For the measurement of hammer impact rate, a vibration transducer (General Radio Co, Type 1560-P52) was held in contact with the rock face, six inches from the hole being drilled. The transducer signals were recorded on a tape recorder (Telefunken Type 300) and displayed in spectrogram form (Kay Electric Co Type 661-A) for counting of individual impacts per unit time.

Measurements of drill rod rotation speed, during actual drilling were made using a stroboscopic flashlight (General Radio Co Type 1531-A).

The several types of integral drill steels used during the testing program are described in Table 2. All drill steels had tungsten carbide chisel insert bits.

TABLE 2

DESCRIPTION OF THE DRILL STEEL USED

Author's Designation	Description
1	Staved shank, 1 in hex, 78 in long, 39 mm bit
2	Rubber collar, 1 in hex, 74 in long, 39 mm bit
3	Rubber collar, 7/8 in hex, 74 in long, 30 mm bit
4	Staved shank, 1 in hex, 74 in long, 39 mm bit
5	Staved shank (Avesta steel), 1 in hex, 72 in long, 39 mm bit.

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2. Cheetham, W. R., and Inett, E. W., "*Factors affecting the performance of percussive drills*", Trans. Instn. Min. Metall., Lond., 63, 1953-54.
3. Te Water, L. H., and Mihulka, A. J., "*The possibilities of increasing productivity by using ammonium nitrate-fuel oil mixtures and narrow diameter holes*" (unpublished).

APPENDIX II

TABLE 1

PISTON IMPACT VELOCITIES AND ENERGIES AS FUNCTIONS OF MACHINE AIR PRESSURE FOR ROCKDRILLS A, B AND C

Machine Pressure lb/in^{2}g	Blow frequency (BPM)	Piston Impact velocity (ft/sec)	Impact energy (ft-lb)
ROCKDRILL A			
40	1 200	17,8	32,8
50	1 290	19,8	40,8
60	1 380	21,8	49,3
70	1 450	23,4	57,2
80	1 500	25,1	65,5
90	1 550	26,6	73,6
95	1 600	27,4	78,0
100	1 660	28,1	81,1
110	1 720	29,4	90,5
120	1 800	30,8	98,8
130	1 850	32,0	106,6
140	1 900	33,2	114,3
ROCKDRILL B			
40	1 500	19,3	27,6
50	1 640	21,4	34,3
60	1 740	23,6	41,5
70	1 830	25,4	48,0
80	1 910	27,2	55,2
90	1 980	28,8	61,9
100	2 080	30,4	69,0
120	2 200	33,3	82,7
130	2 275	34,7	89,5
140	2 475	36,0	97,0
ROCKDRILL C			
40	1 520	16,2	19,9
50	1 600	18,0	24,8
60	1 670	19,8	29,8
70	1 750	21,3	34,7
80	1 900	22,8	39,8
90	2 000	24,2	44,6
100	2 100	25,5	49,6
110	2 180	26,8	55,0
120	2 250	28,0	59,6
130	2 300	29,1	64,6
140	2 350	30,2	69,5

PART III

SYNOPSIS

The problem of providing adequate thrust to manually operated rockdrills operating at air pressures of 70 lb/in^{2}g to 80 lb/in^{2}g with the aid of an air-leg is analyzed. It is shown that adequate thrust is provided by an air-leg or the stiff-leg if it is inclined at an angle to the floor of about 25°. However, this requires that the leg react against some support or protuberance, as the friction force between the leg and the floor is inadequate to contain the thrust.

Conclusions summarizing optimum thrusts, blow frequencies, penetration rates, drill steel life and bit wear are presented.

PRACTICAL IMPLICATIONS

Provision for adequate thrust

As has been pointed out previously, for the pressures at which machines are presently operating in most mines (70-80 lb/in^{2}g) the thrusts that can be applied by a man are approximately one half of those which should be applied for optimum penetration rate and drill steel life. Because of this, it is important to consider how the required thrust might be generated. For most of the experiments discussed thus far, the thrust arrangement as shown in Fig 1 consisted of an air cylinder mounted in line with the rockdrill. This method was found to provide all the thrust required.

