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Device for In Situ Measurement of Coal-Cutting Forces

By James C. Church

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	pct	percent
ft	foot	psi	pound (force) per square inch
hp	horsepower	rpm	revolution per minute
in	inch	s	second
lb	pound		

DEVICE FOR IN SITU MEASUREMENT OF COAL-CUTTING FORCES

By James C. Church[1]

ABSTRACT

The Bureau of Mines devised and demonstrated a portable linear-cutting tester that directly measures and records the in situ cutting forces required of continuous-mining machine picks to cut coal in underground mines. It requires only two operators to transport and operate the tester, which can be assembled and operated through a complete test cycle within a single mine work shift. This report reviews the factors considered in the design and development of the tester and the results of its system verification testing at coal mine sites.

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INTRODUCTION

The designers of continuous-mining machines have rarely had the benefit of credible pick force data on the cuttability of coal at specific sites upon which to base their machine designs. Since the inception of continuous-mining-machine designs in the 1950's, the drum pick forces that the machines have had to provide to cut coal have been determined by the designers through indirect relationships. They have had to develop and understand the complicated relationships between machine force equilibrium and those of power, cutting rate, and the stability of the mining machine (1-2).[2]

Over the years, many devices have been developed to provide an index of the cuttability of face coal in underground mine headings, but each addressed the strength of face coal rather than providing quantified pick force data that could be used directly by equipment designers. Penetrometers were developed that use coal penetration resistance as an index of face coal strength; expanding bolt devices were developed to pull cones from a face; impact strength has been the basis of several devices including Schmidt hammers, Izod testers, and the British Impact Strength Index; and some devices have utilized hydraulic pressure applied to face shothole to break out coal. Few, if any of these devices have gained significant acceptance anywhere in the U.S. mining industry, as shown by an industry survey (3) described in the Literature Search section of this report. However, if directly measured pick force data could be easily acquired at any mine location and made available to designers, the technology to translate these data into the designs of mining machines could be devised. Thus, the power output of mining machines could be sized to the required coal-cutting tasks at specific mine locations.

The Bureau of Mines awarded a contract (3) to design, develop, and demonstrate a portable device that could directly measure and record the pick forces required to cut coal at any underground mine location; the device called the "in-seam-tester," was tested at underground mines in Illinois, Virginia, and West Virginia.

BACKGROUND

The initial phase of the project was a survey of relevant published domestic and foreign literature. The first objective of this survey was to locate and identify devices that have been developed anywhere in the world to measure either in situ or in the laboratory the pick forces required to mine coal. This effort yielded data on 16 devices, which are illustrated, and their source references identified in the appendix, except as noted.

Despite the existence of at least 16 devices for in situ measurements in use throughout the world, none of these devices measure the actual cutting force that a mining machine pick would be required to exert to cut coal. Rather, each of the devices attempts to measure some physical property of coal, which is only useful if it can be extrapolated to pick-cutting force by design engineers. As a result, few of these devices have gained any acceptance by the U.S. mining industry as a credible indicator of coal cuttability. This nonacceptance of available cutting-force-measuring devices, as illustrated by the survey (3), indicated a need to determine the specifications for a device in which manufacturers of coal mining machines and coal-mining companies could have confidence.

A second objective of the literature search was to locate and evaluate research reports that might relate

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[2] Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

recordable cutting parameters to pick force data in such a way as to be useful to designers and users of continuous-mining machines. Available data are cited in the contract report (3).

On the basis of Bureau data (4-8), and using a factor for a peak load of 2, the pick force load for a 3-in depth of cut was estimated at 5,000 lb. Due to power limitations and portability considerations, the maximum cutting force output of the device was ultimately decided to be limited to 3,000 lb, at 1,500-psi hydraulic pressure.

INDUSTRIAL SURVEY RESULTS

To reinforce the material acquired during the literature search phase of the project, a survey of representatives from the mining industry was conducted (3). These representatives included three industrial specialists, four representatives of continuous-mining machine manufacturers, and two mining company representatives. The objective of the survey was to gather suggestions on the design and demonstration of the proposed in-seam tester from the perspective of the users of the data. The following is a summary of their major suggestions.

VARIABLE CUTTING PARAMETERS

Spacing between 1.25 and 4 in and depths of cut from 0.5 to 3 in cut were suggested as field test specifications.

OPERATING CHARACTERISTICS

Tester should operate at or near the working face. Given the option of a mechanism with linear or rotary pick travel, most manufacturers preferred a linear mechanism, while the specialists preferred a rotary device.

DEGREE OF USE

Operators should complete a test in one shift. The data from an in situ tester would be used primarily for machine design and selection. In order to realistically determine degree of use, the device must be proven to the mining industry as a truly useful device for improving machine performance.

ACCEPTANCE BY MINING COMMUNITY

To insure the use of the in-seam tester, it is essential to demonstrate that it accurately measures cutting forces, correlates with other indices of cuttability, and relates to actual machine performance. The primary conclusion of the literature search was that no "best" method of testing coal exists to determine the optimum drum lacing for continuous-mining machines. Further, although a number of research reports were interesting and provided many design consideration, very little hard data directly applicable to the design of a force-measuring tester were uncovered; i.e., data on coring distance, effects of pick velocity on force, and frequency spectrum. This is primarily due to the fact that except for the research conducted by the Bureau of Mines, most of the research in this field has been conducted in the United Kingdom, South Africa, and the Soviet Union. Those researchers have been mostly concerned with the design of longwall ploughs and shearers applicable to the geophysical characteristics of the coal seams in their regions. Although their work can generally be used to predict the forces required to cut U.S. coals, it does not provide useful, finite force data applicable to the design of a tester of U.S. coal seams.

DESIGN AND FABRICATION

An initial phase of the design cycle of the in-seam tester was a tradeoff study of the following four configurations: a borehole rotary device, a linear cutting device, a pivoting beam device, and a rotary device. The geometry of each concept is briefly described as follows.

The borehole rotary tester concept is illustrated by the South African Penetrometer (fig. A-3), but rather than making linear grooves along the bore, the conceptual device would make circular grooves around the circumference of the bored hole in which it would be inserted.

The linear tester concept was utimately selected as the one to be developed and became the base design of the in-seam tester. It involves making linear cuts, vertically down the face coal test area.

The pivoting beam tester concept uses a pivoted beam as a lever to move a pick across a face coal test area and, since the pick follows a large-radius arc, it is similar to the linear tester concept.

With the rotary tester concept, the pick is tied to the innermost of three rectangular telescoping tubes with the outside tube pivoting so that the pick can rotate 180°.

Each of the concepts appeared to be mechanically feasible. A comparison of estimated weight and efficiency showed that they were approximately equal mechanically. Therefore, the tradeoff analysis among these concepts hinged on determining the best compromise among the operating specifications. The essential requirements include providing accurate and useful data on coal cuttability, and acceptance and use by the mining community.

The borehole rotary tester would only cut a single coal layer, so the cutting data may not be sufficiently accurate. Furthermore, since the cutting process is not visible, the potential user might distrust the measurements. A 3-in depth of cut would not be possible with readily available hole-boring equipment.

The linear tester overcame the disadvantages of the borehole rotary tester. Cutting tests could be made on the exposed surface of the coal face, and within limits, several layers of cuts can be made. Although the cutting profile is linear, these data were believed to be sufficiently accurate for the purpose of machine design, as indicated by the survey of mining-machine manufacturers (3).

As stated previously, the pivoting beam tester basically resembles the linear cutter. However, because it must be mounted between roof jacks, it is subject to instability in poor roof or floor conditions.

The rotary tester allows the direct application of the measurements to rotary continuous mining machines. However, the data reduction is more complex than for the linear concepts, and the tester would require a significantly longer amount of time for preparation of the face for testing than would a linear tester.

In the survey of manufacturers (3), most of those surveyed preferred linear cutting because it required the least underground test time while providing the necessary cutting measurements. Based on this and the other factors previously discussed, the linear cutting concept was selected to be designed and fabricated.

The linear cutting tester was designed to consist of three major elements: the main supporting frame (fig. 1), the cutter transport mast (fig. 2), and the dynamometer (fig. 3). This design is based on simplicity with minimum weight to increase reliability and acceptance by the mining industry.

The design and function of each major component were analyzed and each component was evaluated as part of its subassembly and as part of the overall tester. The parts were sized to withstand cutting, normal and side forces of up to

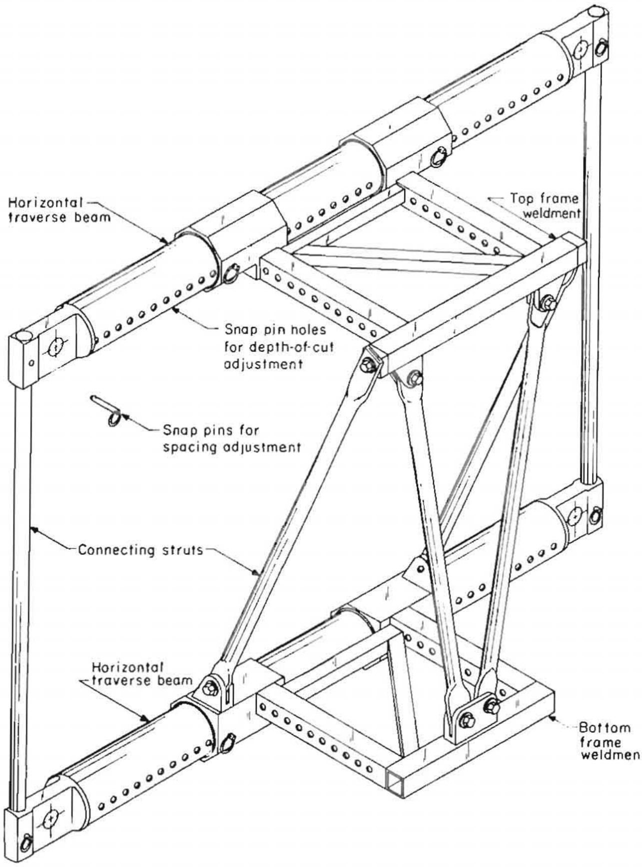

FIGURE 1. - Main supporting frame.

3,000 lb with an aribtrary safety factor of 1.22 established for design purposes.

