

CHAPTER V

CHOICE OF TYPE OF MACHINE, POSITION AND DEPTH OF CUT

THERE is little doubt that the more general adoption of longwall coal cutting machines has been much hindered by imperfect appreciation of the possibilities and limitations of the various types of machines, and by lack of understanding of the essential conditions of the coal face in relation to the application -of longwall coal cutting machines. The more systematic working of the face and its more rapid advance also have an important influence on the face conditions, so that the nature of the roof, the ease with which the coal can be got into the tub, and the character of the floor may be very different in the same seam of coal on hand and machine worked faces respectively.

No two coal seams are really identical, either as regards their general characteristics or their behaviour when being worked, and it is quite impracticable to lay down hard and fast rules as to the type of machine best suited for certain sets of conditions. The conditions best suited for each type of machine have been 50 quoted in describing the various types. The following factors may be considered of prime importance in determining which machines can be expected to give the best overall results:-

- (1) Structural strength of the coal.
- (2) Nature of the roof and floor.
- (3) Character of the holing.

The relative importance of each of these factors must be considered most carefully if longwall coal cutting machines are to be made a real success.

Structural Strength of the Coal. Coal which is invariably tender and falls as soon as it is undercut may preclude the use of any longwall machine except the bar type. The difficulties occasioned by tender coal may sometimes be overcome satisfactorily by cutting in the middle or at the top of a seam, though where overcut coal sticks hard to the floor an overcutting machine is of little use. Again, the structural strength of the coal as regards the ease with which it can be got into the tub is often greatly influenced by the actual bearing of the face in relation to lines of cleavage or "bord" lines in the coal and, following the introduction of machines, it may be good policy to make an alteration in the general direction of the faces. Where any such alteration is impracticable the machine which promises to give the best results under the existing conditions must be chosen.

In this connection it is important to remember that machine faces move forward much more rapidly than hand-worked faces, and that the quicker advance of the face frequently prevents much of the 'weight' from being thrown on to the face itself. The nature of the coal, as regards its behaviour when undercut by a machine, may be quite different from its nature on a face worked entirely by hand. In many cases the structural strength of the coal has more influence on deciding the depth of the cut than on the actual type of machine to be adopted.

The disc type of machine arranged for undercutting is at a serious disadvantage where the coal falls as soon as it is cut, since the coal tends to fall on to and lock the disc as it revolves under the coal. Under such conditions much of the fallen coal is ground to 'small' between the spokes of the disc and the edges of the bracket, and the power consumption of the machine may become excessive. Where, on account of other conditions affecting the choice of machine, the disc type has to be adopted, the difficulty may be partially overcome by plating the disc between the spokes with heavy gauge steel sheet, or, in the case of shallow cuts, by using a solid disc. These are, however, only partial remedies, and disc machines under such conditions cannot be expected to produce their best results.

Machines of the chain and bar type are much better adapted for undercutting in tender seams, since the width of the parts of the actual cutting mechanism under the coal is so much less. The bar machine is seen at its best, as compared with disc and (to a lesser degree) with chain machines, when undercutting a very tender coal which falls as soon as it is cut. With chain and bar machines the undercut coal can be spragged up within a few inches of the actual position of the cut. The bar machine excels in this respect, though the 'plough' cannot generally be used under such conditions

and practically all the holings are left tightly packed in the cut. The chain machine enables the coal to be spragged up much closer to the cut than the disc machine, though not so close as with the bar; the chain always brings a large proportion of the holings out of the cut.

Nature of the Roof and Floor. The more rapid advance of the face with machine mining frequently results in a roof which has given trouble on a hand-worked face becoming much stronger, standing up well on the face and bending down to settle evenly and solidly on the packs or buildings. The straight line of face, which should always be a feature of machine mining, and the greater regularity of timbering both tend to improve the working of the roof on longwall coal cutter faces as distinct from faces worked entirely by hand.

Much the same result follows the introduction of machines as regards the effect on floors which have given trouble on slow moving hand worked faces. Fireclay floors in particular have a tendency to push or 'creep' under the influence of roof weight on the solid coal and on the packs or buildings, and where the face is advanced rapidly there is a reduced likelihood of this occurring actually on the coal face.

It is immaterial as regards actual cutting performance whether machines of the disc and bar types work with the haulage end of the machine in front or behind. Chain machines cannot do satisfactory work except with the jib at the back end of the machine, and when they have to cut to and fro on a face it is necessary to turn them completely round either in the stable at each end of the face, or at the corner gate road end. To turn a machine quickly either in a stable or at a gate road end requires a considerable expanse of roof unsupported by props, though adequate roof support can be given in some seams by using long and heavy bars supported by props at each end. The removal of sufficient timbering or the changing of props as a machine is being turned is quite impracticable in some seams, and may prevent the use of chain machines cutting to and fro on a face. As in the case of other factors influencing the working of machines it may be a more paying proposition to alter the method of working and to flit machines from one end of a face to the other; flitting is not necessarily a lengthy business, and in a considerable proportion of cases it is better practice than cutting to and fro on a face.

As already mentioned, the disc machine cuts equally well whichever end of the machine is leading and need never be turned on the face. The fact that the coal cannot be spragged up after being cut within several feet of the position of the cut may have a bad effect on some roofs, but this is only evident as a rule when the coal falls as soon as cut and thus robs the roof of any support.

Character of the Holing. The nature of the material which has to be cut is in many cases the deciding factor in the choice of the type of machine to be used. Certain types of holing - notably very hard material or material containing much iron pyrites - can only be dealt with satisfactorily by machines of the disc type. The great mechanical strength of this type of machine and its rigidity of construction enables it to cut in material which would cause endless troubles from breakdowns with machines of the other types. The holings from a disc machine are generally considerably finer than from a chain machine, though not so fine as from a bar machine, and this is a serious disadvantage where holing is done in coal and the cuttings are filled out and sent to the screens.

In many cases it is more the texture of the material to be cut than its actual hardness which should be given chief consideration in determining the type of machine to be used. The cutting actions of disc, chain, and bar machines are all quite distinct from one another. The disc gives a relatively slow grinding action, and in many cases the cutters can tear off, the material being cut in relatively large pieces. In the chain machine the cutters are moving much faster, and the action is more of a scraping and rending action which causes the production of only a small proportion of fine particles. The picks of a bar machine travel at a higher speed than those of either a disc or chain machine and reciprocate in and out of the cut as they are cutting: their action is largely of a chipping and filing character.

In a certain number of cases machines would give better general results (i.e. increased yardage with reduced consumption of power) if the correct type of machine were adapted to the precise conditions as regards the character of the holing; that is, if the actual speed of the points of the cutters and the relation between cutter speed and the number of haulage strokes per minute were adapted to the hardness and character of the holing for each individual case.

