THE UNDERGROUND HAULAGE OF COAL.

With the steadily increasing demand of coal for all purposes of industry, deep mining becomes more and more necessary. This is true not only in those regions where coal occurs at great depths, and must be reached by sinking deep shafts, but also in the more favored localities where the veins crop out at the hillside, and the miner, following the strata, is compelled to penetrate for miles into the heart of the mountain. In all cases it is a question of great importance how to convey the coal from the interior working "rooms" to the bottoms of the shafts, or directly to the surface, and from there to suitable shipping places, and it is probably not saying too much to assert that coal mining, considered as an industrial and commercial success, at the present day is principally dependent upon the methods by which this is done. It is easy to understand that sinking numerous shafts in developing mining properties must be expensive and inconvenient, and that it is preferable to transport the coal underground, even great distances, to one centrally located shaft, if this can be done quickly and economically. This is fully demonstrated in the deep mines of England and the European Continent, where for the last twenty-five years the underground haulage of coal by machinery has superseded the older methods. The coal extending over a field of several square miles is now conveyed to the surface through a single deep shaft cheaper and in less time than formerly, where the coal could be mined near the surface, through a number of shallow shafts placed only a few hundreds yards distant from each other. Moreover, the superior machinery for hauling, hoisting and pumping makes it possible to locate this shaft either in the deepest or any other part of the mine, wherever it is most advantageous for draining the water or landing the coal.

In the Monongahela and Ohio coal regions of this country the usual method is by horizontal or slightly dipping "entries," and in the anthracite region by "slopes" and "gangways," through which the coal is brought to the surface without the necessity of vertical hoisting, but it frequently has to be transported long distances within the mine itself. The economy in the use of machinery is also well understood, and in many mines extensive appliances of machinery have been made. Wherever manual or animal labor for transporting coal is still employed, the mine owners contemplate replacing them by steam power, and it is a question of only a comparatively short time when every coal mine in the country will have efficient and improved mechanical arrangements for conveying coal from the interior to the "tipple," or place of shipping.

If we consider that as recently as seventy years ago, in England and Scotland, coal was carried to the surface by women, on their heads; that wheelbarrows or sledges, dragged by hand or by dogs, were used for a long time; that hoisting was done by horses in gins or by water-balance shaft; that even after the introduction of the iron rail until a recent date horses and mules were exclusively employed, all of which could transport only limited quantities of coal—we can better appreciate the immense advantages of modern progress in the perfection of machinery with which now more coal is brought to the surface of the earth in a day than half a century ago was brought in a year.

The many methods applied in mining regions for transporting coal by means of wire rope, though varying from each other in detail, can be grouped in four distinct classes:

I. The Self-Acting or Gravity Inclined Plane.
II. The Simple Engine Plane.
III. The Tail Rope System.
IV. The Endless Rope System.

The motive power for the Self-Acting Inclined Plane is gravity; consequently this mode of transporting coal finds application only in places where the coal is conveyed from a higher to a lower point, where the plane has sufficient grade for one or more loaded descending cars to raise the same number of empty cars to an upper level. Inside the pits such favorable circumstances are rarely met with, but they are of frequent occurrence where coal is transported from the pit-mouth to the tipple. There is hardly a single mine in the Monongahela valley without a gravity inclined plane, varying in length 700 to 1800 feet. The cars are raised and lowered by a wire rope winding and unwinding successively on a drum at the head of the plane.

The name "engine plane" has been given to an inclined plane on which a load is raised or lowered by a single wire rope and stationary steam engine. It is a cheap and simple method of conveying coal underground, and therefore is applied wherever circumstances permit it. It requires only a single track, a rope of the length of the plane, and the power of the engine only half the time. The road may be curved and may have variable grades, provided the fall is in one direction and of sufficient inclination to enable a full or empty set of cars to descend by force of their own gravity, dragging the rope after them. The smallest grade at which this is possible depends on the length and condition of the road, as well as on the weight of the cars and the rope. Under ordinary conditions, such as prevail in the Pennsylvania mine region, a train of twenty-five to thirty loaded cars will descend, with reasonable velocity, a straight plane 5000 feet long, on a grade of 1¾ feet in 100, while it would appear that 2¼ feet in 100 is necessary for the same number of empty cars. English authorities on this subject limit the grade to 3½ feet in 100 for satisfactorily working an engine plane, but the English "tubs" compare unfavorably with American "pit cars," requiring heavier grades to overcome the greater friction. It has been demonstrated in the Monongahela valley that engine planes, even with lighter grades than those mentioned above, work successfully, but it would not be safe to accept it as a rule. For roads longer than 5000 feet, or when containing sharp curves, the grade should be correspondingly larger.