An alternative method of ensuring that the bit and rock were in contact when the blow arrived was by means

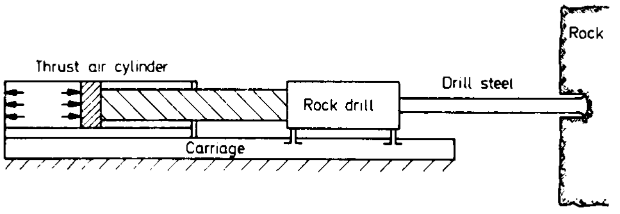

Fig 1 Diagram showing the co-axial thrusting device used for the drilling experiments.

of a screw feed. Again a cradle was used and the rock-drill advanced at a constant displacement rather than under the constant force applied by the thrust cylinder. Penetration rates for rockdrills A and B at Robinson Deep, using the screw feed and the thrust air cylinder described above, are given in Table 1.

TABLE 1

Machine Pressure lb/in²g	ROCKDRILL A †		ROCKDRILL B †	
	Penetration Rates (in/min)		Penetration Rates (in/min.	
	Screw Feed	Thrust Cylinder*	Screw Feed	Thrust Cylinder*
40	3,9	4,5	3,5	3,3
50	4,4	7,0	5,5	4,8
60	7,3	8,1	7,8	7,2
70	9,2	10,2	9,8	9,0
80	9,9	12,7	10,1	11,2
90	14,0	14,7	13,0	14,0
95	12,4	16,2	—	—
100	—	—	15,7	18,4

*Peak penetration rate used

†Drill steel 1 used in all tests.

The two sets of values agree quite well. Because of the weight and size of these two rigs they are impractical for use in narrow workings. A third method, namely, the use of an ordinary air-leg with a rockdrill, as shown in Fig 2, does not possess the disadvantages of bulk

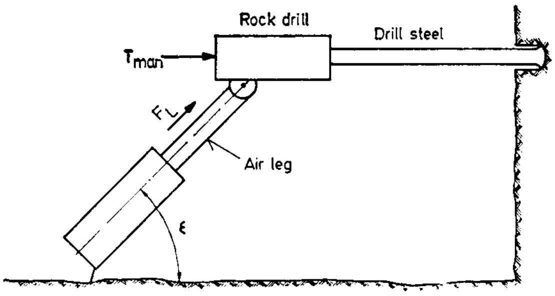

Fig 2 Diagram of an air-leg and rockdrill.

to the same extent. The air-leg is inclined at an angle ζ to the floor. Normally the air pressure to the leg is adjusted so that the drilling machine is supported at the desired level for the hole to be drilled. Assuming that the rockdrill plus attachments weighs V lb, then

$$F_L \sin \zeta = V, \quad (1)$$

$$F_H = F_L \cos \zeta, \quad (2)$$

where

F_L=force of air-leg (lb) directed along the axis of the leg.

$=P_L \times A_p$

P_L=air pressure to leg (lb/in²)

A_p=area of thrust leg piston (in²)

F_H=horizontal force resulting from F_L (lb).

If, in addition to the air-leg thrust, a force T_{man} is applied by a man pushing on the back of the machine in the direction of drilling, the total thrust applied becomes

$$F_t\,(\text{applied}) = T_{man} + F_L \cos \zeta. \quad (3)$$

The restriction on F_L required to keep the machine from accelerating upwards is

$$F_L = \frac{V}{\sin \zeta}. \quad (4)$$

Normally a man can push with a force equal to half his weight so that it can be assumed that $T_{man}=75$ lb. Most percussion machines in use on mines of the Reef weigh approximately 70 lb. Assuming that attachments weigh an additional 30 lbs, then F_L is roughly 100/sin ζ. For $\zeta=45°$, $F_t \approx 175$ lb which is only approximately two-thirds of the optimum thrust required for proper operation at machines pressures of 70 to 80 lb/in²g. If the leg is inclined at a smaller angle, say $\zeta=20°$, then $F_t=350$ lb, which is a satisfactory value for the thrust.

