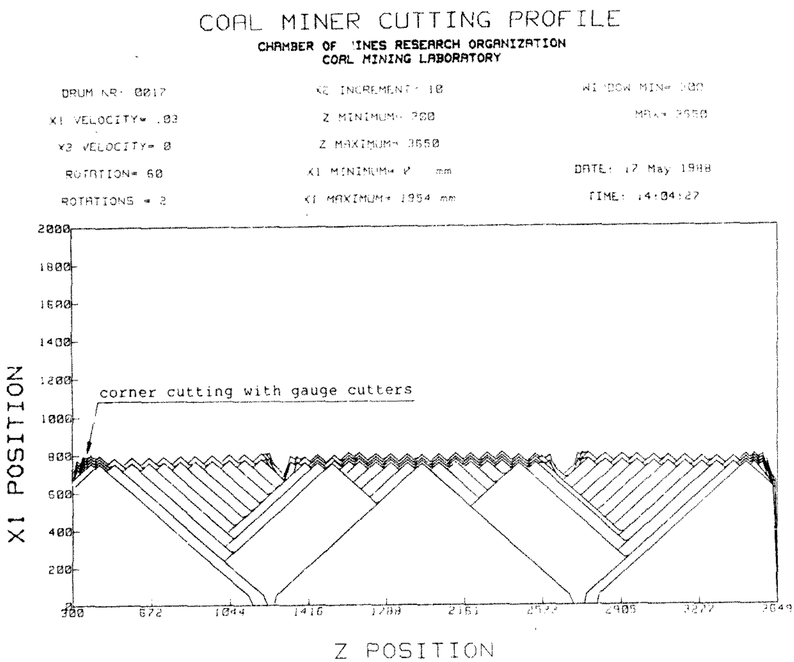


Figure 5.9 The breakout profile cf Joy 14CM 9 continuous miner

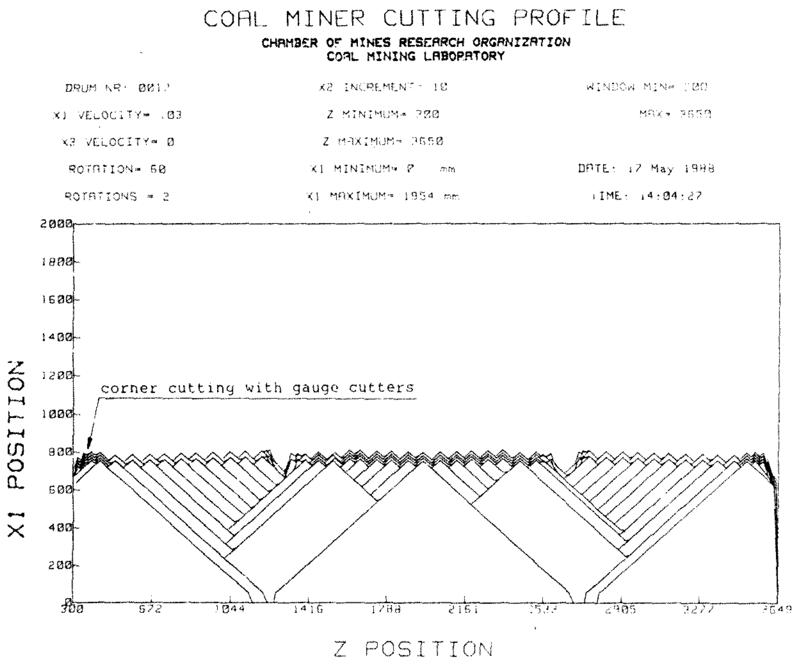


Figure 5.9 The breakout profile of Joy 14CM 9 continuous miner

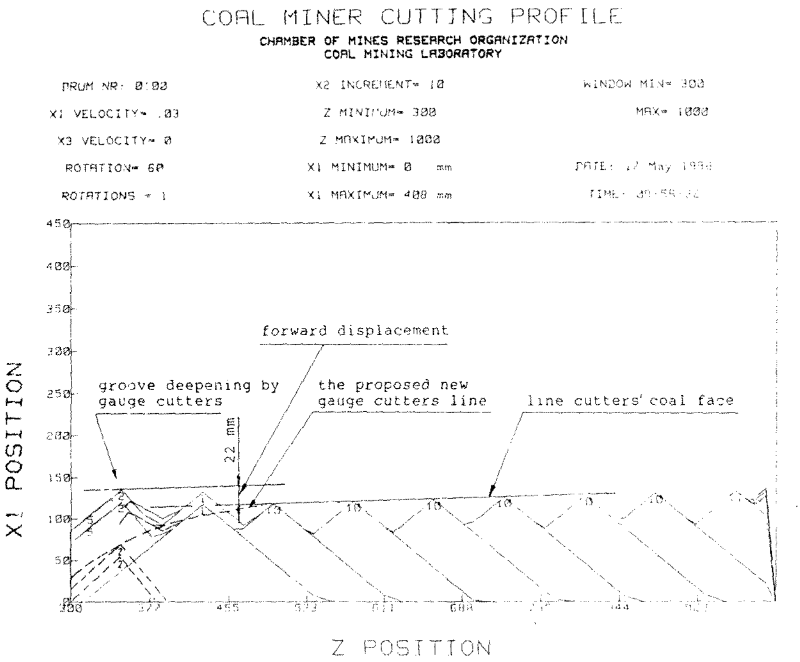


Figure 5.10 Enlargement of the left hand section of Joy 14CM 9 drum

overcoming the problem of groove deepening and no coal will be impeded due to the corner geometry. CUTSIM can simulate easily a new pick lacing by reducing the cutting radius of each pick group involved. By using the scaling technique, the cutting profile of picks 1, 2, 3, 4 and 5 should be brought back to the new curved line or below as shown for pick group 2. This will result in a new cutting radius for each corner pick and not a common radius for each group pick as before.

Table 5.4 shows the old and the new cutting radii for the corner cutters.

Table 5.4 Pick radii of the corner cutters

Pick Group	Original Pick Radius (mm)	New Calculated Radii (mm)	
		Front Pick	Back Pick
1	559	532	505
2	559	492	465
3	549	477	450
4	445	352	325
5	521	422	396

The new cutting profile of the left hand section of the drum is shown in Figure 5.11. Note the new coal face obtained.
Figure 5.12 shows the new coal face of the whole drum obtained by using the new pick radii at both edges. The benefits of this new lacing are demonstrated also by the forces and torque analysis in Table 5.5. Table 5.5 shows that the torque required and the acting vertical and horizontal forces results in an average reduction of 5 per cent for the proposed lacing compared with the original lacing. See Appendix C for more details about the cutting simulations and other related data concerning the corner cutting. Although the proposed lacing shows an improved means of cutting in a corner, one should bear in mind that this approach has not been tried yet in the field.

Table 5.5 Comparison of forces and torque for original and proposed lacing

	Original Lacing		Proposed Lacing	
	Sumping Mode	Shearing Mode	Sumping Mode	Shearing Mode
Average torque (kN m)	96	48	91	46
Average vertical force (kN)	136	112	129	106
Average horizontal force (kN)	-137	-26	-130	-25

The redesign of drum corners could be further improved, probably by reducing the number of picks and using a different lacing. However, machine designers think that the existing corner lacing is the appropriate one for enabling the continuous miner to turn and start a new road. For this specific application, further studies should be done in order to optimize the drum corner lacing.

5.7 Simulation of a cutting drum with ripperveyor

A ripperveyor is a chain laced with picks which usually is located between two sections of solid drum (see Figure 1) and rotates at a different tangential speed to that of a solid drum. Due to the geometrical construction, a cutting simulation of a configuration made of two solid drum sections and a ripperveyor is a complex matter. This is mainly due to ripperveyor having a different cycle time of the pick lacing pattern than the drum sections ie. line AOB (Figure 5.13) will approximately be transformed to line AOCD after one drum revolution. However if the pick lacing pattern of the ripperveyor is fairly simple and made of many identical pick groups, this will make a cutting simulation possible. Such a simulation can show mainly two important aspects, namely

* the cutting performance of the ripperveyor

* the possibility of generating a coal core between the ripperveyor and the solid drum.

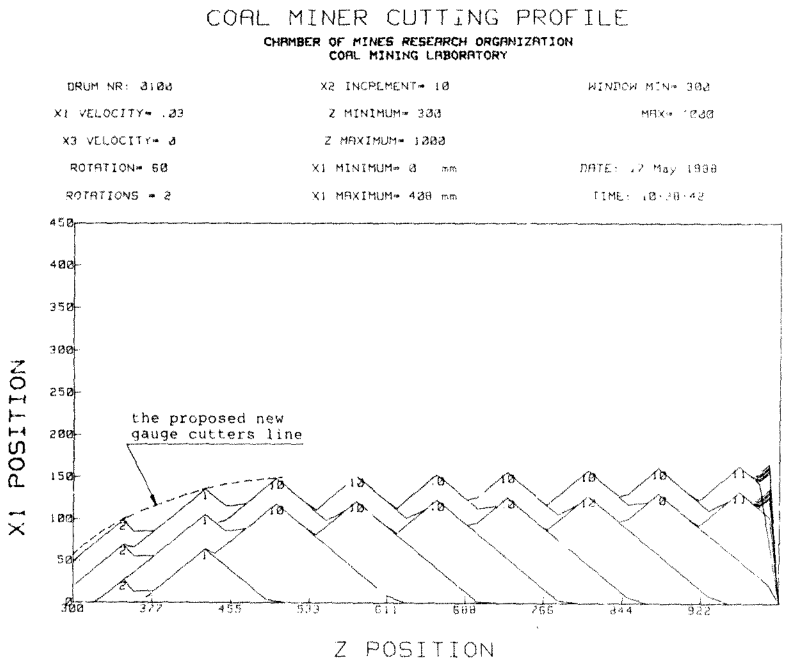


Figure 5.11 The new curved coal face

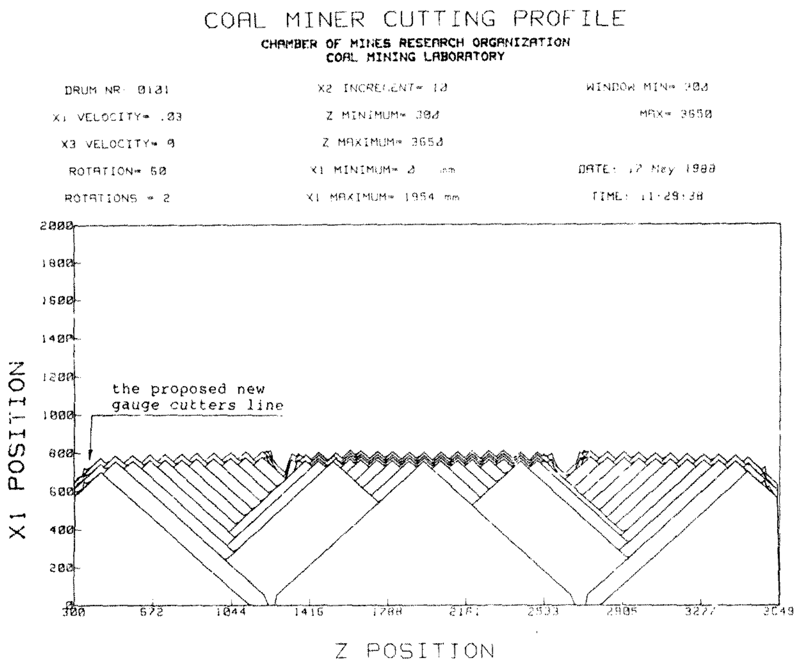
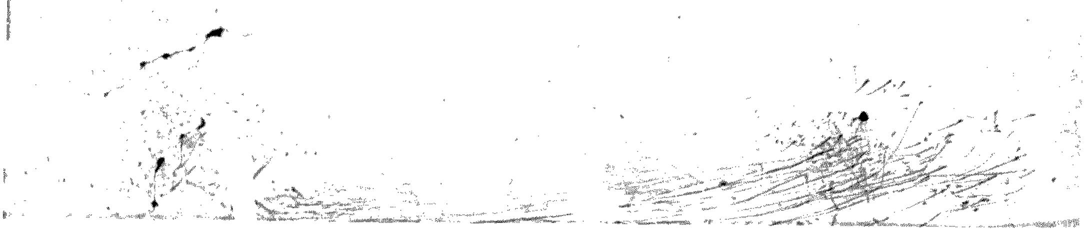


Figure 5.12 The new breakout profile of the whole drum



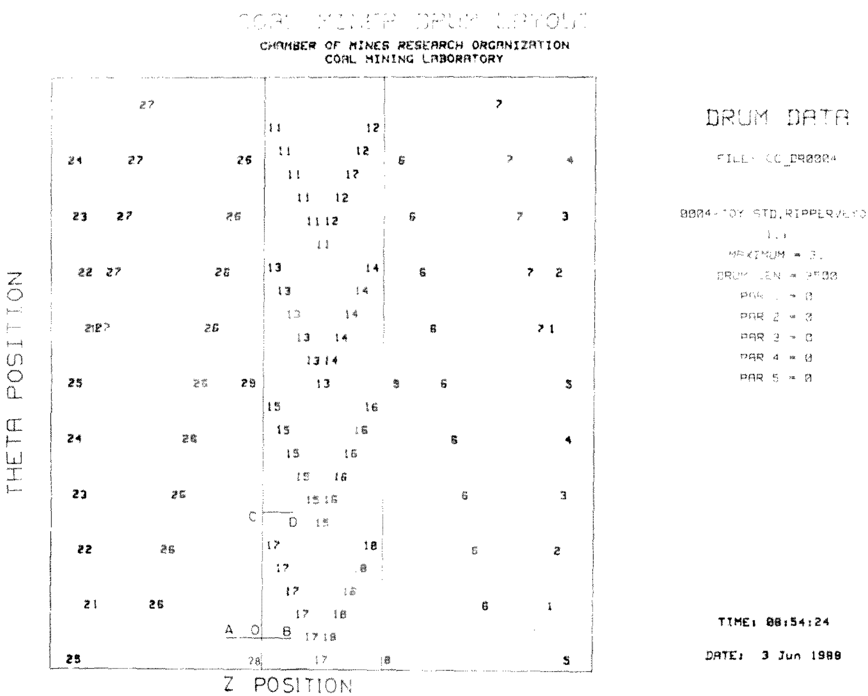


Figure 5.13 The pick lacing of Ripperveyor:Joy 12HM 9

Figure 5.13 shows the lacing patterns of the two solid drum sections and the ripperveyor between them, as used on the drum of the Joy 12HM 9 continuous miner.

This figure shows clearly that the pick density in the ripperveyor section is much higher than in the other two drum sections.

Figure 5.14 shows the cutting profile of the whole drum. The overlaced ripperveyor is clearly seen in comparison to the other two drum sections. For the simplicity of this cutting simulation, it was assumed that all drum sections are rotating with the same tangential speed. This assumption may be wrong but due to the fact that the cutting speed is independent of the generated cutting forces, it is acceptable for such an application.

Figure 5.15 shows the breakout profile of one section of the whole drum for X1 velocity of 30 mm per revolution. The inefficient cutting of the ripperveyor section is very clear. Both Figures 5.14 and 5.15 show a gap of 130 mm between the extreme gauge cutter of the ripperveyor (pick group 11) and the extreme gauge cutter of the left hand drum section (pick group 28). This will result in generating a coal core which will have an adverse effect on the performance of the continuous miner. The overlaced ripperveyor section is the main reason for the large amount of dust generated and small product size. For these reasons the industry is moving away from the ripperveyor type continuous miner to the solid drum continuous miner.

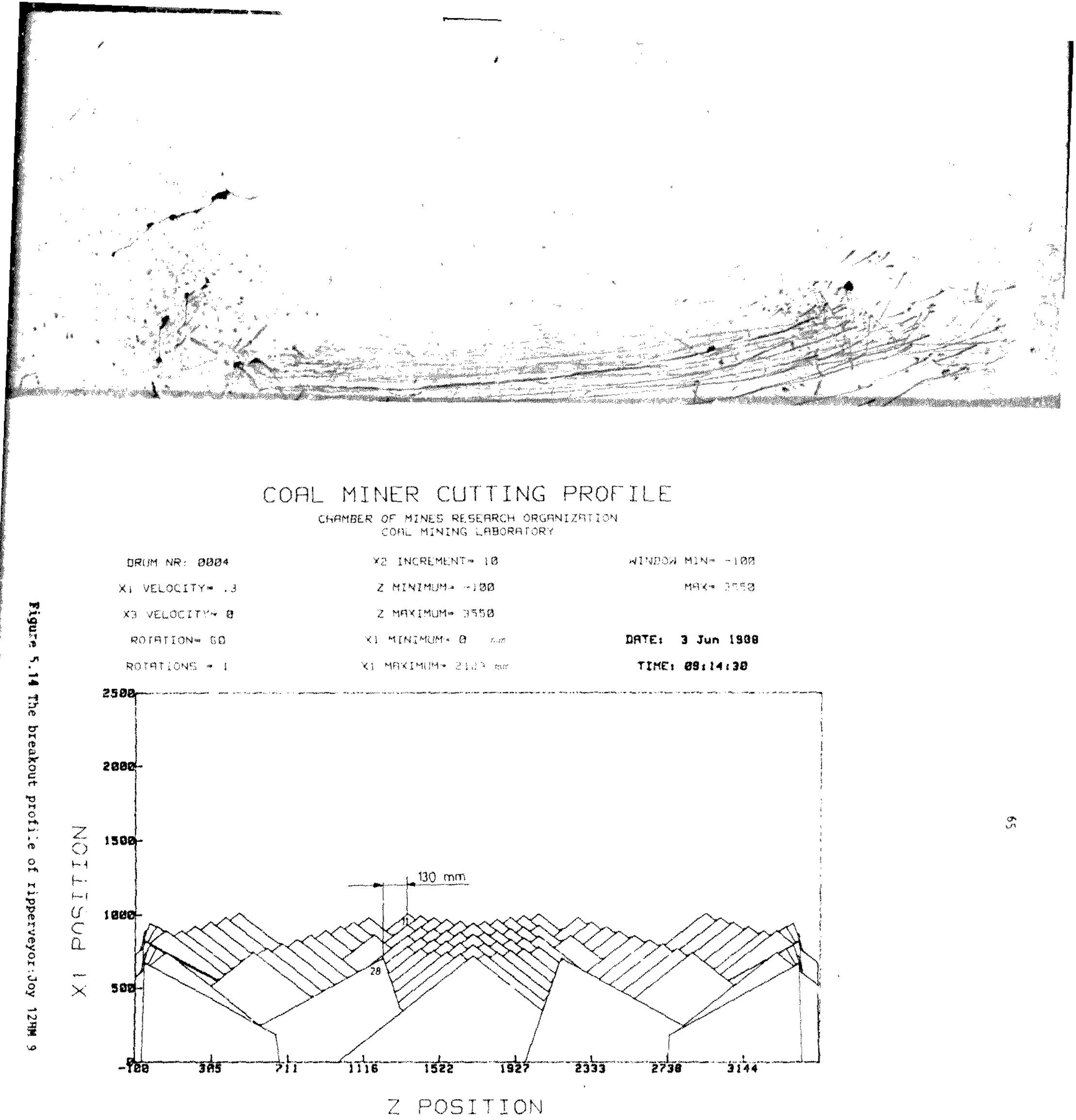
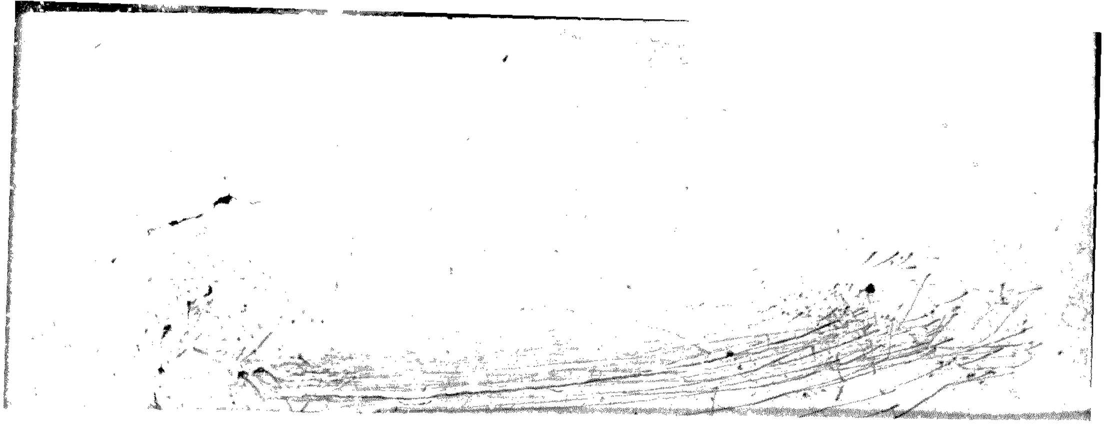


Figure 5.14 The breakout profile of ripperveyor:Joy 12HM 9



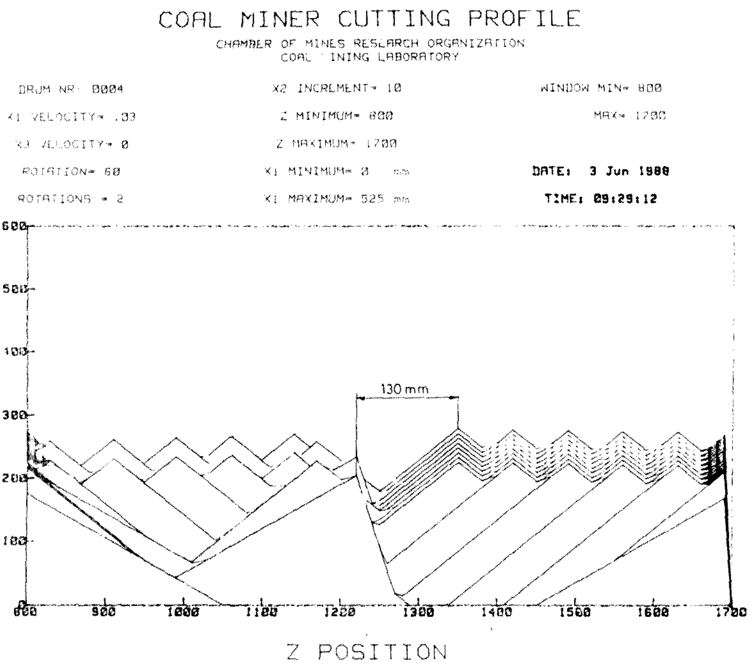


Figure 5.15 The enlarged breakout profile of one section of Joy
Joy 12HM 9

CHAPTER 6 VALIDATION OF FINDINGS

In order to validate the CUTSIM findings, the following three different means were used.

* comparison of simple drum manual calculations with CUTSIM output

* comparison of CUTSIM output with the force analysis of the Lee Norse experimental continuous miner underground trials

* comparison of CUTSIM output with actual tests conducted underground on a production continuous miner.

6.1 Validation against Manually Calculated Forces

A simple drum of only three picks was used for the manual calculation of forces and torque. The manual calculations were then compared with the CUTSIM output.

Figure 6.1 shows the pick locations on the rotating drum. Note the order and notation of the picks.

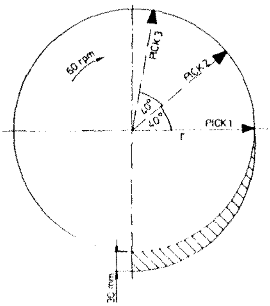


Figure 6.1 The lacing pattern of the test drum

At 0° pick 1 is ready to start cutting. Pick 2 and pick 3 are behind pick 1 at angles of 40 and 80° respectively.