The Position and Depth of the Cut. The position and depth of the cut which will give the most economical results can often be determined without exhaustive experiment. All three types of machines can be built to cut at any position from the floor to near the roof, and to cut to any desired depth. It is, however, generally impracticable to cut to a depth of more than 4ft. 6 ins. with disc machines when cutting dead at floor level. Certain makes of chain machines cannot cut within about 1 in. of floor level, and, in some cases, it is a matter of great difficulty to make bar machines hole dead on the floor level.

In a great many cases the position of the cut is determined by the presence of bands of dirt or of inferior coal in the seam, or by a bed of fire-clay, suitable for holing, immediately under the coal. In such cases it is the depth of cut only that need be considered and in this connection a practical working knowledge of the seam is necessary.

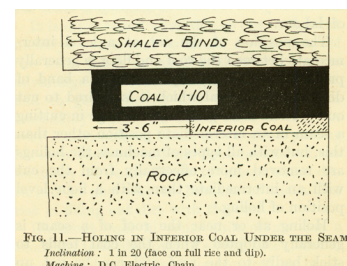
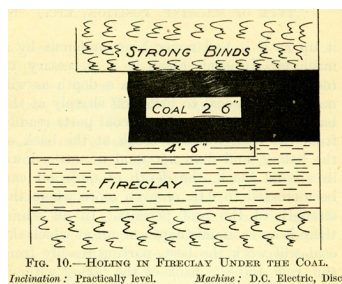
It is often found advisable to cut in the dirt underlying the coal to avoid cutting any of the seam itself to small coal, to obtain the advantage of increased height on the coal face, and to get sufficient dirt to pack the face reasonably tight. In other cases it may be very inadvisable to break into a clean parting between the coal and the floor because of the tendency of some floors to creep when disturbed in any way or because of the added risk of filling out dirt with the coal.

Undercut coal in some thin seams has a tendency to settle down in a solid block, and as much powder and work is required to break it up as if it had never been undercut by a machine. In such cases it is necessary to restrict the undercut to such a depth as will not cause the coal to break off sharply at the back of the holing. Where coal parts readily from the roof, forms a break at the back of the holing, and does not tend to settle down in a solid block, the depth of undercut can be increased to 6ft. or even more where the strength of the roof permits. In all seams there is an economic depth of cut at which the coal will work the best, parting readily from the roof and the back of the holing without settling down in a solid mass, and making the maximum yield of round coal with the minimum of labour.

The position of the cut at a level intermediate between the roof and floor is generally predetermined by the presence of a band of dirt or inferior coal which it is desired to cut out. There is no general advantage in cutting a seam in an intermediate position other than this, but with all types of machines the holings are removed more effectually from the cut with an intermediate than with a floor level position of holing.

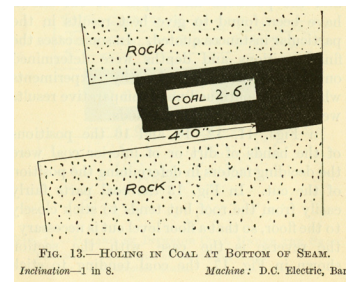
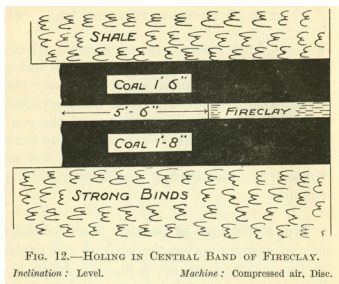
Holing at or near the roof of a seam is generally adopted when the coal tends to stick badly to the roof and can be got up without much difficulty when overcut. Occasionally it may be an advantage to cut out a band of dirt or of inferior coal at or near the roof. This position is far from being an ideal one both from the point of view of the constructional difficulties of the machine, and from the probability of the fouling of the roof or timber by the cutting mechanism during running.

Typical Sections of Seams. Some sections of coal seams showing the position and depth of the undercut are given in Figs. 10 to 17. These sections are taken from actual practice, and the positions and depths of cut shown have been found to give best results in the particular instances quoted. In some cases the final positions and depths were determined only after numerous lengthy experiments which were continued until comparative results were available over long periods.

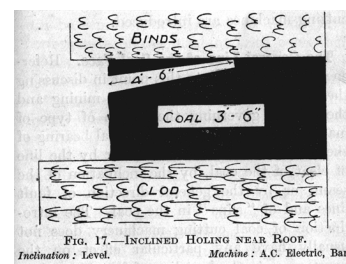
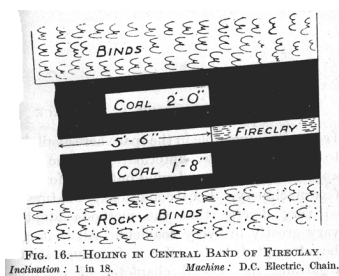
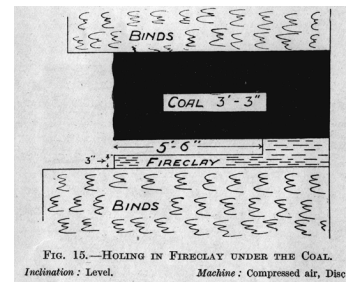
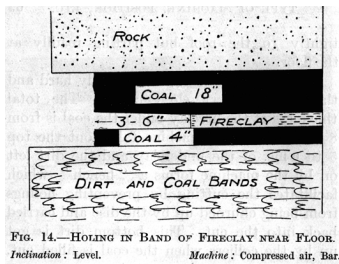


In Figs. 11, 12, 14 and 16 the positions of the bands of dirt or of inferior coal were the deciding factors in determining the position of the cut. In Fig. 13 the coal parts fairly easily from the roof but

tends to stick closely to the floor, so that a floor level cut is necessary; the reverse is the case with the section shown in Fig. 17, the coal tending to stick tightly to the roof but parting readily at the floor.



In Fig. 15 the holing is extremely hard and the material very close-grained. The total thickness of the fireclay under the coal is from 8 to 10ins.; the machine takes out the top 5 to 6ins. of the underclay and the dirt left on by the machine forms a 'bench' which facilitates the cutting by preventing holings from being churned up by the disc and carried back into the cut. This bottom dirt is got up by the colliers when the coal is filled out.



CHAPTER VI

ARRANGEMENT OF WORK AT THE FACE.

IT is quite impossible in the space here available to give any extensive information on the most approved methods of laying out work for coal face machinery. Local conditions are naturally so very diverse that the methods adopted vary greatly in every coalfield. All that can be attempted is to offer a few suggestions regarding the special character of machine mining, and to discuss the essential differences in the working of a mine when longwall coal cutting machines are introduced.