PICK TYPE

The primary cutting tool of the tester is a standard plumb-bob pick. However, because the industry survey (3) revealed an interest in the flexibility that could be achieved by using alternative pick styles on the tester, the design incorporated the ability to interchange picks. All picks are held in the standard free-to-rotate manner. The mounting blocks were designed for a standard plumb bob, minibob, and a pencil pick (fig. 4). The mounting of the pick holder was designed so that the mast will not interfere with a 3-in depth of cut. The pick holder mounts on a force dynamometer. Picks and pick holders can be replaced without removing the dynamometer.

FORCE DYNAMOMETER

To measure cutting forces in two directions, strain gages were used on the full-bridge dynamometer as the sensors of the system's instrumentation. The pick itself was not strain gaged because worn picks must be replaced and alternate pick styles must be accommodated. The pick holder has a complex geometry that would make resoltuion of the forces difficult and, therfore, unsuitable for gaging.

The dynamometer was designed to serve as a load path between the pick holder and the support structure. The ends of the force dynamometer are splined to match two splined collars. This results in relatively free end conditions for the dynamometer while absorbing torque generated by force at the pick tip.

The design shown in figure 3 provided good sensitivity for the dynamometer and provided independent isolated cutting and normal forces without interactions from torque or side load.

MAST

The splined collars, which hold the dynamometer, are bolted to bearing housings that are guided by a vertical slide with Teflon[3] fluorocarbon polymer bearings to reduce frictional losses. The mast structure allows application of cutting loads up to 3,000 lb on the pick tip while resisting reactive loads of equal magnitude. The selected design has two outboard slides with a central hydraulic cylinder. the cylinder provides balanced force application with low-bearing loads from side loads or torque. The cylinder is sized for a maximum pressure of 1,500 psi.

To minimize the size and weight of the mast assembly, a twin-chain arrangement

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[3] Reference to specific products does not imply endorsement by the Bureau of Mines.

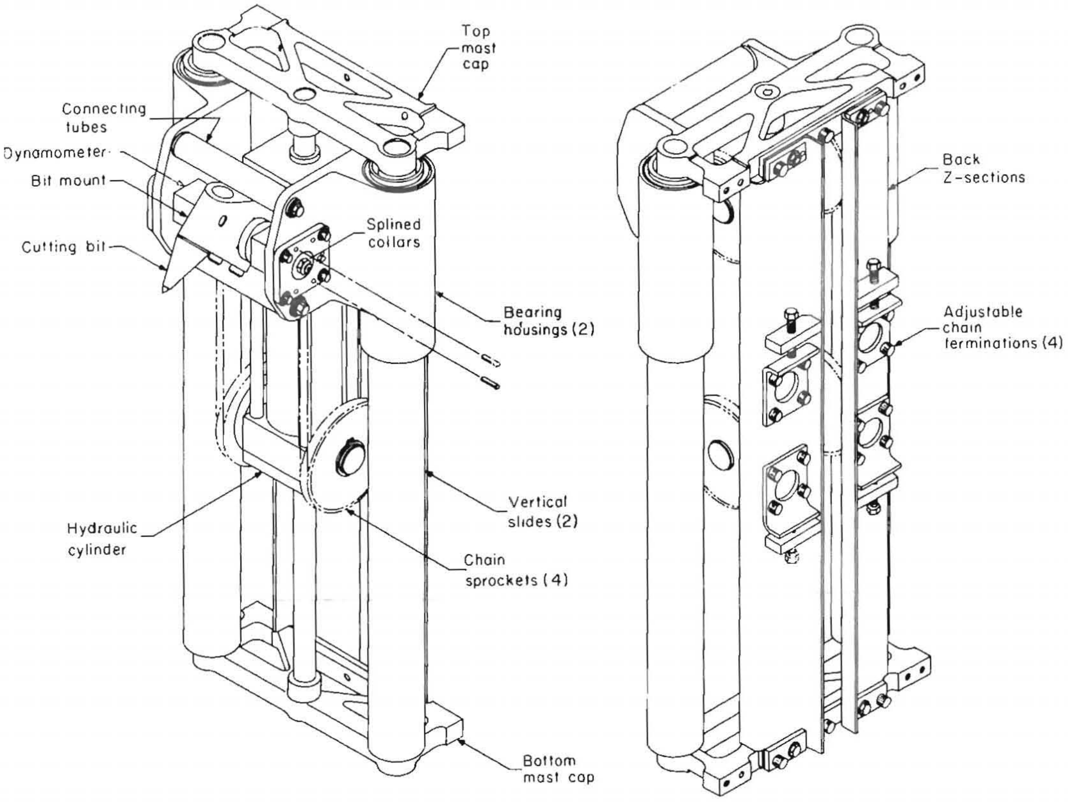
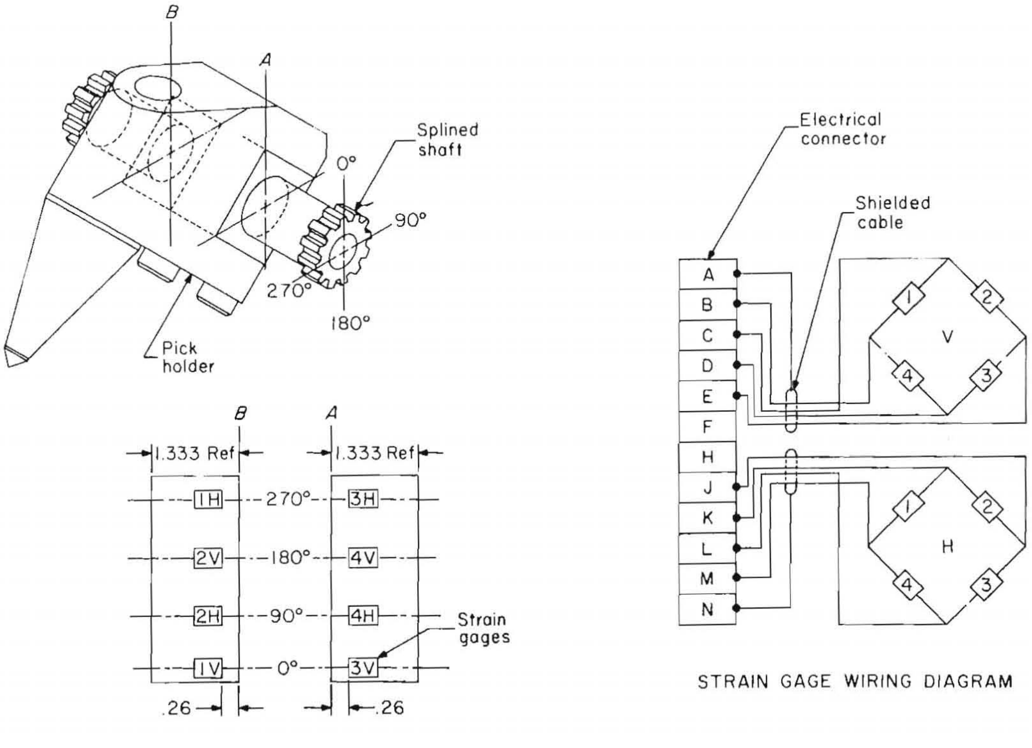


FIGURE 2. - Cutter transport mast.



STRAIN GAGE WIRING DIAGRAM

DEVELOPMENT OF Ø 1.000 PORTION
OF DYNAMOMETER

FIGURE 3. - Cutter dynamometer.

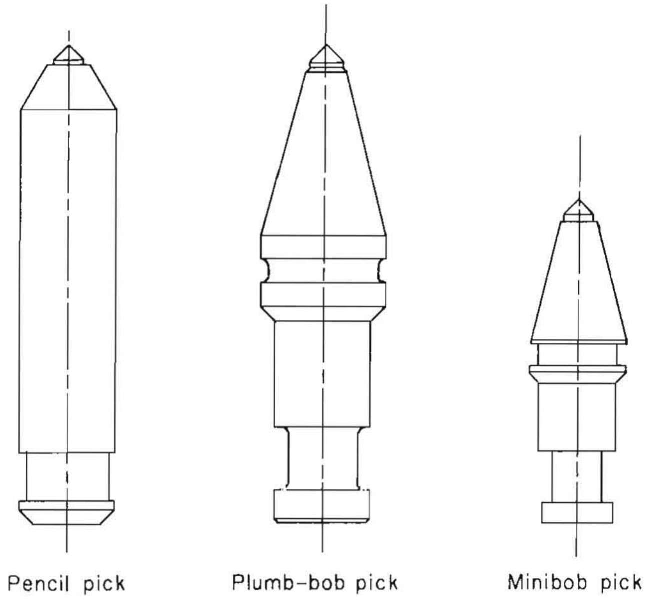


FIGURE 4. - Test bits.

was designed to move the pick through a 20-in cutting stroke with only 10 in of hydraulic cylinder travel. Chain sprocket pairs are mounted on trunions with roller bearings at either end of the cylinder body. The cylinder rod extends through both ends of the cylinder.

Chain reactions are transmitted through two Z-sections behind the mast (fig. 2). The chain termination points are adjustable to accommodate chain stretch or slack. The chain midpoints attach to the splined collars that hold the force dynamometer. Shear pins protect against accidental overloads.

FRAME

The frame allows the mast assembly to be moved, adjusting for both depth of cut and spacing for each groove. Cuts can be made over 23 in across the cutting surface with the spacing adjustments in 1/2-in increments. A total of 4 in of penetration into a flat cutting surface in 1/2-in increments can be achieved with the depth-of-cut adjustments. "Snap" pins in the spaced holes fix movement of the masts within the truss and fix the truss along horizontal traverse beams. Teflon fluorocarbon polymer bearings in the top and bottom frame weldments allow spacing adjustments to be made without mechanical leverage. Quick-release, adjustable-bushing bolts keep the frame rigid, but provide for quick disassembly. The frame was designed for maximum simplicity and minimum weight by employing a truss-style of geometry.

MOUNTING TO COAL SEAM

The frame is attached directly to the coal surface with four 1-in-diam threaded studs, resin-bolted into 1.24-in-diam holes. Spherical nuts and washers compensate for misalignment between the bolts, bearing plate, and traverse beams. Spacers can be placed over the studs to assure that the traverse beams remain in the same plane.

INSTRUMENTATION

The dynamometer converts pick forces into electrical signals, as described previously. The signal is digitized, stored, and printed out as a "time-at-level" histogram; simultaneously, the analog signal is recorded for later analysis.

