MECHANICAL EQUIPMENT.

CONDITIONS BEARING ON MINE EQUIPMENT; WINDING APPLIANCES; HAULAGE EQUIPMENT IN SHAFTS; LATERAL UNDERGROUND TRANSPORT; TRANSPORT IN STOPES.

There is no type of mechanical engineering which presents such complexities in determination of the best equipment as does that of mining. Not only does the economic side dominate over pure mechanics, but machines must be installed and operated under difficulties which arise from the most exceptional and conflicting conditions, none of which can be entirely satisfied. Compromise between capital outlay, operating efficiency, and conflicting demands is the key-note of the work.

These compromises are brought about by influences which lie outside the questions of mechanics of individual machines, and are mainly as follows:—

1. Continuous change in horizon of operations.
2. Uncertain life of the enterprise.
3. Care and preservation of human life.
4. Unequal adaptability of power transmission mediums.
5. Origin of power.

First.—The depth to be served and the volume of ore and water to be handled, are not only unknown at the initial equipment, but they are bound to change continuously in quantity, location, and horizon with the extension of the workings.

Second.—From the mine manager's point of view, which must embrace that of the mechanical engineer, further difficulty presents itself because the life of the enterprise is usually unknown, and therefore a manifest necessity arises for an economic balance of capital outlay and of operating efficiency commensurate with Page 125the prospects of the mine. Moreover, the initial capital is often limited, and makeshifts for this reason alone must be provided. In net result, no mineral deposit of speculative ultimate volume of ore warrants an initial equipment of the sort that will meet every eventuality, or of the kind that will give even the maximum efficiency which a free choice of mining machinery could obtain.

Third.—In the design and selection of mining machines, the safety of human life, the preservation of the health of workmen under conditions of limited space and ventilation, together with reliability and convenience in installing and working large mechanical tools, all dominate mechanical efficiency. For example, compressed-air transmission of power best meets the requirements of drilling, yet the mechanical losses in the generation, the transmission, and the application of compressed air probably total, from first to last, 70 to 85%.

Fourth.—All machines, except those for shaft haulage, must be operated by power transmitted from the surface, as obviously power generation underground is impossible. The conversion of power into a transmission medium and its transmission are, at the outset, bound to be the occasions of loss. Not only are the various forms of transmission by steam, electricity, compressed air, or rods, of different efficiency, but no one system lends itself to universal or economical application to all kinds of mining machines. Therefore it is not uncommon to find three or four different media of power transmission employed on the same mine. To illustrate: from the point of view of safety, reliability, control, and in most cases economy as well, we may say that direct steam is the best motive force for winding-engines; that for mechanical efficiency and reliability, rods constitute the best media of power transmission to pumps; that, considering ventilation and convenience, compressed air affords the best medium for drills. Yet there are other conditions as to character of the work, volume of water or ore, and the origin of power which must in special instances modify each and every one of these generalizations. For example, although pumping water with compressed air is mechanically the most inefficient of Page 126devices, it often becomes the most advantageous, because compressed air may be of necessity laid on for other purposes, and the extra power required to operate a small pump may be thus most cheaply provided.

Fifth.—Further limitations and modifications arise out of the origin of power, for the sources of power have an intimate bearing on the type of machine and media of transmission. This very circumstance often compels giving away efficiency and convenience in some machines to gain more in others. This is evident enough if the principal origins of power generation be examined. They are in the main as follows:—

a. Water-power available at the mine.

b. Water-power available at a less distance than three or four miles.

c. Water-power available some miles away, thus necessitating electrical transmission (or purchased electrical power).

d. Steam-power to be generated at the mine.

e. Gas-power to be generated at the mine.

a. With water-power at the mine, winding engines can be operated by direct hydraulic application with a gain in economy over direct steam, although with the sacrifice of control and reliability. Rods for pumps can be driven directly with water, but this superiority in working economy means, as discussed later, a loss of flexibility and increased total outlay over other forms of transmission to pumps. As compressed air must be transmitted for drills, the compressor would be operated direct from water-wheels, but with less control in regularity of pressure delivery.

b. With water-power a short distance from the mine, it would normally be transmitted either by compressed air or by electricity. Compressed-air transmission would better satisfy winding and drilling requirements, but would show a great comparative loss in efficiency over electricity when applied to pumping. Despite the latter drawback, air transmission is a method growing in favor, especially in view of the advance made in effecting compression by falling water.