The General Line of the Coal Face. Reference has been made to this point in discussing the economic aspect of machine mining and the factors governing the choice of type of machine. In most cases the actual bearing of the coal face is determined either by the line of cleat of the coal, by the inclination of the seam, or by the general direction of fault lines and of "slips" in the coal. The introduction of coal cutting machinery does not usually have any particular effect on the question as to the best line of face to produce the maximum yield of large coal at the lowest cost consistent with the greatest safety to the worker. Even with purely manual labour it is a sound policy to have faces as straight as possible, and sound policy becomes strict necessity where coal cutting machines are introduced if the best results are to be obtained. It should never be left to machines to straighten out irregularities in coal faces, and a little labour spent every now and then in removing angles and irregularities left on the face, in straightening out ribsides that have been getting behind the rest of the faces, and in doing many of the little jobs that go towards simplifying the work of the machine attendants, will be repaid many times over in improved performance of the machine with consequent greater regularity of output. It should be mentioned that 'straight line of face' does not necessarily mean a perfectly straight face from corner to corner: long coal cutter faces are hardly ever dead straight, since the coal tends to work a little more freely towards the middle of the face than at the two ends, and nearly all faces that were originally dead straight tend gradually to assume a slight curvature. In bituminous coal of a moderately soft character it is not uncommon for a face several hundred yards long to have the centre 20 yds. or so in advance of the ends of the face. Such gentle curvature is of no account, but it is important to prevent the curvature from becoming too marked. It is crookedness, sharp bends, and sinuous irregularities that should be avoided on faces where longwall coal cutting machines are at work.

In the valuable papers read before the Institution of Mining Engineers and the South Wales Institute of Engineers by Sir William Garforth (The Application of Coal Cutting Machines to Deep Mining." Trans. Inst. M.E., 1902, Vol. XXIII, page 312.) and Mr. Sam Mavor, (Practical Problems of Machine-mining, 'Trans. Inst. Mining Engineers, Vol. XXXI, p. 378., Machine-mining, with Special Reference to South Wales." Proc. of the S. Wales Inst. of Engineers, Vol. XXVI, No. 6.) these eminent authorities emphasize repeatedly the value of a straight line of cut, with a straight line of timbering and a straight line of roof break.

In many cases machines are put to work originally on an existing hand-worked face where no special care has been taken as a preliminary measure to see that the machine can do itself justice. The machine's performance under such conditions can hardly be anything but disappointing both to the manufacturer and to the management. It is far wiser practice, and an infinite saving of time, trouble, and annoyance, to postpone the introduction of machines until a straight or reasonably straight face of the desired length can be prepared. Good results cannot be obtained merely by laying on power lines to an existing face and putting a machine to work; it is very much better in such circumstances to make haste slowly.

As regards the working of seams where the measures are inclined, coal cutter faces can be worked satisfactorily at any angle with the rise and dip line where the inclination is only moderate. In working faces on the strike of the measures at steep inclinations machines have a tendency to fall into the cut when the face is worked to the dip, and to fall away from the face when the latter is worked to the rise, thus putting a great strain on the goaf side props. It is more usual to arrange machine faces at some angle nearer the line of full rise and dip. A method which has the merit of increased safety combined with greater ease of filling out the coal is to lay off the faces a few degrees off the full rise and dip of the measures, with the top of the face in advance of the bottom. When the coal is cut it tends to settle towards the back of the cut rather than to fall over the machine; in filling out, less coal is likely to be lost by falling into the waste or goaf.

Where there are slips in the coal running at an angle with the line of the face, the coal generally shows a tendency to fall when the machine commences cutting under the edge of the slip. In such cases it is always best to arrange the direction of the machine so that its line of progress approaching the slip forms an acute angle with the line of the slip; it is easier to sprag up the coal when cutting in this direction. When cutting in the reverse direction the coal tends to come away as it is cut to the back of the holing, and may cause considerable delay as well as loss of coal due to admixture with dirt.

The Length of the Coal Faces. Apart from the influence of such factors as the presence of faults, and existing goaf lines and pillars to be left, faces may be developed either of a length which can be cut by a machine in one shift, or of considerable length so that several machines may be at work on it.

Short Faces. Where it can be arranged to clear out the coal cut by a machine in a day it is usually the best plan to arrange short faces which can normally be traversed by a machine in a shift, and to make the machine cut to and fro on the face. Practical experience of the working of each individual seam is required to determine what the length of each face should be, though experience gained as a result of working seams of similar general characteristics is often a useful guide. In estimating the length of face which is to be set out it is always advisable to under-estimate in the first place and to arrange a length of face which can actually be cut in a little more than half the shift. Thus, if the actual cutting speed of a machine in a seam is estimated at 20yds. per hr., the length of the face should not be more than 80 to 90yds. The balance of time on the cutting shift will then allow for getting the machine into position at the commencement of the shift, changing picks, laying out the haulage rope or chain when required, changing over cables or hose from one gate to another, delays occasioned by unexpected difficulties in the cutting, and the routine examination of the machine at the beginning and end of the shift. Where the machine has to be turned on the face, as, for instance, in the case of most types of chain machines, and, in some cases, with bar machines, either the turning must be done on a second shift, or further time must be allowed and the length of face to be set out will be correspondingly shorter.

Long Faces. The inclination of the measures, or the presence of 'slips' in the coal having a general direction forming an acute angle with the line of the face frequently makes it necessary to run machines in one direction only. It may be found necessary on this account, or for other reasons determined as a result of experience, to lay out long faces and have two or more machines following each other round and always cutting in the same direction. Where this is done it is necessary to flit machines round from one end of the face along the gate roads to the other end of the face. In some cases, as, for instance, in highly inclined seams where the faces are on practically the full rise and dip of the measures, it is usual to flit the machine along the face itself, but under normal conditions this cannot be regarded as a satisfactory practice.

The alternative to flitting on long faces is, of course, to cut to and fro, but this method is generally inadvisable, since after reaching the end of a long face the machine cannot return until the coal which has been last cut is all filled out. In practice, cutting to and fro on long faces means constant delays in the progress of the machine and irregularity of output; irregularities of the face line are very liable to occur at the points where one machine finishes its run and where another machine has turned back to commence its return journey.

The difficulty of filling out the coal immediately behind the machine towards the ends of a long face can be overcome to some extent by arranging the gate roads nearer together at the end than in the centre of the face. Thus, if the centre gates are, say, 44 yds. apart, the end gates at each corner of the face may be only 30 yds. apart, with the rib side at each corner, say, 11 yds. inclusive of the width of the stable - usually 3 to 32 yds. With an arrangement of this sort the coal at each end of the face can be cleared more quickly than at the centre of the face.