Any number of cuts within the limit of the data acquisition unit can be recorded and automatically averaged before the force levels are printed out. A memory readout module interfaces with a calculator and monitors the dynamometer from zero to its maximum reading. Cutting and normal forces are recorded. The calculator can selectively print out either the cutting or normal force histogram and calculate mean force, standard deviation of the signal, and the total time (seconds) during which data were accumulated.

Field design specifications were established as follows:

1. Size: 42 in high by 50 in wide by 18 in long.

2. Weight: 250 lb.

3. Power: 1,500 psi hydraulic - 10 hp.

4. Maximum cutting force: 3,000 lb at 1,500 psi.

5. Maximum cutting length: 20 in.

6. Maximum of 4-in cutting-depth variable in 1/2-in increments.

7. Spacing between cuts variable in 1/2-in increments.

8. All instruments operated by internal battery.

Factory tests verified that the designed equipment met these field design specifications. The tests realistically simulated the test conditions of actual underground coal mine test sites where the equipment was later tested. In addition, a field test in an aboveground mine was conducted at Morris No. 5 Mine near Marion, IL, to establish test procedures and to evaluate the equipment under less restrictive operating conditions than exist in underground mines.

FIELD TESTS

The in-seam tester has been used underground in several mines during its final system verification. The tester is shown in use in figure 5; a closeup of the mast and cutter area is shown in figure 6. A face after several different tests have been completed is shown in figure 7. The underground testing proved the versatility of the tester. It also demonstrated the ease with which the device can be transported by a variety of mine vehicles or by two people carrying

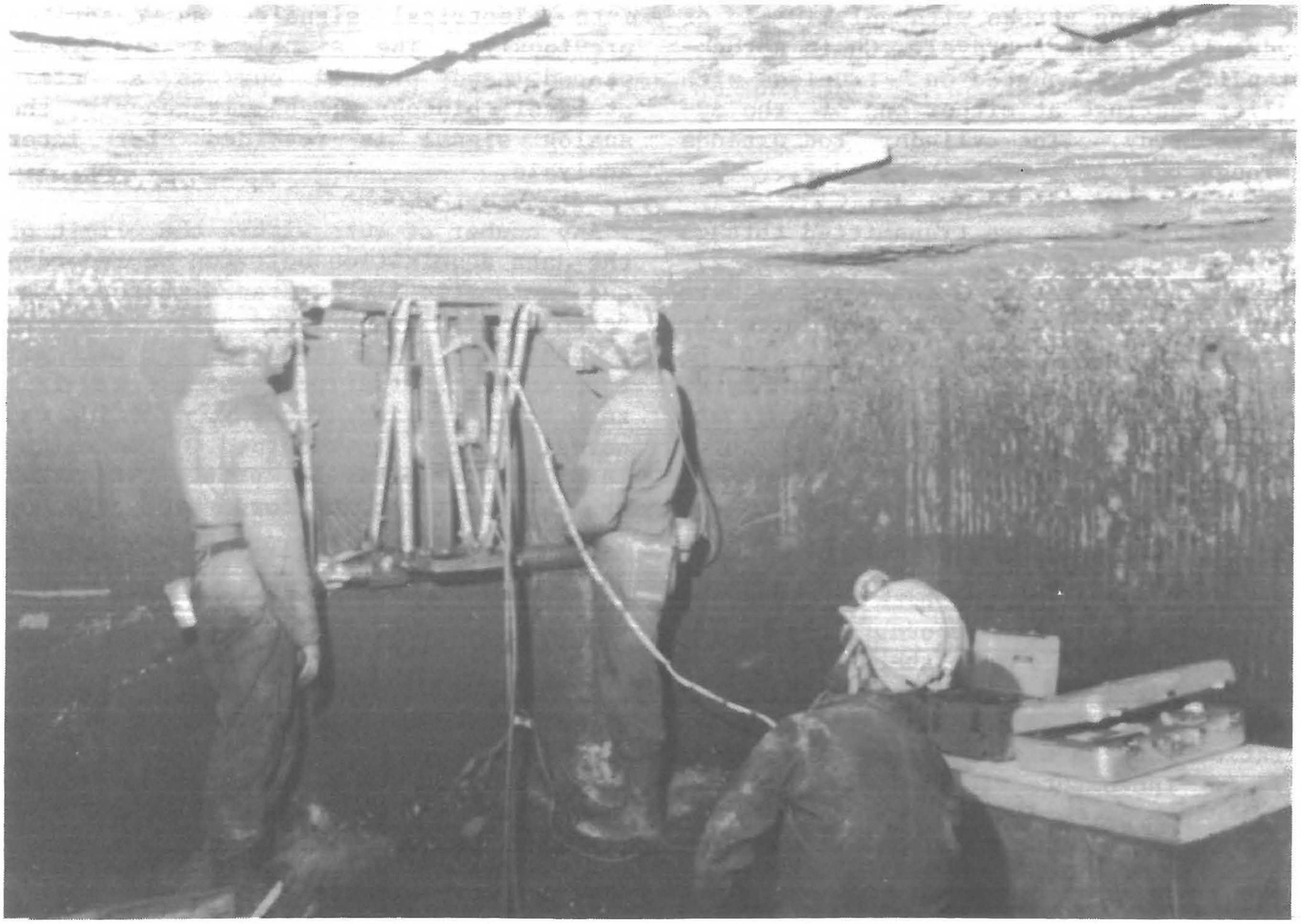


FIGURE 5. - Field testing of in-seam tester.

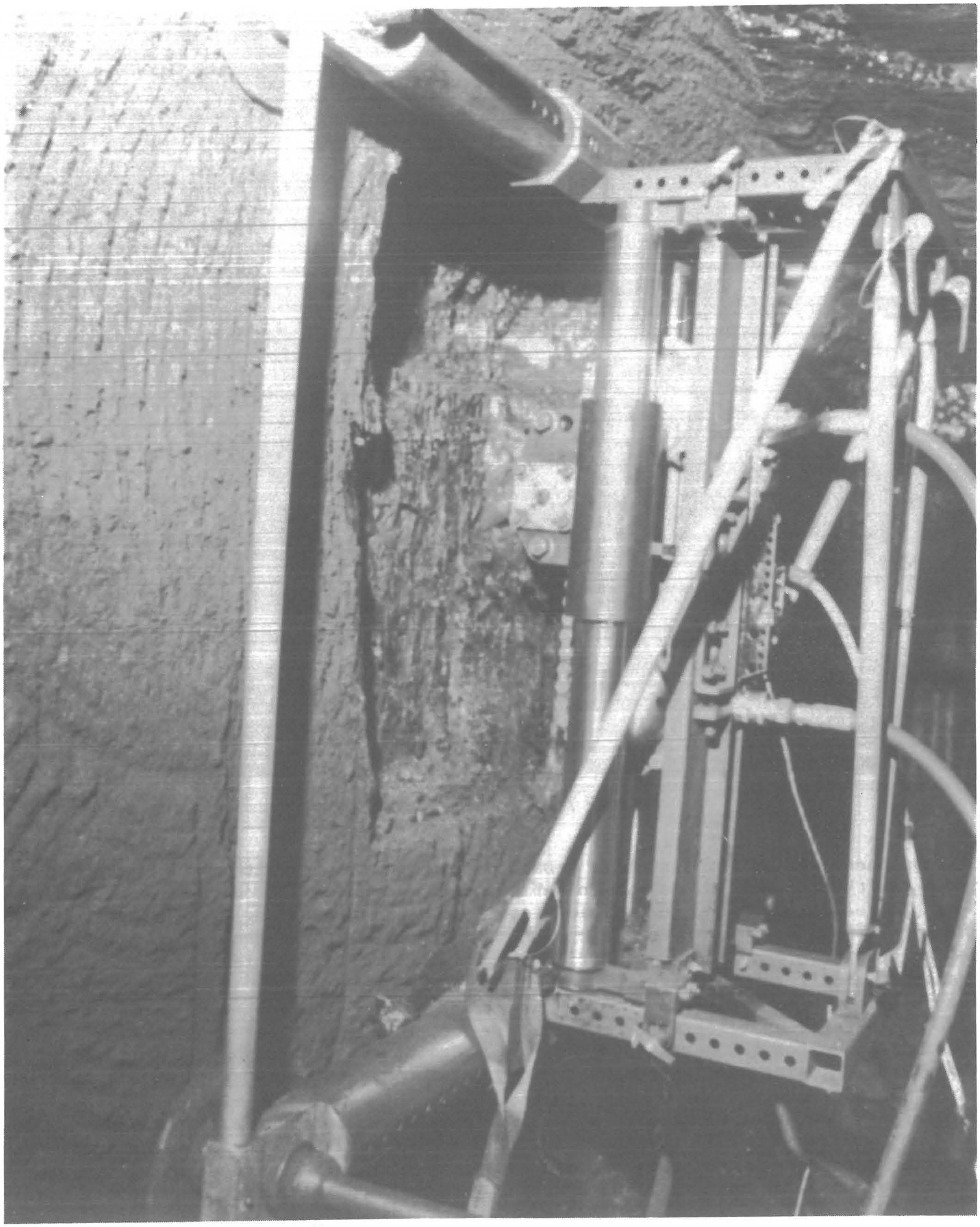


FIGURE 6. - Closeup of mast-and-cutter subassembly.

FIGURE 7. - Completed test faces.

the component parts for assembly. Data taken in three seams are show in table 1-3. Tables 2 and 3 show information for the Splash Dam seam in West Virginia. The tests were made in two different areas with different operators. At the second Splash Dam seam, the tester data were taken for comparison with force measurements made for the Bureau of Mines by a contractor using an instrumented Lee-Norse (LN456) mining machine. Table 3 summarizes the tester results.

Table 4 presents the face pick-force data provided by the Bureu of Mines from the contract results of the LN456 tests. Although the overall average force measurements from the LN456 data do not compare closely with force measurements of the tester, it does demonstrate the problem of trying to instrument a continuous-mining machine to obtain cutting force information by the tester.