The *pick spacing* is 76 mm (Joy standard lacing). Figure 6.2 shows three picks on the test drum. Table 6.1 shows the entered data on the drum file for this particular simulation.

Table 6.1 Pick la ng data of the test drum

Pick Group	Pick Detail	No of Picks	Pick Code	Skew Angle	Cutting Radius (mm)	θ min	θ max	Z min (mm)	Z max (mm)
1		3	A0	0	457	0	80	100	252

Ft(θ) = K·Sinθ·(max DOC) ...... from equation (6)
The max DOC is obtained for θ = 90.

The following assumptions are made for the simplicity of calculation:
The max DOC in coal is 30 mm per drum revolution.
K=1 (the slope of the cutting force against DOC is 45°). Fc=Fn.
This results in P_1=Fc/Fn = 1
Hence for max DOC Ft(90) = 1·Sin (90)·30=30 kN
P2 = Ft(max)/max DOC ...... *from equation (3)*
Hence: P2 = 30/30 = 1 kN/mm

Using CUTSIM with these values for P1 and P2 gives the following results:

* the coal cutting profile with pick group number as shown in Figure 5.3.

* the CUTSIM continuous miner forces and torque analysis for the *shearing mode* as shown in Figure 6.3.

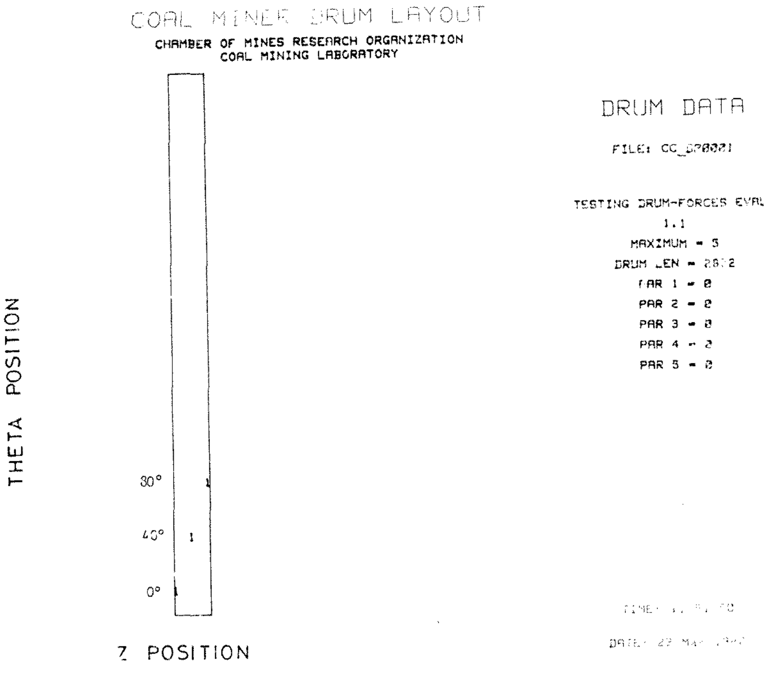
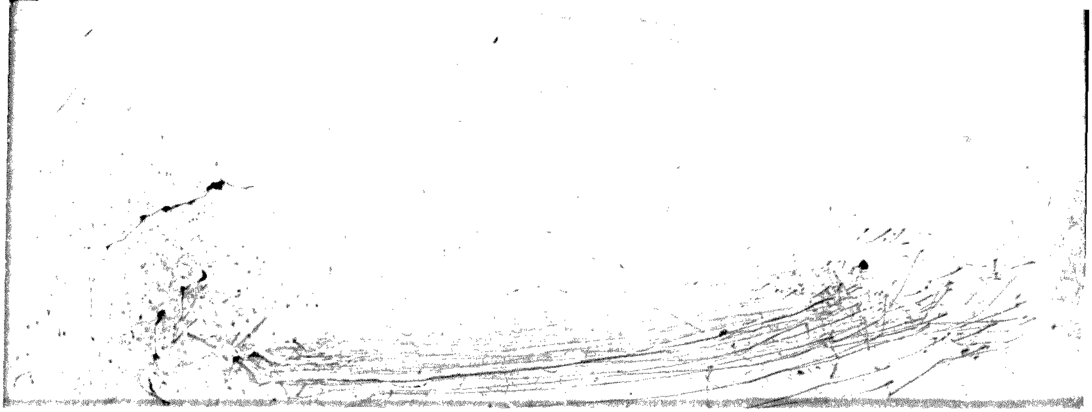


Figure 6.2 The lacing pattern of the test drum



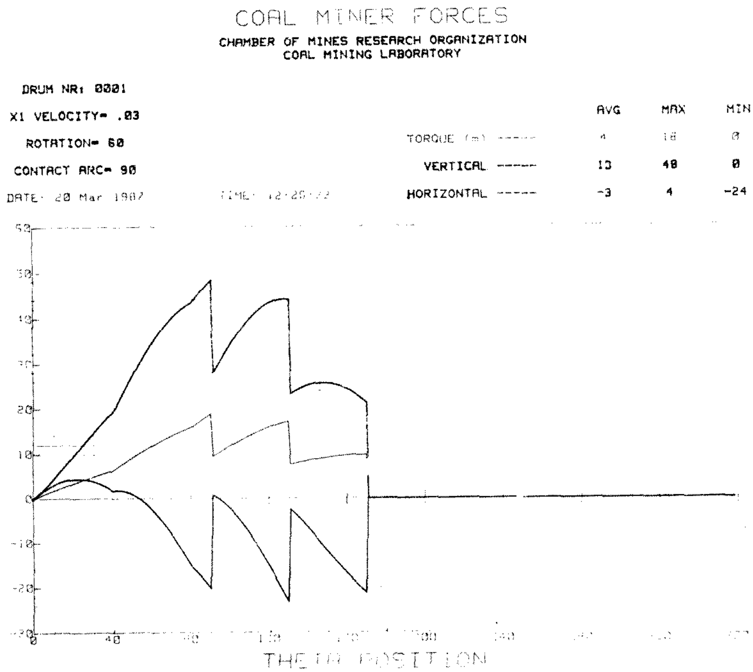


Figure 6.3 The cutting forces and torque of the test drum

The manual calculations which follow are detailed in order to demonstrate typical forces and torque calculations for two different pick positions. The output of these manual calculations is then compared with the CUTSIM analysis for validation.

Figure 6.4 shows the position of pick 1 at θ1=10° and the forces acting.

The pick radius is assumed to be r=457 mm which similar to that of a Joy 14CM 9 cutting drum.

At θ1=10° only pick No 1 is cutting.

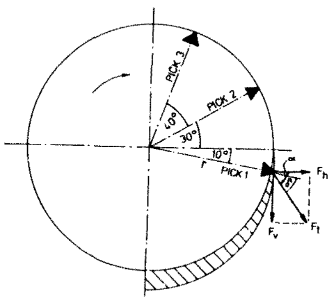


Figure 6.4 Pick position for θ1 = 10°

Depth of cut for pick No. 1 (DOC1) is:

DOC1=Sin(θ1)*(max DOC)=Sin(10)*30=5,2 mm .....from equation (4).

The total force acting on pick No. 1 (Ft1) is:

$Ft1 = K * DOC1 = 1 * 5,2 = 5,2$ kN .....from equation (5).

$\beta1 = Tan^{-1}(P1) = Tan^{-1}(1) = 45°$..... from equation (11).

$\alpha1 = \beta1 + \theta1 = 45 + 10 = 55°$

The vertical force acting on pick No. 1 (Fv1) is:

$Fv_1 = Ft1 * Sin(\theta1+\beta_1) = 5,2 * Sin(10+45) = 4,26$ kN

The horizontal force acting on pick No. 1 (Fh1) is:
$Fh1 = Ft1 * Cos(\theta1+\beta1) = 5.2 * Cos(10+45) = 2,98$ kN

The torque (T1) generated by pick No. 1 is:
$T1 = Ft1 * Sin(\beta1) * r = 5,2 * Sin 45 * 0,457 = 1,68$ kN*m

Thus for the angle of $\theta1 = 10°$
$\Sigma Fv = Fv1 = 4,26$ kN
$\Sigma Fh = Fh1 = 2,98$ kN
$\Sigma T = T1 = 1,68$ kN*m

The manual calculations for *a second pick position* (Figure 6.5) are indicated below.
Pick No. 1 is now positioned at $\theta1 = 55°$ and pick No. 2 at $\theta2 = 15°$

$\beta2 = Tan^{-1}(P1) = Tan^{-1}(1) = 45°$

DOC1=Sin$(\theta1)$*(max DOC) = Sin(55)*30 = 24,57 mm

DOC2=Sin$(\theta2)$*(max DOC) = Sin(15)*30 = 7,76 mm

$Ft1 = K * DOC1 = 1 * 24,57 = 24,57$ kN

$Ft2 = K * DOC2 = 1 * 7,76 = 7,76$ kN

$Fv1 = Ft1 * Sin(\beta1+\theta1) = 24,57 * Sin(45+55) = 24,2$ kN

$Fh1 = Ft1 * Cos(\beta1+\theta1) = 24,57 * Cos(45+55) = -4,27$ kN

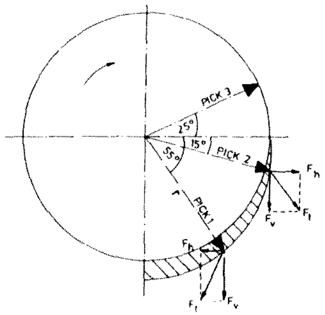


Figure 6.5 Pick position for θ1 = 55° and θ2 = 15°

T1=Ft1 * Sin(β1) * r = 24,57 * Sin(45)*0,457 = 7,94 kN/m

Fv2=Ft2 * Sin(β2+θ2) = 7,76 * Sin(45+15) = 6,72 kN

Fh2=Ft2 * Cos(β2+θ2) = 7,76 * Cos(45+15) = 3,88 kN

T2=Ft2 * Sin(β2)*r = 7,76 * Sin(45)*0,457 = 2,51 kN*m

Integration of all force components and torque gives:

ΣFv = Fv1+Fv2 = 24,2+6,72 = 30,92 kN

ΣFh = Fh1+Fh2 = -4,27+3,88 = -0,39 kN

ΣT = T1+T2 = 7,94+2,51 = 10,45 kN*m

These manual calculations for two selected pick positions are typical of computer calculations for any pick at any location.

Additional manually calculated forces for 26 different points for each of the vertical forces, horizontal forces and torque are detailed in Appendix F.

Figure 6.6 shows a plot of the manual calculations, namely the vertical force, the horizontal force and the torque for the shearing mode. Both plots of the manual calculations (Figure 6.6) and the CUTSIM output (Figure 6.3) are identical.

This excellent correlation of manual calculations and CUTSIM output is part of the validation used to prove the reliability of CUTSIM program.

6.2 Comparison of CUTSIM with the Lee Norse Findings

The CUTSIM output has been compared with the findings of the Lee Norse continuous miner detailed in Research report 23/79[4] by King et al.

The Lee Norse miner used the following parameters:

Nominal drum rotation speed	42 r/min
Drum diameter	1130 mm
Max. drum torque	162 700 N*m

The comparison with CUTSIM was based on four different pick lacing patterns used on the Lee Norse. These four Lee Norse pick lacings (Figure 6.7) were simulated by CUTSIM using the same parameters as far as possible. However, where relevant data was missing, reasonable assumptions were made in order to provide the missing data.

Simulations were performed for four lacing patterns, using depths of cut of 10,20,30 and 40 mm with pick spacings of 50,100,150 and 200 mm respectively. Details are provided in Appendix H.

It was assumed that all skewed picks on the Lee Norse drums were at 30° (positive or negative angle). Parameters P1 and P2 for the Lee Norse Simulation were obtained by cutting a sample of coal from Majuba colliery with a straight pick. By keeping the pick spacing to depth of cut ratio at 3:1, the parameters P1 and P2 were calculated as:

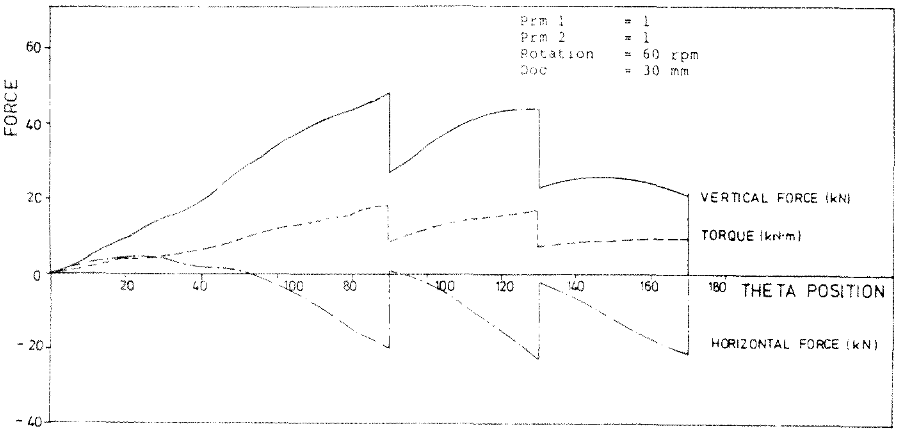


Figure 6.6 Manual calculation of forces and torque

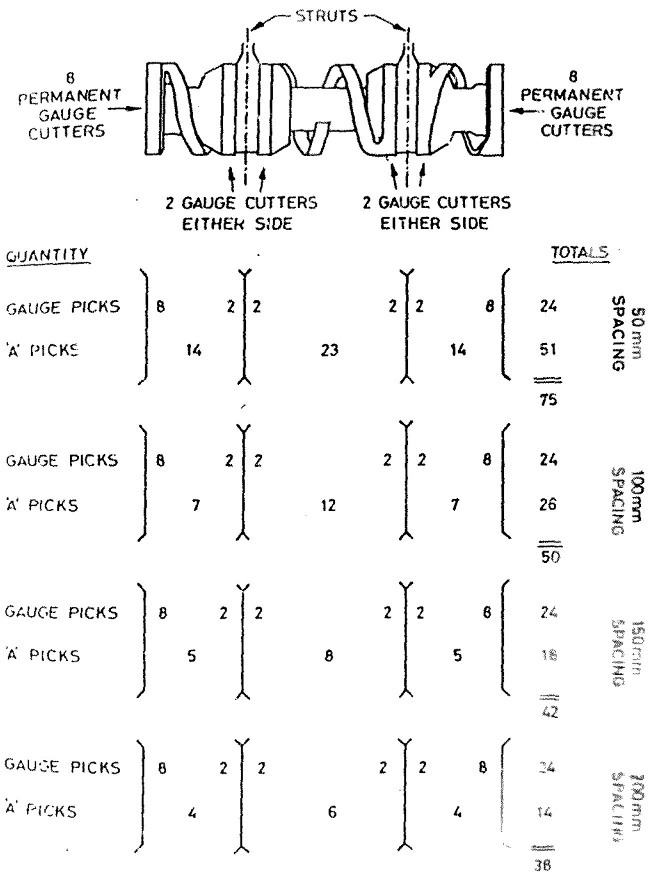


Figure 6.7 The lacing patterns for various spacings used with the Lee Norse drum

For 0° skewed pick (straight pick) P1 = 0,71 and P2=0,34 kN/mm.
For 30° skewed pick P1=5,78 and P2=0,65 kN/mm. (See Table E.5).

Table 6.2 details the normal forces and torques of the Lee Norse as calculated using CUTSIM. Appendix I details the CUTSIM simulations of the Lee Norse tests. The Table also indicates the derived cutting forces and torques from these simulations.

For this comparison, the shearing and sumping modes described in the Lee Norse report are equivalent to arc of contacts of 90° and 180° in the CUTSIM program respectively. Figures 6.10 and 6.11 show graphically the comparison between the Lee Norse torque and the CUTSIM torque for 180° and 90° arc of contact respectively. In Figure 6.9 the average normal force and the maximum normal force of CUTSIM are respectively below and above the nominal boom force of Lee Norse. Figure 6.9 reflects the general tendency seen in Figures 6.10 and 6.11 considering the circumstance of this comparison, it is an acceptable correlation. Figure 6.8 is unusual as it shows that the Lee Norse boom force is much higher than the maximum normal force of CUTSIM. For 200 mm pick spacing the difference between CUTSIM maximum normal force and Lee Norse boom force is 117 per cent for the sumping operation.

The differences between the CUTSIM calculated forces and torques and the Lee Norse measured boom forces and torques could be due to the following:

* CUTSIM program does not take into consideration any resistance of the broken coal. It was found, in an actual coal cutting test, that the broken coal increased the measured forces significantly.

* According to the Lee Norse report[4] (Page 37), the depth of cut was not a controlled variable in the tests conducted. 'The machine advance could be roughly predicted according to the amount of thrust or shear pressure to be applied. Consequently the procedure was to aim for a 'deep', 'shallow' or 'medium' depth and to set the hydraulic pressures accordingly'.

Table 6.2 Lee Norse: CUTSIM generated normal forces and torque

CUTSIM - Normal forces and torque output								
	Shearing - Arc of Contact 90°				Sumping - Arc of Contact 180°			
Depth of cut (mm)	10	20	30	40	10	20	30	40
Pick spacing (mm)	50	100	150	200	50	100	150	200
Drum number	0030	0027	0028	0029	0030	0027	0028	0029
Average normal force (kN)	32	43	46	49	[illegible]	45	51	54
Max. normal force (kN)	39	58	65	75	47	65	63	75
Average torque (kN*m)	13	22	23	25	27	44	45	50
Max. torque (kN*m)	18	37	36	39	29	58	53	58

Table 6.3 details the boom forces and torques measured during the Lee Norse tests.

Table 6.3 Lee Norse: measured boom forces and drum torques

	Lee Norse - Boom forces and torque readings							
	Shearing - Arc of contact 90°				Sumping - Arc of contact 180°			
Depth of cut (mm)	10	20	30	40	10	20	30	40
Pick spacing (mm)	50	100	150	200	50	100	150	200
Nominal boom force (kN)	17,8	50,1	62,5	85,1	58,2	91,3	112,5	163,1
Nominal torque (kN*m)	12	19,5	29,3	45,5	14,8	24,6	37,9	50,5

Figures 6.8 and 6.9 show graphically the comparison between the Lee Norse boom forces and the CUTSIM normal forces, for 180° and 90° arc of contact respectively.

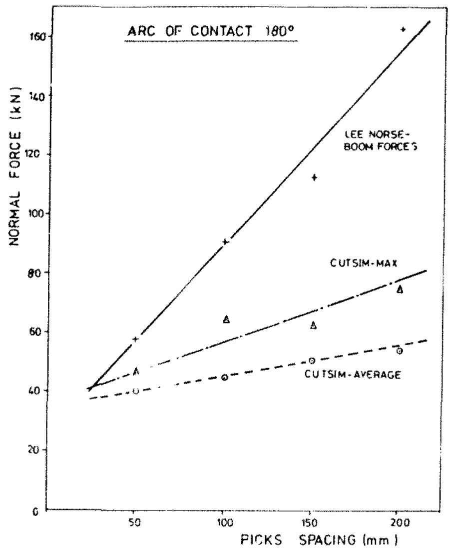


Figure 6.8 Comparison of Lee Norse Boom forces and CUTSIM normal forces - sumping mode

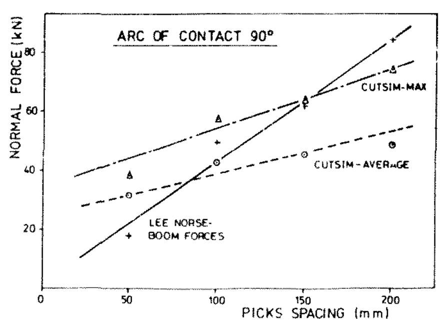


Figure 6.9 Comparison of Lee Norse Boom forces and CUTSIM normal forces - shear mode

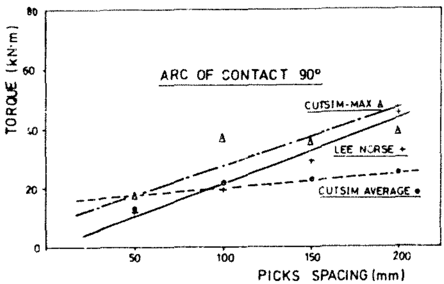


Figure 6.10 Comparison of Lee Norse and CUTSIM torque - shear mode

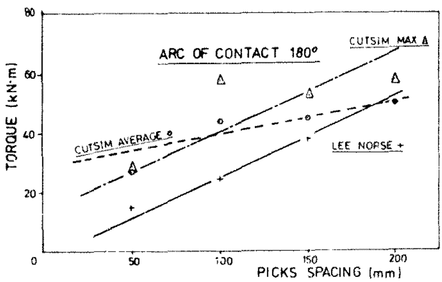


Figure 6.11 Comparison of Lee Norse and CUTSIM torque - sumping mode

* The forces in the Lee Norse report are given in two components; namely, force along the boom and the cutting force which is vertical to the boom force. Assuming a boom angle of 20° from the floor, which is an approximate average working angle of the boom this will result in a 6 per cent reduction in the total force if it is resolved into horizontal and vertical components as in the CUTSIM program. (See Figure 6.12).

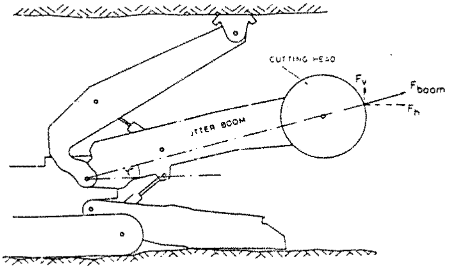


Figure 6.12 Boom force given in Lee Norse report compared with Fv and Fh in CUTSIM

* In the Lee Norse tests, the centre drum was laced with 12 picks at 100 mm spacing (See Figure 6.7), but CUTSIM simulates the use of 11 picks on the centre drum as specified in the Lee Norse manual by the manufacturer.

* The CUTSIM program assumes sharp picks throughout the cutting process which contributes to minimal acting forces (see Section 4.2). During the Lee Norse tests, not all of the picks were new and sharp during cutting trials.

* The exact geometry of the pick lacing on the Lee Norse drum(4) is not fully available and various techniques of interpolation and scaling have to be applied in order to get approximate figures.

* CUTSIM uses two different cutting parameters P1 and P2 as already mentioned. These parameters are obtained by cutting tests on a sample of coal from the relevant seam,performed on the linear cutting machine at the Coal Mining Laboratory (CML) of the Chamber of Mines. Due to the nature of the coal, these parameters can vary for each seam of coal, the coal cutting conditions and the quality

of the cutting tool. It is known that the coal cut by the Lee Norse and the coal cut at CML for the parameter extractions had different characteristics.

* The forces and torques presented in the Lee Norse report(4) were determined from hydraulic pressure readings which was dependent on the setting of the machinery and regular calibrations being done. This could have led to additional inaccuracies.

* In the Lee Norse tests, the ratio of pick spacing to depth of cut was 5:1. This ratio is too high for good cutting interaction and contributes to very high cutting forces. The parameters P1 and P2 used in the cutting simulation of CUTSIM are based on laboratory cutting tests using 3:1 ratio. This ratio is ideal for cutting interaction and ensures that cutting forces are at a minimum.