Page 127*c*. In the situation of transmission too far for using compressed air, there is no alternative but electricity. In these cases, direct electric winding is done, but under such disadvantages that it requires a comparatively very cheap power to take precedence over a subsidiary steam plant for this purpose. Electric air-compressors work under the material disadvantage of constant speed on a variable load, but this installation is also a question of economics. The pumping service is well performed by direct electrical pumps.

d. In this instance, winding and air-compression are well accomplished by direct steam applications; but pumping is beset with wholly undesirable alternatives, among which it is difficult to choose.

e. With internal combustion engines, gasoline (petrol) motors have more of a position in experimental than in systematic mining, for their application to winding and pumping and drilling is fraught with many losses. The engine must be under constant motion, and that, too, with variable loads. Where power from producer gas is used, there is a greater possibility of installing large equipments, and it is generally applied to the winding and lesser units by conversion into compressed air or electricity as an intermediate stage.

One thing becomes certain from these examples cited, that the right installation for any particular portion of the mine's equipment cannot be determined without reference to all the others. The whole system of power generation for surface work, as well as the transmission underground, must be formulated with regard to furnishing the best total result from all the complicated primary and secondary motors, even at the sacrifice of some members.

Each mine is a unique problem, and while it would be easy to sketch an ideal plant, there is no mine within the writer's knowledge upon which the ideal would, under the many variable conditions, be the most economical of installation or the most efficient of operation. The dominant feature of the task is an endeavor to find a compromise between efficiency and capital outlay. The result is a series of choices between unsatisfying alternatives, a number of which are usually found to have been wrong upon further extension of the mine in depth.

In a general way, it may be stated that where power is generated on the mine, economy in labor of handling fuel, driving engines, generation and condensing steam where steam is used, demand a consolidated power plant for the whole mine equipment. The principal motors should be driven direct by steam or gas, with power distribution by electricity to all outlying surface motors and sometimes to underground motors, and also to some underground motors by compressed air.

Much progress has been made in the past few years in the perfection of larger mining tools. Inherently many of our devices are of a wasteful character, not only on account of the need of special forms of transmission, but because they are required to operate under greatly varying loads. As an outcome of transmission losses and of providing capacity to cope with heavy peak loads, their efficiency on the basis of actual foot-pounds of work accomplished is very low.

The adoption of electric transmission in mine work, while in certain phases beneficial, has not decreased the perplexity which arises from many added alternatives, none of which are as yet a complete or desirable answer to any mine problem. When a satisfactory electric drill is invented, and a method is evolved of applying electricity to winding-engines that will not involve such abnormal losses due to high peak load then we will have a solution to our most difficult mechanical problems, and electricity will deserve the universal blessing which it has received in other branches of mechanical engineering.

It is not intended to discuss mine equipment problems from the machinery standpoint,—there are thousands of different devices,—but from the point of view of the mine administrator who finds in the manufactory the various machines which are applicable, and whose work then becomes that of choosing, arranging, and operating these tools.

The principal mechanical questions of a mine may be examined under the following heads:—

1. Shaft haulage.
2. Lateral underground transport.

3. Drainage.
4. Rock drilling.
5. Workshops.
6. Improvements in equipment.

SHAFT HAULAGE.

Winding Appliances.—No device has yet been found to displace the single load pulled up the shaft by winding a rope on a drum. Of driving mechanisms for drum motors the alternatives are the steam-engine, the electrical motor, and infrequently water-power or gas engines.