The tests demonstrated that there is good correlation between the direct readings obtained through use of the in-seam tester and those obtained by instrumenting the continuous-mining machine. The development of the tester provides a potential technique for characterizing coal seams. The instrumentation of the tester has a capability of measuring a total pick force of 3,200 lb consisting of 64 equal load cells (or levels), each about 50 lb. The pick forces are sampled

TABLE 1. - In-seam tester data for coal from Illinois No. 5 Seam, by ratio of depth of cut to spacing

Layer No.	Number of cuts	Cutting force (46.83 lb/cell), lb		Normal force (49.23 lb/cell), lb	
		Average cell	Average force	Average cell	Average force
6:1 ratio:[1]					
1.............	6	8.18	383.07	7.99	393.25
2.............	6	8.15	381.66	8.55	420.92
3.............	6	8.04	376.61	7.17	352.98
4.............	6	7.92	370.89	8.86	436.18
Total or av	24	8.07	378.04	8.14	400.86
3:1 ratio:[2]					
1.............	6	12.91	604.58	13.74	676.42
2.............	6	16.05	751.62	15.74	774.88
3.............	6	15.16	709.94	14.62	719.74
Total or av	18	14.71	688.71	14.70	723.68

[1] Depth of cut = 1/2 in; spacing = 3 in.
[2] Depth of cut = 1 in; spacing = 3 in.

TABLE 2. - In-seam tester data, Splash Dam Seam, first test area, by ratio of depth of cut to spacing

Layer No.	Number of cuts	Cutting force (46.83 lb/cell), lb		Normal force (49.23 lb/cell), lb	
		Average cell	Average force	Average cell	Average force
		COAL			
2:1 ratio:[1]					
1.................	9	2.59	121.29	4.00	196.92
2.................	9	3.03	141.89	2.53	124.55
3.................	9	2.98	139.55	2.48	122.09
Total or av.....	27	2.87	134.25	3.00	147.85
4:1 ratio:[2]					
1.................	10	1.69	79.14	3.69	181.66
2.................	8	2.78	130.19	4.17	205.29
3.................	9	1.86	87.10	4.28	210.70
4.................	9	1.86	87.10	3.43	168.86
Total or av.....	36	2.02	94.46	3.88	190.97
4:1 ratio:[3]					
1.................	4	4.24	198.56	4.59	225.97
2.................	1	8.20	384.01	8.37	412.06
		ROCK			
4:1 ratio:[4]					
1.................	9	24.39	1,142.18	18.01	886.63
2.................	9	22.27	1,042.90	17.44	858.57
3.................	9	22.26	1,042.44	17.85	878.76
Total or av.....	27	22.97	1,075.84	17.77	874.65
8:1 ratio:[5]					
1.................	4	27.44	1,285.02	21.03	1,035.31
2.................	4	45.36	2,124.21	30.39	1,496.10

[1] Depth of cut = 1 in; spacing = 2 in.
[2] Depth of cut = 1/2 in; spacing = 2 in.
[3] Depth of cut = 1 in; spacing = 4 in.
[4] Depth of cut = 1/2 in; spacing = 2 in.
[5] Depth of cut = 1/2 in; spacing = 4 in.

TABLE 3. - In-seam tester data, Splash Dam Seam, second test area (Blue Star No. 3)

Depth of cut, in	Spacing, in	Cleat direction	Force, lb			
			Measured		Derived	
			Cutting	Normal	Axial	Bending
1.......	2	Face....	415	375	559	28
1.......	2	Butt....	440	346	556	66
1.......	4	Face....	541	365	641	124
1.......	4	Butt....	656	463	791	136
2.......	2	Butt....	830	568	989	185
2.......	4	Butt....	947	577	1,078	262
2.......	4	Face....	1,091	726	1,285	258

TABLE 4. - Instrumented LN456 pick force data (Blue Star No. 3)

Test No.	Av depth of cut, in	Spacing, in	Drum speed, rpm	Cutting mode	Force, lb			
					Measured		Derived	
					Cutting	Normal	Axial	Bending
1.......	1.9	2	51	Sump...	908	130	734	550
1.......	1.2	2	51	Shear..	871	274	810	442
6.......	2.7	2	18	Sump...	910	51	679	607
6.......	2.5	2	18	Shear..	985	132	602	789
7.......	1.9	2	18	...do..	NAp	100	NAp	NAp
10......	2.1	2	18	Sump...	951	NAp	NAp	NAp
Av......	2.05	2	NAp	NAp.....	925	85	706	592

NAp Not applicable.

10,000 times per second and for each sample, a count is added to the appropriate cell. The tester's instrumentation stores these histograms in real time. For analysis, the values are plotted with the cells (force) on the horizontal axis and the counts (time) on the vertical axis, i.e., cumulative frequency distribution.

The total area under the histogram is energy, which can be divided by the volume of coal cut to obtain specific energy. In addition, a vertical line dividing the total area into equal halves intersects the horizontal axis at the mean force level. The force values may be accurately interpolated between cells when the histogram comprises more than 7 to 10 cells (i.e., the horizontal axis may be viewed as a continuum). The right side of the tail of the histogram may be fitted with a curve. The peak force then may be specified as that force which, for example, is exceeded 1 pct of the time. This analysis of peak force will provide a significant improvement over the more aribtrary methods commonly used.

Besides these routine measures of pick forces, preliminary experience using histograms indicates that their shape assists in establishing a coal signature to characterize the coals. This characterization represents only a first attempt to give meaning to various shapes and must be considered preliminary

In figure 8, panels *A* through *F* illustrate, qualitatively, the way in which the curves plotted from these histograms may characterize coal seams. These curves have approximately the same mean and maximum forces, but a variety of shapes. Coals with curves as in figure 8*A* would be expected to have a high degree of prefracturing, as indicated by the predominance of low force values. In panels 8*B*, 8*C*, and 8*D*, the predominant force levels progressively increase, indicating increasingly competent coal formations.

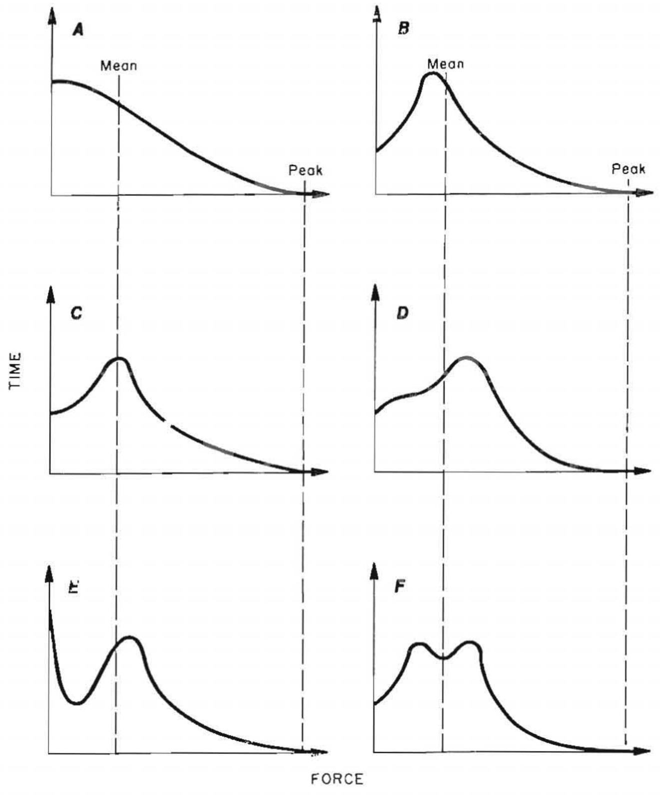


FIGURE 8. - Coal signature histograms.

The sequence of panels *A*-*D* also may indicate coals that are characterized by a tendency to core. While 8*A* is typical of friable coals, which cut easily, the predominance of higher forces in 8*D* indicates coal that tends to burst out of the core areas with great energy release, causing excessive respirable dust to become airborne.

Large amounts of coal cutting with near-zero forces, as indicated in figure 8, panels *A* and *E*, may suggest such breakouts generally occurring at or near cleats. This type of curve may indicate preferred direction of cutting to take advantage of high degree of cleating. The direction of cutting with respect to cleats may have a significant effect on the measured forces in these coals.

Any of these curves may indicate the presence of two materials; for example, coal and inclusive rock in the test area may be seen in a curve as a double peak, as in panel 8*F*.

CONCLUSIONS

The in-seam tester, designed, developed, and given preliminary field testing as part of the Bureau's continuing fundamental coal-cutting research program, is the first such device for direct in situ coal-cutting measurements that can supply quick, in situ data on any coal face. This enables designers of continuous-mining machines to optimize their machines for productivity and satisfies a mining industry need for a standard measurement device. The tester is light and compact enough to be carried easily to the coal face. It can be assembled, mounted on the coal face, and ready for cutting tests within 1 hour of arrival in the face area. It directly measures the forces required to cut the coal and to maintain the cutting depth. Different types and sizes of bits, cutting angles, spacing between grooves, and depths of cut can be tested. Multiple layers at various depths with several cuts per layer may be made.

Using data from the tester, designers of continuous-mining machines can select the type of pick, spacing, lacing, depth of cut, and drum rotation speed to improve machine performance. Thus, a machine may be optimized for a particular coal seam, thereby reducing respirable dust and energy while increasing productivity.

The use of the tester has been an ongoing activity within the Bureau since the completion of the development contract (3), and a data bank of in situ cutting forces and energy is being built on a wide variety of seams. In addition, a method for obtaining primary dust generation from the cutting fragmentation has been developed; field testing will begin shortly. The Bureau is continuing to seek cooperative working arrangements with mine operators interested in obtaining this type of coal seam information. The minimum time at any site is usually 1 week. If cleat effects are to be evaluated, additional time is needed. One operator has already indicated a 15-pct increase in productivity by reorienting the direction of seam cutting based on early results from the tester. The increased productivity indicates optimized fragmentation, which would indicate a regulation in dust and energy. Although the device is still a research tool, it has already demonstrated a potential for helping operators improve the coal and machine interface. It has been shown by previous research (4-8) that optimum cutting should reduce fines at the face area and at the preparation plant, to the economic advantage of the operators.

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[3] Material enclosed in parentheses are translations from the language in which the item was published.

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APPENDIX.--DEVICES USED FOR IN SITU MEASUREMENTS OF COAL-CUTTING FORCE

M.R.E. Penetrometer.--Average and peak resistance to penetration are recorded by this device. Average resistance is called the RP values, which bear a linear relationship with cutting force (9) but do not predict force (fig. A-1).