However, assuming a coefficient of friction, μ, between the air-leg feet and the floor, the maximum force that can be resisted by the friction is

$$F_{max} = 100\mu \sin \zeta. \quad (5)$$

The smallest inclination angle ζ that the leg can make with the floor without the leg slipping is, therefore,

$$\zeta = \cos^{-1} \frac{1}{2\mu}\left[-1+\sqrt{1+4\mu^2}\right]. \quad (6)$$

For $\mu=1$, $\zeta \approx 38°$. Thus, although an angle of inclination of 20° could provide the necessary thrust, the frictional resistance is not sufficient and the air-leg will slide backwards. If roof supports, or other devices are present in the stopes against which the air-leg can react, the limitation of the frictional resistance between the feet of the air-leg and the floor need not be applied.

Figs 3 and 4 show the results obtained when an ordinary air-leg was used to provide the thrust for the drilling machine. The analysis is complicated by the fact that the holes were drilled at an angle of from 10 to 30 degrees above the horizontal. The angle of inclination in these figures is that between the leg and the footwall. The effective angle would need to be modified depending on the hole angle. For an angle of inclination of about 35 degrees the penetration rates approach those attained with an in-line air leg. For increasing angles the penetration rates decrease.

The penetration rate as a function of the angle of inclination when an air-leg was used is shown in Fig 5. The experimental points cover the range of 54 to 74 degrees (for these tests the rockdrill was horizontal).

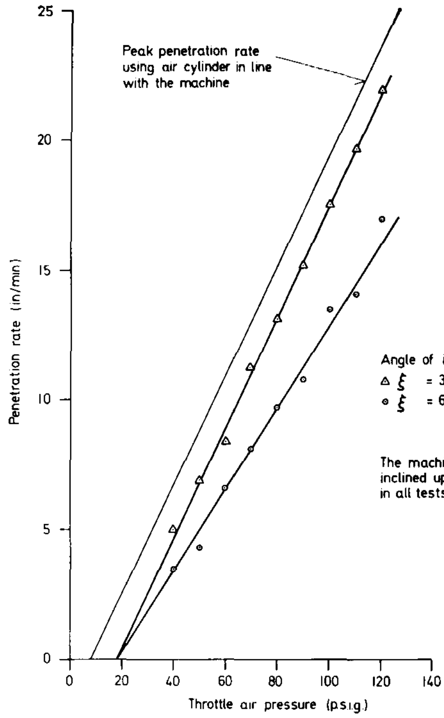

Fig 3 Comparison of penetration rates using an air-leg at different angles of inclination (ζ) Vlakfontein Mine, Rockdrill C, Rifle bar 1.30, Bit 30 mm diameter.

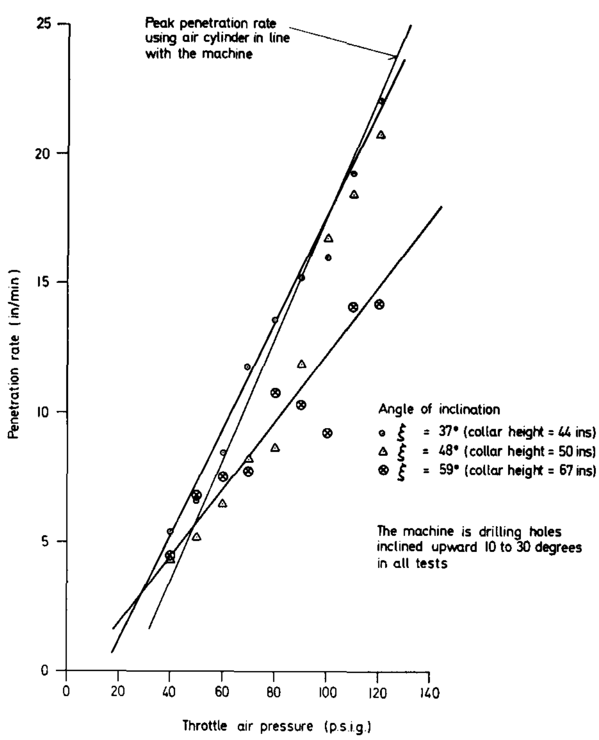

Fig 4 Comparison of penetration rates using an air-leg at different angles of inclination (ζ), Vlakfontein Mine, Rockdrill A, Rifle bar 1:30, Bit 30 mm diameter.

