The starting of motors larger than about 1 h.p. gives rise to so large a current as to cause disturbing fluctuations of pressure in the distributing wires. A starter is, therefore, required for large motors. An apparatus of this kind consists of a multiple switch connected to various resistance coils. Generally a magnetic spark-extinguisher is used, which, by means of its strong magnetic field, puts out instantly the spark developed when the starter is switched off.

Polyphase current motors are divided into two classes, viz. :—

(*a.*) Synchronous.

(*b.*) Asynchronous.

The former type is not suitable for mines, because they necessitate being run up to synchronism before being loaded, and are apt to stop when overloaded. Moreover, it is necessary to excite them with continuous current; in fact, a synchronous motor is a generator used as a motor.

Asynchronous motors consist of a stationary part called stator, into which the current is fed, and of a rotary part called rotor, in which currents are induced. There are three types of these motors, classified according to the construction of the rotor, viz. :—

1. Polyphase current motor, with three slip rings for use with a starter.
2. Ditto, with closed circuit winding on the rotor.
3. Ditto, with counter winding and switch.

The motors with slip-rings require a starting resistance for regulating the induced currents in the rotor. They develop at starting the full torque, without taking a stronger current than that required at normal speed and full load. The torque, as in the case of direct current motors, can be increased if stronger currents are sent into the motor at starting. This type of polyphase motor is superior to the other two; in one respect it can be run for a short time as slowly as desired. Its efficiency is then, of course, lower.

Polyphase current motors with closed circuit windings on the rotor, that is, with the winding short-circuited and without slip-rings and brushes, therefore with no outer connection, should be used only in cases which occur rarely in mines, viz., when the output is not greater than 1·5 h.p., or for the transmission from the generator to a single motor or set of motors, which can be started and stopped simultaneously with the generator. It is not desirable to connect up closed-circuit motors of about 5 h.p. and upwards to a constant pressure network of mains, on account of the disturbances in pressure which the strong starting currents give rise to, and the uncertain working of such motors. The torque is small, although the current is strong, so that loose pulleys are often required.

Polyphase current motors with counter windings have a rotor of special construction, patented by Siemens and Halske. Motors of this type are made for outputs up to 10 h.p., when the torque required at starting does not exceed three-quarters the torque at normal load. This type is also used for motors up to 100 h.p., when they start at no load.

Electro-motors, whether direct or polyphase current, have, in addition to the advantages of small dimensions and weight, another important one, viz., their rotation can be easily reversed. Sparking at the reversing gear cannot be avoided, but reversers with carbon contacts diminish the flame, and have been found more durable than others. By means of this reversing gear all the operations incidental to hoisting machines can be conducted with ease; small up-and-down motions can be quickly executed, so that the cage or skip can be stopped at the exact height required. When the motion has to be reversed, the motor must be stopped by means of a mechanical brake before it receives current in the reverse direction. It is, therefore, necessary to manipulate the reversing gear and brake in correct succession.

As the speeds of electro-motors (especially the smaller sizes) are generally higher than those of the machines to be worked, reduction gearing is necessary, for which belts, spur-wheels, and sometimes worm-gear and pitch-chains are used Fast-speed gear should, in respect of material and construction, be thoroughly good, so as to diminish as much as possible noise and loss by friction. The spur-wheels should be cut, despite the extra first costs, and the pinion be made of compressed leather or other suitable material.

Whenever it is possible to have the speed of the motor the same as that of the machine to be worked, the armature is either mounted direct on the lengthened axle of the machine, or the two axles are joined together by means of a coupling.

In the preceding description the polyphase current system has been rather fully treated, because it is in general less known than the direct current. The two systems must be regarded as alternative, the fact being that each has its own distinctive field. An engineer in possession of all the necessary data for the working out of any particular project will scarcely ever be in doubt as to which system to choose. Naturally there are cases where the one system can be used as advantageously as the other, the choice depending upon the degree of importance that may be attached to the merits and demerits respectively of the two systems. For short distances both would need to be considered, but for distances long enough to require the use of pressures higher than would be admissible for direct current work, the latter would have to give way to the polyphase current. The chief advantages of the two systems may be compared :—Direct current dynamos can be coupled in parallel with ease, so that several machines can supply current to the mains simultaneously, whereas polyphase generators require care and skill to couple them in parallel.

By means of direct current secondary batteries can be charged, whereby additional working security is obtained, and in certain cases a decrease in working costs.

The direct current is simpler for running electric locomotives, because the polyphase current requires three conducting wires, which make the arrangements more complicated, especially where there are numerous cross-overs and sidings. As iron conductors are inadmissible for alternating currents, the rails cannot be utilised for electric traction by means of polyphase currents. Direct currents cause less disturbance to neighbouring telephone lines than polyphase currents and plants of moderate size; for the direct current are, on an average, cheaper than corresponding ones for polyphase current.

Polyphase current dynamos and motors can be wound for much higher pressures than direct current machines. The high pressures are developed only in the stationary windings or stator of the machine, which can be thoroughly insulated without difficulty. The danger, therefore, to men in charge is reduced to a minimum. The supervision of polyphase current machines is less, because there is no commutator. Any sudden increase above the normal of the current strength is less likely to short-circuit polyphase current machines. Polyphase current transformers have no moving parts, and require no attention at all, hence they are superior to motor-dynamos or direct current transformers. As the high pressure of the polyphase current is easily transformed to a lower one, this current is specially serviceable when light is required as well as power.