M.R.E. Expanding Bolt Tester.--This device measures the breakout force. The breakout force shows a linear relationship to cutting force, but the relationship to forces for different picks and spacings has not been developed.

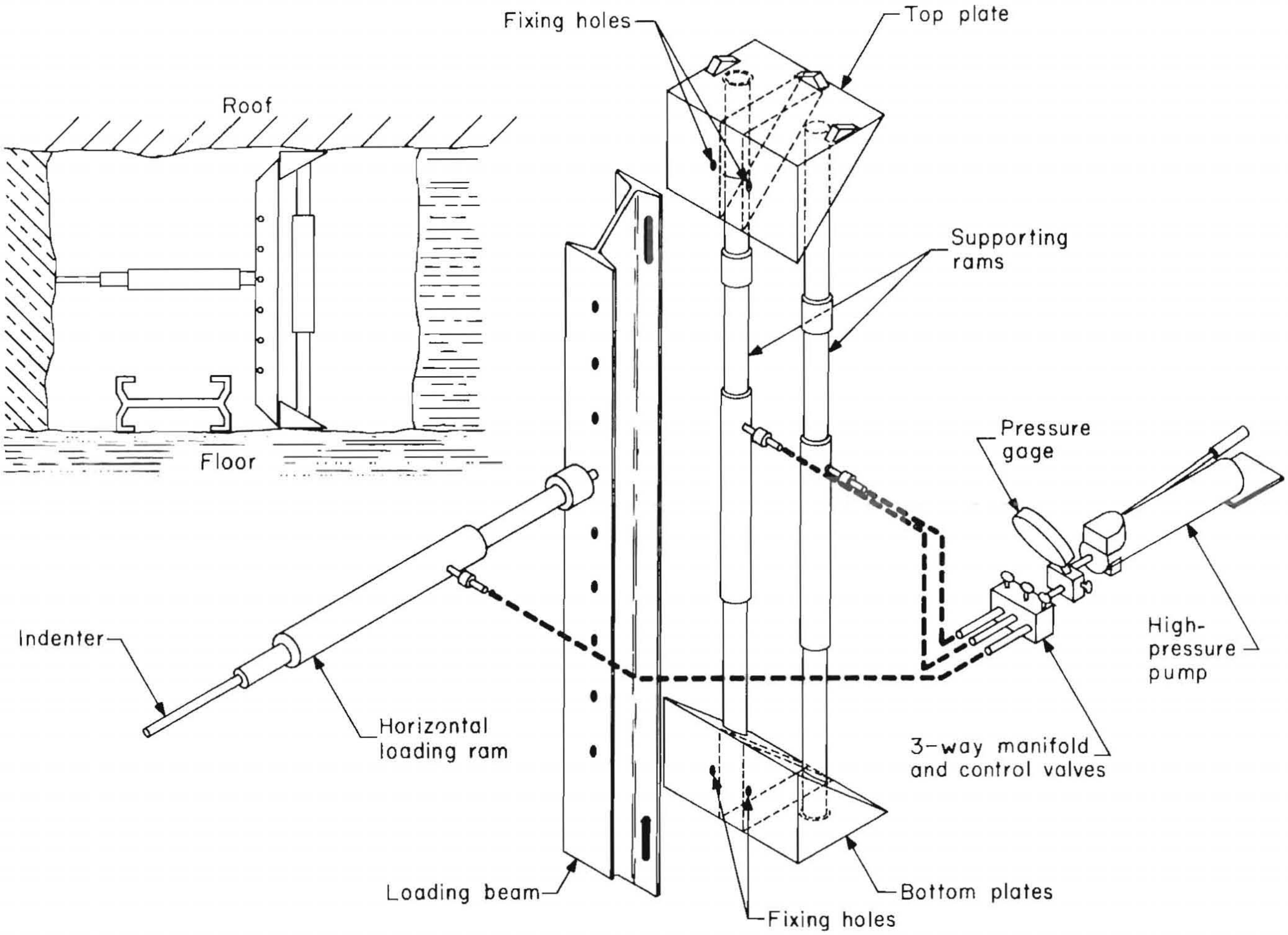

FIGURE A-1. - M.R.E. penetrometer (10).

South African Penetrometer.--This device measures indent and plough forces, which show a good correlation with other measures of coal cuttability. The device does not allow for the measurement of interactions between spaced grooves (fig. A-2).

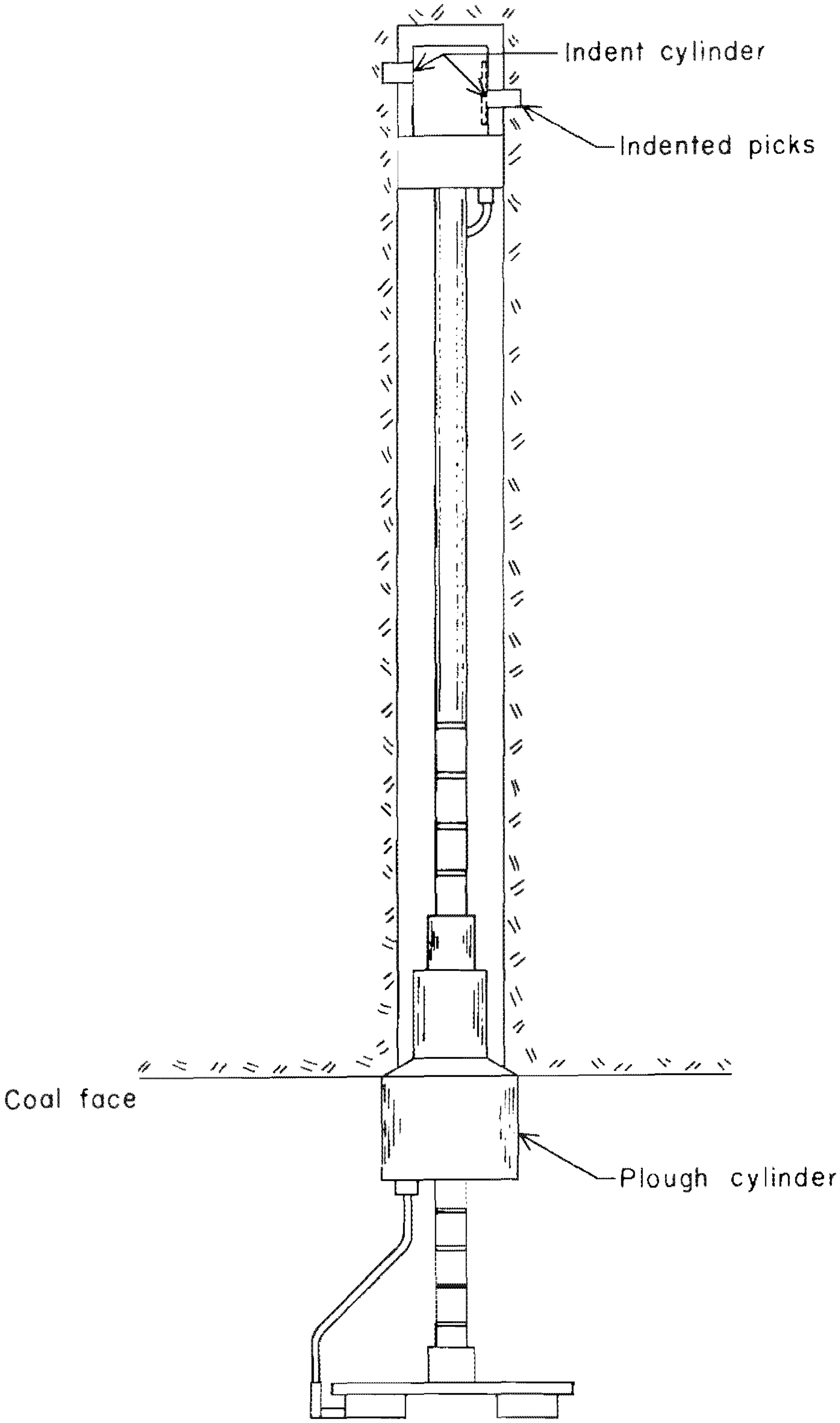

FIGURE A-2. - South African penetrometer (11).

King's College Wedge Tester.--This device measures the cutting force and displacement. It does not easily permit spaced grooves (fig. A-3).

