ELECTRICAL TRANSMISSION OF POWER IN MINES.

(A Paper read before the Sydney University Engineering Society)

NOVEMBER 8TH, 1899.

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FOR mining operations—such as haulage, the raising of water, the driving of various machines, working of rock-drills, &c.—considerable motive power is required. The places where the power is required are generally wide apart, and in most cases underground. The power is usually generated at the surface, and transmitted to the various points where the machines are set up. Formerly, this transmission was effected almost exclusively by steam; then compressed air and hydraulic pressure came into use, and latterly electricity is being more and more widely adopted. In considering the characteristics, as well as the specific advantages and disadvantages of the various systems of transmission of power, two questions arise: Firstly, "What is the efficiency of the system—that is, how large is the loss entailed in the conversion of the power?" and secondly, "What difficulties have to be overcome with regard to the means used for transmission?"

The efficiency of an engine is expressed by the steam consumption per horse-power, which depends chiefly on the size of the engine, and whether it is single, compound, or triple expansion, with or without condensation. Mining engines, whether used above ground for the treatment of ores and similar purposes, or in the workings below, are generally single-cylinder engines, of medium size, working without condensation. The steam consumption of such engines might vary from 30 to 50 lbs. per brake horse-power, or double to treble that of a large condensing engine, such as might be used in the case of electrical transmission of power.

Steam transmission by pipes is attended with considerable losses, even when the pipes are lagged with non-conducting material. The lengths are frequently great, and in some instances the losses may amount to about 40 per cent. The high temperature of the steam causes longitudinal expansion of the pipes, which is usually remedied by compensation joints, but which makes it necessary to provide heavy bracing for the piping. Sometimes the method is adopted of keeping the pipes continually under steam, even when the engine is at rest; but this causes condensation losses, which are prejudicial to economy of working. The heated steam-pipes also raise the temperature of the workings, thus injuring the miner's health, destroying the timbering more rapidly, and probably interfering with the removal of fire-damp.

In the case of air compressors and motors, the disadvantages are of a different nature. When air is compressed, heat is liberated, and as this heat escapes from the air compressors through the cylinders to the surrounding air, a loss of energy results. On the other hand, when expansion of air takes place in the motors, heat is abstracted from the surrounding air, and the temperature falls so low as to cause a formation of ice. Compression and expansion by gradations, ingress and egress of heat by artificial means, &c., have been introduced as remedies. Such aids, however, involve the use of complicated machinery, which can, no doubt, be worked in a central station above ground, but not at the numerous points in the mine where power is needed. The compressed air motors can be worked with full charge, so as to avoid expansion and formation of ice, but the efficiency of the plant is then only 40 to 50 per cent.

The pipe connections for compressed air have to be very carefully set up, as even leakages so small as to be difficult to find and repair cause great losses. Working by means of compressed air has one important advantage—viz., the air at the face can be kept fresh by means of the exhaust without special arrangements. It should, however, be borne in mind that at the working face the ventilation would fail at the moment it is most required—that is, immediately after firing the shots, if the compressed air were not allowed to rush out exclusively for ventilating purposes.

Hydraulic pressure for the transmission of power has a fairly high efficiency when the load is uniform. This condition is exceptional, and is only fulfilled in the case of a single transmission to a hydraulic motor; as a rule, several motors have to be worked, and the loads are variable. Piston motors are the usual type. Their efficiency becomes less with decrease of load, because the pressure has to be partly throttled, in order to lessen the work done by the motor. The pipe connections must be established with as much care as those for compressed air. The great weight, relatively, of the water is also a disadvantage. If the flow is suddenly stopped at any point, the momentum of the water causes shocks which are harmful. The use of an air chamber reduces the evil, but does not entirely prevent it, and damage to pipes is frequently traced to the shocks. In levels having no downward slope to the shaft, the removal of the waste water is difficult, and special pumps have to be erected for raising this water to the drains. It is, no doubt, on account of these drawbacks that so few hydraulic pressure plants are used in mines.