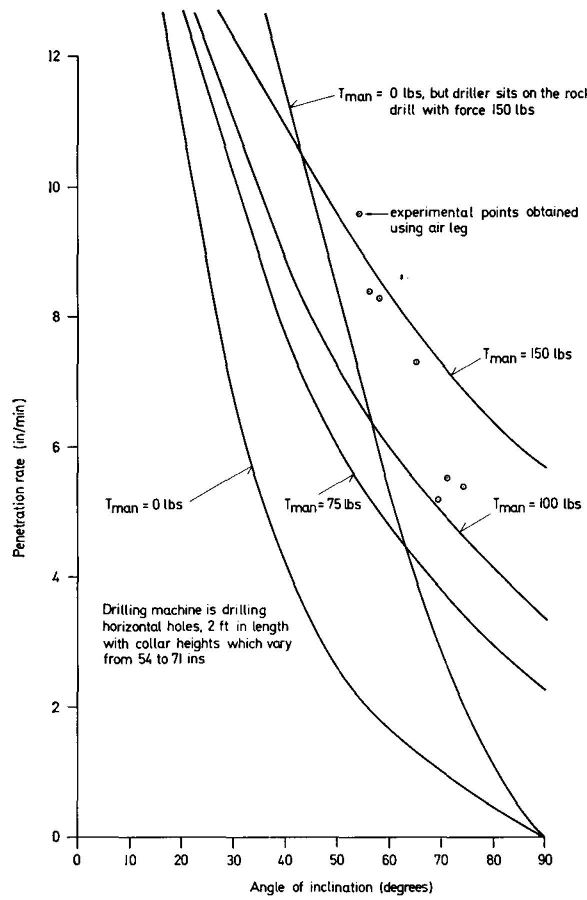

Fig 5 Penetration rate as a function of the angle of inclination (ζ) for a rockdrill using an air-leg. Vlakfontein Mine, Rockdrill A, air pressure 80 lb/in², Bit 30 mm.

The peak penetration rates and the thrust at which they occur for rockdrill A at 80 lb/in^{2}g, taken from Fig 10, Part II, have been used to calculate curves of penetration rate as a function of the angles of inclination for various values of T_{man} (V is assumed to be 100 lbs). From these curves it is seen that to obtain the experimental results, T_{man} must have been between 120 and 160 lb. This is too large a thrust for one man to apply and suggests that perhaps an error was made in the drilling rate measurements. All the theoretical curves have been derived assuming that μ is large enough to prevent slipping of the air-leg. To ensure that the inclination is less than about 38°, the leg would have to be supported by a ridge in the floor, against a man's foot or some other support.

If instead of pushing at the back of a rockdrill with a force of 75 lb, a man weighing 150 lb were to sit on the drill and thereby allow the air pressure in the cylinder to be increased, so that

$$V=250 \text{ lb},$$

$$F_L=\frac{250}{\sin \zeta},$$

and

$$F_t=250 \cot \zeta,$$

the curve plotted in Fig 5 shows that for a machine pressure of 80 lb/in²g and angles of inclination of less than about 65 degrees it is better for the man to sit on the rockdrill than to push on it. The peak penetration rate at this machine pressure was found to be 12,7 in/min. To achieve this rate using an air-leg with the assistance of a man, the following inclinations of the air-leg should be used:

TABLE 2

T_{man} (lb)	Inclination (degrees)
0	17
75	20
100	22
150	27

If the man sits on the rockdrill, the inclination can be increased to 36 degrees.