Of all methods for conveying coal underground by wire rope, the Tail Rope System has justly found the most application. It can be applied under almost any condition. The road may be straight or curved, level or undulating, in one continuous line or with side branches—in all cases this system works with equal certainty and economy. In general principle a tail rope plane is the same as an engine plane worked in both directions with two ropes. One rope, called the "main rope," serves for drawing the set of full cars outward; the other, called the "tail rope," is necessary to take back the empty set, which on a level or undulating road cannot return by gravity. The two drums may be located at the opposite ends of the road, and driven by separate engines, but more frequently they are on the same shaft at one end of the plane. In the first case each rope would require the length of the plane, but in the second case the tail rope must be twice as long, being led from the drum around a sheave at the other end of the plane and back again to its starting point. When the main rope draws a set of full cars out, the tail rope drum runs loose on the shaft, and the rope, being attached to the rear car, unwinds itself steadily. Going in, the reverse takes place. Each drum is provided with a brake to check the speed of the train on a down grade and prevent it overrunning the forward rope. As a rule, the tail rope is strained less than the main rope, but in cases of heavy grades dipping outward it is possible that the strain in the former may become as large, or even larger, than in the latter, and in the selection of the sizes reference should be had to this circumstance.

The principal features of the wire rope system are as follows:

1. The rope, as the name indicates, is endless.

2. Motion is given to the rope by a single wheel or drum, and friction is obtained either by a grip-wheel or by passing the rope several times around the wheel.

3. The rope must be kept constantly tight, the tension to be produced by artificial means. It is done in placing either the return-wheel or an extra tension wheel on a carriage and connecting it with a weight hanging over a pulley, or attaching it to a fixed post by a screw which occasionally can be shortened.

4. The cars are attached to the rope by a grip or clutch, which can take hold at any place and let go again, starting and stopping the train at will, without stopping the engine or the motion of the rope.

5. On a single-track road the rope works forward and backward, but on a double-track it is possible to run it always in the same direction, the full cars going on one track and the empty cars on the other.

There are several mines in the Monongahela and Ohio valleys, and one in the Pennsylvania anthracite region, which have adopted this method of conveying coal, but as a rule it has not found as general an introduction as the tail rope system, probably because its efficacy is not so apparent and the opposing difficulties require greater mechanical skill and more complicated appliances. The advantages of this system are, first, that it requires one-third less rope than the tail-rope system. This advantage, however, is partially counterbalanced by the circumstance that the extra tension in the rope requires a heavier size to move the same load than when a main and tail rope are used. The second and principal advantage is that it is possible to start and stop trains at will without signaling to the engineer. On the other hand it is more difficult to work curves with the endless system, and still more so to work different branches, and the constant stretch of the rope under tension or its elongation under changes of temperature frequently causes the rope to slip on the wheel, in spite of every attention, causing delay in transportation and injury to the rope. The pulling rope runs in the center of the track, supported by wooden rollers, while the loose or pulled rope generally runs on the side of the road, supported by rollers, either on the ground or sometimes overhead, similar to the tail rope. As the strain in the latter is considerably smaller than it is in the pulling rope, it may, like a tail rope, consist of a smaller size in cases where the rope works backward and forward. On a double track, however, where the load changes from one to the other, it must be of one size throughout.

Wire ropes are usually made of six wire strands, laid around a hemp heart or center. A greater or lesser number may be used, but it is seldom done. For special purposes a wire strand is sometimes substituted for the hemp center; at times, also, a hemp center is put in each of the strands. Each wire strand is composed of either nineteen or seven wires; any other number does not make a compact strand, and is therefore not advisable. Using either nineteen or seven wires, and six strands with a hemp heart, gives one hundred and fourteen and forty-two wires respectively for the total number in the rope; its strength is therefore equal to the aggregate strength of the one hundred and fourteen or forty-two wires, less ten per cent., which loss is due to the twisting. The number of wires and the "lay" of the rope, whether long or short, have advantages and disadvantages.

The opinions of mine superintendents vary much as to which kind of rope is best. Special conditions govern almost every case. In the mines of the Monongahela region preference is mostly given to steel ropes, with seven wires to the strand, and made with moderately long lay.

For general rules regarding the different kinds of wire ropes it may be said:

1. Ropes with 19 wires to the strand, being more pliable, are

preferable in vertical hoisting and in cases where the rope is led around sharp curves, provided it does not drag over the ground and that friction is avoided as much as possible.

2. Ropes with 7 wires to the strand are stiffer and require larger drums or sheaves than those with 19 wires, but the thicker wire can stand considerable wear, and these ropes are therefore preferable on straight or nearly straight roads, and where the rope is exposed to much abrasion and other injuries.

3. Ropes with a long twist stretch little and glide easily over rollers; they are therefore well adapted for the tail-rope system and wire rope tramway.

4. A short-twisted rope is very elastic, and consequently stretches considerably. On account of this property such a rope is to be recommended for all inclined planes, where the rope is occasionally exposed to sudden dangerous shocks which may prove fatal to the less elastic long-twisted rope. It is also easier to make a stronger and more durable splice in a short-twisted than in a long-twisted rope. For the endless rope system, where a good splice is a necessity but where at the same time a great stretch is inconvenient, a medium twist is therefore preferable.