The electric transmission of power has one great advantage—its efficiency always keeps within satisfactory limits, whether large motors or small are in use, and the load big or little. On an average the efficiency is 75 per cent., it reaches 80 per cent. and more when the power transmitted is large.

Although the gearing usually required on the motors somewhat impairs the useful effect, a considerably higher efficiency than that obtained by means of steam, compressed air, or hydraulic pressure can always be obtained. The chief characteristics which make electro motors specially suitable for mining work are ready reversibility, small dimensions, and relatively light weight. The connecting wires or cables can be easily put up, and as they are very flexible, and admit of being shifted about with ease, they offer no such difficulties as are common to pipe lines. The value of the advantages referred to is best proved by the facility with which machines are worked in any part of a mine by means of electrical transmission of power.

Another important point is the lighting of the mine by means of the same system. In the workings the electric light renders the work of supervision easier, and is safer for the miners. This light is also of great service in the engine-room and mine manager's offices. Although in the foregoing remarks stress has been laid on the superior efficiency of electrical transmission, it should be borne in mind that this advantage would not, in all cases, be the chief inducement for the adoption of the system. For instance, in collieries, where energy is cheap, the question of efficiency would be of less importance than that of lowest first cost. In order, however, to fix upon the most advantageous system in that respect, it is necessary, in nearly all cases, to make a close investigation of the special local conditions and requirements. On the other hand, there are cases having such conditions as render it impossible for any other system to compete with the electrical. Hence, in extensive workings, where power is wanted at many different points, its tranmission by electricity is the only rational method. Take, also, the case of water power, situated some distance from the mine, or the distribution to an entire district of power generated in a central station, and it will be readily conceded that only by means of electricity can power be transmitted without undue losses over the distances usually met with in cases of this kind.

Electrical Transmission.

In electrical transmission of power the mechanical energy of steam engines, gas engines, turbines, or other prime movers, is converted, by means of a dynamo, into electrical energy—that is, an electric current of a certain pressure and strength. This current is transmitted by means of conductors—generally of copper, of a cross section, proportional to the current strength—to the electro motor, the armature of which it sets in rotation, so that mechanical energy is reproduced. The conductors generally consist of blank wires for long distance transmission of power above ground, and for electric locomotives, and of suitably insulated wires or cables for underground work. The current is either direct or alternating—that is, its direction is steady or varying. The product of pressure and current (viz., volts × ampères = Watts) is a measure of the electrical energy; consequently, in the transmission of a given amount of energy, the higher the pressure the smaller the current strength, and, therefore, the less area of the conductors required.

In dealing with alternating currents, we have to consider the "phase" difference between the voltage and current, and the self-induction in the conductors and transformers. Phase difference, or lag between the voltage and the current, appears at the point where the energy is consumed, when the current produces any appreciable magnetization—in other words, when there is inductance in the circuit, for instance, motors and transformers. If the load consist of incandescent lamps only, the circuit will be free from induction, and no lag will occur.

Consequently, in the case of alternating currents, the energy also depends on a third factor—cosine ρ, or the so-called factor of output. This has the value of about 1 for incandescent lighting, and lies between 0·7 and 0·85 for good motors under normal load.

The alternating current system has this advantage—that the dynamos and apparatus can without endangering the safety of working, be constructed for higher pressures than direct current machines. This is, of course, important when long distances intervene between the generator and the motor. The alternating current has this additional advantage—that the pressure can be altered within any limits, and at any point, by means of apparatus, so-called transformers, which are very simple, having no moving parts, and requiring no attendant. In spite of these advantages, the alternating current was confined for years to lighting only, because all attempts to construct a suitable motor had failed. Of late, however, a particular combination of alternating currents, known as the polyphase current system, has come into use for the electrical transmission of power.