* Due to the lack of exact data on Lee Norse pick lacings, it was assumed that all skewed picks on the Lee Norse drum were at angles of 30 or -30°. The CUTSIM simulation was based on this assumption which may have been incorrect.

6.3 Experimental Underground Tests

This section demonstrates how CUTSIM can be used in order to improve the cutting performance of a given lacing.

Cutting tests, using a Joy 14CM 9 continuous miner with different pick lacings were conducted at New Denmark colliery in order to obtain data for a physical validation of CUTSIM. Appendix J gives the full details of these cutting tests.

A drum of 80 picks was giving a poor penetration rate and a CUTSIM analysis was performed. Tables 6.4 and 6.5 show the result of CUTSIM simulations of alternative lacing patterns analysed in the search for optimum patterns for the shearing and sumping modes respectively. These drum lacings were also tried in practice and the results of the field trials are also reported in Appendix J.

Table 6.4 Results of lacing pattern tests and related forces and torque for shearing mode

Test Number	1	2	3	4
Number of picks	80	67	69	65
Average horizontal force [kN]	26	25	26	25
Max.horizontal force [kN]	59	51	50	50
Average vertical force [kN]	112	107	110	106
Max.vertical force [kN]	149	143	140	138
Average torque [kN*m]	48	45	48	46
Max. torque [kN*m]	67	64	63	62
Comments from field trials at New Denmark Colliery	poor penetration rate	drum tends to generate vibration	good performance of drum	good performance of drum

Table 6.5 Results of lacing pattern tests and related forces and torque for sumping mode

Test Number	1	2	3	4
Number of picks	80	67	69	65
Average horizontal force [kN]	137	130	135	130
Max.horizontal force [kN]	171	162	156	153
Average vertical force [kN]	136	129	134	129
Max.vertical force [kN]	170	160	155	155
Average torque [kN*m]	96	92	95	91
Max torque [kN*m]	114	107	102	104
Comments from field trials at New Denmark Colliery	poor penetration rate	drum tends to generate vibration	good performance of drum	good performance of drum

These results show how CUTSIM could be used for improving an existing lacing pattern. In this case a reduction in the number of picks from 80 to 67 led to a reduction in the horizontal and vertical forces by an average of 4 per cent. The penetration rate also improved. However this lacing (67 picks) tend to generate two vibrations per cycle (Figures J7 and J8). An analysis of the forces plot show that a minimum occurs in Theta position of 170°. This is due to less cutting picks in that area. By adding two picks there (picks 29 and 37 in Figure J9) the total number of picks came to 69 and the forces analysis of this lacing shows a more balanced performance. The underground test using this lacing *showed a smoother cutting action. The breakout profile of the 69 pick lacing (Figure J10) shows 4 picks (group 6 and group 44) cutting twice per cycle.* By removing these 4 picks, the final recommended lacing was 65 picks (19 per cent reduction). According to the CUTSIM analysis, this lacing would result in up to a 15 per cent reduction in maximum horizontal forces, up to 7 per cent reduction in the required maximum torque and a better cutting performance.

Four additional cutting tests were done by the technical staff from Joy. By using a Joy 14CM 9 continous miner, as well as the same pick type used in the above tests, and the same coal seam, the following results were obtained (see Appendix J for full details).

Table 6.6 Lacing pattern tests conducted by Joy

Test Number	1	2	3	4
Number of picks	110	98	80	66
Average sumping rate [mm/s]	13,5	18,4	22	15,3
Average shearing rate [mm/s]	12,3	24,9	40,7	34,1
DC volt consumption [V]	75-85	45-55	45-55	45-55

According to Table 6.6, the lacing pattern of 80 picks would have the best performance. This pick lacing results in 27 per cent reduction in the number of picks, a 63 per cent increased average sumping rate and 394 per cent increased average shearing rate, compared with the original lacing of 110 picks.

A careful comparison of the results obtained by the underground tests carried out by COMRO and the tests carried out by Joy shows the following. The best drum in respect of forces and the required torque is the 65 pick drum tested by COMRO. On the other hand Joy claim that the best drum in respect of production rate is the 80 pick drum. In order to optimize the drum design for all aspects i.e. forces, torque and production rate, further research is required.

showed a smoother cutting action. The breakout profile of the 69 pick lacing (Figure J10) shows 4 picks (group 6 and group 44) cutting twice per cycle. By removing these 4 picks, the final recommended lacing was 65 picks (19 per cent reduction). According to the CUTSIM analysis, this lacing would result in up to a 15 per cent reduction in maximum horizontal forces, up to 7 per cent reduction in the required maximum torque and a better cutting performance.

Four additional cutting tests were done by the technical staff from Joy. By using a Joy 14CM 9 continous miner, as well as the same pick type used in the above tests, and the same coal seam, the following results were obtained (see Appendix J for full details).

Table 6.6 Lacing pattern tests conducted by Joy

Test Number	1	2	3	4
Number of picks	110	98	80	66
Average sumping rate [mm/s]	13,5	18,4	22	15,3
Average shearing rate [mm/s]	12,3	24,9	40,7	34,1
DC volt consumption [V]	75-85	45-55	45-55	45-55

According to Table 6.6, the lacing pattern of 80 picks would have the best performance. This pick lacing results in 27 per cent reduction in the number of picks, a 63 per cent increased average sumping rate and 394 per cent increased average shearing rate, compared with the original lacing of 110 picks.

A careful comparison of the results obtained by the underground tests carried out by COMRO and the tests carried out by Joy shows the following. The best drum in respect of forces and the required torque is the 65 pick drum tested by COMRO. On the other hand Joy claim that the best drum in respect of production rate is the 80 pick drum. In order to optimize the drum design for all aspects i.e. forces, torque and production rate, further research is required.

CHAPTER 7 CONCLUSIONS

This report describes the development of a mathematical model for simulating the cutting action of a rotating drum. It appears to be an ideal tool which requires minimum effort for obtaining an optimum pick lacing concerning the cutting forces and torque of a given drum. The advantages that CUTSIM can offer to the coal industry and to the mining machine manufacturers are:

* A tool for designing a totally new cutting drum or for redesigning and analysing existing drum lacings.

* CUTSIM enables the user to simulate any possible cutting situation with ease and to analyse it quickly, accurately and at low cost.

* CUTSIM can enable the following parameters to be analysed either individually, or in respect to one another.

(a) type of material cut
(b) type of pick
(c) condition of picks
(d) assisted cutting with water jets
(e) different lacing patterns
(f) movement of continuous miner in forward and vertical direction
(g) velocity of rotating drum
(h) analysing a cutting drum by sections or as a whole unit
(i) different contact angles of cutting drum with the coal
(j) interaction between various sections of the cutting drum (including ripperveyor and solid drum section)

* CUTSIM is user friendly software which can be used by any technical/production staff from mines or from manufacturers of any rotating cutting drum. For a full specific simulation, the user should have the lacing pattern of the drum, a sample of mineral to be cut and various picks proposed for cutting.

* CUTSIM is currently used for various collieries in order to assess the most suitable pick lacing for their own requirements. Another use is for comparing the performance of various picks and selecting the most suitable one.

* The existing CUTSIM program as described in this report is limited to machines with rotating drums, such as continuous miners and longwall shearers. However, if the need for the simulation of machines with a global movement like roadheaders or a linear movement such as a plough arises, it could be handled by a further expansion of CUTSIM.

As a result of the significant forces and torque reduction obtained by using CUTSIM, a smaller and lighter continuous miner or longwall shearer will be capable to replace the bigger and heavier machine without loss of performance capability. Such a machine with lower thrust and lighter weight will be cheaper in price and have more manoeuverability in the confine section of coal producing. This in turn will persuade the collieries to purchase more cutting machines and increase coal production with reduced cost.

APPENDIX A

DESCRIPTION OF COAL SAMPLES FOR CUTTING TESTS

The coal samples used in the laboratory cutting tests described in this report, had the following physical characteristics.

Source: 1. Upper half, No. 2 seam, Douglas colliery, Witbank Coalfield, Transvaal.

2. Gus seam coal, Majuba Coalfield, Transvaal.

Size: Approximately 700 x 700 x 1200 mm.

Treatment: 1. Painted in rubberized coating to retard weathering.

2. Cast in concrete to facilitate mounting on coal-cutting machine.

Uniaxial compressive strength of No. 2 seam, Douglas Colliery: 18-27 MPa.

Uniaxial compressive strength of the Gus seam - not determined.

APPENDIX B

DESCRIPTION OF EXPERIMENTAL EQUIPMENT AND TECHNIQUE

The linear cutting machine, on which all cuts were made, is a workshop planing machine that has been adapted for coal and rock cutting experiments. (See Figure B1). Maximum cutting speed capability is 200 mm/s and maximum force in the direction of movement of the sample relative to the pick is approximately 30 kN.

The pick being tested is mounted on a triaxial dynamometer, (see Figure B2) which in turn is mounted in the stationary cross-beam. Prior to cutting, the cross-beam is moved vertically, and the dynamometer and pick are moved laterally to achieve the desired position of the pick relative to the coal sample.

The coal sample of 700 x 700 x 1200 mm is encased in concrete to facilitate mounting on the traversing table, and is traversed relative to the pick during cutting tests by a hydraulic ram.

The dynamometer resolves the force acting on the pick into three orthogonal components, representing the in-line cutting force Fc, the normal force, Fn or penetrating force acting at right angles to the coal surface and the lateral or sideways force, Fs. (See Figure 2.2). All three force components are recorded during cutting and are represented as analogue traces on a high speed chart recorder.

Average forces are electronically measured by recording the time-integral of the force and dividing this by the time duration of the cut. The average forces have been measured exclusively in this experiment as being the most meaningful in describing the underground case.

For statistical validity, each cut at a certain depth of cut is performed twice and calculations are based on the average recorded forces. Figure B3 shows the various pick holders for various skew angles used to obtain the acting forces on a single skewed pick.

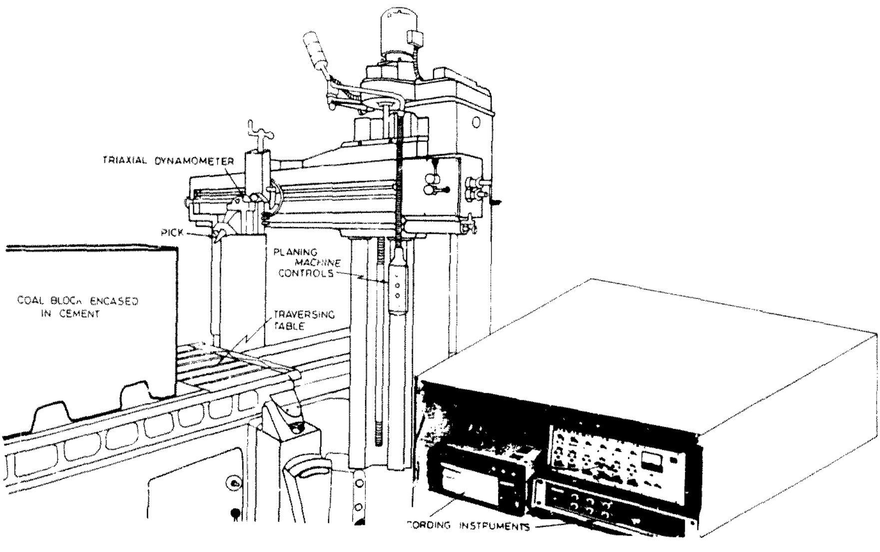


Figure B1 Sketch of the linear cutting machine

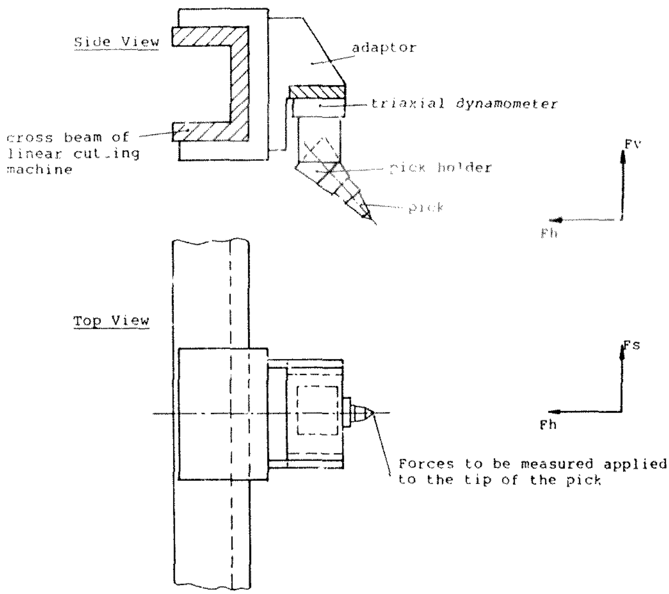


Figure B2 Sketch of the position of the dynamometer on the linear cutting machine

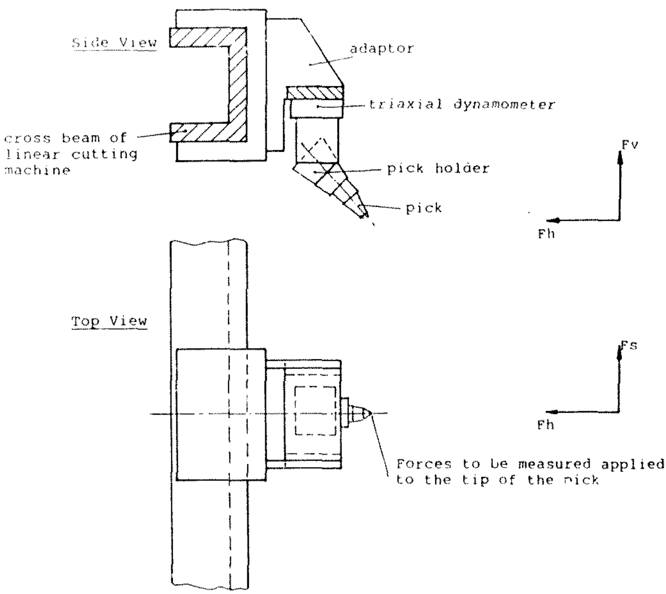


Figure B2 Sketch of the position of the dynamometer on the linear cutting machine

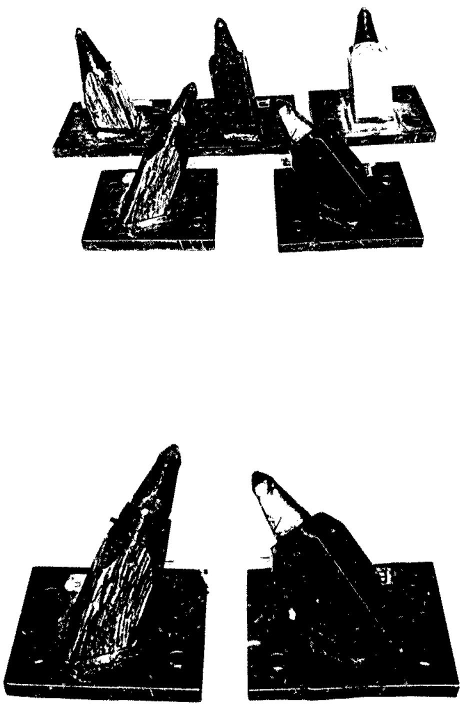


Figure B3 Photograph of the CUTSIM pick holders for various skew angles

SIMULATION OF CORNER CUTTING

Figure 5.10 in section 5.6 shows the cutting profile obtained by reducing the pick radii of the gauge cutters on a particular drum. A typical example of calculating the required pick radius of pick group No. 2 (Figure 5.10) is as follows:

The front pick of pick group No. 2 is 15 mm in front of the proposed new gauge cutters' line (dotted line in Figure 5.10). Using the scaling of 'X1 position' ie. 100 mm on the graph represent 450 mm, means that the pick on the actual drum should be brought back about 67 mm.

Therefore: New radius = Old radius - forward displacement
New radius = 559 - 67 = 492 mm.

The same technique was applied with the other pick groups namely 1, 3, 4 and 5.

The new position of pick group No. 2 is shown in Figure 5.11 (Section 5.6). Figures C1 and C2 show the acting forces and torques on the complete drum (see Figure 5.2) using the original pick radii for the shearing and sumping modes respectively.

Figures C3 and C4 show the acting forces and torques on the same complete drum using the modified pick radii for the shearing and sumping modes respectively.

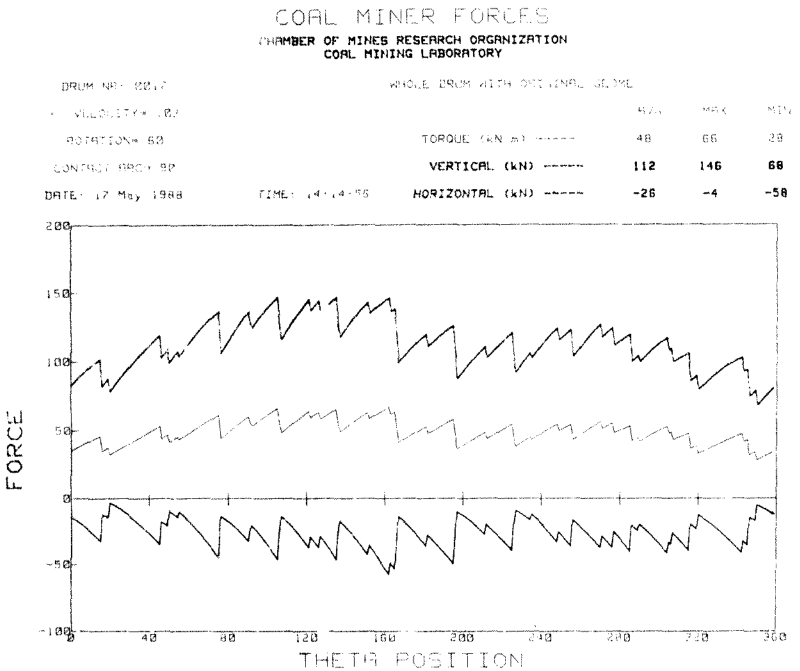
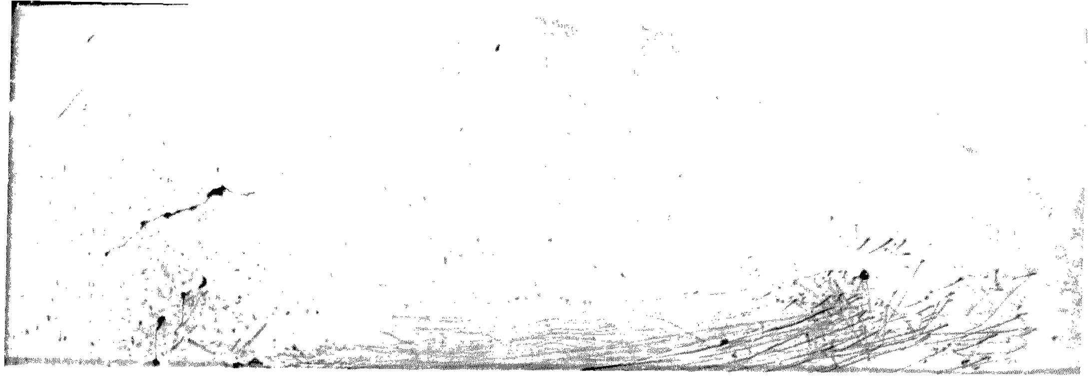


Figure C1 The acting forces and torque on the original drum



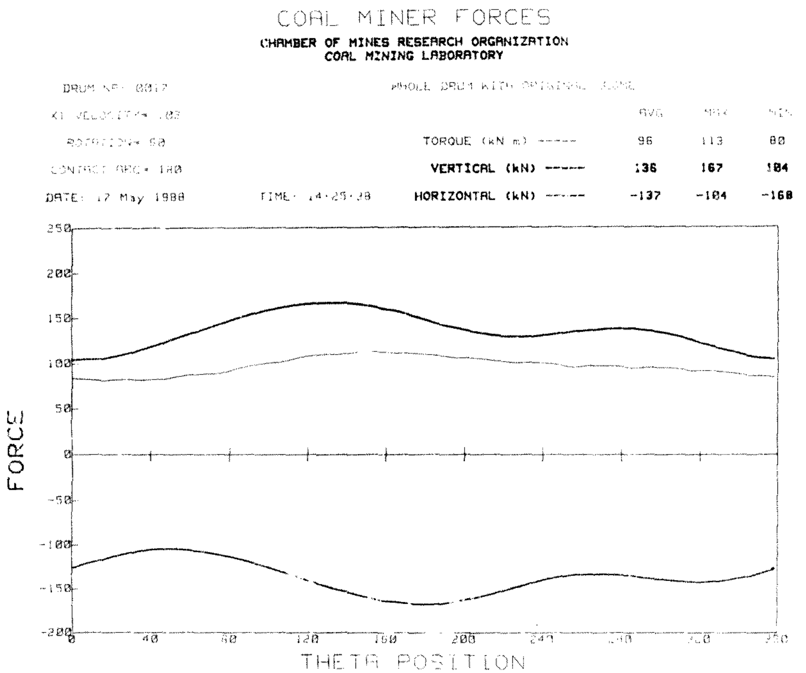
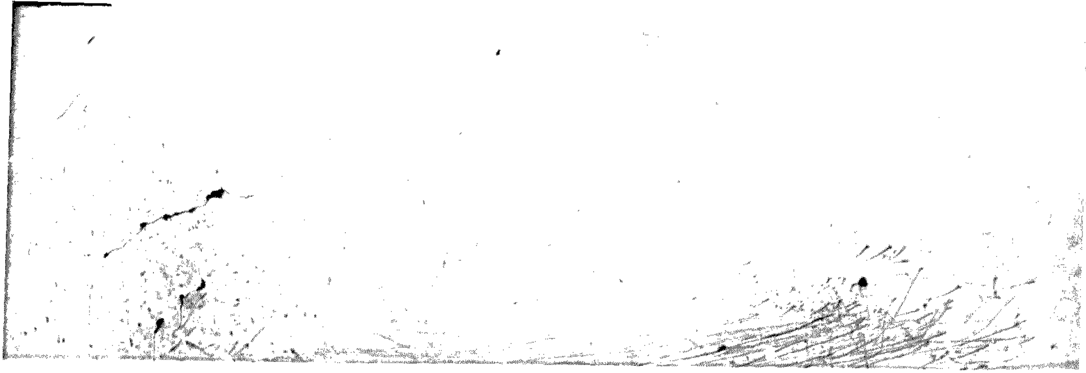


Figure C2 The acting forces and torque on the original drum



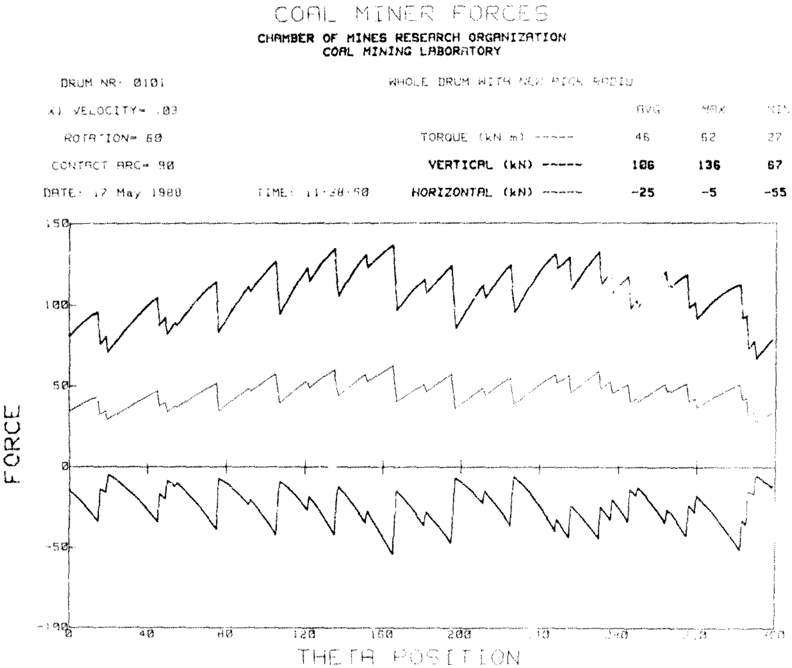


Figure C3 The acting forces and torque on the proposed drum

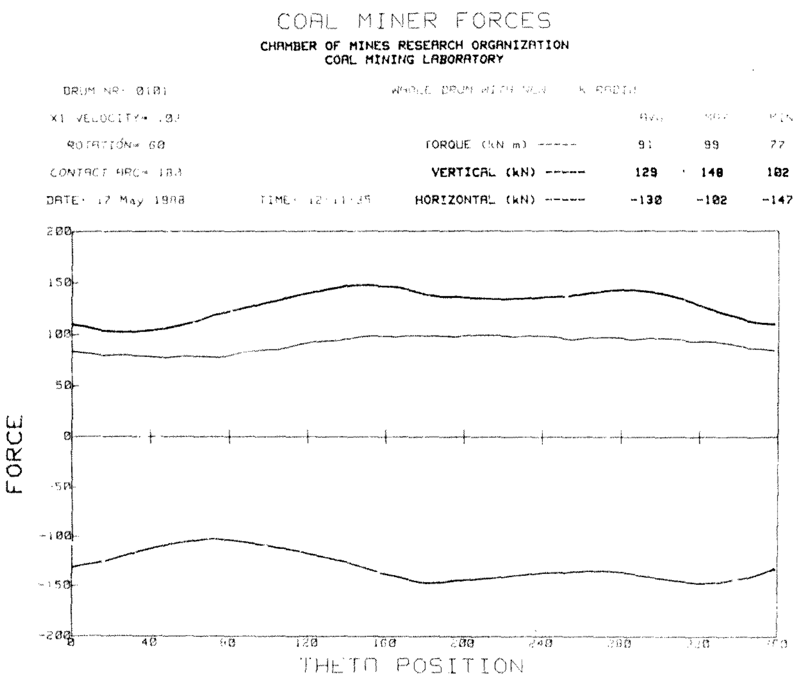


Figure C4 The acting forces and torque on the proposed drum

APPENDIX D

DESCRIPTION OF PICK CONDITIONS

This section details the following pick parameters which affect the cutting process.