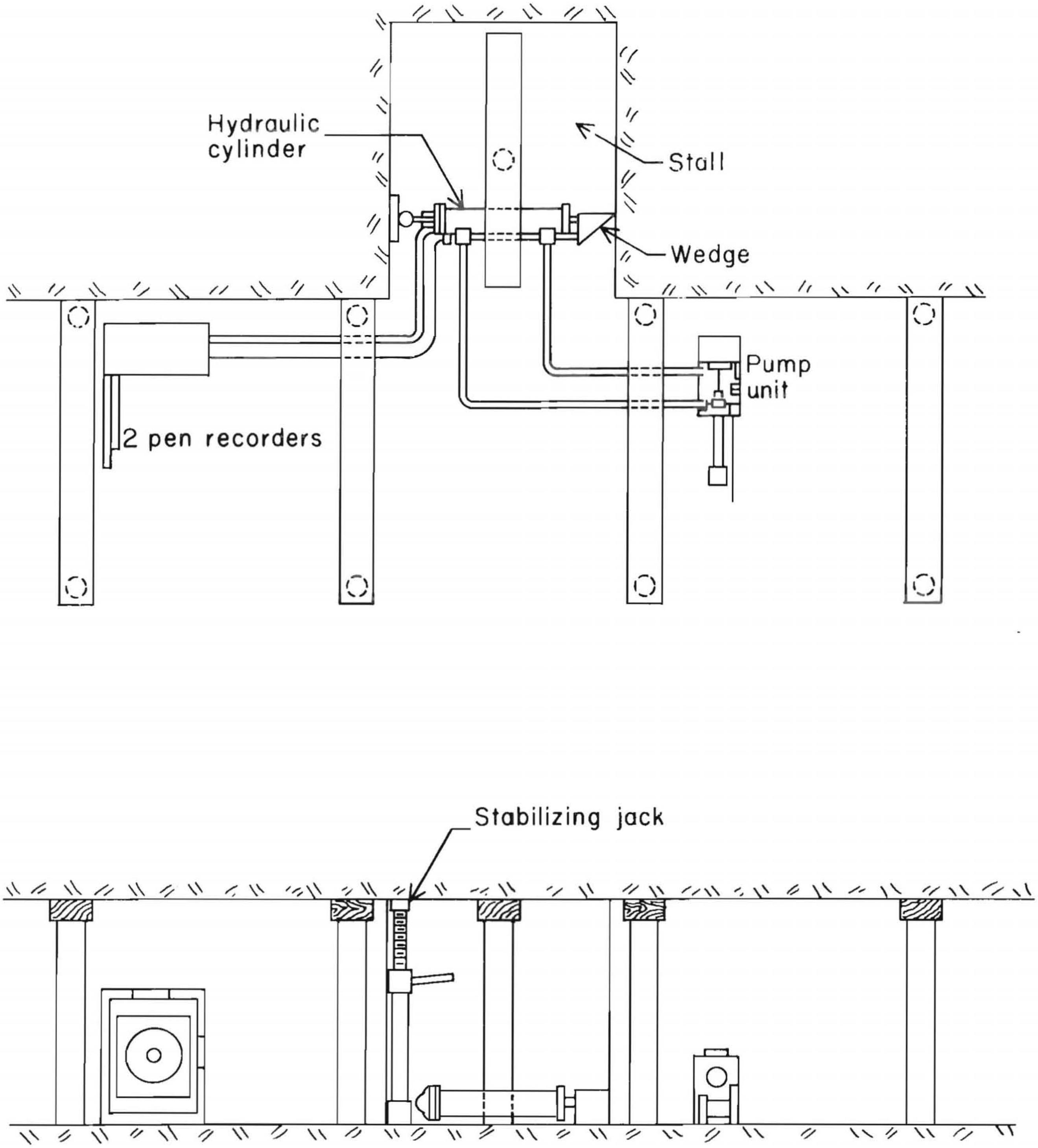

FIGURE A-3. - King's College wedge tester (12).

U.S.S.R. Rotary Tester.--The cuttability index for this device is expressed as the ratio of cutting force to depth of cut. There is limited information on the operation of the device (fig. A-4).

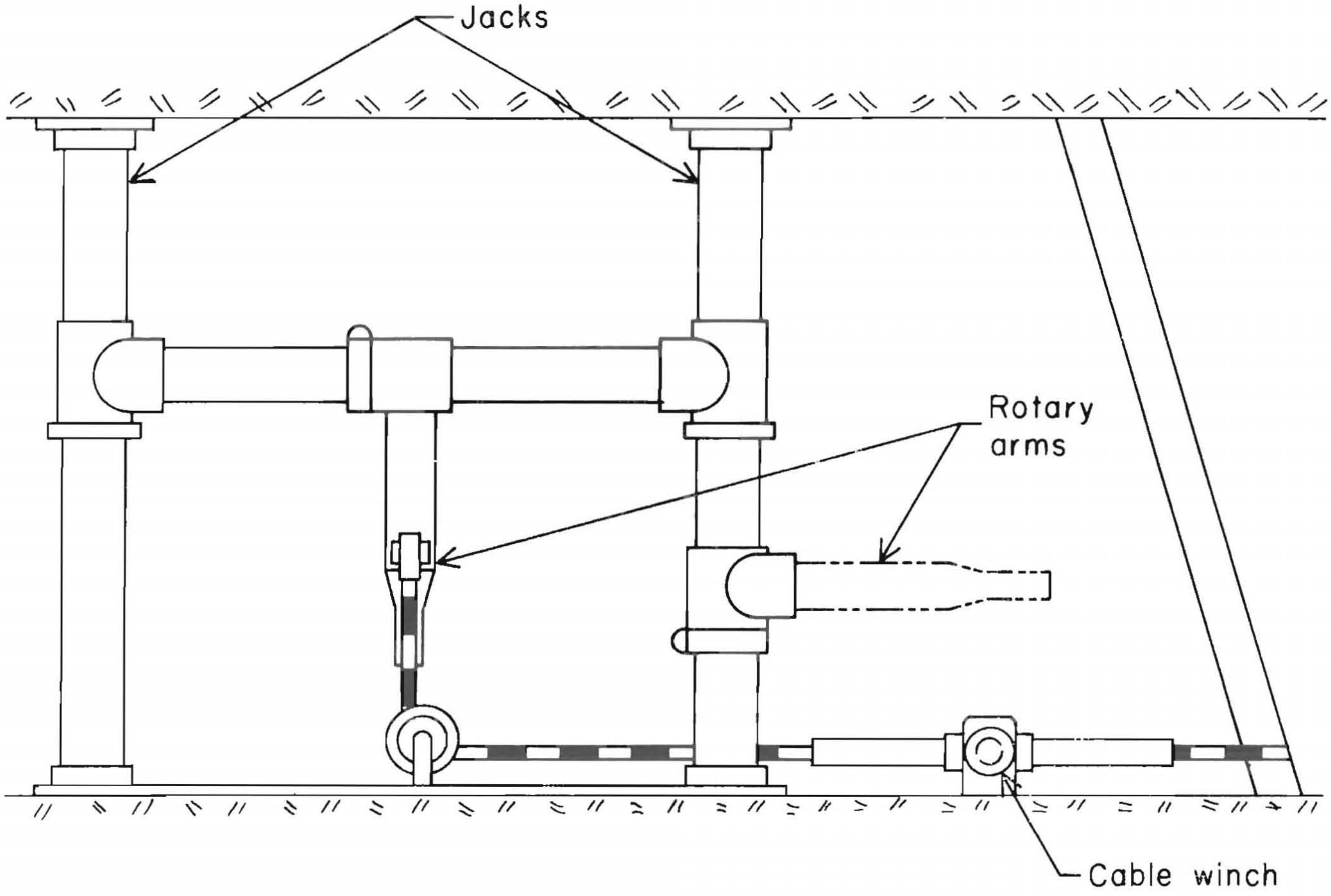

FIGURE A-4. - U.S.S.R. rotary tester (13).

Russian Lubimov Borehole Tester.--The ratio of the pull force to the volume of coal cut is the measure of cuttability for this tester (fig. A-5).

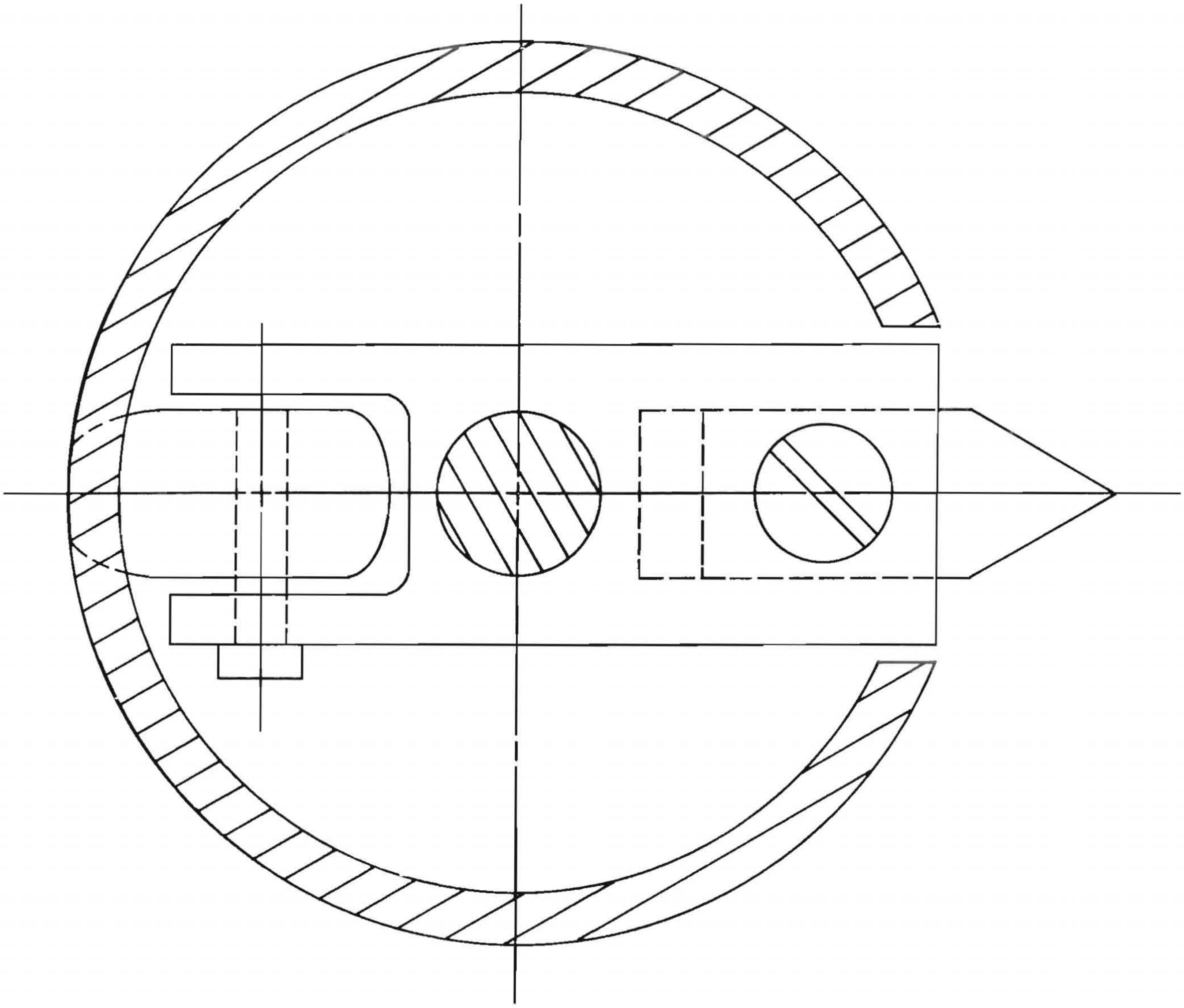

FIGURE A-5. - Russian Lubimov borehole tester.

Russian Przenasny Pryzrzad PR-5 Borehole Tester.--The ratio of the pull force to the cut is the measure of cuttability of this tester (fig. A-6).