The polyphase current is based on the simultaneous use of three different alternating currents of equal period—that is, the time each current is making a complete alternation (from zero through its positive and negative maxima, and back to zero) is the same, and for all three currents the extreme positive and negative values attained in each period are equal. The currents, however, are not in phase, so that they do not reach these maximum values simultaneously, but in regular succession, the time interval being the same for each.

Hence, the three current strengths at a given moment are different in value, or have, as it is termed, a difference of phase, whence the designation "3-phase currents." This combination would hardly have come into practical use if each of the three alternating currents composing it had required its own pair of conducting wires. As, however, the alternating currents from the dynamo have very nearly a sine form, their strength and direction change in each period as the sine of an angle, which increases rapidly from 0 to 2π; and a three-phase current, composed of three such alternating currents, has a remarkable property, viz., the sum of any two of the currents is at each instant equal and opposite in sign to the third, so that the sum of all three is zero. Instead, therefore, of using three pairs of lines, it is possible to reduce this number to three single ones, having their ends joined together. The total cross section of these three wires is about equal to that of two direct current wires, intended for a pressure of a similar value.

Another characteristic of the three-phase current, which has chiefly conduced to its present degree of importance, is that motors can be worked by it equally as well as by direct current. When the alternating currents constituting a three-phase current are sent in a given succession through three coils (or any multiple of three), arranged in a circle, their combined action gives rise to a rotary magnetic field within the circle. A clearer idea of the action may be gained from a mechanical analogue. Consider, for instance, a shaft with three cranks, set at 120° from one another. In this case the successive action of the cranks produces a uniform rotation of the axle. Similarly, the three alternating currents which follow one another into the coils of the fixed outer portion of a polyphase current motor, produce a uniformly rotating magnetic field, which pulls round the short circuited coils of wire forming the armature, in accordance with well-known physical laws.

The plant for electrical power transmission consists of—

I. The generating station in which dynamos convert the mechanical energy of a prime mover into electrical energy.

II. The conductors, blank wires or cables, which transmit the current to the distant points where work has to be done.

III. The electro motors, which re-convert the electrical energy into mechanical energy.

The generating station contains, in addition to the prime movers and generators, a switch-board, on which are mounted the requisite regulating, measuring, and switching apparatus. The dynamos, whether for direct or polyphase currents, can, according to the speed required, be driven by means either of belts or ropes, or may be coupled direct to the prime mover. In the latter case the shaft of the engine or turbine, &c., is made a prolongation of the axle of the revolving part of the dynamo.

The conducting mains above ground are usually bare copper wires, supported on insulators. The underground portion consists generally of insulated wires, also attached to insulators, fixed either along the roof or side walls. It is only in places where the conductors are likely to be damaged, or where they are exposed to destructive chemical action, that it is necessary to use armoured cables. Electrical wires and cables are exceedingly portable and flexible, hence they are superior to all other connecting lines for the transmission of power, especially when transportable machines, such as rock-drills, pumps, &c., have to be worked.

The method of establishing the connections is as follows :— The fixed portion of the conducting wires is led into a junction-box, situated as near as possible to the place where the work has to be done. A short length of cable, fitted with suitable connecting pieces, conveys the current from the junction-box to a very flexible double or triple cored cable, which is wound on a portable drum, and can be brought with ease to the motor geared to the machine to be worked.

In the case of continuous current motors, the current passes not only to the fixed magnet coils, but also to the movable armature coils. To bring the current to the armature there is placed on the axle a cylindrical commutator, composed of a large number of copper segments, which are in connection with the different sections of the armature winding. Against the commutator, the segments of which are carefully insulated from one another and from the axle, press copper or carbon brushes. These brushes are adjustable, and must be so set as to be in firm contact with each segment as it passes under the brush, in order that the current may pass to the commutator without sparking. The commutator requires constant care, otherwise sparks cannot be avoided, even when the brushes are properly set.