* degree of sharpness of the pick
* pick shape
* skew angle of the pick

Table E1 in Appendix E details the effect of pick wear[17] on the cutting parameters P1 and P2. The pick wear classification is based on the wear profile and the mass loss of the pick. The wear profile classification is a visual categorization in an ascending order of wear as follows:

Class I	New condition.
Class II	Wear on insert and shoulder.
Class III	Increased wear on insert and shoulder but shoulder still clearly defined.
Class IV	Excessive wear of both insert and shoulder, the latter being worn away.
Class V	Non-rotation wear. Only root of insert still remaining. Shoulder non-existent.

The classes of wear are graphically presented in Figure D1.

Figure D2 shows the average wear profile of 6 groups of picks with similar mass loss in grammes, i.e each mass loss contour is the best curve fitting of number of picks with about the same mass loss.

Three picks of those mentioned in Table E3 (Appendix E) are drawn in Figure D3. According to Table E3, of all the three picks in Figure D3 the insert geometiy ' tl.e Kennametal full cup pick results in a lower requirement to cut the coal.

Figure D4 shows graphically the effect of the skew angle on the cutting force and normal force. The parameters P1 and E2 in Table E5 (Appendix E), are derived from this figure and shows that the greater the angle of skew, the higher tne forces required to perform a cut at the same depth.

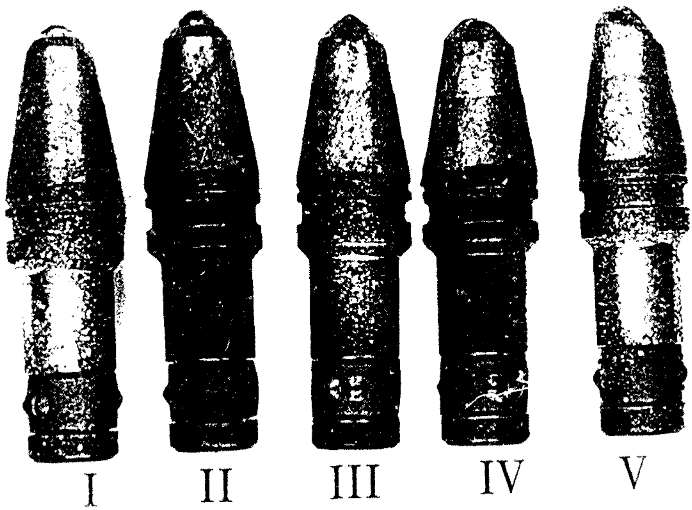


Figure D1 The pick classes of five Sandvik button picks

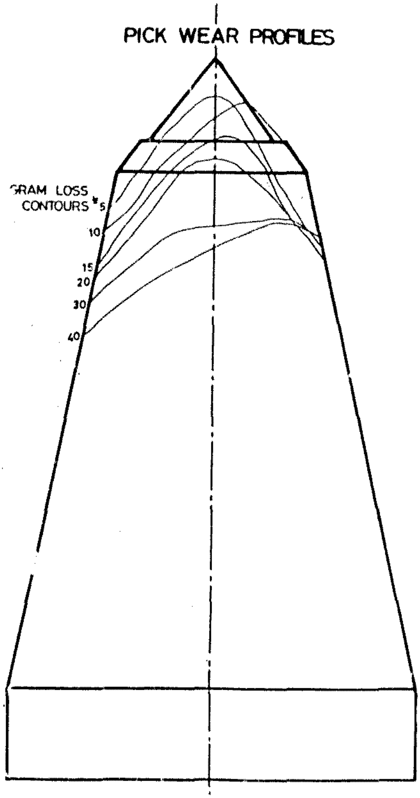
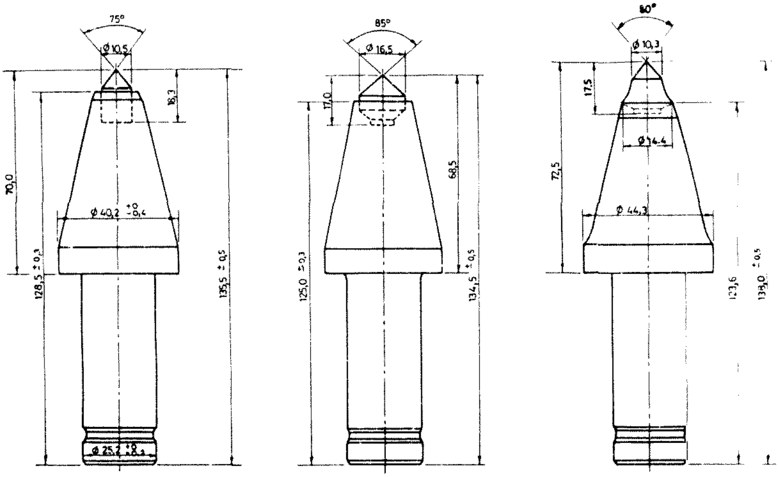


Figure D2 Various wear profiles of Hagersta point attack pick showing the average mass loss of the profile



FAGERSTA NORMAL PICK
MASS 637,1 grm

FAGERSTA CAPPED PICK
MASS 637,1 grm

KENNAMETAL – FULL CAP
MASS 654,6 grm

Figure D3 Various pick shapes

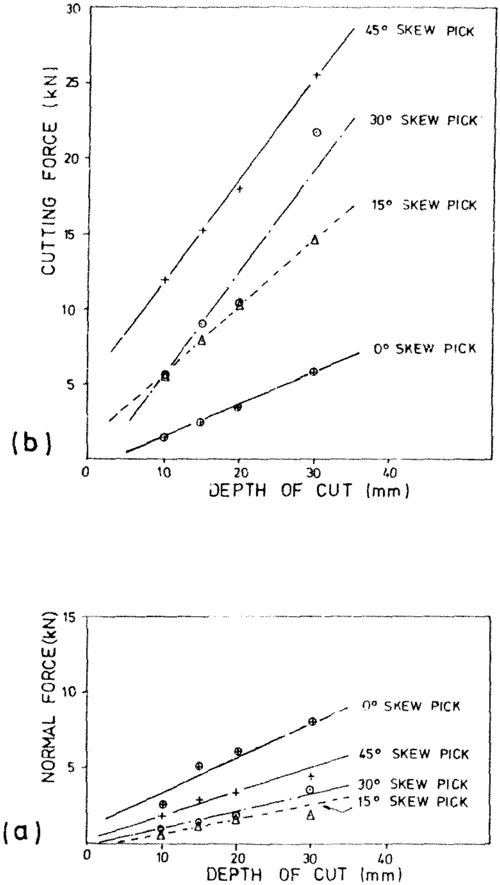


Figure D4 Comparison of various skew angle picks

APPENDIX E

PARAMET[illegible] AS AFFECTED BY VARIOUS CUTTING CONDITIONS

The cutting parameters P1 and P2 are used in CUTSIM for simulating most of the cutting conditions.

Tables E1 to E5 illustrate various values of P1 and P2 for simulating the following cutting conditions:

* degree of sharpness (bluntness) of the pick (or pick mass loss)[19]
* mineral type
* pick shape
* water jet assisted cutting[14]
* skew angle of the pick

Table E1 The cutting parameters P1 and P2 for various pick mass losses

Pick Class	Pick Shape	Type of Mineral	Pick spacing/Doc	P1	P2 kN/mm
I	Point attack	Phoenix no. 4 seam	1,71:1	5,35	0,14
II	Point attack	Phoenix no. 4 seam	1,71:1	4,88	0,15
III	Point attack	Phoenix no. 4 seam	1,71:1	2,55	0,17
IV	Point attack	Phoenix no. 4 seam	1,71:1	1,99	0,18
V	Point attack	Phoenix no. 4 seam	1,71:1	1,09	0,26

Table E2 The cutting parameters P1 and P2 for various coal seams

Type of Mineral	Pick spacing/Doc	Pick Shape	P1	P2 kN/mm
Majuba-Gus seam	3:1	Sandvik	0,71	0,34
No. 4 seam - Witbank		button insert	0,63	0,15
No. 2 seam - Douglas	3:1	Sandvik button insert	1,27	0,35

Table E3 The cutting parameters P1 and P2 for various pick shapes

Pick Shapes	Pick spacing/Doc	Type of Mineral	P1	P2 kN/mm
Fagersta-normal pick	3:1	Majuba-Gus seam	5,79	0,61
Fagersta-capped pick	3:1	Majuba-Gus seam	5,39	0,83
Kennametal-full cap	3:1	Majuba-Gus seam	6,84	0,59
Synpick-PCD (new pick)	3:1	Majuba-Gus seam	3,93	1,22
Sandvik-button insert	3:1	Majuba-Gus seam	0,71	0,34

Table E4 The cutting parameters P1 and P2 as affected by waterjet assisted cutting

Cutting Speed mm/s	Type of Mineral	Pick spacing/Doc	Pick Shape	P1 (dry)	P2 (dry) kN/mm	P1 (Water-jet)	P2 (Water-jet) kN/mm
90	Bosjes-spruit coal	3:1	Reinforced button-nose	0,66	0,14	0,54	0,07
580	Bosjes-spruit coal	3:1	Reinforced button-nose	0,56	0,1[illegible]	0,70	0,12
1070	Bosjes-spruit coal	3:1	Reinforced button-nose	0,63	0,20	0,79	0,15
3940	Bosjes-spruit coal	3:1	Reinforced button-nose	0,54	0,19	0,51	0,19

The results of water jet assisted cutting are based on tests carried out by S. McVey 1987[14].

Table E5 The cutting parameters P1 and P2 for various skew angles(*)

Skew Angle (degree)	Pick spacing/ Doc	Type of Mineral	Pick Shape	P1	P2 kN/mm
0	3:1	Majuba-Gus seam	Sandvik button-insert	0,64	0,36
15	3:1	Majuba-Gus seam	Sandvik button-insert	6,39	0,50
30	3:1	Majuba-Gus seam	Sandvik button-insert	5,78	0,65
45	3:1	Majuba-Gus seam	Sandvik button-insert	5,13	0,87

(*) A definition of skew angle is provided in Figure 5.1.

APPENDIX F

MANUAL CALCULATION OF FORCES AND TORQUE

Section 3.1.2 details the manual calculations of the numerical model of horizontal forces, vertical forces and torque. Table F1 details 26 different points of these manual calculations which were required in order to plot Figure 6.6. Two examples of the manual calculations for $\theta 1=10°$ and for $\theta 1=55°$ are detailed in Section 6.1. The same method was used to calculate the forces and torque for the other points.

Table F1 Manual calculation of forces for test drum in shearing mode

Degree	0	1	10	20	30	39	41	45	55	65	75	79	81	89	90	91	100	110	120	129	131	140	150	160	169	170
doc_1	-	0,5	5,2	10,3	25	18,9	19,7	21,2	24,6	27,2	29	29,4	29,6	29,6	30											
doc_2	-	-	-	-	-	-	0,5	2,6	7,8	12,7	17,2	18,9	19,7	22,3	23	21,3	26,0	28,2	29,5	29,6						
do_3	-	-	-		-	-	-	-	-	-	-	-	0,5	4,7	5,2	5,7	10,3	15	19,3	22,3	23,3	26,0	28,2	29,5	[illegible]9,6	30
θ_i																										
θ_1	-	1	10	20	30	39	41	45	55	65	75	79	81	89	90											
θ_2	-	-	-	-	-	-	1	5	15	25	35	39	41	49	50	51	60	70	80	89						
θ_3	-	-	-	-	-	-	-	-	-	-	-	-	1	9	10	11	20	30	40	49	51	60	70	80	89	90
$\alpha=\theta+\hat{i}=\theta+45$																										
α_1	-	46	55	65	75	84	86	90	100	110	120	124	126	134	95											
α_2	-	-	-	-	-	-	46	50	60	70	80	84	86	94	95	96	105	115	125	134						
α_3	-	-	-	-	-	-	-	-	-	-	-	-	46	54	55	56	65	75	85	94	96	105	115	125	134	135
F_1 Vertical	-	0,4	4,3	9,3	14,5	18,8	19,6	21,2	24,2	25,5	25,1	24,4	24,0	21,3	21,2											
F_2 Vertical	-	-	-	-	-	-	0,4	2,0	6,7	11,9	16,9	18,8	19,6	22,3	22,9	23,2	25,1	25,5	24,2	21,3						
F_3 Vertical	-	-	-	-	-	-	-	-	-	-	-	-	0,4	3,8	4,3	4,7	9,3	14,5	19,2	22,1	23,2	25,1	25,[illegible]	24,2	21,3	21,2
F Total·Cos α F_1 Horizontal	-	0,4	3,0	4,3	3,9	2,0	1,4	-	-4,3	-9,3	-14,5	-16,4	-17,4	-20,6	-21,2											
F_2 Horizontal	-	-	-	-		-	0,4	1,7	3,9	4,3	3,0	2,0	1,4	-1,6	-2	-2,4	-6,7	-11,9	-16,9	-20,6						
F_3 Horizontal	-	-	-	-	-	-	-	-	-	-	-	-	0,4	2,8	3	3,2	4,3	3,9	1,7	-1,6	-2,4	-6,7	-11,9	-16,9	-20,6	-21,2
F Total 0,3215 Torque 1	-	0,2	1,7	3,3	4,8	6,1	6,4	6,9	7,9	8,8	9,3	9,5	9,6	9,6												
Torque 2	-	-	-	-	-	-	0,2	0,8	2,5	4,1	5,6	6,1	6,4	7,2	7,4	7,5	8,4	9,1	9,5	9,6						
Torque 3	-	-	-	-	-	-	-	-	-	-	-	-	0,2	1,5	1,7	1,8	3,3	4,8	6,2	7,2	7,5	8,4	9,1	9,5	9,[illegible]	
Total Vertical	-	0,4	4,3	9,3	14,5	18,8	20.0	23,[illegible]	30,9	37,4	42,0	43,2	44,[illegible]	46,4	48,4	27,9	34,4	40,0	43,4	43,6	23.2	25,1	25,5	24,2	21,3	21,2
Total Horizontal	-	0,4	3,0	4,3	3,7	2,0	1,8	1,7	-4,0	-5,0	-11,5	-14,4	-15,6	-19,4	-20,2	0,8	-2,4	-8,0	-15,2	-22,2	-2,4	-6,7	-11,9	-16.9	-20,6	-21,2
Total Torque	-	0,2	1,7	3,3	4,8	6,1	6,6	7,7	10,4	12,9	14,9	15,6	16,2	18,3	18,8	9,3	11,7	13,9	15,7	16,8	7,5	8,4	9,1	9,5	9,6	9,7

APPENDIX G

TABULATED RESULTS OF LABORATORY COAL CUTTING

Results of all tests conducted for this report are listed here.

Test No. 1: Coal seam - Gus
Pick - Sandvik, button insert
DOC/spacing of cuts = 1:3
Coal surface condition prior to cutting - cut smooth

Table G1 Cutting Test No. 1

Cut No.	DOC [mm]	Fc [kN]	Fn [kN]	Fs [kN]	$\overline{Fc}$ [kN]	$\overline{Fn}$ [kN]	$\overline{Fs}$ [kN]
1	10	1,54	2,50	0,816	1,54	2,50	0,613
2	10	1,54	2,50	0,41			
3	15	2,5	5	0,735	2,5	5	0,78
4	15	2,5	5	0,816			
5	20	3,465	6,25	0,49	3,47	5,75	0,96
6	20	3,465	5,25	1,428			
7	30	6,16	10	1,632			
8	30	5	6,25	2,448			
9	30	5,775	7,5	0,816	5,77	8,15	1,63
10	30	5,39	8	2,448			
11	30	6,54	9	0,816			

Test No. 2: Coal seam - Gus
Pick - Fagersta normal pick
DOC/spacing of cuts = 1:3
Coal surface conditions prior to cutting - cut smooth

Table G2 Cutting Test No. 2

Cut No.	DOC [mm]	Fc [kN]	Fn [kN]	Fs [kN]	$\overline{Fc}$ [kN]	$\overline{Fn}$ [kN]	$\overline{Fs}$ [kN]
1	10	6,41	1,51	0,94	6,09	1,32	1,12
2	10	5,77	1,13	1,31			
3	15	9,62	1,7	2,06	10,58	1,7	1,45
4	15	11,54	1,7	0,83			
5	20	12,82	2,41	1,5	14,1	2,53	1,88
6	20	15,38	2,64	2,25			
7	30	17,95	3,32	0,75	17,95	3,1	1,13
8	30	17,95	2,87	1,5			

Test No. 3: Coal seam - Gus
Pick - Fagersta normal pick
DOC/spacing of cuts = 1:3
Coal surface conditions prior to cutting - cut smooth

Table G3 Cutting Test No. 3

Cut No.	DOC [mm]	Fc [kN]	Fn [kN]	Fs [kN]	$\overline{Fc}$ [kN]	$\overline{Fn}$ [kN]	$\overline{Fs}$ [kN]
1	10	6,41	1,51	0,94	6,09	1,32	1,12
2	10	5,77	1,13	1,31			
3	15	9,62	1,70	2,06	10,58	1,7	1,45
4	15	11,54	1,70	0,83			
5	20	12,82	2,41	1,5	14,1	2,53	1,88
6	20	15,38	2,64	2,25			
7	30	17,95	3,32	0,75	17,95	3,1	1,13
8	30	17,95	2,87	1,5			

Test No. 4: Coal seam - Gus
Pick - Kennametal, full cap
DOC/spacing of cuts = 1:3
Coal surface conditions prior to cutting - cut smooth

Table G4 Cutting Test No. 4

Cut No.	DOC [mm]	Fc [kN]	Fn [kN]	Fs [kN]	$\overline{Fc}$ [kN]	$\overline{Fn}$ [kN]	$\overline{Fs}$ [kN]
1	10	7,05	1,32	0,3	6,09	1,13	0,45
2	10	5,13	0,94	0,675			
3	15	7,7	1,6	0,68	8,33	1,55	0,86
4	15	8,97	1,5	1,03			
5	20	10,26	1,73	0,8	11,8	2,18	0,9
6	20	13,33	2,64	0,8			
7	30	17,95	2,79	1,35	17,31	2,53	[illegible]
8	30	16,67	2,26	2,81			

Test No. 5:

Coal seam - Gus
Pick - Sandvik button insert
Cutting with 15° skewed pick
DOC/spacing of cuts = 1:3
Coal surface conditions prior to cutting - cut smooth

Table G5 Cutting Test No. 5

Cut No.	DOC [mm]	Fc [kN]	Fn [kN]	Fs [kN]	$\overline{Fc}$ [kN]	$\overline{Fn}$ [kN]	$\overline{Fs}$ [kN]
1	10	5,1	0,6	-0,6	5,75	0,675	-0,6
2	10	6,41	0,75	-0,6			
3	15	7,7	1,06	-0,6	8,1	1,06	0,86
4	15	8,5	1,06	1,12			
5	20	9	1,5	0,75	10,25	1,7	1,12
6	20	11,5	1,9	1,5			
7	30	17,9	2,3	0,75	14,7	2,1	1,69
8	30	11,5	1,9	2,63			

Test No. 6:

Coal seam - Gus
Pick - Sandvik, button insert
DOC/spacing of cuts = 1:3
Coal surface conditions prior to cutting - cut smooth

Table G6 Cutting Test No. 6

Cut No.	DOC [mm]	Fc [kN]	Fn [kN]	Fs [kN]	$\overline{Fc}$ [kN]	$\overline{Fn}$ [kN]	$\overline{Fs}$ [kN]
1	10	6,15	1,0	0,45	5,65	1,06	0,49
2	10	5,15	1,13	0,53			
3	15	10,26	1,66	0,3	8,97	1,58	0,3
4	15	7,69	1,51	0,3			
5	20	10,26	2,11	0,75	10,26	1,81	0,75
6	20	10,26	1,51	0,75			
7	30	23,08	3,77	1,51	21,8	3,58	1,3
8	30	23,51	3,39	1,12			

Test No. 7: Coal seam - Gus
Pick - Sandvik button insert
Cutting with 45° skewed pick
DOC/spacing of cuts = 1:3
Coal surface conditions prior to cutting - cut smooth

Table G7 Cutting Test No. 7

Cut No.	DOC [mm]	Fc [kN]	Fn [kN]	Fs [kN]	$\overline{Fc}$ [kN]	$\overline{Fn}$ [kN]	$\overline{Fs}$ [kN]
1	10	12,82	2,26	0,75	12,18	1,81	0,675
2	10	11,54	1,36	0,6			
3	15	15,38	3,02	0,8	15,38	2,95	0,8
4	15	15,38	2,87	0,8			
5	20	17,95	3,45	1,05	17,95	17,95	1,03
6	20	17,95	3,39	1,0			
7	30	25,64	4,52	1,8	25,32	25,32	1,75
8	30	25,0	4,8	1,7			

APPENDIX H

LACING PATTERNS USING LEE NORSE TESTS

All data concerning the lacing patterns and other data such as the geometry of the pick holders, was obtained from the manual 'Lee Norse miner' - Ingersoll Rand, Underground mining equipment, model CM456-2 -2R, date 3.5.1976, and drawings CM-1303 bit pattern.