All these have to cope with one condition which, on the basis of work accomplished, gives them a very low mechanical efficiency. This difficulty is that the load is intermittent, and it must be started and accelerated at the point of maximum weight, and from that moment the power required diminishes to less than nothing at the end of the haul. A large number of devices are in use to equalize partially the inequalities of the load at different stages of the lift. The main lines of progress in this direction have been:—

a. The handling of two cages or skips with one engine or motor, the descending skip partially balancing the ascending one.

b. The use of tail-ropes or balance weights to compensate the increasing weight of the descending rope.

c. The use of skips instead of cages, thus permitting of a greater percentage of paying load.

d. The direct coupling of the motor to the drum shaft.

e. The cone-shaped construction of drums,—this latter being now largely displaced by the use of the tail-rope.

The first and third of these are absolutely essential for anything like economy and speed; the others are refinements depending on the work to be accomplished and the capital available.

Steam winding-engines require large cylinders to start the load, but when once started the requisite power is much reduced and the load is too small for steam economy. The throttling of the engine for controlling speed and reversing the engine at periodic stoppages militates against the maximum expansion and condensation of the steam and further increases the steam consumption. In result, the best of direct compound condensing engines consume from 60 to 100 pounds of steam per horse-power hour, against a possible efficiency of such an engine working under constant load of less than 16 pounds of steam per horse-power hour.

It is only within very recent years that electrical motors have been applied to winding. Even yet, all things considered, this application is of doubtful value except in localities of extremely cheap electrical power. The constant speed of alternating current motors at once places them at a disadvantage for this work of high peak and intermittent loads. While continuous-current motors can be made to partially overcome this drawback, such a current, where power is purchased or transmitted a long distance, is available only by conversion, which further increases the losses. However, schemes of electrical winding are in course of development which bid fair, by a sort of storage of power in heavy fly-wheels or storage batteries after the peak load, to reduce the total power consumption; but the very high first cost so far prevents their very general adoption for metal mining.

Winding-engines driven by direct water- or gas-power are of too rare application to warrant much discussion. Gasoline driven hoists have a distinct place in prospecting and early-stage mining, especially in desert countries where transport and fuel conditions are onerous, for both the machines and their fuel are easy of transport. As direct gas-engines entail constant motion of the engine at the power demand of the peak load, they are hopeless in mechanical efficiency.

Like all other motors in mining, the size and arrangement Page 131 of the motor and drum are dependent upon the duty which they will be called upon to perform. This is primarily dependent upon the depth to be hoisted from, the volume of the ore, and the size of the load. For shallow depths and tonnages up to, say, 200 tons daily, geared engines have a place on account of their low capital cost. Where great rope speed is not essential they are fully as economical as direct-coupled engines. With great depths and greater capacities, speed becomes a momentous factor, and direct-coupled engines are necessary. Where the depth exceeds 3,000 feet, another element enters which has given rise to much debate and experiment; that is, the great increase of starting load due to the increased length and size of ropes and the drum space required to hold it. So far the most advantageous device seems to be the Whiting hoist, a combination of double drums and tail rope.

On mines worked from near the surface, where depth is gained by the gradual exhaustion of the ore, the only prudent course is to put in a new hoist periodically, when the demand for increased winding speed and power warrants. The lack of economy in winding machines is greatly augmented if they are much over-sized for the duty. An engine installed to handle a given tonnage to a depth of 3,000 feet will have operated with more loss during the years the mine is progressing from the surface to that depth than several intermediate-sized engines would have cost. On most mines the uncertainty of extension in depth would hardly warrant such a preliminary equipment. More mines are equipped with over-sized than with under-sized engines. For shafts on going metal mines where the future is speculative, an engine will suffice whose size provides for an extension in depth of 1,000 feet beyond that reached at the time of its installation. The cost of the engine will depend more largely upon the winding speed desired than upon any other one factor. The proper speed to be arranged is obviously dependent upon the depth of the haulage, for it is useless to have an engine able to wind 3,000 feet a minute on a shaft 500 feet deep, since it could never Page 132 even get under way; and besides, the relative operating loss, as said, would be enormous.