Another important consideration is the avoidance of sparks in fire-damp mines. In such mines no other conducting mains should be used than strongly-armoured cables. All motors, switches, and fusible cut-outs should be carefully enclosed in caps. The fittings for incandescent lamps must be so constructed that the glowing filament is immediately extinguished when a lamp breaks.

Electrically-Driven Machines and Tools.

The machinery for mines, and the work performed by it, may be classified under the following five heads :—

1. The Raising of Water—Drainage of the main drives and workings, feed-pumps, sinking pumps.
2. The Supply of Fresh Air—Ventilation of drives and workings, fans, blowers.
3. Haulage—Winding drums for inclined drives ; rope, chain, and locomotive haulage in main drives ; hoisting at shafts, carriage of material, etc., above ground ; elevators, capstans for assembling trucks, traversers.
4. Working at the Face—Drilling machines, hewing or cutting machines.
5. Treatment cf Materials above Ground—Dressing of ores, briquette manufacture, etc.

All the special machines under the above heads can be worked by means of electro-motors.

In order to apply the power of the motor as practically as possible, the construction and mode of working of the different types of mining machines have to be carefully studied.

The electrical working of some of the more important mining machines will now be considered somewhat more in detail. In the electrical working of pumps the gearing between the electro-motor and axle of the pump presents a difficulty, because a noisy gearing would prevent the action of the pump-valves from being heard. With a pinion of compressed leather and clean-cut teeth on the high-speed wheel of the motor-axle this difficulty can be overcome. In some cases it is preferable to mount the armature of the motor direct on the pump-axle, but this is more costly.

Small pumps up to about 50 h.p., with electro-motors, can be worked from the distributing mains in the mine, but for various reasons it is preferable to drive larger machines of this class from a generator provided solely for them. The switching in and out of very large motors, or great fluctuations of their speed, would give rise to inconvenient disturbances of pressure. Dynamo and motor are in a sense coupled electrically. The diminution of the number of revolutions can be carried to whatever extent the peripheral mass of the machine permits. By means of such an arrangement all starting devices can be dispensed with, as the motor always starts and stops simultaneously with the generator. Another advantage of using the polyphase current is that motors with closed windings on the armature can be used for the largest outputs.

There is also another important consideration, viz., the provision of a large reserve pump with electro-motor in mines where electrical transmission of power is established. In such case the other motors could be stopped, and the entire power of the generating plant utilised for this reserve machine, so that any sudden inrush of water into the mine could be coped with effectually.

The question of the best method of underground haulage—that is, whether ropes, chains, or electric locomotives should be used—cannot be satisfactorily decided without a complete knowledge of the local requirements and conditions. Haulage by means of ropes or chains is only advantageous where the drives are fairly straight, as all bends present difficulties. At the usual speed of 90 to 180 feet per minute, trucks should be attached at every 60 to 100 feet.

For short inclines rope or chain haulage is preferable to hauling by locomotives, but the latter system is superior where there are several branch tracks, or where the material excavated in making drives or in exploration work has to be removed, because the locomotive can be run to the face. An accident to a locomotive does not disturb the entire haulage plant. The locomotive system is generally more expensive than that of rope or chain haulage.

Without doubt, rock drills are the most important machines at the face. An important feature of these drills is that each kind can be worked from any electrical distributing network, whether for direct or polyphase current, and the amount of energy they absorb is small.

The first trial with electric rock drills was made in 1879, by Werner von Siemens, who constructed the solenoid motor. In the new electric rock drills of Siemens and Halske the usual rotary motor is employed, while by a purely mechanical process the rotary motion is changed, with the aid of a crank and system of powerful springs, into a striking movement.

Two kinds of electric rock drills are employed—rotary for soft rock, and percussive for hard rock. Both types of drill are driven in exactly the same manner, by a 1 h.p. motor, contained, with all accessories, in a motor-box, the motion being transmitted by means of a flexible shaft.

The rotary drill is provided with an automatic feed, which adjusts itself according to the hardness of the stone met with; the load, therefore, on the motor remains constant, and the motor as well as drill are protected from being overloaded.

The percussion drill gives exceedingly powerful blows, and, notwithstanding its small size, it does quite as much work as the largest compressed air drill, which requires as much as 10 h.p. at the steam-engine. This electrical drill has also considerable retractive force when the bit gets jammed, so that a stoppage of the machinery rarely occurs, and even conglomerate can be drilled without trouble. The crank percussion drill is so constructed that the operation of transferring the bits is done from the back. Hence each hole can be completed without altering the position of the drill, or making the diameter of the hole larger in the beginning. For cartridges of about 1 inch the diameter of the hole at the commencement need only be about $1\frac{3}{8}$ inch, even for holes of 5 to $6\frac{1}{2}$ feet deep. The machine has a range of feed of about 15 inches. This length can be bored in hard granite in four to five minutes.

For six percussion or rotary drills 10-brake h.p. are required at the pulley of the prime mover. The usual consumption of the machine at full output is 0·8 to 1·3 kilowatts; on an average, 1 kilowatt. The percussive rock drill bores rock of every hardness, and performs an output of 2 to 12 inches per minute, with a width of hole from about 1·2 to 1·4 inch. The rotary drill is only used for softer rock and bores, according to its hardness, to a depth of 4 to 20 inches per minute, with a width of hole from 1·6 to 1·8 inch. In rocksalt the 1-metre bore-hole is made in about three minutes, in minette interstratified with lime, the iron ore in Lorraine and Luxemburg. The operation is performed in five minutes.