Figure H1 details the various pick holders used a during the Lee Norse tests.

Figures H2 - H5 detail the four different pick lacings of the drums which were simulated, using 50,100,150 and 200 mm pick spacings.

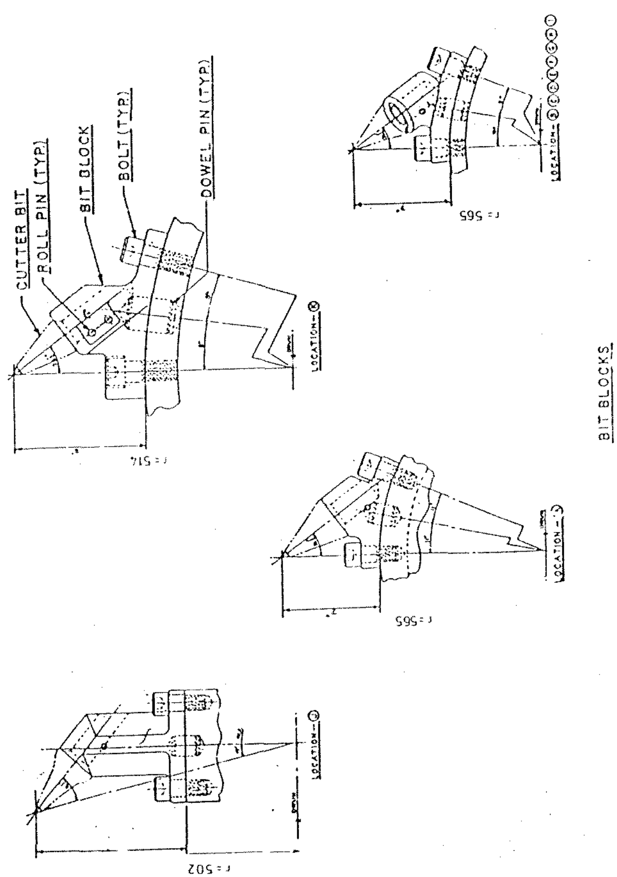


Figure H1 Various pick holders used at Lee Norse tests

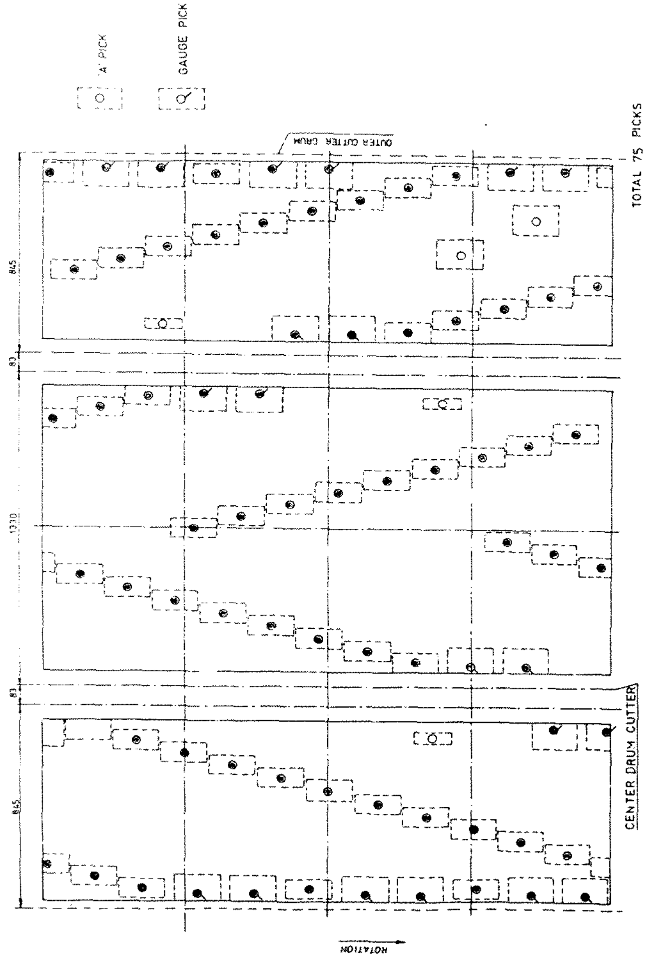


Figure H2 Pick lacing pattern for 50 mm spacing

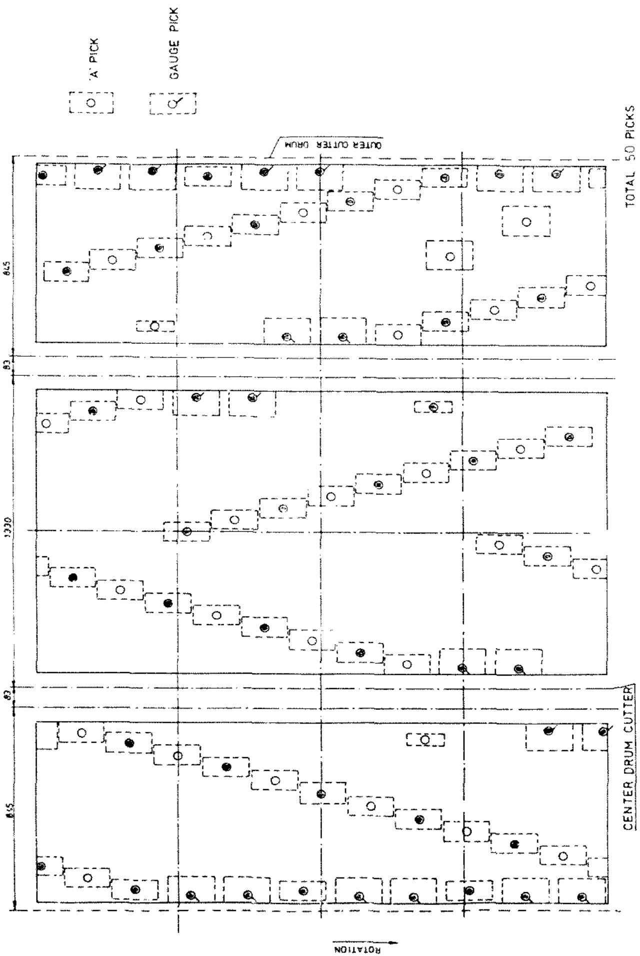


Figure H3 Pick lacing pattern for 100 mm spacing

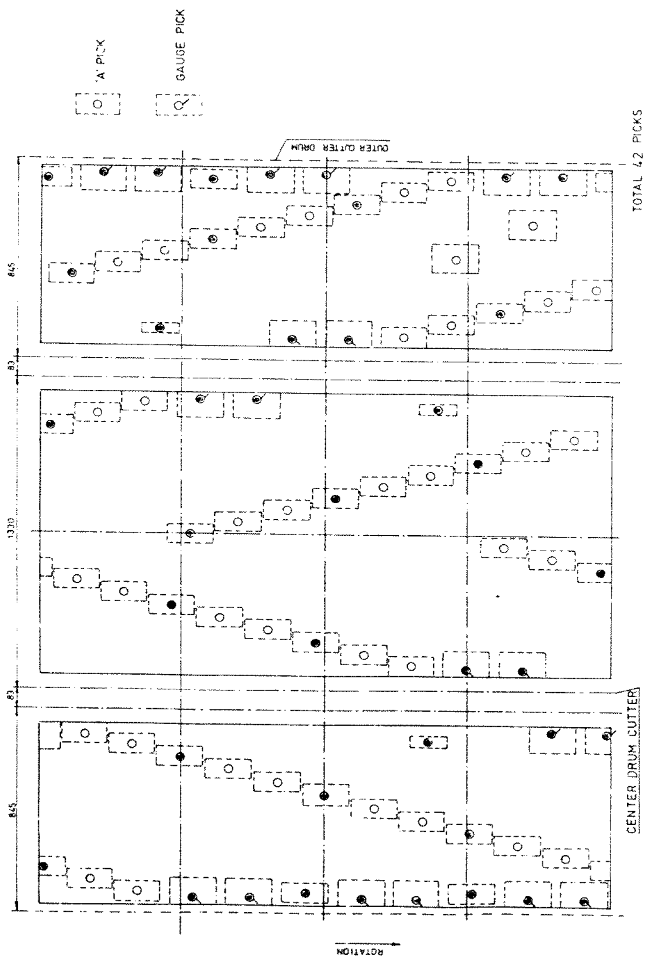


Figure H4 Pick lacing pattern for 150 mm spacing

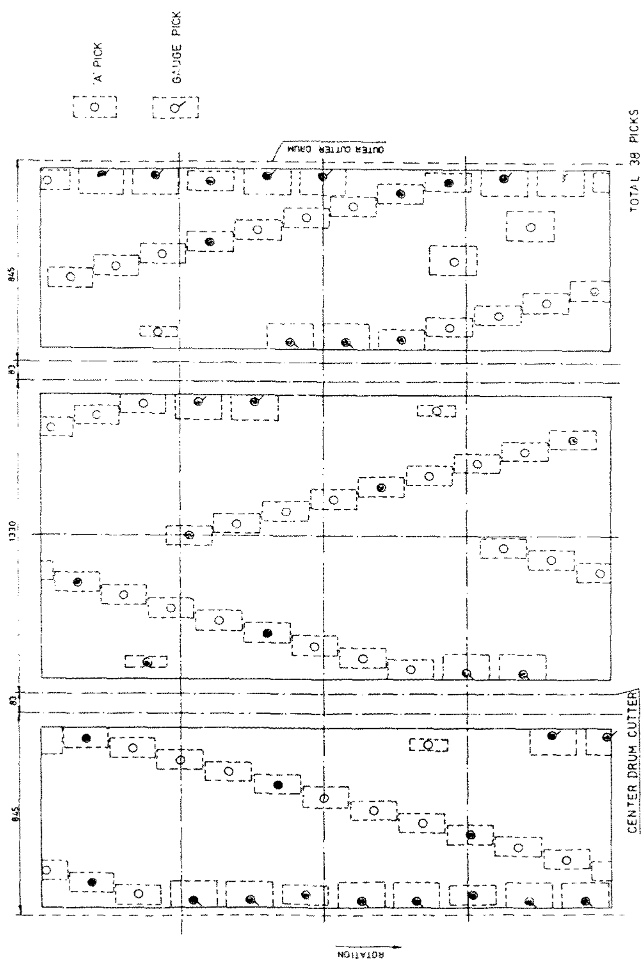


Figure H5 Pick lacing pattern for 200 mm spacing

APPENDIX I

CUTSIM SIMULATION OUTPUT OF LEE NORSE PICK LACING

The four different lacing patterns used during the Lee Norse underground tests weresimulated with CUTSIM as four different drums numbered 0027 to 0030. See Table 6.2 and Section 6.2.

The cutting simulations were made for 90° arc of contact as shearing mode and 180° as sumping mode.

Figures I1 to I8 detail the CUTSIM simulations of the Lee Norse pick lacings and give the vertical force horizontal force and torque for each lacing.

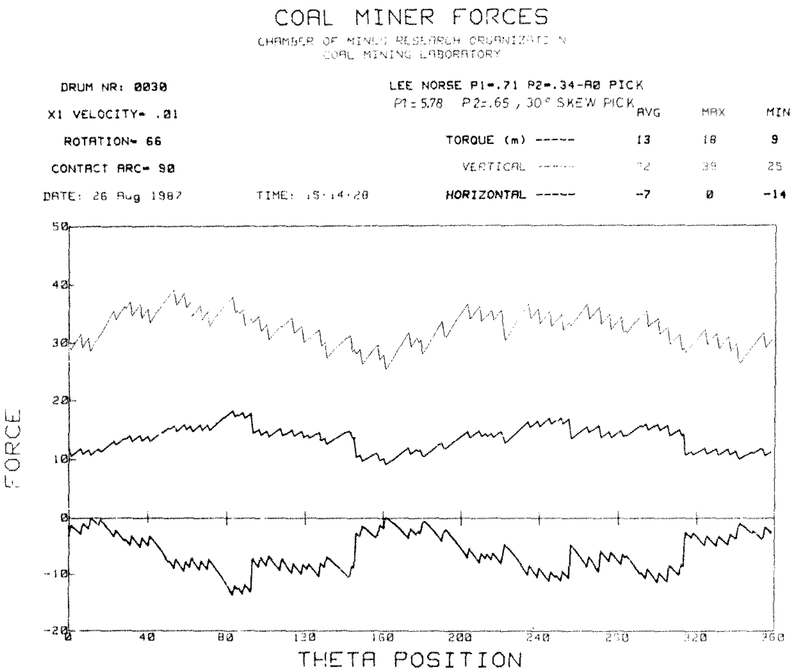
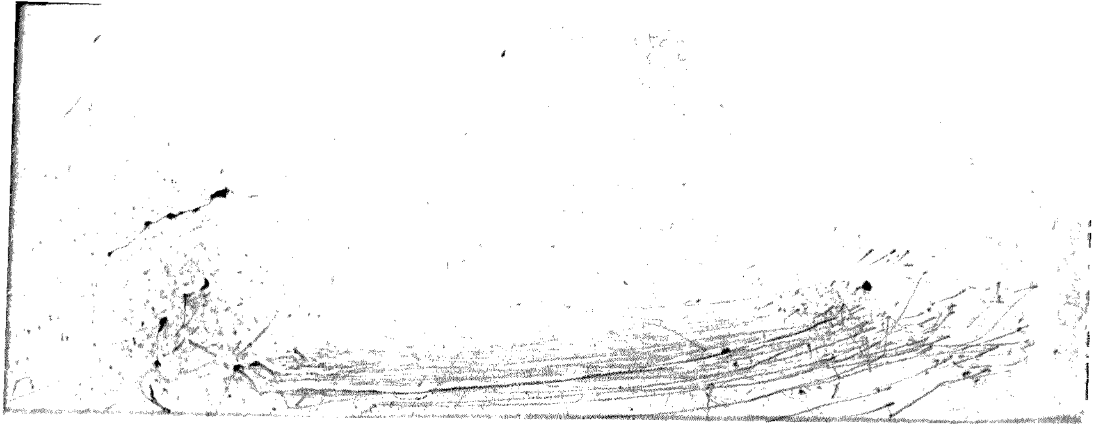


Figure 11 CUTSIM simulation of Lee Norse drum



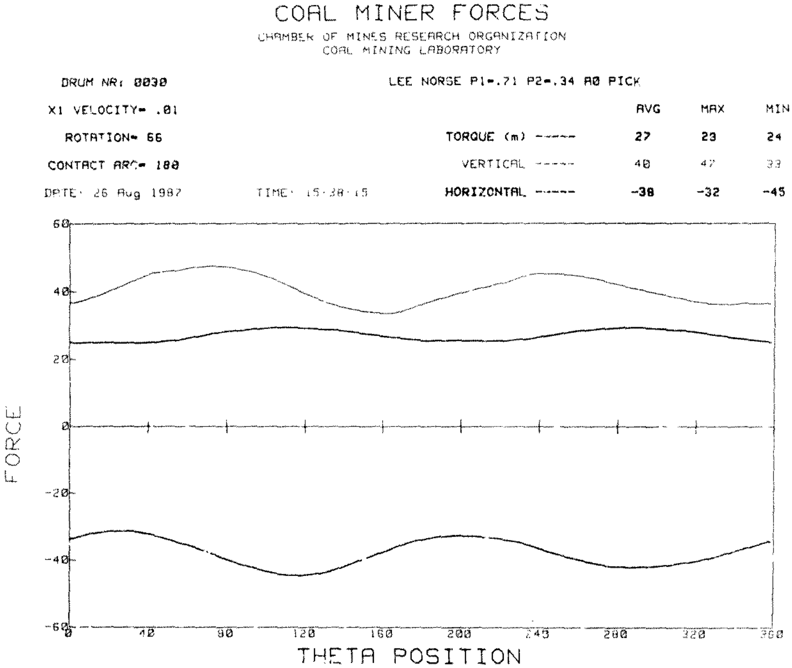


Figure 12 CUTSIM simulation of Lee Norse drum

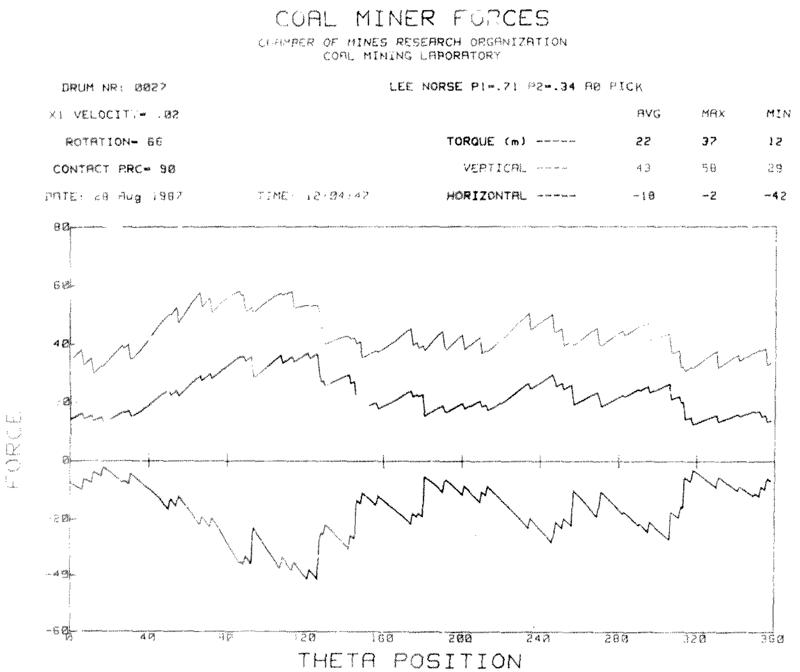
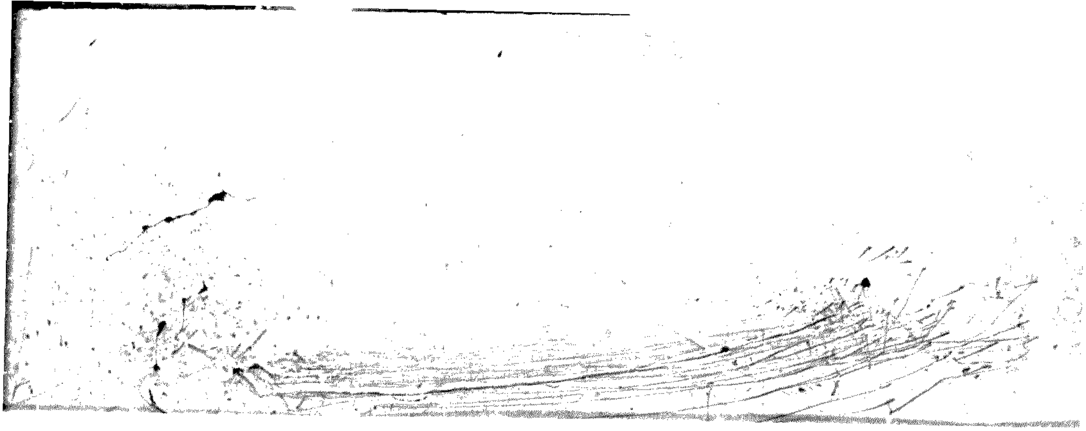


Figure I3 CUTSIM simulation of Lee Norse drum



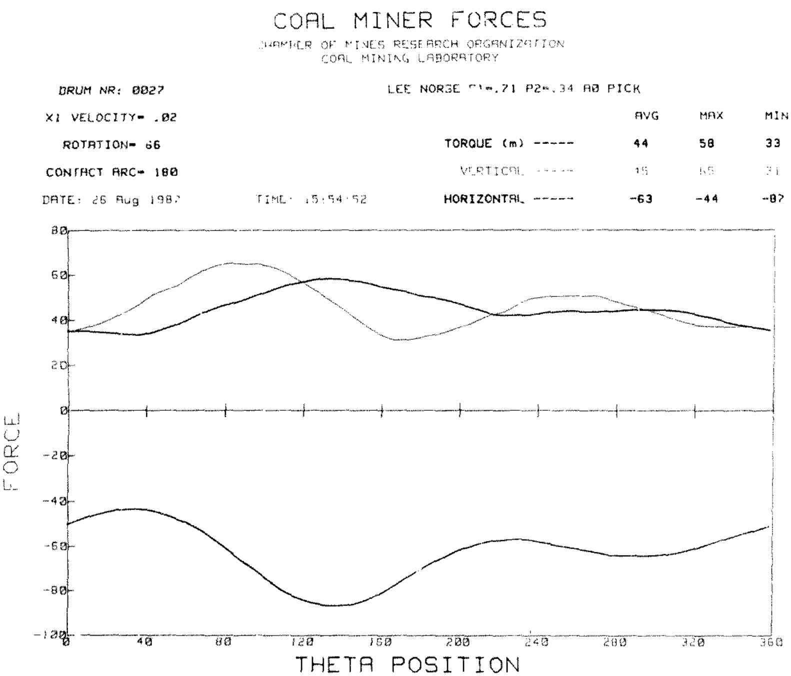
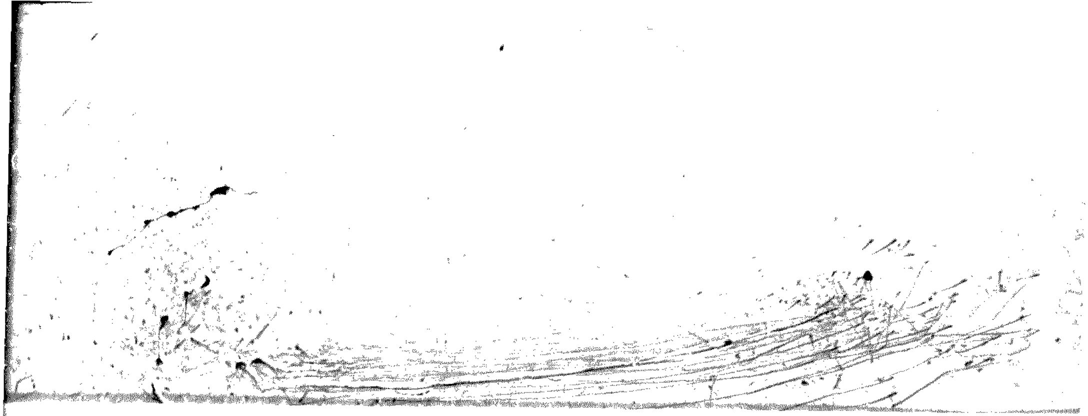