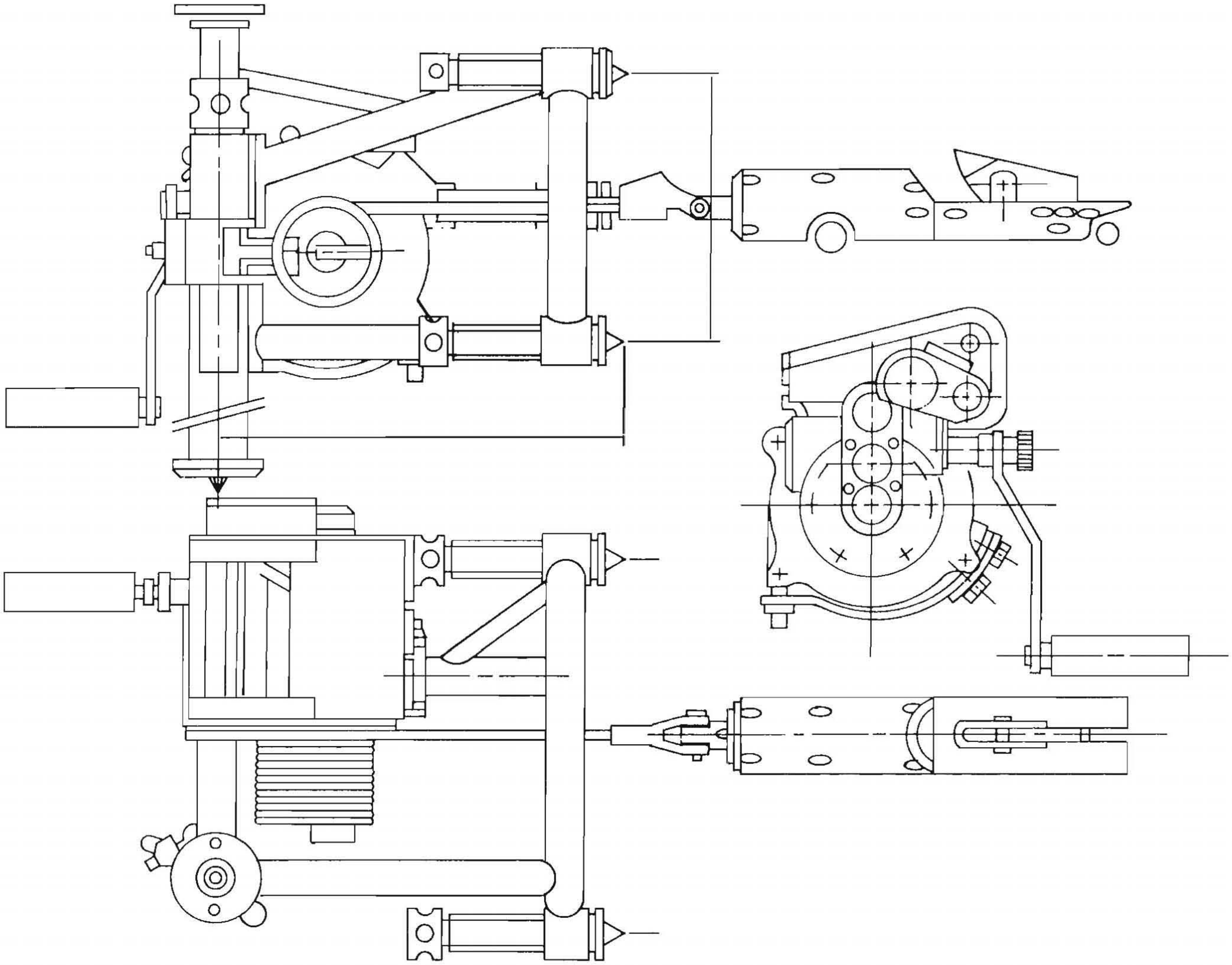

FIGURE A-6. - Russian Przenasny Pryrzad PR-5 borehole tester.

Russian Przyrzad SDM-1 Hole-Expander Drill.--The force resisting the hole-expanding drilling operation is recorded, and the area under the force-distance curve is integrated. An average force is derived for the cuttability index (fig. A-7).

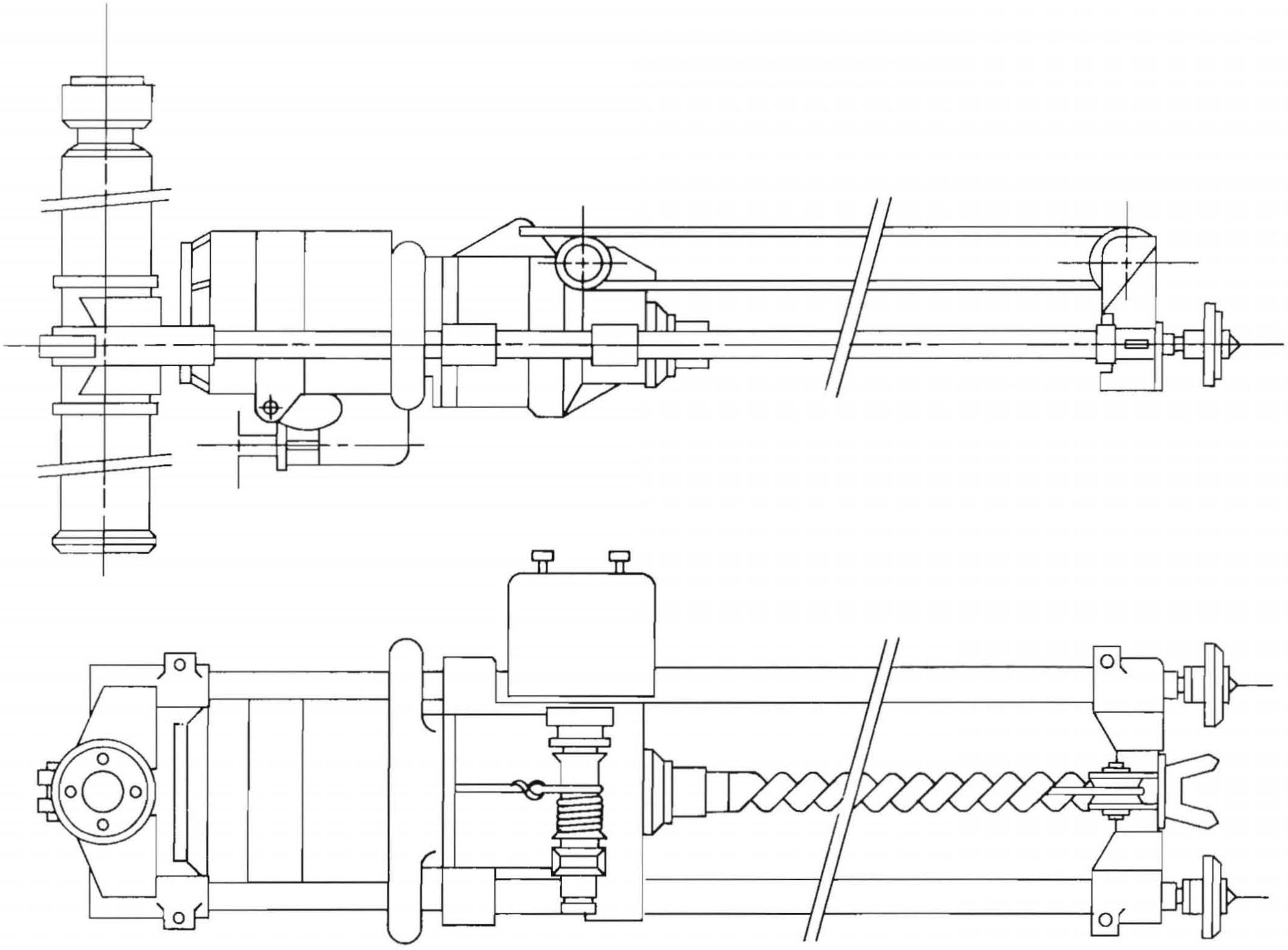

FIGURE A-7. - Russian Przyrzad SDM-1 hole-expander drill.

Polish Sikora Borehole.--For this device, the coal cuttability is defined as the ratio of the mean cutting force to the depth of cut.

Polish Haremza Spring-Loaded Linear Cutter.--Knowing the spring constant and the measured cut length achieved by the available spring force, the work required to cut coal is calculated. This is considered to be a measure of coal cuttability (fig. A-8).

Polish Potepski Linear Cutter.--For this device, the coal cuttability is defined as the ratio of cutting force to the cutting volume.

Polish Drill Power System.--The ratio of average power consumption to coverage drilling rate gives a cuttability index.

Polish Komag Rotary Cutter.--The ratio of the mean force to the mean depth of cut is used in conjunction with the lateral breakout angle of the coal for a measure of cuttability (fig. A-9).

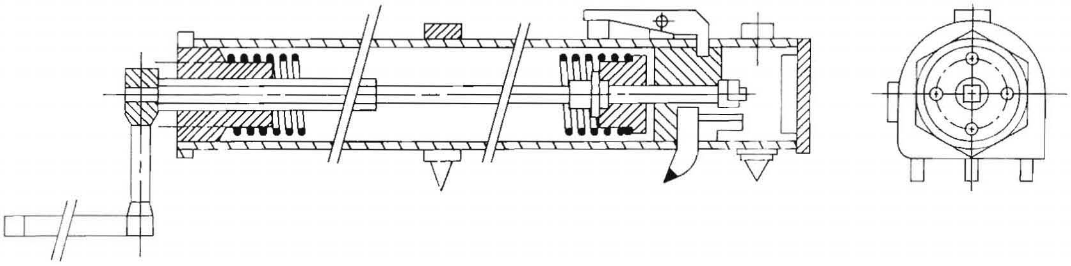

FIGURE A-8. - Polish Haremza spring-loaded linear cutter.