5. In going around curves it is always better for the wear of the rope to lead it over one single sheave, provided this is made large enough, than over a number of smaller rollers.

6. In most cases a steel rope is to be recommended in preference to an iron rope. It is cheaper than an iron rope of equal strength; also much lighter, less bulky, more elastic, harder, and therefore more durable. On the other hand, sometimes its elasticity is inconvenient, causing the rope, when wound on a small drum, to uncoil and jump off after the strain has been released. Its hardness, though a good quality for the rope, is injurious to rollers and sheaves, wearing them out more rapidly than an iron rope.

This variety of qualities makes it possible to select in any case a wire rope most suitable for the desired purpose.

The durability of a rope depends principally on the diameter of the drum or sheave around which it is coiled. If an iron bar or single wire is bent, certain fibres are elongated, others contracted, producing a tensile or compressive strain equal to the force of a direct pull or pressure which would elongate or compress the fibres to the same extent. The quantity of this force, and hence the strain per unit of sectional area, depends upon the modulus of elasticity of the material, the thickness of the wire, and the proportion of the elongation to the original length. The smaller the drum, the sharper is the bend and the greater the strain; therefore in determining the size of a drum or sheave, the consideration is guiding that the strain produced by bending, combined with the direct pull of the working load, should not exceed a certain maximum. For this maximum we take the limit of elasticity of the material—the limit to which it can be strained a great many times without permanent injury. From the nature of the rope it follows that the size of the drum does not depend upon the diameter of the rope, but only upon the diameter of the wire of which it is made. It is true that, in consequence of the twist, a certain friction exists between the individual wires of the rope, but it is so small originally, and with a free application of oil is still more reduced, that it can be safely neglected; consequently the drums need not be larger than for a single wire.

The following table has been calculated under the assumption that the working load of the rope is one-fifth of its ultimate strength, and that the modulus and limit of elasticlty, both for steel and iron, have an average value based on the latest researches:

Diameter of Rope.	SMALLEST DIAMETER IN FEET OF DRUM OR SHEAVE.			
	Steel Ropes.		*Iron Ropes.*	
	19 Wires to the Strand.	7 Wires to the Strand.	19 Wires to the Strand.	7 Wires to the Strand.
Inches,	Feet.	Feet.	Feet.	Feet.
2¼	8.6	...	13.0	...
2	8.0	...	12.0	...
1¾	7.2	...	9.5	...
1⅝	6.3	...	8.6	...
1½	5.7	8.6	7.8	13.0
1⅜	...	8.0	7.6	12.0
1¼	5.0	7.2	6.7	10.8
1⅛	4.5	6.3	6.0	9.5
1	4.0	5.7	5.4	8.6
⅞	3.6	5.0	4.6	7.6
¾	3.0	4.5	4.0	6,7
11/16	...	4.0	...	6.0
⅝	2.3	3.6	3.4	5.4
9/16	1.7	3.0	2.6	4.6
½	1.5	2.6	2.3	4.0
7/16	...	...	...	3.4
⅜	...	2.0	...	2.8
5/16	...	1.7	...	2.6

It appears from this table that, contrary to the ordinary belief, iron ropes require larger drums and sheaves than steel ropes. This is owing to the fact that iron wire, having about the same modulus of elasticity, posseses only an ultimate strength and a limit of elasticity of less than one-half that of steel wire. There are frequently practical reasons for choosing, in certain cases, larger drums than the sizes stated in the table; for instance, to avoid the recoiling and jumping off of the steel ropes after releasing the tension.

If the working load produces in the straight part of the rope less strain than one-fifth of its breaking strength, the drum diameters *may* be smaller without injury to the rope, but if the working load is greater than one-fifth of the rope's ultimate strength, the drums *must* be correspondingly larger if the strain shall not exceed the limit of elasticity.

In leading wire ropes around curves it is often impossible, for lack of space, to use a large sheave, and recourse must be had to a number of small rollers. With this arrangement many mistakes have been made, in consequence of which there has been a speedy wearing-out of the rope. The success in one case, the failure in another, and the varied opinions of practical men concerning the best methods, are a proof of this, and demonstrate the importance of the matter. Close observation and the comparison of many facts collected in the Monongahela coal regions seemed to indicate that similarly to the law governing the diameter of a single-wire sheave there would also be another law determining the number and position of the small rollers, so that no part of the rope would be strained beyond its limit of elasticity. Theoretical investigations corroborate this, and show that with the proper arrangement a rope can be taken around a curve by means of small rollers with the same safety as by means of one large sheave. This is of great advantage in practice, but only true when the rollers are corectly arranged. A general rule cannot be given for such an arrangement on account of differing circumstances. It is necessary to investigate each case separately and to go through the whole course of calculations, but the benefit derived from it in doubling or tripling the durability of a rope is well worth the trouble.