Arrangement of Face Work. There is an absolute necessity for the closest co-ordination between all work done at the coal face where the output from a district or a seam is largely dependent on the work of coal cutting machines. The output can only be maintained provided the machine does its work regularly and adequately, and the arrangement of all coal face work must be subordinated to the work to be done on the coal cutting shift. This rule applies wherever coal cutting machines are used, and most particularly so when short faces are being worked, which have to be cleared of coal every 24 hours, the machine cutting to and fro along the face.

Coal face operations which must be carried out without interfering in any way with the performance of the machine are:-

- (1) Filling out of coal which has been cut.
- (2) Ripping or dinting of gate roads and packing of dirt on the face.
- (3) Timbering the face.

Filling Out of Coal which has been cut. Provided the gate roads are the correct distance apart, delays in filling out coal are due mainly to absenteeism or to inadequate supplies of empty tubs. Absenteeism is at all times a source of endless worry to successful management, and where the output is largely dependent on the regular performance of longwall coal cutting machines the evils of absenteeism are liable to be felt most acutely. The only suggestion that can be put forward to mitigate this evil is that the colliers with the best records of attendance should always be given stalls on coal cutter faces. It is generally easy to attract good men to such places, for they are generally at least as good as any other places in the pit, and the regularity of systematic work is an added inducement.

Ripping or Dinting of Gate Roads and Packng of Dirt on the Face. No little care is required in arranging the work of making height on gate roads where coal cutting machinery is in use. Bearing in mind the fact that the regularity of output from the face depends essentially on the regularity of the work of the machine, it is of the first importance to see that no delays to the progress of the machine are occasioned by the presence of dirt from the ripping or dinting being on the face at the time when the machine is due to pass; packing dirt on the face must always be arranged so as to avoid any interference with the progress of the machine.

Timbering the Face. The men timbering the face as the coal is filled out must always set the timber the correct distance from the face to allow the machine to pass. Disc machines and, in some cases, bar machines require to be held up to their work when cutting, the goaf side timber set by the colliers being used as a guide for the machine. Where the cutting is of a very hard nature the machine may require a trailing rail to distribute the thrust of the machine over a larger number of props, and to give increased leverage for keeping the machine up to the coal face. Chain machines tend to hug the face very closely and usually do not touch the goaf side props at all.

Timber set too far from the face has frequently to be reset by the machine attendants, and is an annoying source of delay. When props are set too near the face the machine men may try to force the machine between such props and the coal; this practice is a fruitful source of breakdowns and mechanical failures of machines.

CHAPTER VII

MOTIVE POWER FOR LONGWALL COAL FACE MACHINERY

IT is beyond the scope of this book to give a detailed description of the numerous accessories required in the provision of power for longwall coal cutting machines. In the majority of cases, particularly at collieries that have been working for many years, the power that will be used at the face is already installed in the mine, and all that is necessary is the extension of the power lines to the coal face.

At the present time motive power for longwall coal face machinery is limited to electricity and compressed air. A brief survey of their use at the coal face, as regards safety and efficiency, will be of service.

Electricity: Home Office Regulations. Either direct current or alternating current can be used at the coal face. Special regulations as to the use and installation of electricity have been drawn up by the Home Office under the Coal Mines Act, 1911. (General Regulations as to the Installation and Use of Electricity, unth Explanatory Memorandum. Published by the Home Office, us Mines and Quarries Form No. 11, price 1d.) The more important of these regulations, as regards coal face machinery, are as follows:-

125. (a) All metallic sheaths, coverings, handles, joint-boxes, switchgear frames, instrument covers, switch and fuse covers and boxes, and all lampholders, unless efficiently protected by an earthed or insulating covering made of fire resisting material, and the frames and bed plates of generators, transformers, and motors (including portable motors), shall be earthed by connection to an earthing system at the surface of the mine.

(b) Where the cables are provided with a metallic covering constructed and installed in accordance with Regulation 129 (e), such metallic covering may be used as a means of connection to the earthing system. All the conductors of an earthing system shall have a conductivity at all parts and at all joints at least equal to 5,0 per cent. of that of the largest conductor used solely to supply the apparatus a part of which it is desired to earth. Provided that no conductor of an earthing system shall have a cross sectional area of less than 0.022 sq. in.

(c) All joints in earth conductors and all joints to the metallic covering of the cables shall be properly soldered or otherwise efficiently made, and every earth conductor shall be soldered into a lug for each of its terminal connections. No switch, fuse, or circuit breaker shall be placed in any earth conductor.

This rule shall not apply (except in the case of portable apparatus) to any system in which the pressure does not exceed low pressure (Normally not exceeding 250 volts where the electrical energy is used.) direct current or 125 volts alternating current.

126. (a) Where electricity is distributed at a pressure higher than medium pressure (Normally above 250 volts, but not exceeding 650 volts where the electrical energy is used.) it shall not be used without transformation to medium or low pressure except in fixed machines in which the high or extra-high pressure parts are stationary; and (ii) motors under 20 h.p. shall be supplied with current through a transformer stepping down to medium or low pressure.

127. Switchgear and all terminals, cable-ends, cable-joints and connections of apparatus shall be constructed and installed so that:-

(i) All parts shall be of mechanical strength sufficient to resist rough usage.

(ii) All conductors and contact areas shall be of ample current carrying capacity and all joints in conductors shall be properly soldered or otherwise efficiently made.

(iii) The lodgment of any matter likely to diminish the insulation, and of coal dust on or close to live parts shall be prevented.

(iv) All live parts shall be so protected or enclosed as to prevent accidental contact by persons and danger from arcs or short circuits, fire or water.

(v) Where there may be risk of igniting gas, coal dust, or other inflammable material, all parts shall be so protected as to prevent open sparking.

128. (d) Every motor shall be controlled by switchgear for starting and stopping, so arranged as to cut off all pressure from the motor and from all apparatus in connection therewith, and so placed as to be easily worked by the person appointed to work the motor.

129. (f) Cables and conductors where joined up to motors, transformers, switchgear, and other apparatus, shall be installed so that (i) they are mechanically protected by securely attaching the metallic covering (if any) to the apparatus, and (u) the insulating material at each cable end is efficiently sealed so as to prevent the diminution of its insulating properties. Where necessary to prevent abrasion or to secure gas tightness there shall be properly constructed bushes.