Figure I4 CUTSIM simulation of Lee Norse drum



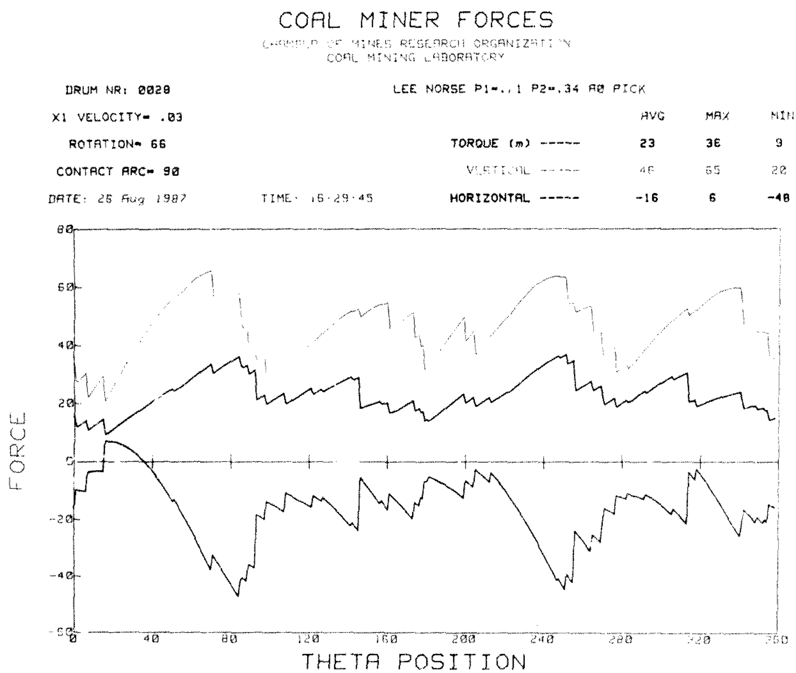


Figure 15 CUTSIM simulation of Lee Norse drum

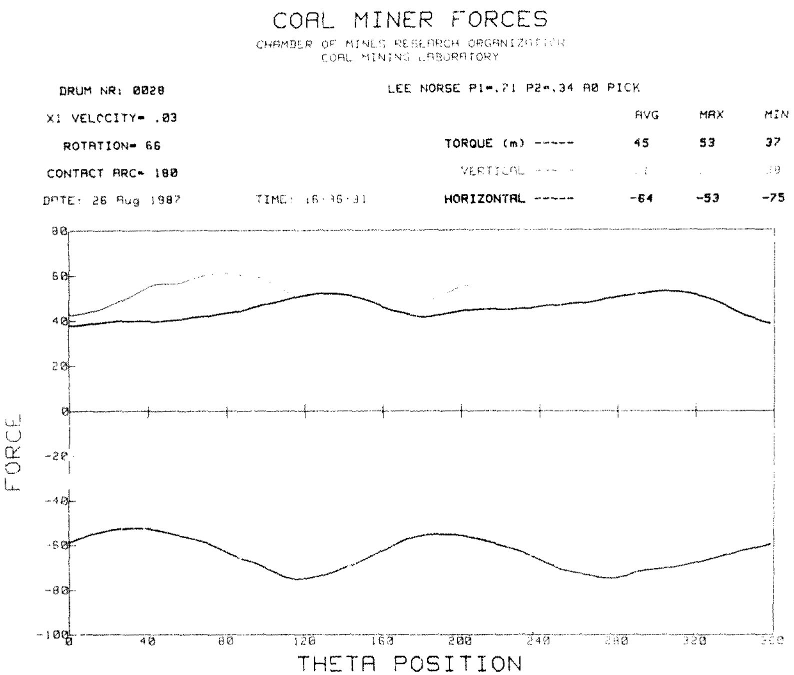


Figure I6 CUTSIM simulation of Lee Norse drum

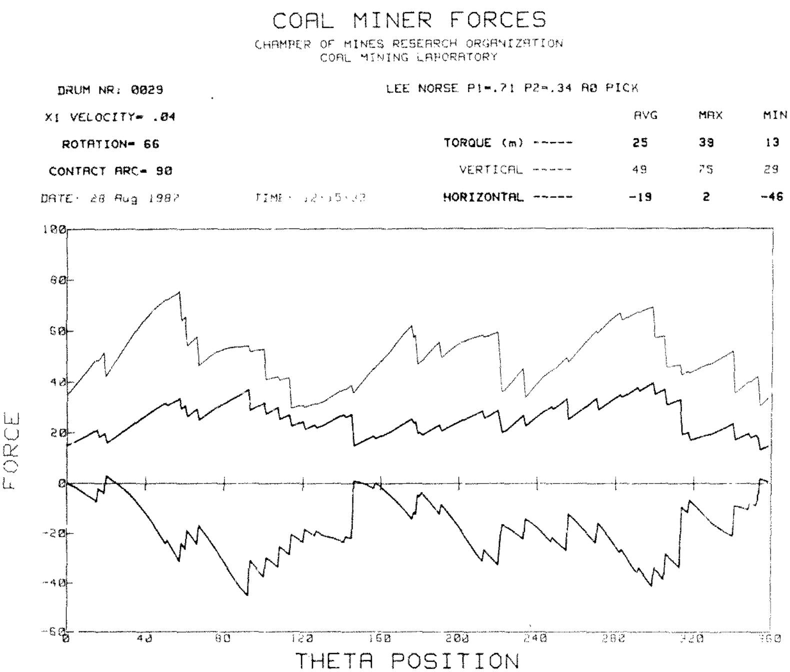


Figure 17 CUTSIM simulation of Lee Norse drum

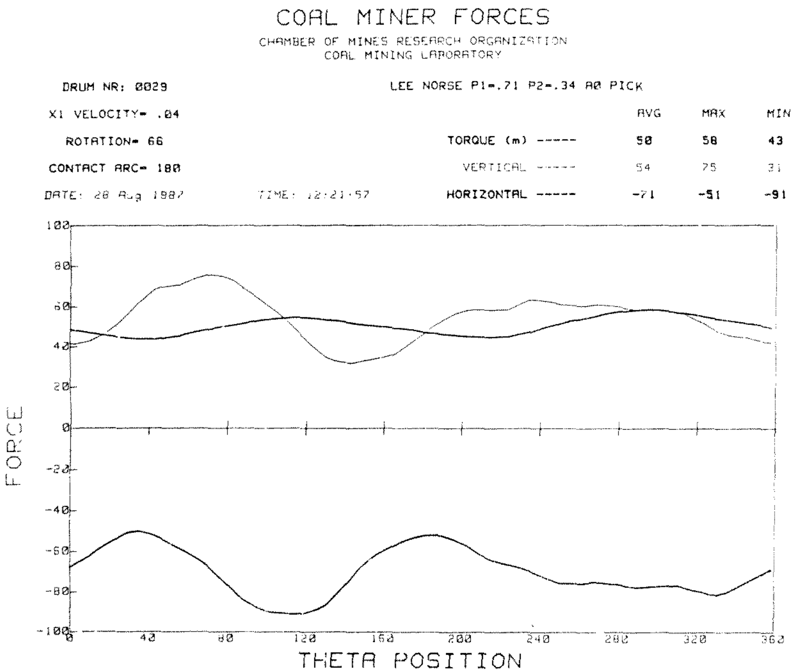


Figure 18 CUTSIM simulation of Lee Norse drum

APPENDIX J

UNDERGROUND TESTS AT NEW DENMARK COLLIERY AND THE SUBSEQUENT SIMULATIONS

See also Section 6.3.

This section details the results of eight cutting tests, using a Joy 14CM 9 continuous miner with different pick lacings. All tests were conducted at New Denmark in the same day and cutting with the same type of pick, Sanvik, button insert.

The first four cutting tests were conducted by the author as part of CUTSIM validations and the results are as follows:

Figure J1 shows the original lacing of this drum using 80 picks. The penetration rate was poor with this lacing.

Figure J2 details the cutting profile of the original 80 pick drum. Note the effect of double cutting per cycle in the central drum. The difficulties in cutting appear to be due to an overlaced drum.

Figure J3 shows the acting forces and torque for the shearing mode.

Figure J4 shows the acting forces and torque for the sumping mode.

The second cutting run was done in order to show that a reduction of the number of picks from 80 to 67 could enhance the continuous miner performance.

Figure J5 details the lacing of this test, using 67 picks only.

Figure J6 gives the cutting profile of the 67 pick lacing and shows that the double cutting problem on the central drum has been eliminated, although two extra picks, which were added to each side of the drum (Picks 6 and 44), were cutting twice per cycle.

Figure J7 shows the acting forces and torque for the shearing mode and shows that the 67 pick drum tends to generate more vibrations than the 80 pick drum, although the average acting forces and torque of the second drum are lower by 4 per cent.

A similar result of increased vibration is shown in Figure J8 for the acting forces and torque of the sumping mode.

In order to reduce the vibration of the drum, a third lacing test was performed. Picks number 1 and 40 both at theta position of 180°, (see Figure J9) were removed from the gauge cutters on each side of the drum and placed in the internal gauge cutters of the same drum (picks No. 12 and 46). Two extra gauge cutters were added to the central drum (picks 29 and 37).

The cutting profile of this lacing is shown in Figure J10. Note that picks 6 and 44 are still cutting twice per cycle. The last pick lacing results in much less vibration as was confirmed during the underground tests.

This is also supported by the CUTSIM output shown in Figure J11. The trend of the average acting forces and torque is smoother and about 3 per cent higher than the second test results. However, the maximum of the acting forces and torque is lower by about 2 per cent and this contributes to less vibration. This smoother cutting action is shown also in Figure J12 for the sumping mode.

In the last cutting test, the four picks (picks 6 and 44) which are still cutting twice per cycle were removed. This resulted in the final lacing of 65 picks only (19 per cent reduction) as shown in Figure J13. Figure J14 shows the cutting profile of this drum. Note the unified profile in all drum sections. This lacing contributes to further reduction in any force component and torque. See Figure J15 and J16 for shearing and sumping modes respectively. In comparison to the original lacing of 80 picks, there is up to a 15 per cent reduction in maximum horizontal forces, up to 7 per cent reduction in the required maximum torque and a better cutting performance for the shearing mode.

The last four cutting tests were conducted by the technical staff of Joy and the following results were received:

Test No. 1: Lacing pattern of 110 picks (See Figure J17)

Table J1 Cutting test using 110 picks

	Shearing mode		Sumping mode	
	Length[mm]	Time [s]	Length[mm]	Time [s]
	634 634	50 53	600 550 700	40 45 54
Average rate [mm/s]	12.3		1.35	
DC Volt [V]				
Cutter head amps [A]	80-100		90-100	

Test No. 2: Lacing pattern of 98 picks (See Figure J18)

Table J2 Cutting test using 98 picks

	Shearing mode		Sumping mode	
	Length[mm]	Time [s]	Length[mm]	Time [s]
	734 734	29 30	800 700 800 840	40 32 50 49
Average rate [mm/s]	24,9		18,4	
DC volt [V]	45-55		45-55	
Cutter head amps [A]	80-100		80-95	

<u>Test No. 3</u>: Lacing pattern of 80 picks (See Figure J19)

Table . Cutting test using 80 picks

	Shearing Mode		Sumping Mode	
	Length[mm]	Time [s]	Length[mm]	Time [s]
	814 814 814	18 22 20	800 650 750 650 1000	40 26 36 26 47
Average rate [mm/s]	40,7		22	
DC volt [V]	45-55		45-55	
Cutter head amps [A]	90-110		75-95	

<u>Test No. 4</u>: Lacing pattern of 66 picks (See Figure J20)

Table J4 Cutting test using 66 picks

	Shearing Mode		Sumping Mode	
	Length[mm]	Time [s]	Length[mm]	Time [s]
	535 535 535	15 17 15	700 500 740 535	53 35 39 15
Average rate [mm/s]	34,1		15,3	
DC volt [V]	90-120		45-55	
Cutter head amps [A]	090-12		90-100	

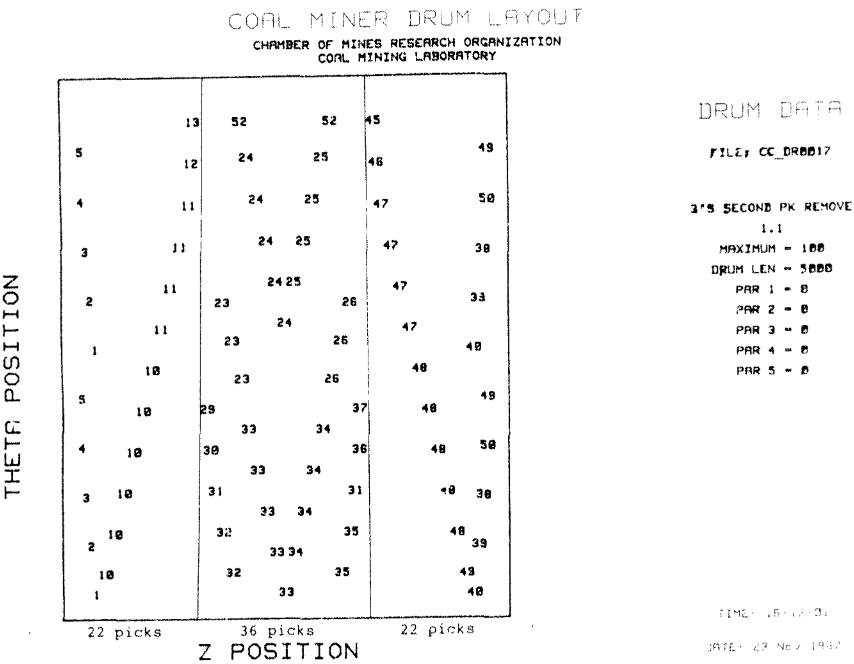
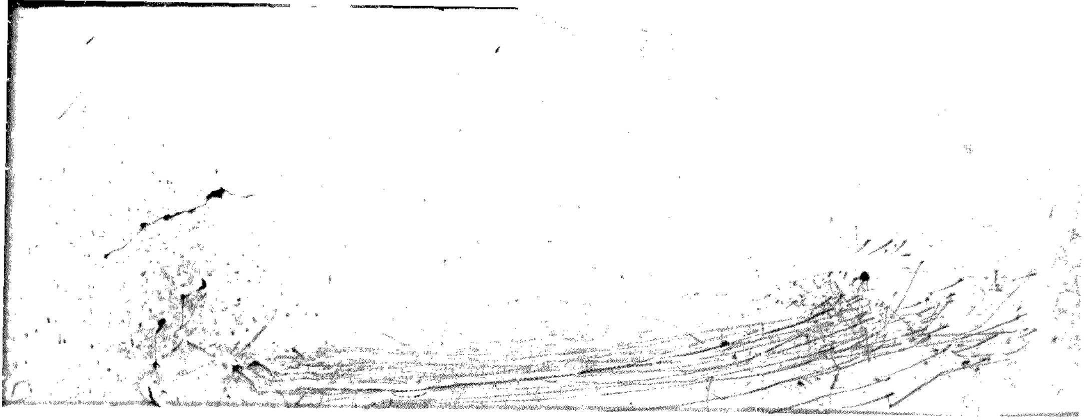


Figure J1 The lacing of the test drum using 80 picks



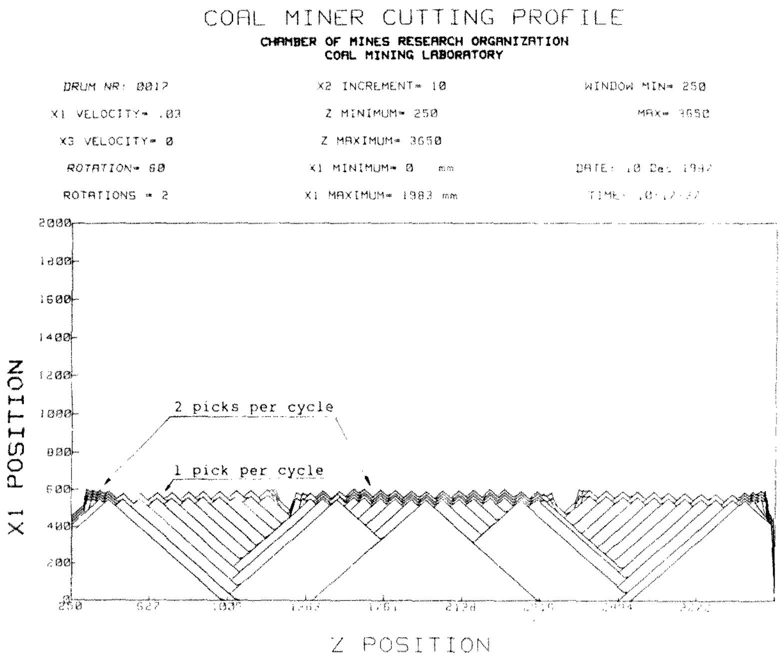
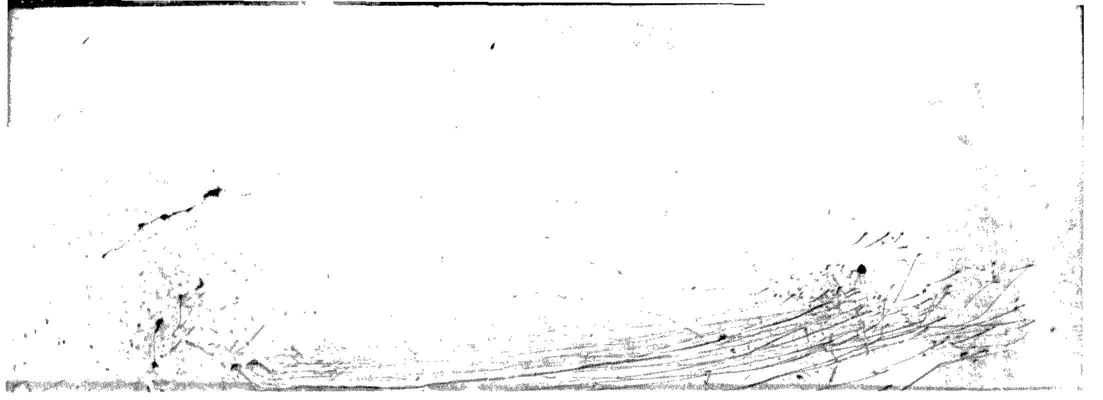


Figure J2 The cutting profile of the 80 picks drum



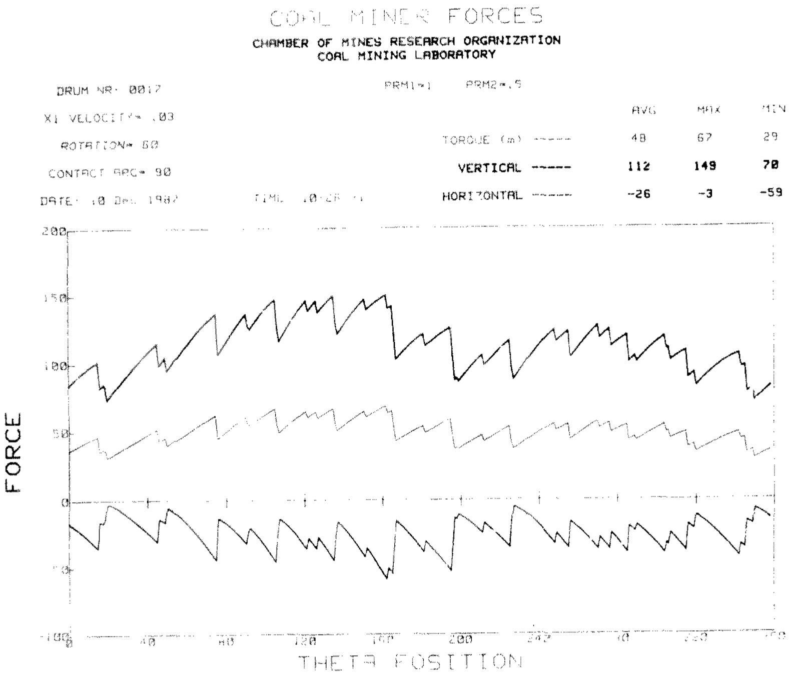
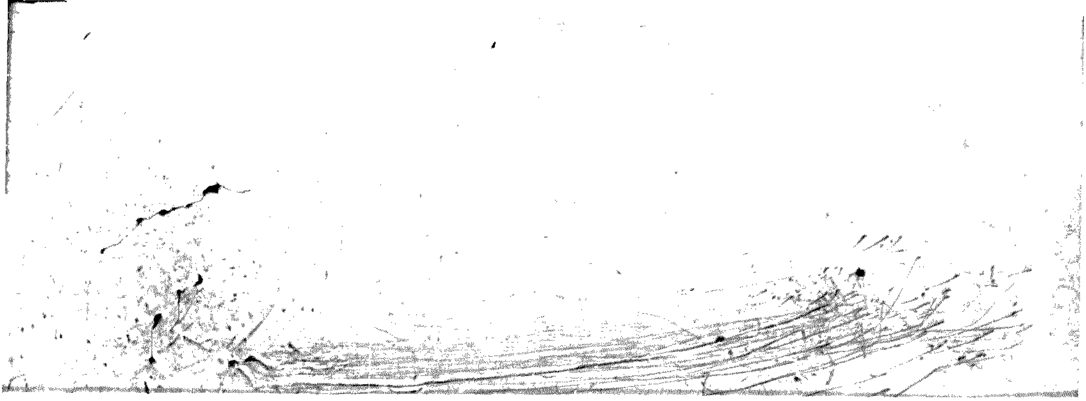