Haulage Equipment in the Shaft.—Originally, material was hoisted through shafts in buckets. Then came the cage for transporting mine cars, and in more recent years the "skip" has been developed. The aggrandized bucket or "kibble" of the Cornishman has practically disappeared, but the cage still remains in many mines. The advantages of the skip over the cage are many. Some of them are:—

a. It permits 25 to 40% greater load of material in proportion to the dead weight of the vehicle.

b. The load can be confined within a smaller horizontal space, thus the area of the shaft need not be so great for large tonnages.

c. Loading and discharging are more rapid, and the latter is automatic, thus permitting more trips per hour and requiring less labor.

d. Skips must be loaded from bins underground, and by providing in the bins storage capacity, shaft haulage is rendered independent of the lateral transport in the mine, and there are no delays to the engine awaiting loads. The result is that ore-winding can be concentrated into fewer hours, and indirect economies in labor and power are thus effected.

e. Skips save the time of the men engaged in the lateral haulage, as they have no delay waiting for the winding engine.

Loads equivalent to those from skips are obtained in some mines by double-decked cages; but, aside from waste weight of the cage, this arrangement necessitates either stopping the engine to load the lower deck, or a double-deck loading station. Double-deck loading stations are as costly to install and more expensive to work than skip-loading station ore-bins. Cages are also constructed large enough to take as many as four trucks on one deck. This entails a shaft compartment double the size required for skips of the same capacity, and thus enormously increases shaft cost without gaining anything.

Page 133Altogether the advantages of the skip are so certain and so important that it is difficult to see the justification for the cage under but a few conditions. These conditions are those which surround mines of small output where rapidity of haulage is no object, where the cost of station-bins can thus be evaded, and the convenience of the cage for the men can still be preserved. The easy change of the skip to the cage for hauling men removes the last objection on larger mines. There occurs also the situation in which ore is broken under contract at so much per truck, and where it is desirable to inspect the contents of the truck when discharging it, but even this objection to the skip can be obviated by contracting on a cubic-foot basis.

Skips are constructed to carry loads of from two to seven tons, the general tendency being toward larger loads every year. One of the most feasible lines of improvement in winding is in the direction of larger loads and less speed, for in this way the sum total of dead weight of the vehicle and rope to the tonnage of ore hauled will be decreased, and the efficiency of the engine will be increased by a less high peak demand, because of this less proportion of dead weight and the less need of high acceleration.

LATERAL UNDERGROUND TRANSPORT.

Inasmuch as the majority of metal mines dip at considerable angles, the useful life of a roadway in a metal mine is very short because particular horizons of ore are soon exhausted. Therefore any method of transport has to be calculated upon a very quick redemption of the capital laid out. Furthermore, a roadway is limited in its daily traffic to the product of the stopes which it serves.

Men and Animals.—Some means of transport must be provided, and the basic equipment is light tracks with push-cars, in capacity from half a ton to a ton. The latter load is, however, too heavy to be pushed by one man. As but one car can be pushed at a time, hand-trucking is both slow and expensive. At average American or Australian wages, the cost works out Page 134between 25 and 35 cents a ton per mile. An improvement of growing import where hand-trucking is necessary is the overhead mono-rail instead of the track.

If the supply to any particular roadway is such as to fully employ horses or mules, the number of cars per trip can be increased up to seven or eight. In this case the expense, including wages of the men and wear, tear, and care of mules, will work out roughly at from 7 to 10 cents per ton mile. Manifestly, if the ore-supply to a particular roadway is insufficient to keep a mule busy, the economy soon runs off.

Mechanical Haulage.—Mechanical haulage is seldom applicable to metal mines, for most metal deposits dip at considerable angles, and therefore, unlike most coal-mines, the horizon of haulage must frequently change, and there are no main arteries along which haulage continues through the life of the mine. Any mechanical system entails a good deal of expense for installation, and the useful life of any particular roadway, as above said, is very short. Moreover, the crooked roadways of most metal mines present difficulties of negotiation not to be overlooked. In order to use such systems it is necessary to condense the haulage to as few roadways as possible. Where the tonnage on one level is not sufficient to warrant other than men or animals, it sometimes pays (if the dip is steep enough) to dump everything through winzes from one to two levels to a main road below where mechanical equipment can be advantageously provided. The cost of shaft-winding the extra depth is inconsiderable compared to other factors, for the extra vertical distance of haulage can be done at a cost of one or two cents per ton mile. Moreover, from such an arrangement follows the concentration of shaft-bins, and of shaft labor, and winding is accomplished without so much shifting as to horizon, all of which economies equalize the extra distance of the lift.