130. (a) Flexible cables for portable apparatus shall be two-core or multi-core and covered with insulating material which shall be efficiently protected from mechanical damage. If a flexible metallic covering be used, either as the outer conductor of a concentric system or as a means of protection from mechanical damage the same shall not alone be used to form an earth conductor for the portable apparatus.

(b) Every flexible cable for portable apparatus shall be connected to the system and to the portable apparatus itself by a properly constructed connector.

(c) At every point where flexible cables are joined to main cables a switch capable of entirely cutting off the pressure from the flexible cables shall be provided.

131. (a) Every person appointed to work, supervise, examine, or adjust any apparatus shall be competent for the work that he is set to do. No person except an electrician or a competent person acting under his supervision shall undertake any work where technical knowledge or experience is required in order adequately to avoid danger.

(f) All apparatus shall be kept clear of obstruction and free from dust, dirt and moisture, as may be necessary to prevent danger.

(h) The person authorized to work an electrically driven coal cutter or other portable machine shall not leave the machine while it is working, and shall, before leaving the working place, ensure that the pressure is cut off from the flexible trailing cable which supplies such coal cutter or other portable machine. Trailing cables shall not be dragged along by the machine when working.

(131 (a) Every flexible cable shall be examined periodically (if used with a portable machine, at least once in each shift by the person authorized to work the machine), and if found damaged or defective it shall forthwith be replaced by a spare cable in good and substantial repair. Such damaged or defective cable shall not be further used underground until after it has been sent to the surface and there properly repaired.

132. In any part of a mine in which inflammable gas, although not normally present, is likely to occur in quantity sufficient to be indicative of danger, the following additional requirements shall be observed:—

(i) All cables, apparatus, signalling wires and signalling instruments, shall be constructed, installed, protected, worked, and maintained, so that in the normal working thereof there shall be no risk of open sparking.

(ii) All motors shall be constructed so that when any part is live all rubbing contacts (such as commutators and slip-rings) are so arranged or enclosed as to prevent open sparking.

(iii) The pressure shall be switched off apparatus forthwith if open sparking occurs, and during the whole time that examination or adjustment disclosing parts liable to open sparking is being made. The pressure shall not be switched on again until the apparatus has been examined by the electrician or one of his duly appointed assistants and the defect (if any) has been remedied or the adjustment made.

(v) A safety lamp shall be provided and used with each motor when working, and should any indication of fire-damp appear from such safety lamp, the person appointed to work the motor shall forthwith cut off the pressure therefrom and report the matter to a fireman, examiner or deputy or other official.

It must be noted that the Regulations noted above are extracts only from the existing Home Office Regulations, a careful reading of the whole series of Regulations necessary to become conversant with the full conditions governing the use of electricity in coal mines.

There is nothing very stringent in the Home Office Regulations, and the use of electricity at the coal face would never cause a moment's uneasiness were it not for two factors, namely, the constant necessity for guarding against the unforeseen, and the 'human element.' The aim both of official restrictions and of the manufacturers of coal face machinery has always been directed towards guarding against all manner of possible contingencies, and towards the rendering of all apparatus as 'fool-proof' as possible.

Dangers Associated with the Use of Electricity. Dangers associated with the use of electricity at the coal face may be divided under two heads, namely:—

(1) Short-circuiting and earthing. (2) Open sparking.

Short-Circuiting and Earthing. These faults on an electrical system may be considered as the passage of an electric current along a path where no such passage ought to exist. They are usually caused either by the failure of the material surrounding a conductor as regards its insulating properties, or by the rubbing away of the insulating material consequent on mechanical damage. Moisture is a most prolific cause of breakdown in the insulating properties of a material, and anything which tends to bruise or remove the insulation of a conductor is a further enemy of electrical safety at the coal face.

Short-circuiting results in an increase in the amount of current passing along one or more of the conductors between the source of electrical energy and the point where the fault has occurred since the current passing through an electric circuit is inversely proportional to the resistance of the circuit. Under the conditions of a short circuit the current has found an easier path so that there is an increase in the current, and this may be more than some part or parts of the electrical system can carry. To provide against such contingencies overload releases and fuses are provided, which, by functioning at the correct time, should prevent breakdown of parts of: the motor and connections.

The motors of longwall coal cutting machines are not usually fitted with overload releases, and it is usually the fuses which save the motor windings and connections from being burned out when a

short circuit takes place. Fuses are always provided for this purpose - and, of course, to prevent the motor from being overloaded - in the gate end switch boxes.

When a breakdown of the electrical system results in current going to the 'general mass of earth,' (See Eteneral Regulations as to the Installation and Use of Electricity, etc., Section 118.) the system is said to have developed an "earth." In such cases the current or part of the current is returning to the source of electrical energy through the earth or ground instead of by one of the normal paths.

The passage of an electric current to earth is not usually attended by such serious dangers of breakdown to the various parts of motors, but may have very serious consequences by causing electric shock to machine attendants and others. The Home Office Regulations quoted above lay down definite provisions for the safe-guarding of machine attendants from possibilities of dangerous electric shock by ensuring that in the event of a leakage of current to earth there shall be a free path for it of low resistance. In such circumstances a shock experienced by machine attendants is unlikely to have serious results; the leakage current passes directly through the earthing connections to the special earthing system at the surface of the mine. Special stress is laid throughout the Regulations on the maintenance of the earthing system in an efficient condition, and, in particular, that it is electrically continuous throughout.

Open Sparking. In an atmosphere favourable to the propagation of an explosion in a mine open sparking may be the originating cause thereof. The atmosphere may be favourable to the propagation of explosion due to the presence either of fire-damp in sufficient quantity, or of coal dust in the air. Without the presence of fire-damp it is necessary to have a very dense coal dust cloud and a very intense electric arc for an appreciable interval for an explosion to originate. Whilst such conditions may be thought improbable, they are by no means impossible. It is necessary also for the coal dust suspended in the atmosphere to be relatively free from admixture of inert dust particles. On the other hand, a small explosion of firedamp may raise sufficient volumes of coal dust into the atmosphere to allow of the propagation of explosion through any contiguous part of the mine where there are sufficient quantities of fine coal dust relatively free from inert matter; so that a very small fire-damp explosion may develop into a disaster of vast extent.

The parts of an electrical system at the coal face where sparking inevitably occurs at one time or another are:-

- (1) Commutators of direct current motors and slip rings of alternating current motors.
- (2) Switches or controllers of motors.
- (3) Gate end switch boxes.