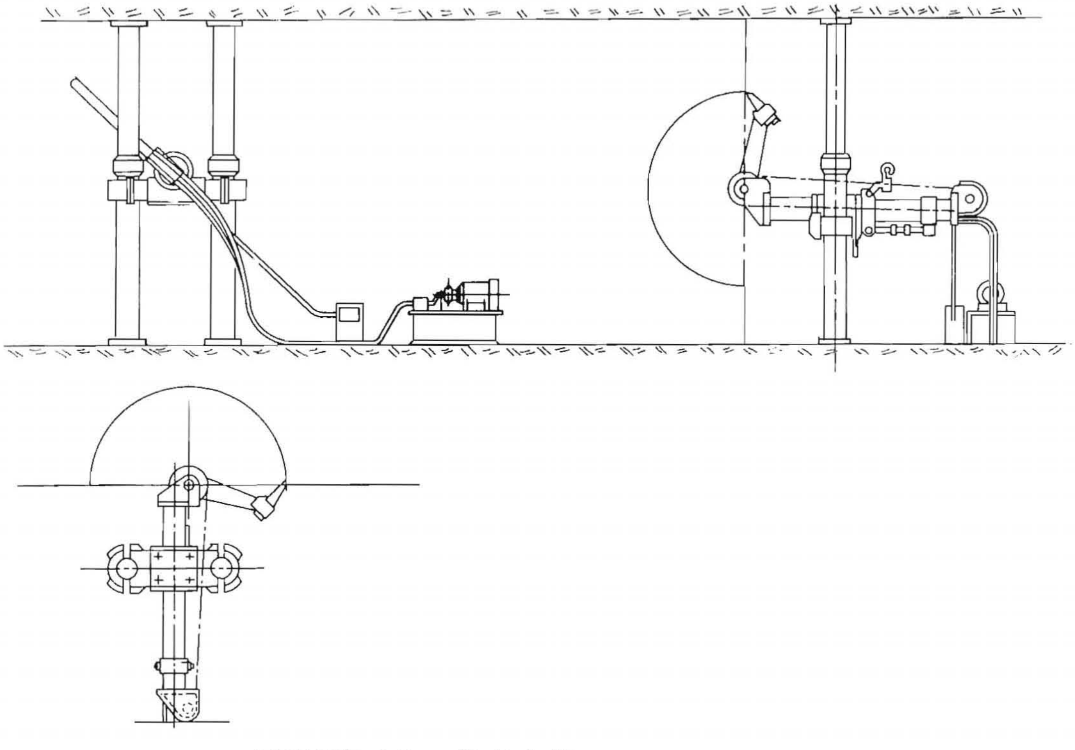

FIGURE A-9. - Polish Komag rotary cutter.

Czech. ZP-1 Hydraulic Linear Cutter.--The ratio of cutting force to depth of cut is used as the cuttability index (fig. A-10).

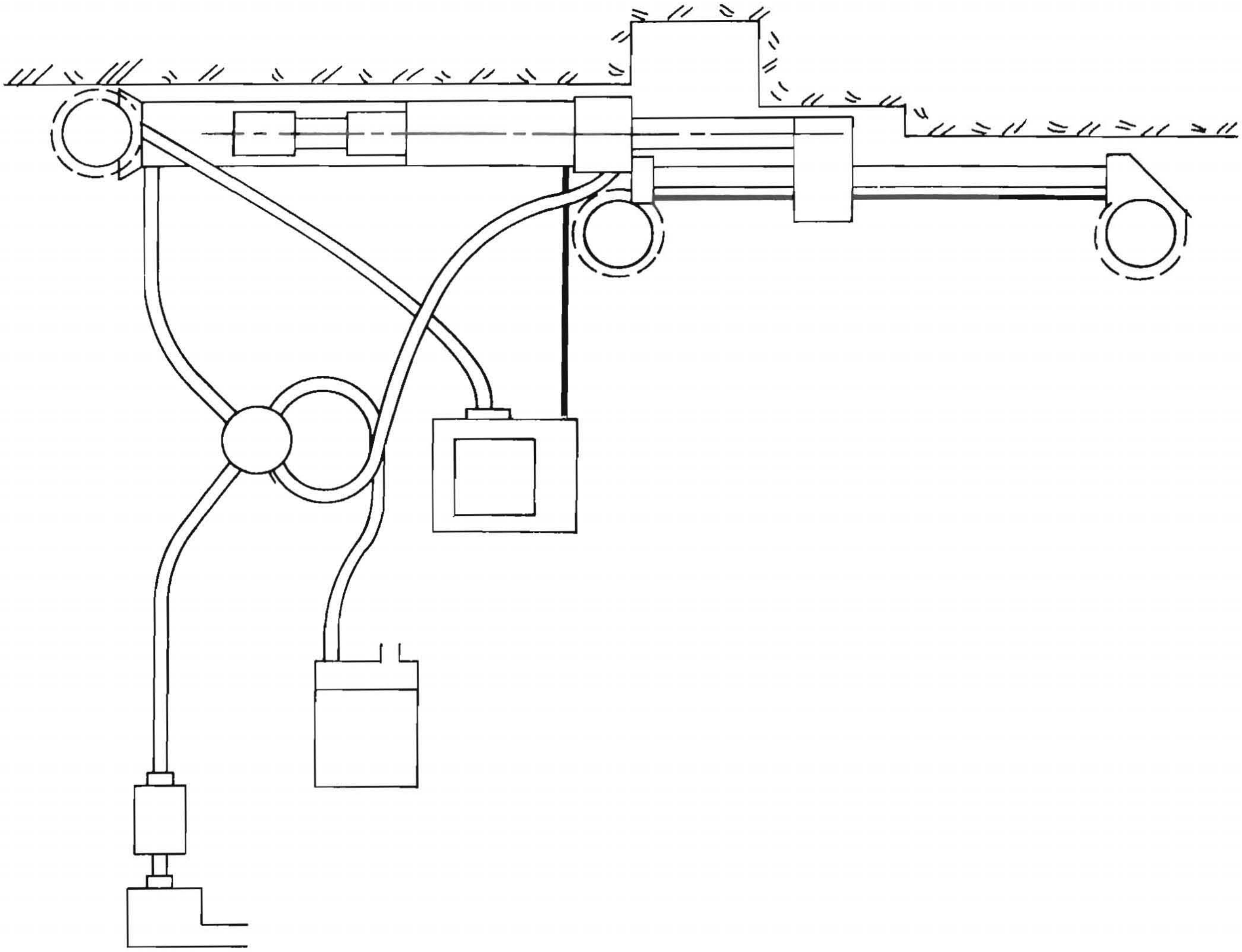

FIGURE A-10. - Czech. ZP-1 hydraulic linear cutter.

U.S.B.M. Microminer.--Basically a dust research device, the power requirement and mass of the cutterhead makes the device rather heavy and cumbersome (14-15).

Borehole Shear-Strength Tester.--The shearing strength (cutting force) and the angle of internal friction determine the cuttability (fig. A-11).

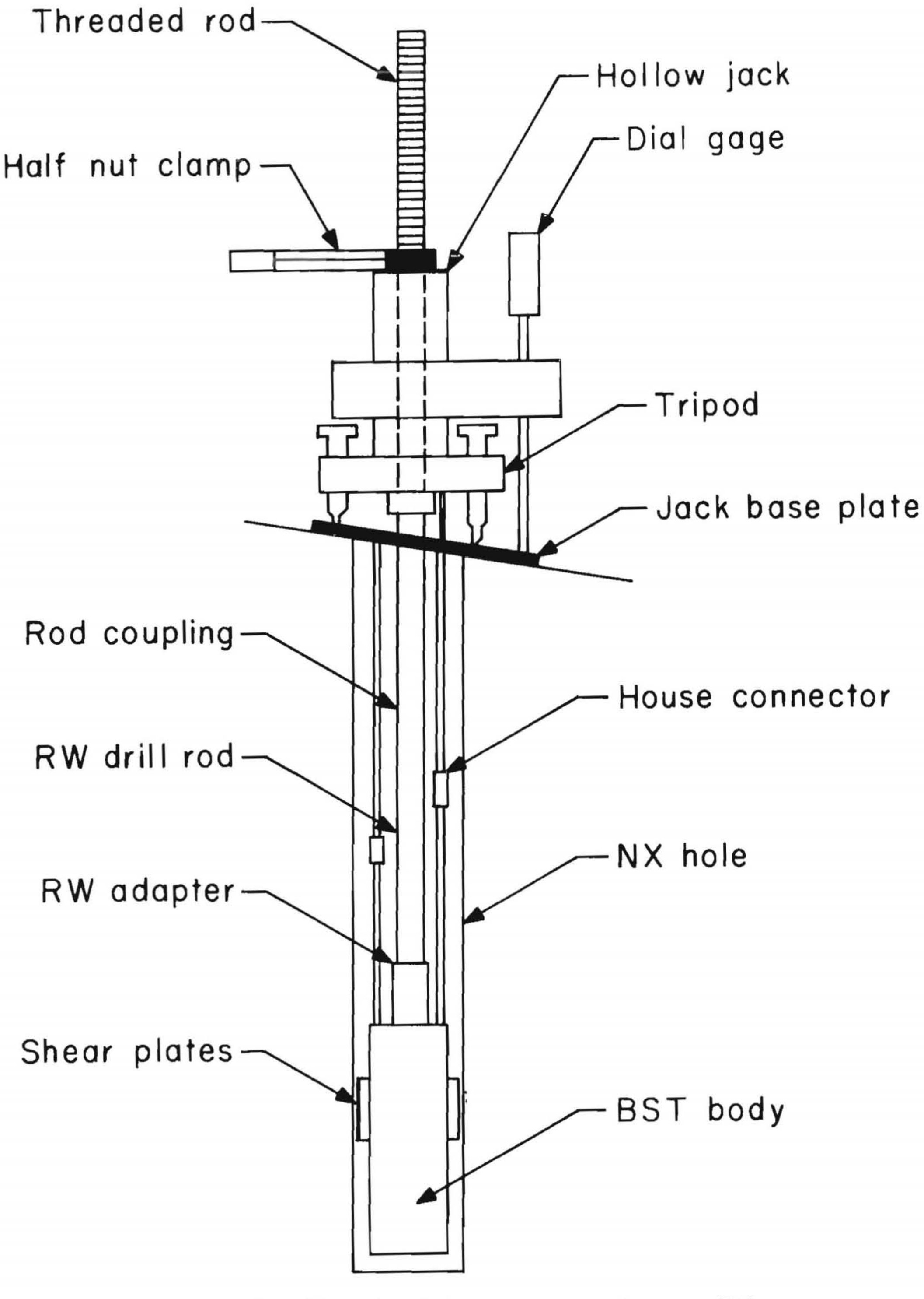

FIGURE A-11. - Borehole shear-strength tester (16).