There are three principal methods of mechanical transport in use:—

1. Cable-ways.
2. Compressed-air locomotives.
3. Electrical haulage.

Cable-ways or endless ropes are expensive to install, and to work to the best advantage require double tracks and fairly straight roads. While they are economical in operation and work with little danger to operatives, the limitations mentioned preclude them from adoption in metal mines, except in very special circumstances such as main crosscuts or adit tunnels, where the haulage is straight and concentrated from many sources of supply.

Compressed-air locomotives are somewhat heavy and cumbersome, and therefore require well-built tracks with heavy rails, but they have very great advantages for metal mine work. They need but a single track and are of low initial cost where compressed air is already a requirement of the mine. No subsidiary line equipment is needed, and thus they are free to traverse any road in the mine and can be readily shifted from one level to another. Their mechanical efficiency is not so low in the long run as might appear from the low efficiency of pneumatic machines generally, for by storage of compressed air at the charging station a more even rate of energy consumption is possible than in the constant cable and electrical power supply which must be equal to the maximum demand, while the air-plant consumes but the average demand.

Electrical haulage has the advantage of a much more compact locomotive and the drawback of more expensive track equipment, due to the necessity of transmission wire, etc. It has the further disadvantages of uselessness outside the equipped haulage way and of the dangers of the live wire in low and often wet tunnels.

In general, compressed-air locomotives possess many attractions for metal mine work, where air is in use in any event and where any mechanical system is at all justified. Any of the mechanical systems where tonnage is sufficient in quantity to justify their employment will handle material for from 1.5 to 4 cents per ton mile.

Tracks.—Tracks for hand, mule, or rope haulage are usually built with from 12- to 16-pound rails, but when compressed-air or electrical locomotives are to be used, less than 24-pound rails Page 136are impossible. As to tracks in general, it may be said that careful laying out with even grades and gentle curves repays itself many times over in their subsequent operation. Further care in repair and lubrication of cars will often make a difference of 75% in the track resistance.

Transport in Stopes.—Owing to the even shorter life of individual stopes than levels, the actual transport of ore or waste in them is often a function of the aboriginal shovel plus gravity. As shoveling is the most costly system of transport known, any means of stoping that decreases the need for it has merit. Shrinkage-stoping eliminates it altogether. In the other methods, gravity helps in proportion to the steepness of the dip. When the underlie becomes too flat for the ore to "run," transport can sometimes be helped by pitching the ore-passes at a steeper angle than the dip (Fig. 36). In some cases of flat deposits, crosscuts into the walls, or even levels under the ore-body, are justifiable. The more numerous the ore-passes, the less the lateral shoveling, but as passes cost money for construction and for repair, there is a nice economic balance in their frequency.

Mechanical haulage in stopes has been tried and finds a field under some conditions. In dips under 25° and possessing fairly sound hanging-wall, where long-wall or flat-back cuts are employed, temporary tracks can often be laid in the stopes and the ore run in cars to the main passes. In such cases, the tracks are pushed up close to the face after each cut. Further self-acting inclines to lower cars to the levels can sometimes be installed to advantage. This arrangement also permits greater intervals between levels and less number of ore-passes. For dips between 25° and 50° where the mine is worked without stope support or with occasional pillars, a very useful contrivance is the sheet-iron trough—about eighteen inches wide and six inches deep—made in sections ten or twelve feet long and readily bolted together. In dips 35° to 50° this trough, laid on the foot-wall, gives a sufficiently smooth surface for the ore to run upon. When the dip is flat, the trough, if hung from plugs in the hanging-wall, may be swung backward and forward. The use of this "bumping-trough" saves much shoveling. For handling Page 137filling or ore in flat runs it deserves wider adoption. It is, of course, inapplicable in passes as a "bumping-trough," but can be fixed to give smooth surface. In flat mines it permits a wider interval between levels and therefore saves development work. The life of this contrivance is short when used in open stopes, owing to the dangers of bombardment from blasting.