Under the stipulations of the Home Office Regulations all these parts where sparking may occur during normal running must be totally enclosed in flame-proof cases of such a nature that in the event of an ignition of gas occurring inside the casing the flame cannot pass through the joints and cause ignition of fire-damp outside the casing. The term gas-proof is sometimes used in regard to such casings, but it is quite incorrect: an absolutely gas-tight casing is practically impossible for such purposes. A properly constructed casing of this type is flame-proof because the surfaces at the joints are sufficient in area to present a large cooling surface to the passage of flame so that, in escaping through the joints, the products of combustion are cooled below the ignition point of gas which may be outside the casing. The casing is also explosion-proof when the strength of all its parts is such that it can resist the effect of internal explosion without risk of fracture of the parts or blowing off the covers.

It is, of course, of vital importance to see that the fittings of gate end switch boxes and the covers of totally enclosed motors are maintained in perfect condition.

Open sparking may also occur through accidental injury to some part or parts of the system carrying current, and the Home Office Regulations are designed to reduce risks under this head as far as possible.

Until comparatively recent years a peculiarly vulnerable part of the installation for electrically driven coal cutting machinery was the trailing cable. This cable is at all times subject to rough usage by falls of roof and of coal on the face, and by accidental blows from timber or from coal tubs; it is also in some cases liable to damage, as regards its insulation, by water. The introduction of cab tyre sheathed

cable has improved this hitherto weak point very considerably, and trailing cables of this type are now used very extensively for coal cutting machines; one of these cables is shown coiled on the drum in Fig. 18.

Direct Current v. Alternating Current Systems. The respective advantages and disadvantages of these two systems for electric power installations for general purposes are largely dealt with in all modern text books on electric power. Apart from general considerations of economy and efficiency in generation and transmission there are a few special considerations as regards their respective advantages and disadvantages as motive powers for coal face machinery.

Direct Current. The modern direct current motor for coal cutting machines is an extremely efficient unit, capable of being made very low in overall height without appreciable loss of electrical efficiency. It possesses a very high starting torque, especially with series or with compound windings. Two conductors only are required, apart from the earthing wire, and the switch gear and wiring are rather less complicated than for a.c. motors.

On the other hand, a commutator is essential, and this must be suitably enclosed because more or less sparking will inevitably occur at the brushes. Where the electrical system is very extensive the loss of power due to voltage drop in the conductors may be very considerable.

Alternating Current. Where alternating current is used the three-phase system only is now adopted. With three-phase induction motors of the squirrel cage type there are no rubbing contacts in the motor, and consequently no sparking occurs during normal running. For equal virtual voltages there is a saving in the weight of copper in the conductors of about 12 per cent. Where extensive electrical installations are at work there is a considerable economy in the transmission losses, since for all but the actual underground work current can be carried at very high voltage, the economy of transmission being roughly inversely proportional to the voltage. Alternating current at high voltage can be transformed down to low voltage by means of a static transformer, i.e. without the use of rotary machinery, with a loss of from 3 to 8 per cent. only.

Against the very real advantages obtained in transmission and voltage transformation by the use of the three-phase alternating current system, a.c. motors do not possess as good a starting torque as direct current motors, and the current required for starting may be very large. Three conductors are required, in addition to an earthing wire. Three-phase motors for coal cutting machines of very low overall height are not so efficient as direct current motors of the same overall dimensions and horsepower, and they usually have rather a low power factor. Switchgear and wiring systems are necessarily somewhat more complicated.

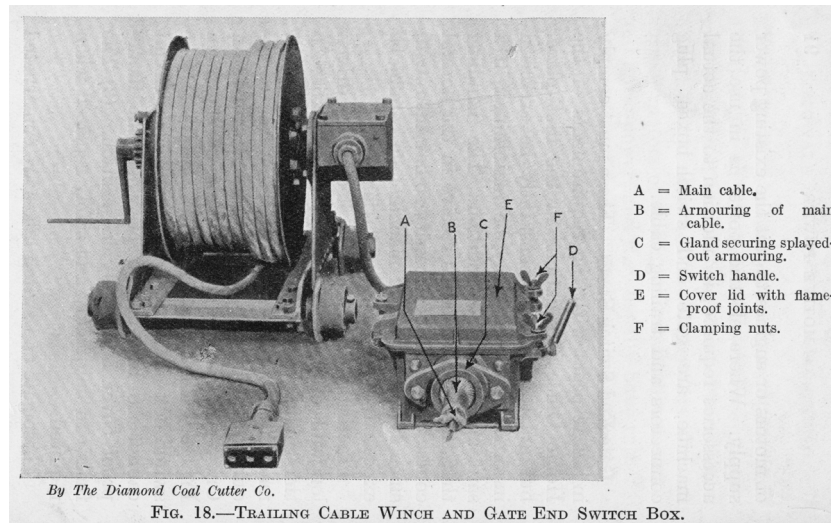
Until recent years the lack of standardization of frequency in alternating current work was an appreciable obstacle to the more extensive adoption of the three-phase alternating current system, particularly as regards the interconnection of two or more a.c. networks. Even to-day frequencies from 15 to 100 cycles per sec. are used in this country, but it is now generally recognized that the frequency of 50 cycles per sec., standardized by the British Engineering Standards Association, should be adopted wherever possible. In America, the standard frequencies are 25 and 60 cycles per sec., both being used extensively.

In the majority of collieries the question of the type of power to be used is already determined by existing power plant; the application of machinery to the coal face in such cases simply means an extension of the power lines up to the face, and the ordering of motors or engines to suit the existing power supply. Where electric power is in use the accessories required, in addition to the actual machine, are gate end switch boxes, plug connectors and trailing cable.

Gate End Switch Boxes. These must comply in all respects with the requirements of the Home Office Regulations in the first place, but great care must constantly be exercised in order that they may be maintained in a safe and efficient condition. The handling that these switch boxes receive in the normal course of work is of necessity somewhat rough, since even the best of machinemen cannot be expected to be skilled electricians.

Practically all makers of electrically driven longwall coal cutting machines specialize in the manufacture of gate end switch boxes, made to comply in all respects with the requirements of the Home Office Regulations. One type of these switch boxes is shown in Fig. 18. The special features are that:- (1) The switch box is flame-proof. (2) The circuit cannot be broken, except when the

flameproof cover is securely in position. (3) The fuses can be quickly and safely replaced when required.



These gate end switch boxes are constructed very solidly, and, given reasonable care, they should never cause any trouble. The main cable is shown at A, the three cores being shown separated; the armouring B of the main cable is held firmly to the gate end switch box by the gland and clamp (~). The switch handle D cannot be operated unless the lid E is closed and secured tightly by the clamping screws FF.

Trailing Cables. Trailing cables are generally made up in lengths of 110 yds. Where power is brought up to the face along the centre gate road, a length of about 200 yds. can be cut without changing over the trailing cable, provided the cables in the gate roads are kept extended reasonably near the face as it moves forward. On faces longer than 200 yds. it is, of course, necessary to have the power supply brought along more than one gate road and to change over the trailing cable from one gate to another when required.