Figure J3 The forces acting and torque on the 80 picks drum



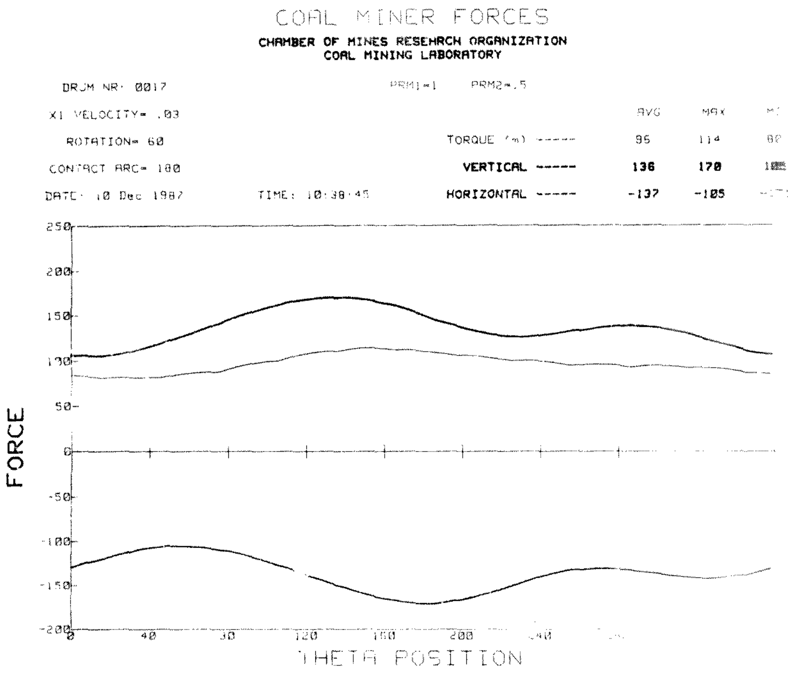


Figure J4 The forces acting and torque on the 80 picks drum

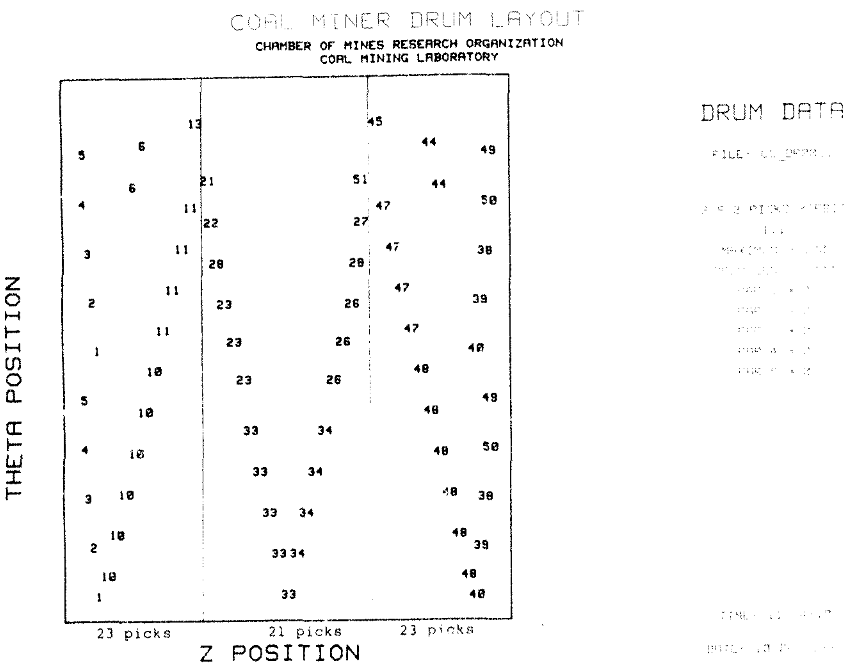


Figure J5 The lacing of the test drum using 67 picks

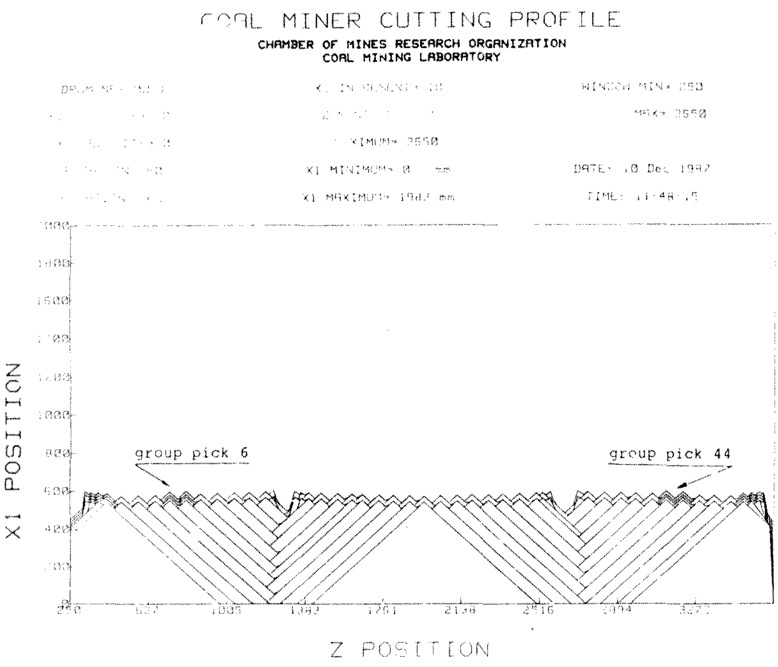
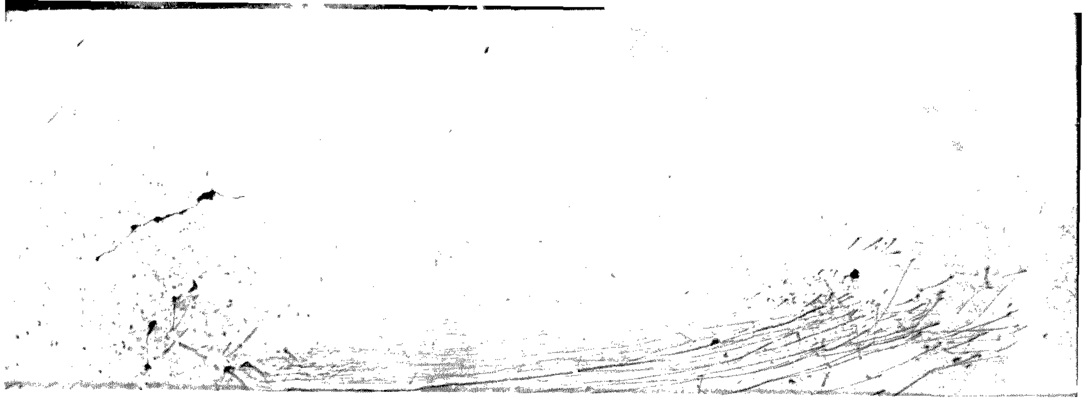


Figure J6 The cutting profile of the 67 picks drum



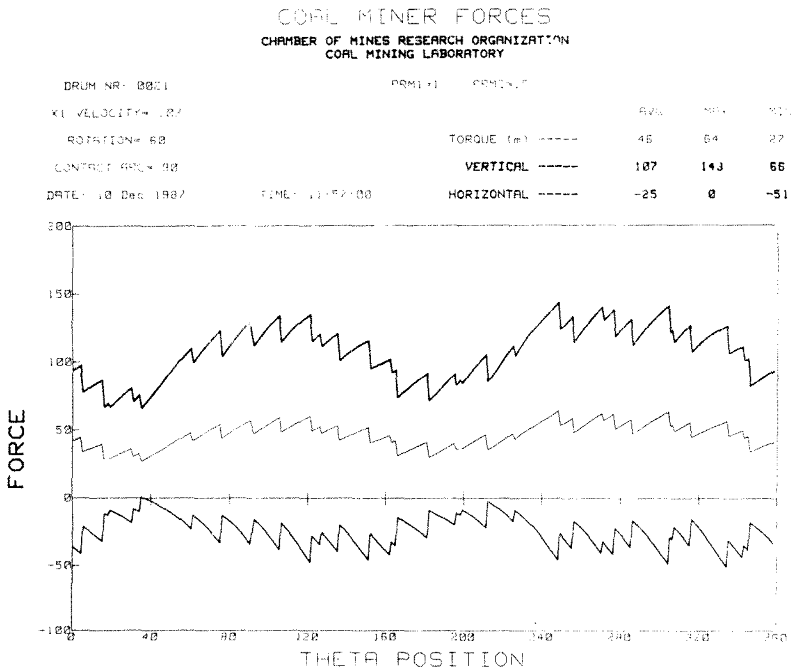
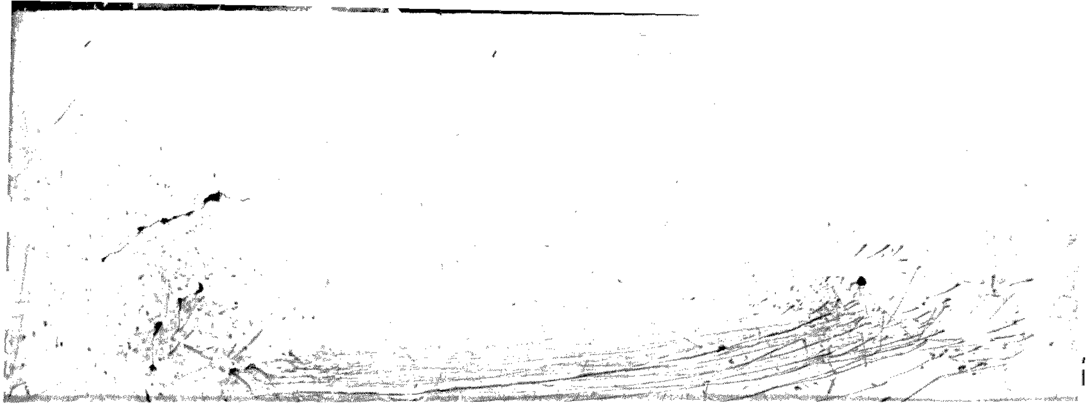


Figure J7 The forces acting and torque on the 67 picks drum



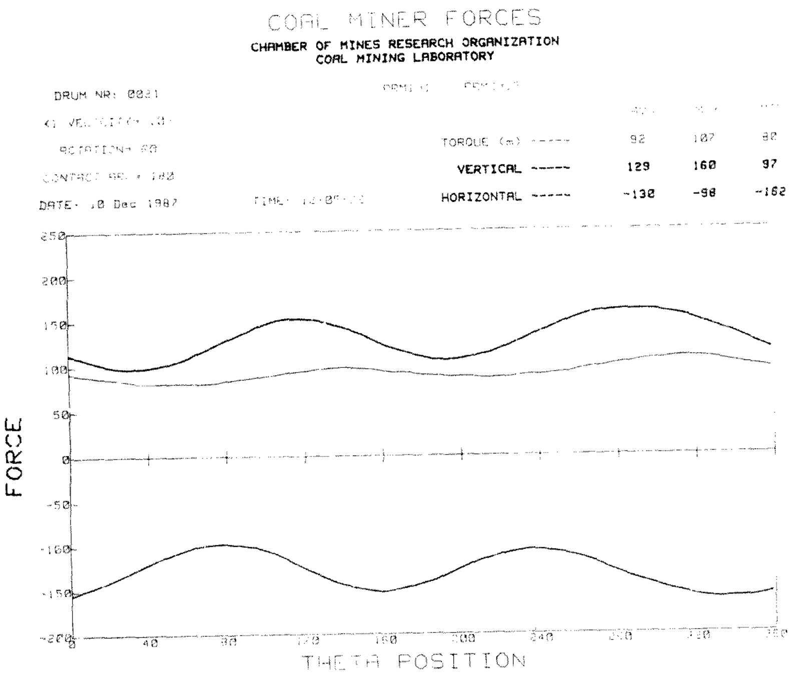


Figure J8 The forces acting and torque on the 67 picks drum

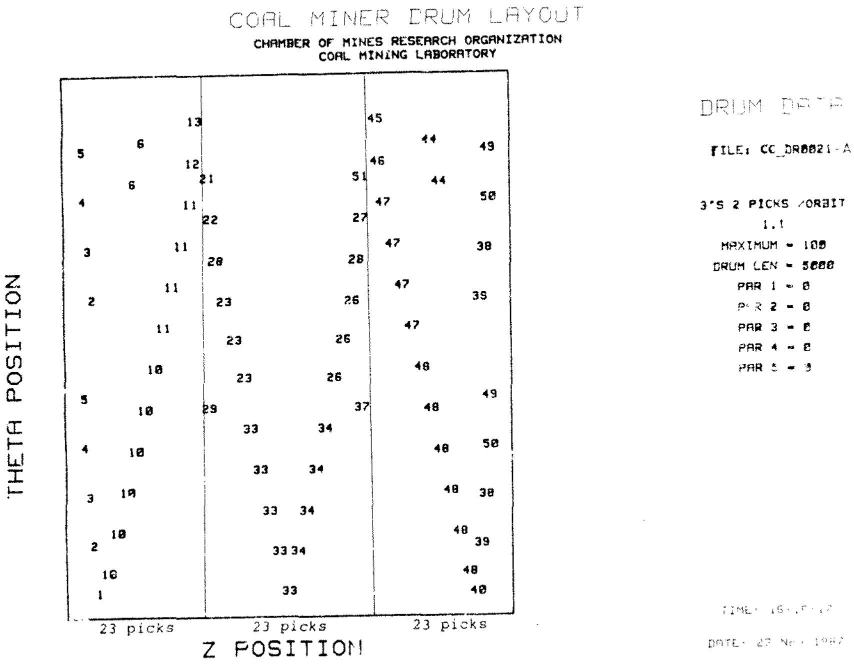
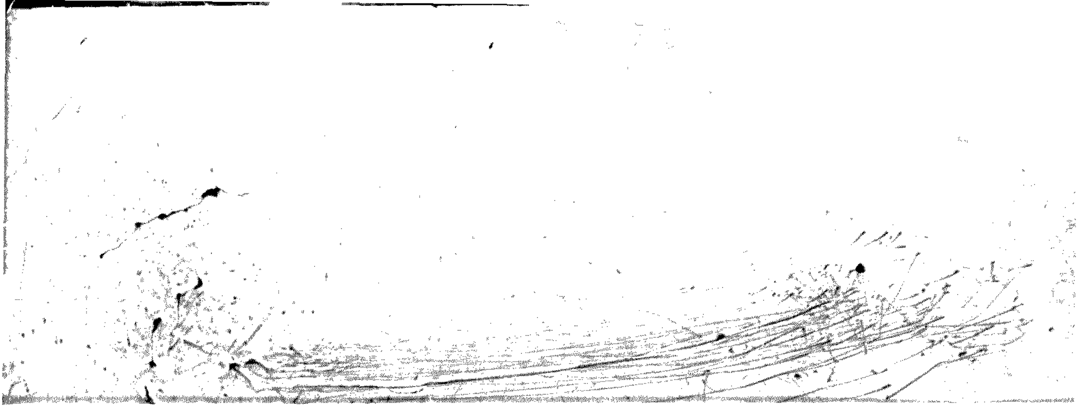


Figure J9 The lacing of the test drum using 69 picks



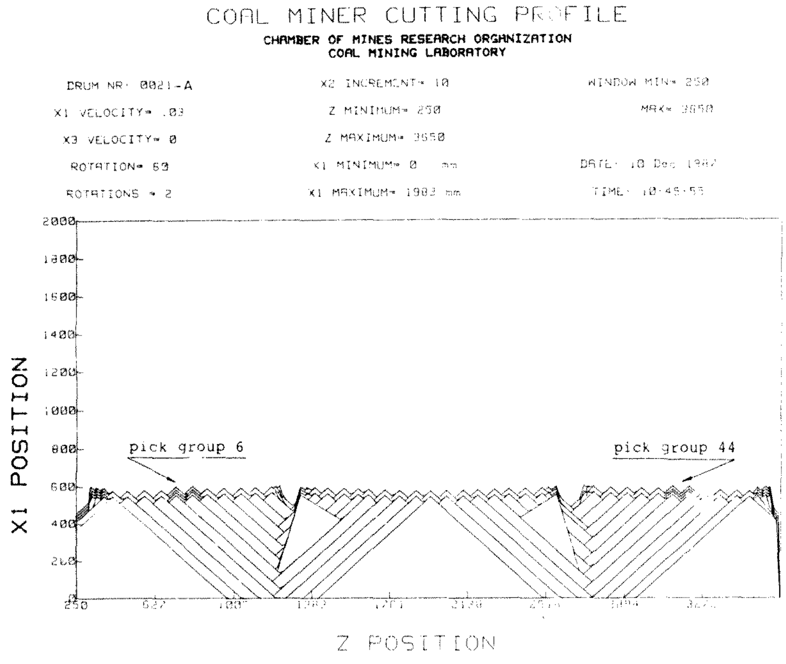
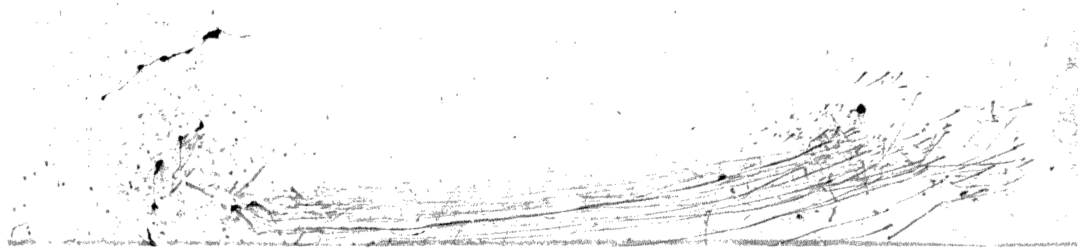


Figure J10 The cutting pr file of the 69 picks drum



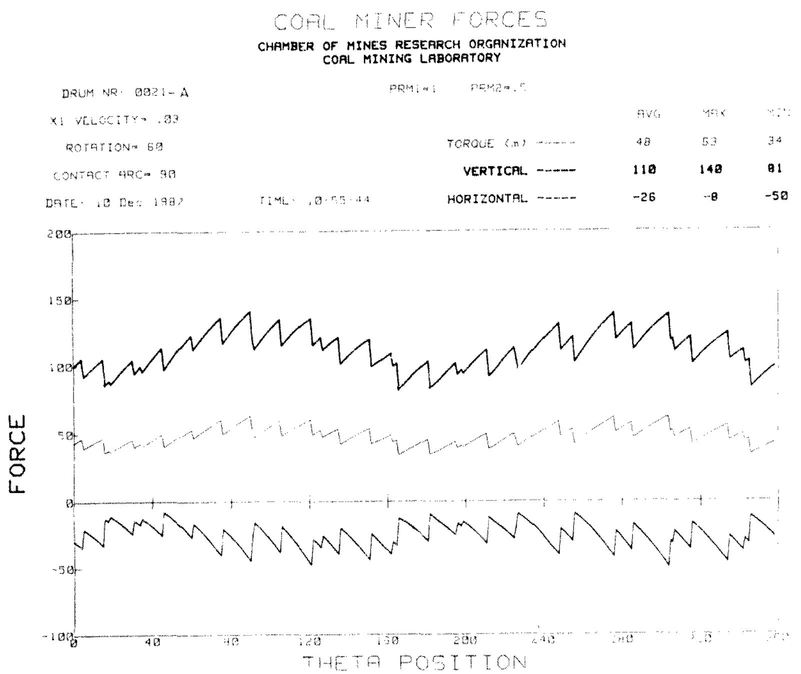


Figure J11 The forces acting and torque on the 69 picks drum

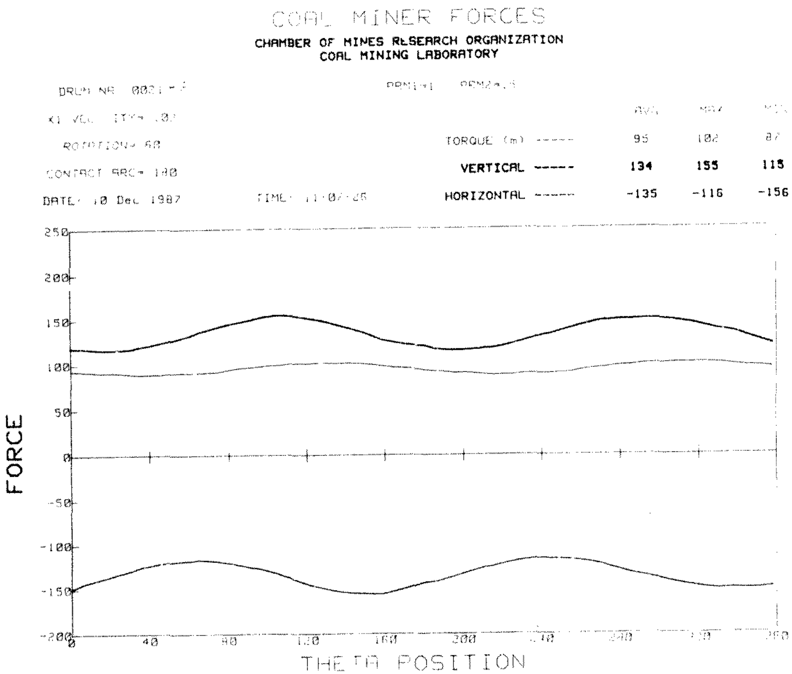
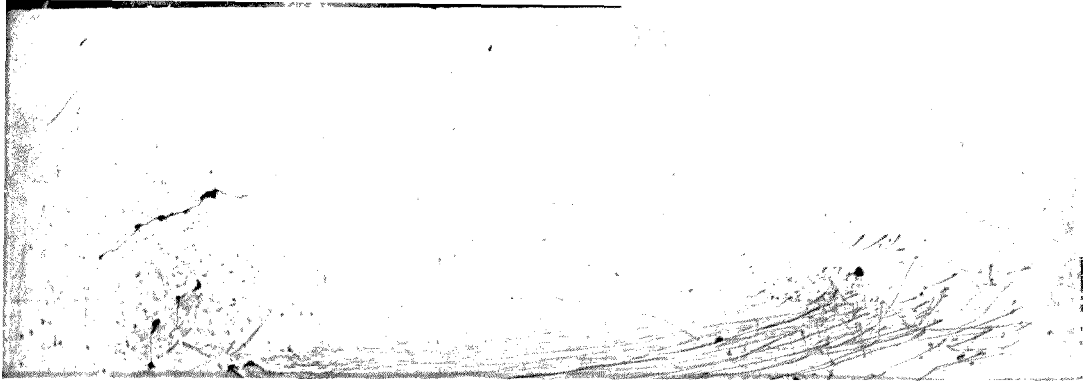


Figure J12 The forces acting and torque on the 69 picks drum



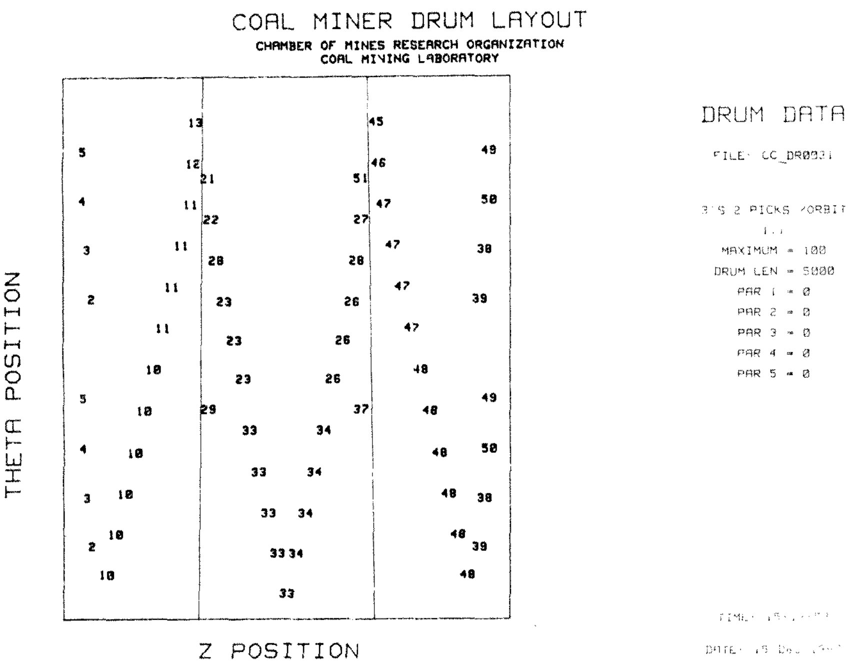


Figure J13 The lacing of the test drum using 65 picks

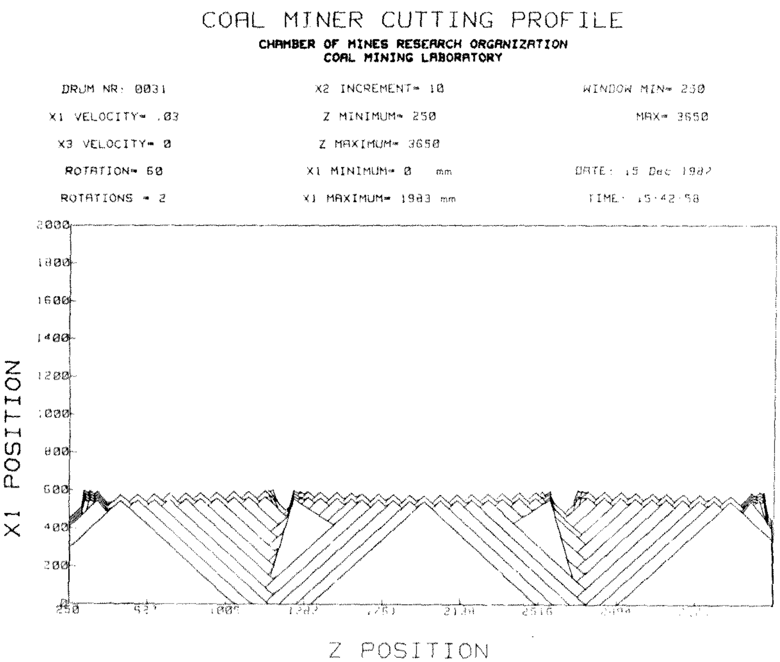
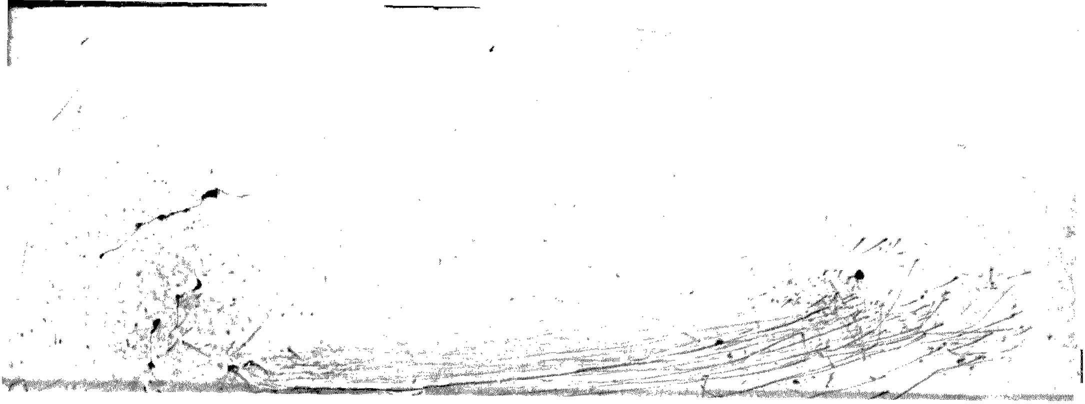