A fourth method of applying the necessary thrust is through the use of a so-called "stiff" leg, a device developed and tested by Dr Becker of the Mining Research Laboratory of the Chamber of Mines of South Africa. It is very similar to the air-leg discussed above; however, instead of compressed air being used to support the machine and provide the thrust, a rack and gear arrangement is used. In principle it is similar to the screw feed discussed earlier except that the screw is advanced by hand. This leg, which weighs some 20 lb (approximately half that of an air-leg) is attached to the rockdrill in a similar fashion. Since the forward thrust is now not limited by the weight of the machine but rather by the alignment, very large thrusts can be generated. In Figs 6 and 7 the penetration rates are plotted as functions of machine air pressure obtained using rockdrill *C* and the stiff-leg. Also plotted in the Figs are the peak penetration rate curves obtained when the same machine was used with thrust applied co-axially by and air cylinder. For angles of inclination to the leg to the floor of approximately 30°, the results are very similar to those obtained using the air-leg; as the inclination approaches 90°, the drilling rates are reduced, as expected. The limitation on the thrust is the friction force between the floor and the feet of the stiff-leg.

Conclusions

From the results of this research the following conclusions may be drawn.

1. Hand-held drilling machines when operated at air pressures of 70 to 80 lb/in²g are greatly underthrusted. The thrust which should be applied is given by

$$F_t = 0{,}5\ Ap$$

where

A=area of piston head (in²)
p=applied machine air pressure lb/in²g
F_t=optimum thrust (lb).

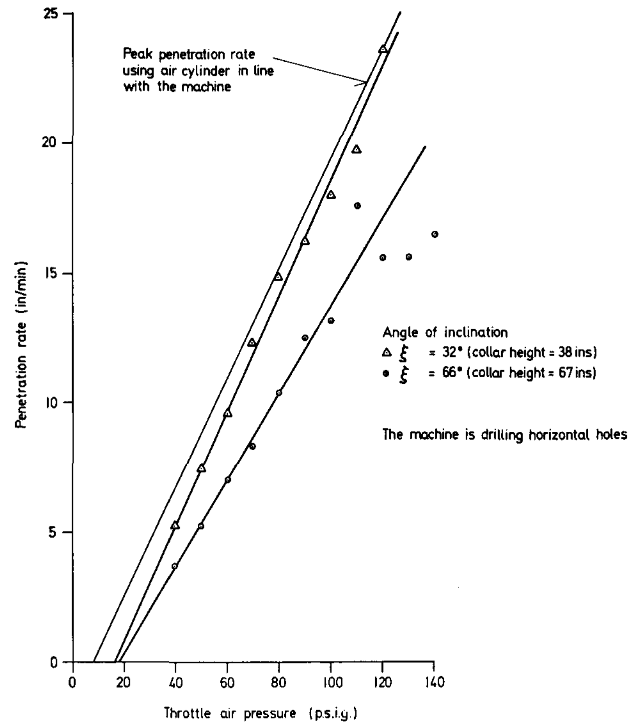

Fig 6 Penetration rate for different angles of inclination (ζ) using the "stiff" leg. Vlakfontein Mine, Rockdrill C, Rifle bar 1:30, Bit 30 mm.