Trailing cables are very expensive items, and are worth the exercise of considerable care to maintain them in a safe and undamaged condition. It is very important to remove them from the face when the machine is not cutting, and to store them in such a way that they will escape accidental injury during coal getting and repairing shifts. Special gate end cable winches are used at some collieries, and one of these is illustrated in Fig. 18 coupled up to a gate end switch box. The drum carries a full length of 110 yds. of cab tyre sheathed cable, and the trailing cable can be wound on or off the drum when required by means of a handle keyed to the drum shaft. A ratchet and pawl arrangement is provided to lock the drum in position when required.

Compressed Air. It is not possible here to go fully into the use of compressed air as a motive power. All that can be attempted is to discuss, briefly, its advantages and disadvantages, compared with electricity, as a motive power for longwall coal cutting machines.

The usual pressure to which air is compressed for this service is from 60 to 80 lbs. per sq. in. above atmospheric pressure. Pressures below 60 lbs. per sq. in. at the compressor are of very little use in an extensive mining-system for coal face work. The air consumption of compressed air engines is always given in cubic feet of free air per minute, that is, the volume of air passing through the engine measured at normal temperature and pressure. (That is the measured volume of air which passes through a compressed air engine, after it has expanded to normal temperature (60° F.) and normal barometric pressure (29-92 ins. of mereury column).

When air is compressed, work is done upon it, and there is a rise in temperature of the air during the actual compression. Losses of efficiency in a compressor, due to this increase of temperature of the air being compressed, are counteracted to some extent by attempts to subtract the heat from the air during the process of compression, and for this purpose the air cylinders of compressors are surrounded by water jackets, the water being kept as cool as possible by constant renewal. The actual cooling of the air by simple water jacketing has, however, only a relatively small effect as regards lowering the final delivery temperature of the compressed air, since only a small fraction of the air

under compression is ever in contact with the water-jacketed surfaces. A method involving the use of considerably more complicated machinery, but effecting an appreciable increase in the actual cooling of the air during the process of compression, consists of doing the work on the air in two or more stages, and cooling the air in what are termed 'inter-coolers' between each stage of compression.

Adiabatic and Isothermal Compression. The terms 'adiabatic' and 'isothermal' are frequently used in discussing the work of air compressors. Adiabatic compression is compression under such conditions that no heat enters the air from outside the compressor cylinder, neither does any heat escape from the latter; the temperature of the air rises during adiabatic compression in proportion to the amount of work expended on it. Isothermal compression is compression carried out at constant temperature, the heat developed in the air (by the work expended upon it) being removed at the same rate as it is produced; approximately this condition can be secured in practice by using a suitable cooling system for the compressor.

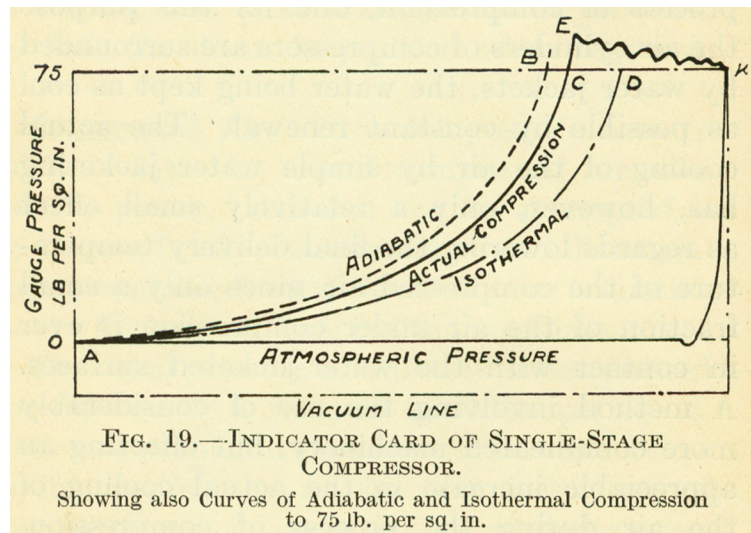


Fig. 19 shows the curves of adiabatic and isothermal compression of air to a pressure of 751bs. per sq. in. In practice, the indicator card of an air cylinder of a compressor shows a line intermediate between these two curves, the actual compression curve being very near the adiabatic curve when the cooling has only a small effect, and approaching nearer to the isothermal curve when the effect of cooling during compression is at a maximum.

Advantage of Multi-Stage Compression Table I shows the large saving which can be effected by multistage compression with efficient intercooling. It should be pointed out, however, that the percentage of work lost by the heat of compression is based on isothermal compression, that no account is taken of jacket cooling, and that the two- and fourstage figures are based on reduction to atmospheric temperature, i.e. the original temperature of the air on its admission to the first stage of compression, between the stages of compression.

The figures in Table I are, of course, theoretical, since perfect cooling between stages of compression is not practicable, and there is a small absorption of heat by water jackets and by the parts of the air compressor itself, they serve to show the great economy which can be effected by multi-stage compression with efficient intercooling. It has already been pointed out that simple water jackets on air cylinders have only a small effect on the cooling of the air whilst work is being done upon it. The reason why properly constructed intercoolers are so much more effective is that the air is split up into thin layers, and can then be cooled much more efficiently in a short time; this is not possible during the actual process of compression.

TABLE I.—ENERGY LOST BY HEAT OF COMPRESSION.
Showing Advantage of Multi-Stage Compression.

Gauge Pressure Lb. per sq. in.	ONE STAGE		TWO STAGE.		FOUR STAGE.	
	Per cent. of work lost in terms of Isothermal Compression.	Per cent. of work lost in terms of Adiabatic Compression.	Per cent. of work lost in terms of Isothermal Compression.	Per cent. of work lost in terms of Adiabatic Compression.	Per cent. of work lost in terms of Isothermal Compression.	Per cent. of work lost in terms of Adiabatic Compression.
60	30	23.00	13.38	11.8	4.65	4.45
80	34	25.26	15.12	13.12	5.04	4.80
100	38	27.58	17.10	14.62	8.00	7.41

Cooling During Expansion. The second cause of the low efficiency of compressed air as a motive power is the loss of heat in the engine or turbine driven by the compressed air. During compression, work is done on the air and its temperature rises. If it were possible to use this hot compressed air at the instant that it leaves the compressor and before it had lost any of its heat of compression, a very considerable economy would be effected, but in the ordinary colliery installation the compressed air enters the engine to be driven at, or about, the temperature of the surrounding atmosphere. In the engine the air does work and, consequently, its temperature decreases as the air expands, and the temperature of the exhaust air from an engine is generally far below that of the surrounding atmosphere.