Figure J14 The cutting profile of the 65 picks drum



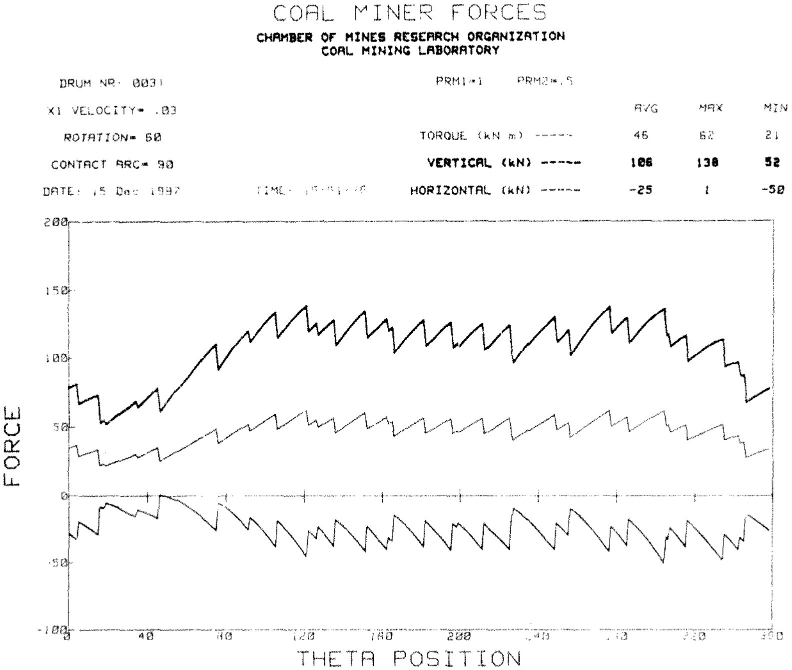
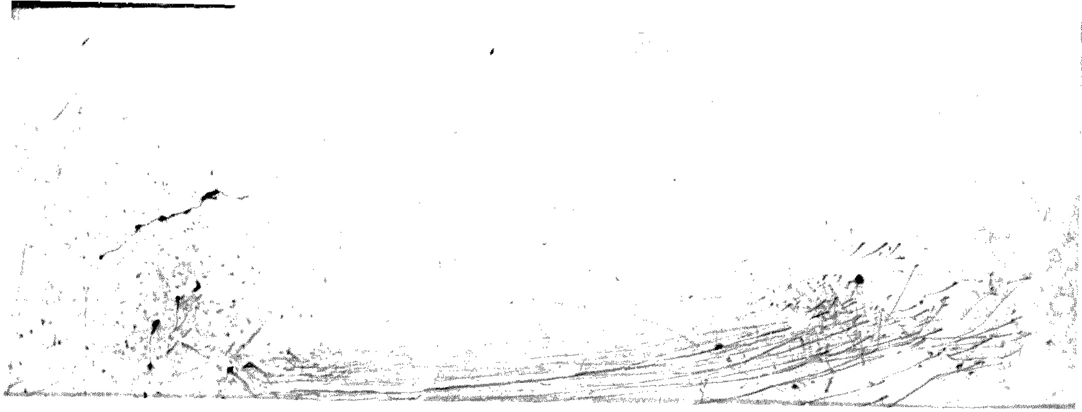


Figure J15 The forces acting and torque on the 65 picks drum



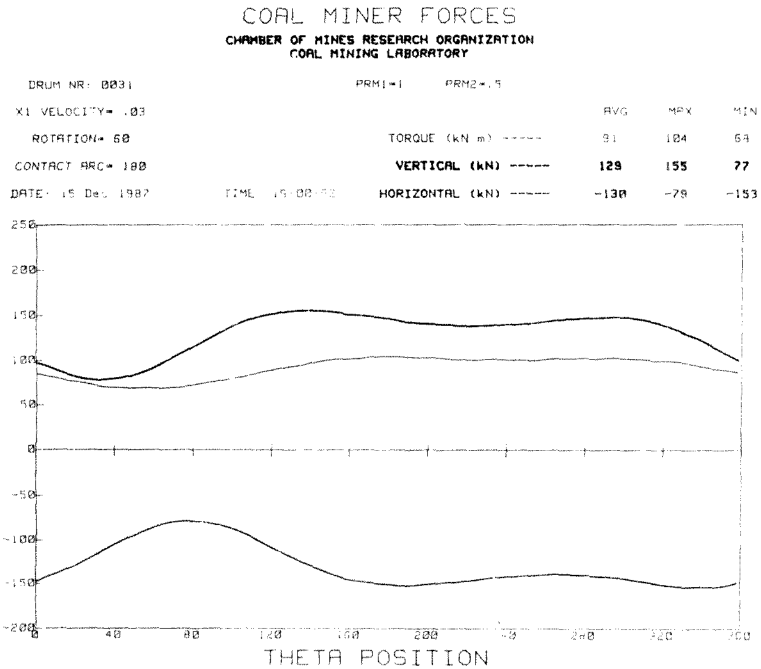
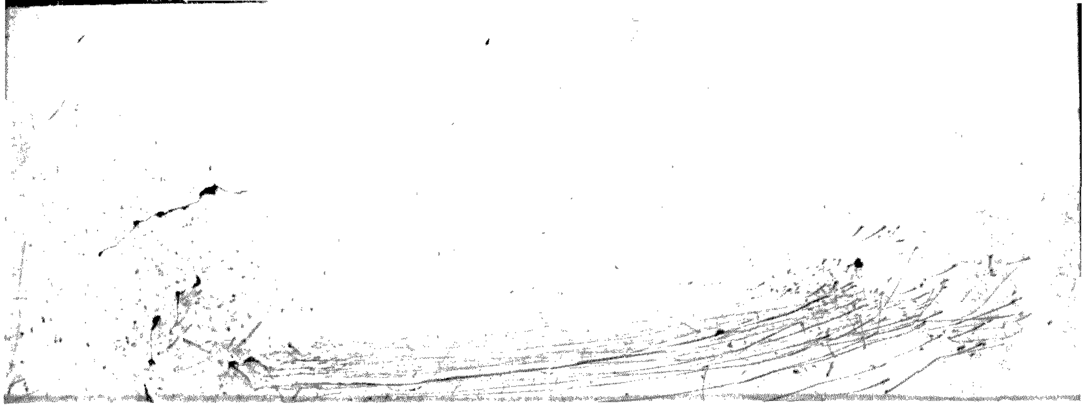


Figure J16 The forces acting and torque on the 65 picks drum



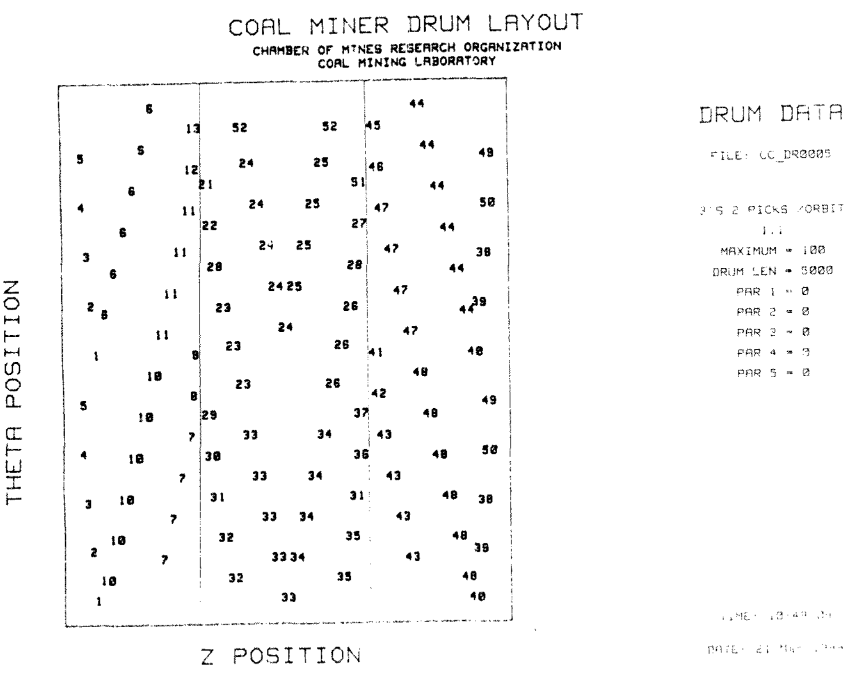


Figure J17 Joy test drum using 110 picks

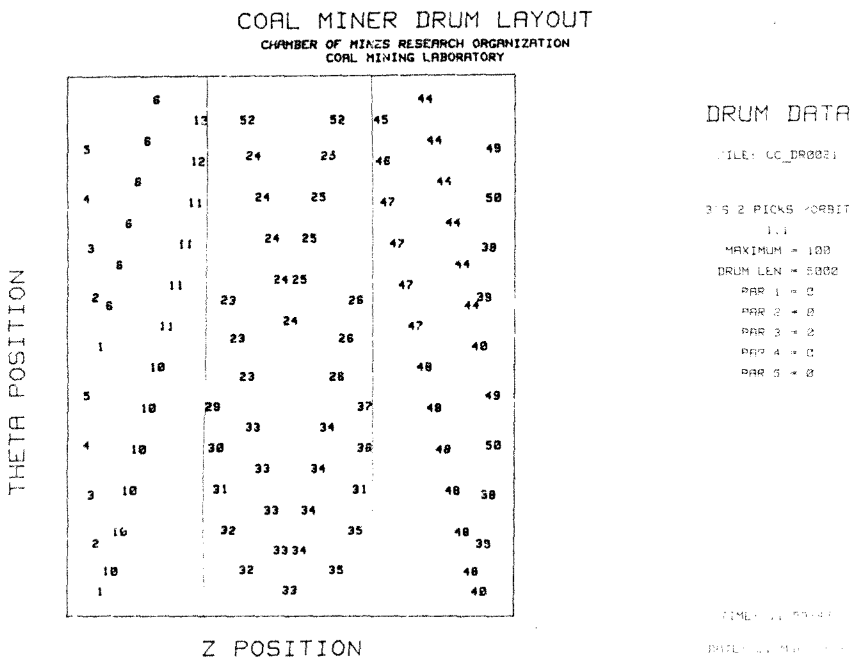
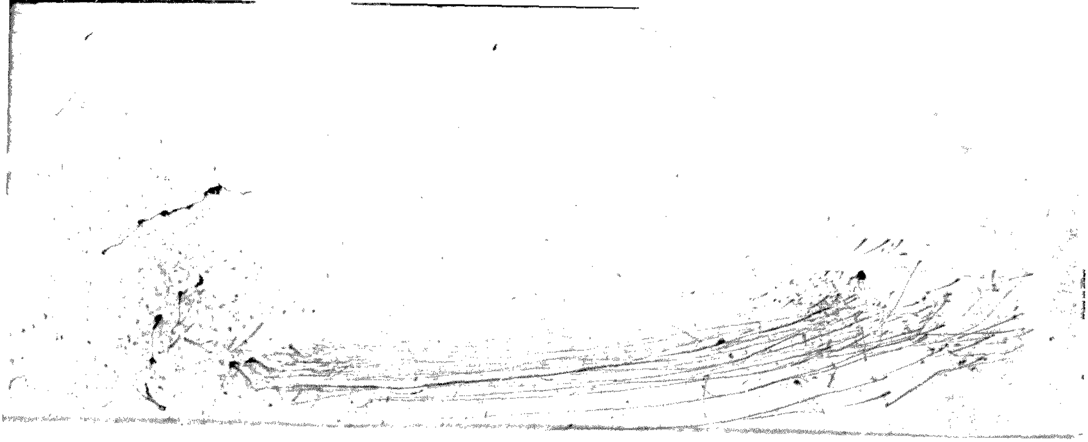


Figure J18 Joy test drum using 90 picks



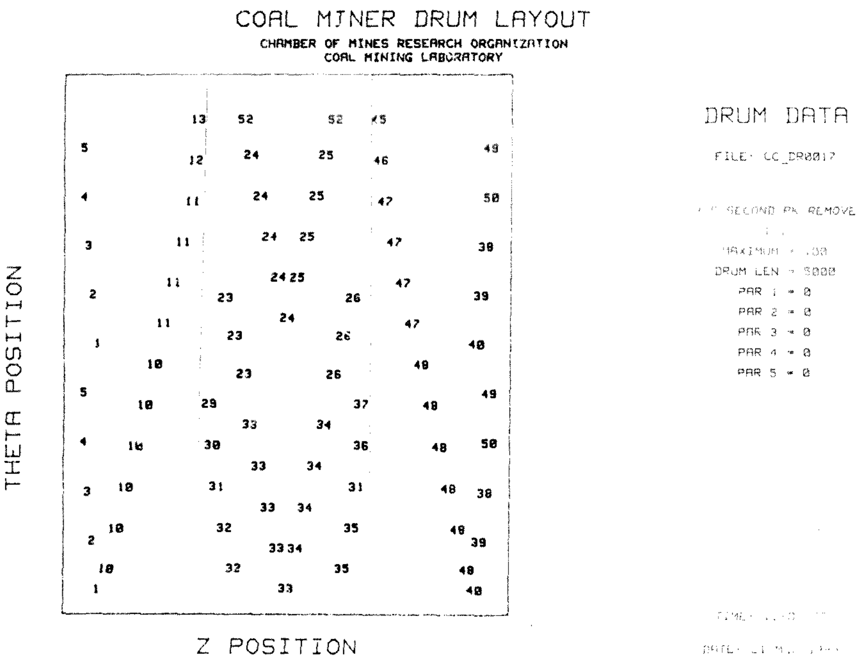
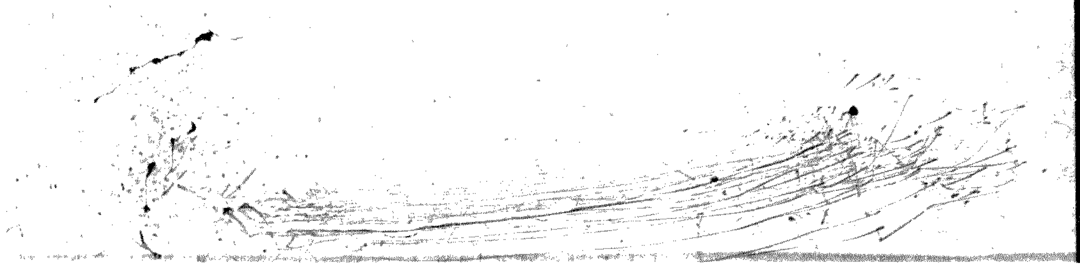


Figure J19 Joy test drum using 80 picks



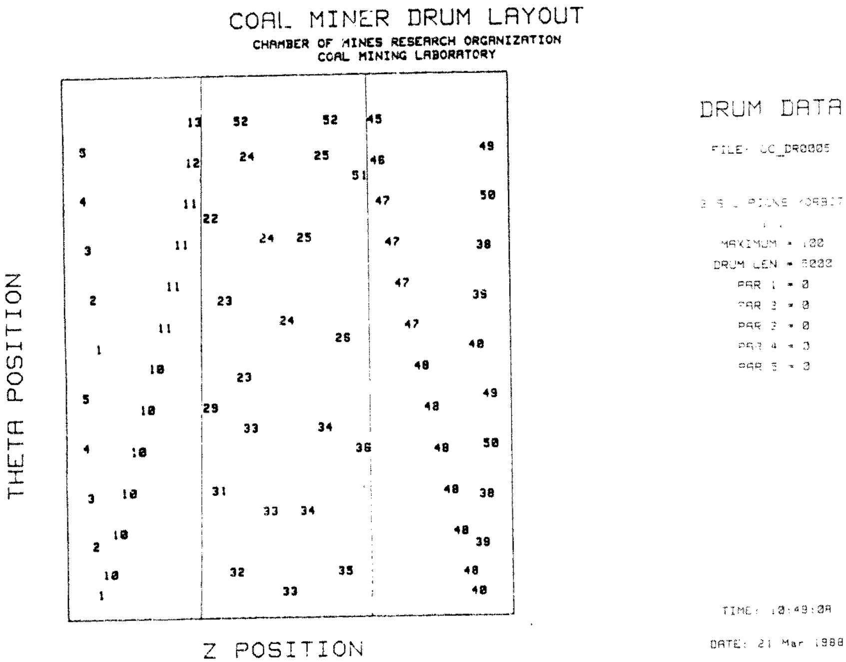


Figure J20 Joy test drum using 66 picks

APPENDIX K

FLOWCHART OF ACTIVITIES FOR USING CUTSIM

This section illustrates the order of entering data and running the cutting simulation and performing the force analyses using CUTSIM. (See Figure K1).

If the data files of pick, drum and coal are complete, the user can start the simulation process from the box shown 'start analysis'.

All the right hand boxes in this figure represent the output which may be obtained from CUTSIM.

The user may process only part of the program, for example in order to obtain the plot of the drum layout or to analyse the breakout profile of the drum only.

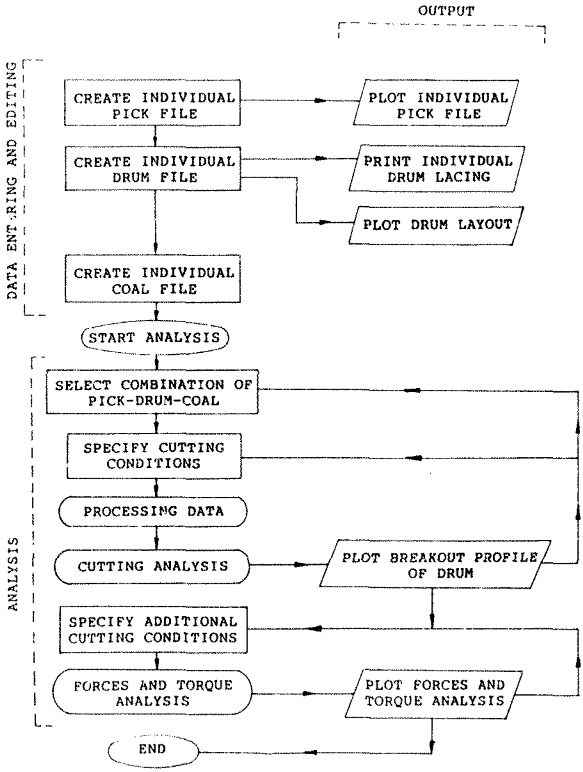


Figure K1 Flowchart of activities for running CUTSIM

REFERENCES

1. Brigi , ., S.A. Mining Coal, Gold and Base Minerals, June 1958.

2. Cook, A, A special brief for all employees, Middelburg and Rietspruit Mining News Paper of 1987. Rand Mines, 1987.

3. Report of the Department of Mineral and Energy Affairs including reports of the Government Mining Engineer for the year ended 31 December 1986.

4. King, P., Roxborough, F.F., Pedroncelli, E.J. and Boardman, P.A, Investigation into coal cutting using a continuous miner. Research Report No. 23/79, Johannesburg, June 1979.

5. Hood, M. (1985), Water jet assisted rock cutting systems - the present state of the art. International Journal of Mining Engineering.

6. Evans, I. and Pomeroy, C.D, The strength, fracture and workability of coal. Permagon, London, 1966.

7. Roxborough, F. ., Phillips, H.R, Applied rock and coal cutting mechanics. Workshop Courses 158/61, Adelaide, May 1981.

8. Phillips, H.R., Grant, I.L., Pieterse, J.Z.C. and Jones, J.S, Laboratory coal cutting with corner cutting conical picks. Research Report No. 35/83, Johannesburg, April 1983.

9. Goodrich, R.H. (1956), High pressure rotary drilling machines. Syposium on Mining Research at the University of Missouri.

10. Tutluoglu, L., Hood, M. and Barton, C. (1983), An investigation into the mechanisms of water jet assistance on the rock cutting process, 24th U.S. Symposium on Rock Mechanics, June, pp.743-749.

11. Evans, I, A theory of the basic mechanics of coal ploughing. Proc. Int. Symp: on Min. Research, Permagon, London, 1962.

12. Pomeroy, C.D. and Brown, J.H, Laboratory investigations of cutting processes applied to coal mining machines. Journal of Strain Analysis, 1968, Vol 3, No. 3.

13. Wojno, L., Jones J.S. and Pieterse, J.Z.C. (1983), A pilot study of the effect of a high pressure water jet on the performance of drag bit coal cutting, Chamber of Mines of South Africa Research Organization, Research Report No. 7/83.

14. Mcvey, S.A, Waterjet assisted coal cutting, MSc Dissertation. The University of the Witwatersrand RSA, Johannesburg, 1987.

15. Merchant, M.E, Basic mechanic of the metal cutting process. Journal of Applied Mechanics, Vol. II, 1945.

16. Potts, E.L.J. and Shuttleworth, P, A study on the ploughability of coal. Trans. Institute Mining Engineers, (London) Vol. 117, May 1959.

17. Nishimatsu, Y. (1972), The mechanics of rock cutting. International Journal of Rock Mechanics and Mining Science, Vol. 9.

18. Roxborough, F.F. (1973), Cutting rock with picks, The Mining Engineer, June, pp.445-455.

19. Baker, R.H., Jones, G.J. and Hardman, D.R, An assessment of pick wear and its effect on continuous miner performance. Research Report No. 10/81, Jonannesburg, January 1981.

16. Potts, E.L.J. and Shuttleworth, P, A study on the ploughability of coal. Trans. Institute Mining Engineers, (London) Vol. 117, May 1959.

17. Nishimatsu, Y. (1972), The mechanics of rock cutting. International Journal of Rock Mechanics and Mining Science, Vol. 9.

18. Roxborough, F.F. (1973), Cutting rock with picks, The Mining Engineer, June, pp.445-455.

19. Baker, R.H., Jones, G.J. and Hardman, D.R, An assessment of pick wear and its effect on continuous miner performance. Research Report No. 10/81, Johannesburg, January 1981.