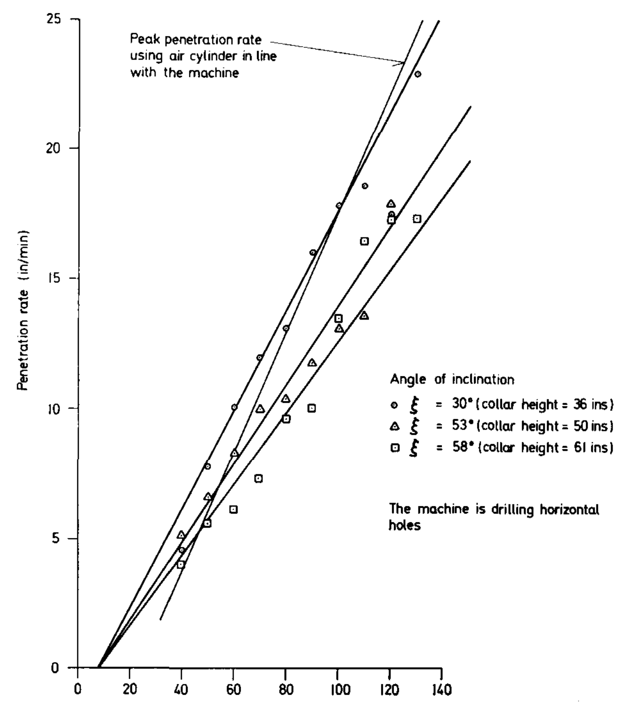

Fig 7 Penetration rate for different angles of inclination (ζ) using the "stiff" leg. Vlakfontein Mine, Rockdrill A, Rifle bar 1:30, Bit 39 mm.

For a particular rockdrill the value of the thrust is independent of the type of rock drilled and of the areas of the hole.

2. Increasing the thrust to the optimum value would result in increases in the penetration rate by factors of up to about 2 and increases of similar magnitude in drill steel life.

3. For the three machines used, the blow frequency f, the piston impact velocity V_s and blow energy E_i can be calculated using the equations

$$\bar{\xi}=22\sqrt{\frac{6pAg}{SW}}\ ,$$

$$V_s=,68\sqrt{\frac{SpAg}{6W}}\ ,$$

$$E_i=1/2\frac{W}{g}V_s^2$$

where

g=acceleration of gravity — ft/sec²
S=nominal piston stroke — in
W=piston (with rifle nut) weight — lb
f=blow frequency — BPM
V_s=piston impact velocity — ft/sec
E_i=piston blow energy — ft/lb

4. The penetration rate in quartzite is given by

$$PR=12\times\frac{E_i\times\bar{f}\times T_R}{A_H\times E_V}\ ,$$

where

PR=penetration rate (in/min)
$T_R\approx 0{,}8$
$E_V\approx$uniaxial compressive strength of the rock drilled (lb/in²)
A_H=area of hole drilled (in²).

The above equations can be used to check the drilling performances observed for individual mines.

5. In terms of penetration rate and air consumption the three drills tested performed with nearly the same efficiency: rockdrills A and B giving approximately the same penetration rates with that of rockdrill C some 20 percent less.

6. The penetration rate varies inversely as the area of hole drilled. Thus the penetration rate obtained while drilling a 30 mm diameter hole should be approximately 1,7 times that obtained while drilling a 40 mm diameter hole.

7. Bit gauge wear is related to the footage drilled L by the following relationships,

d_h=40 mm bit
bit gauge$=d_h-4{,}5(L)^{1/3}+17{,}5,\ L>59$ ft.
d_h=30 mm bit
bit gauge$=d_h-3{,}2(L)^{1/3}+13{,}5,\ L>75$ ft.

8. Penetration rates obtained when an in-line air-leg or screw feed were used to provide thrust were identical.

9. Penetration rates using an ordinary air leg or the "stiff" leg approached those for the in-line air leg as the angle of inclination between the leg and the floor aproached 30 degrees.

10. From (3) and (4) it follows that with smaller diameter holes smaller drilling machines can yield the same rate of penetration as larger machines do in larger diameter holes, and, more important, from (1) that smaller machines require less thrust for optimum operation.

ACKNOWLEDGEMENTS

The author is much indebted to Dr N. G. W. Cook and Mr F. H. Lancaster for writing the Introduction to this paper and for preparing the three parts of it from a report written when he was working for the Mining Research Laboratory of the Chamber of Mines of South Africa, while on leave from the Colorado School of Mines during June through August, 1969.

All the data used in the report and presented in this paper, except where otherwise noted, were obtained by Dr E. C. H. Becker when working for the Chamber of Mines at drilling sites provided by Gold Fields of South Africa, Limited.

The author wishes to thank Mr Botha of Gold Fields of South Africa, Limited, Mr Wolvaardt of Delfos and Atlas Copco (Pty) Limited, Mr Fredrickson of Victoria Engineering Works (Pty) Limited, Mr Wallace of The Steel Engineering Company, Limited, for their help, as well as his colleagues in the Mining Research Laboratory.