Where compressed air engines of a fixed character are in use, air heaters are sometimes used; these give a very considerable increase in the efficiency of compressed air engines. Up to the present time, however, no satisfactory form of air heater has been introduced for use with portable engines, such as are used on coal cutting machines.

Air Transmission Losses. The third cause of inefficiency in compressed air installations is transmission losses on pipe lines, and the throttling of the compressed air at stop valves, bends and other constrictions. It is of first importance that pipe lines of ample capacity be installed to convey the compressed air without excessive drop in pressure. Losses by leakage at pipe joints and stop valves may also be very considerable, and in order to keep down these losses as far as possible, pipe lines on gate roads and elsewhere in a mine should always be readily accessible; they should never be buried below the level of a roadway, except where it is necessary to cross over from one side of a road to another. All stop valves must, of course, be of the full-way type to reduce resistance as far as possible.

The importance of keeping the pipe line of as large a diameter as possible will be realized when it is considered that 650 cu. ft. of free air per minute passing through a straight pipe of 3 ins. diameter loses approximately 3 lbs. per sq. in. pressure, due to friction, for every 300 ft. of travel. Corresponding figures for 4-in. and for 5-in. pipes are, respectively, only 4 lb. and ~ lb. per sq. in.

Air Consumption. As regards the consumption of free air per minute per indicated horse-power, it is very difficult to arrive at precise figures where longwall coal cutting machines are concerned. From a number of tests carried out some years ago on compressed air engines of from 10 to 20 indicated horse-power, the consumption of free air was found to range from 14 to about 18 cu. ft. of free air per minute. The consumption of engines of coal cutting machines is probably nearer 18 cu. ft. of free air per minute per indicated horse-power than the lower figure.

Overall Efficiency. The overall efficiency of a compressed air installation varies very greatly according to the respective efficiencies of the air compressing plant and the engine, and the adequate character of the pipe line. The average ranges of efficiencies for colliery installations are probably as follows:-

Highest Lowest

	per cent.	per cent.
Compressor .	80	60
Engine .	80	50
Pipe line, etc.	90	70

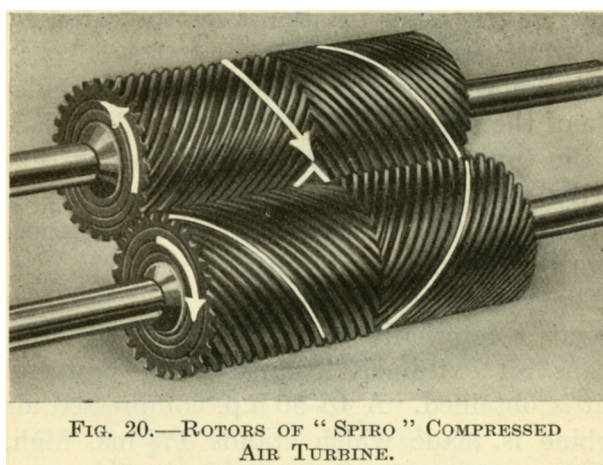
On this basis, the overall efficiencies range from a maximum of 57 per cent. to a minimum of 21 per cent. The average for many large installations is certainly not higher than 33 per cent.

Compressed air, as a motive power for coal face machinery, is thus flagrantly inefficient, but against this low efficiency must be set the indisputable fact that, whereas electricity may, under certain conditions, be a fruitful source of danger, compressed air is absolutely safe as regards fire and explosion. Also, the exhaust from engines assists to some small extent in the work of ventilation. In many cases it is far better to have an absolutely safe source of power of low efficiency, rather than one that is of much higher efficiency but a constant potential source of danger.

The 'Spiro' Compressed Air Turbine. It is unnecessary to describe the ordinary single or doubleacting engine generally used on longwall coal cutting machines. The use of any form of motor, other than a reciprocating engine, is comparatively recent. A form of turbine has been introduced with considerable success and, as the constructional details of this simple but ingenious machine are comparatively unknown, the following description may be of service.

The 'Spiro' turbine was originally designed and developed to be run by steam; it is, however, peculiarly well adapted for use with compressed air, and particularly so for use as the power unit for coal face machinery.

The turbine consists essentially of two helical gear wheels meshing together and revolving in a very close fitting casing. These gear wheels, generally termed the rotors, are shown in Fig. 20; it will be observed that the rotors are much longer axially, in proportion to their diameter, than the helical gears normally used for power transmission.



Steam or compressed air is admitted to the pockets formed at the point indicated by the central arrow head in Fig. 20. The motive fluid occupies the space between two adjacent teeth, and this space is closed at the tooth points by the close fitting casing. The motive fluid, being initially under pressure, tends to expand and occupy a larger space, and to do this it must move the rotors round; the tooth space occupied by the air increases in length until the motive fluid escapes, when the outer ends of the teeth pass the line of contact between the two rotors. The increase in length of the tooth space occupied by the air is shown by the outer white lines in Fig. 20, as compared with the length of the tooth space at the point of admission, indicated by the white arrow head.

The motive fluid is admitted on the under side of the rotors, and the exhaust takes place at the top; the weight of the rotors is thus partly carried by the air pressure, which is greatest on the under side and decreases towards the exhaust on top.

The rotors are carried on ball bearings mounted internally in the casing; by this means an extremely compact and powerful unit is obtained. A 40-50 h.p. compressed air turbine is made which stands 17t ins. high, 264 ins. wide, and 214 ins. long; the working speed of this turbine is 1,800 r.p.m.

It is claimed by the makers of this turbine that the economy effected by its use is equal to that of a high speed single-cylinder automatic engine of corresponding horse-power, which is 20 per cent. more efficient than a turbine of the impact and reaction type. In common with all other forms of plant using compressed air as a motive power, the economy is increased by preheating the compressed air immediately before admission to the turbine. Apart from the question of efficiency, however, the important feature of the "'Spiro' turbine is that there are only two running parts, as against a great number in a reciprocating engine; consequently, the maintenance of a turbine is much more economical than the reciprocating engine. There is, of course, a corresponding simplicity in operation.

The construction of the turbine calls for the very highest class of workmanship, since anything but a perfect fit between the teeth of the two rotors and between the rotors and the casing must cause a serious decrease in power, and an excessive consumption of air. The rotors should have a life of several years hard work, but must be replaced immediately any signs of wear become evident.

A general view of a complete 'Spiro' compressed air turbine, built into a chain type coal cutting machine, is given in Fig. 5; the cover is removed to show the rotors and gearing.