In dips steeper than 50° much of the shoveling into passes can be saved by rill-stoping, as described on page 100. Where flat-backed stopes are used in wide ore-bodies with filling, temporary tracks laid on the filling to the ore-passes are useful, for they permit wider intervals between passes.

In that underground engineer's paradise, the Witwatersrand, where the stopes require neither timber nor filling, the long, moderately pitched openings lend themselves particularly to the swinging iron troughs, and even endless wire ropes have been found advantageous in certain cases.

Where the roof is heavy and close support is required, and where the deposits are very irregular in shape and dip, there is little hope of mechanical assistance in stope transport.

MECHANICAL EQUIPMENT. (*Continued*).

DRAINAGE: CONTROLLING FACTORS; VOLUME AND HEAD OF WATER; FLEXIBILITY; RELIABILITY; POWER CONDITIONS; MECHANICAL EFFICIENCY; CAPITAL OUTLAY. SYSTEMS OF DRAINAGE,—STEAM PUMPS, COMPRESSED-AIR PUMPS, ELECTRICAL PUMPS, ROD-DRIVEN PUMPS, BAILING; COMPARATIVE VALUE OF VARIOUS SYSTEMS.

With the exception of drainage tunnels—more fully described in Chapter VIII—all drainage must be mechanical. As the bulk of mine water usually lies near the surface, saving in pumping can sometimes be effected by leaving a complete pillar of ore under some of the upper levels. In many deposits, however, the ore has too many channels to render this of much avail.

There are six factors which enter into a determination of mechanical drainage systems for metal mines:—

1. Volume and head of water.
2. Flexibility to fluctuation in volume and head.
3. Reliability.
4. Capital cost.
5. The general power conditions.
6. Mechanical efficiency.

In the drainage appliances, more than in any other feature of the equipment, must mechanical efficiency be subordinated to the other issues.

Flexibility.—Flexibility in plant is necessary because volume and head of water are fluctuating factors. In wet regions the volume of water usually increases for a certain distance with the extension of openings in depth. In dry climates it generally decreases with the downward extension of the workings Page 139after a certain depth. Moreover, as depth progresses, the water follows the openings more or less and must be pumped against an ever greater head. In most cases the volume varies with the seasons. What increase will occur, from what horizon it must be lifted, and what the fluctuations in volume are likely to be, are all unknown at the time of installation. If a pumping system were to be laid out for a new mine, which would peradventure meet every possible contingency, the capital outlay would be enormous, and the operating efficiency would be very low during the long period in which it would be working below its capacity. The question of flexibility does not arise so prominently in coal-mines, for the more or less flat deposits give a fixed factor of depth. The flow is also more steady, and the volume can be in a measure approximated from general experience.

Reliability.—The factor of reliability was at one time of more importance than in these days of high-class manufacture of many different pumping systems. Practically speaking, the only insurance from flooding in any event lies in the provision of a relief system of some sort,—duplicate pumps, or the simplest and most usual thing, bailing tanks. Only Cornish and compressed-air pumps will work with any security when drowned, and electrical pumps are easily ruined.

General Power Conditions.—The question of pumping installation is much dependent upon the power installation and other power requirements of the mine. For instance, where electrical power is purchased or generated by water-power, then electrical pumps have every advantage. Or where a large number of subsidiary motors can be economically driven from one central steam- or gas-driven electrical generation plant, they again have a strong call,—especially if the amount of water to be handled is moderate. Where the water is of limited volume and compressed-air plant a necessity for the mine, then air-driven pumps may be the most advantageous, etc.

Mechanical Efficiency.—The mechanical efficiency of drainage machinery is very largely a question of method of power application. The actual pump can be built to almost the same efficiency for any power application, and with the exception of Page 140the limited field of bailing with tanks, mechanical drainage is a matter of pumps. All pumps must be set below their load, barring a few possible feet of suction lift, and they are therefore perforce underground, and in consequence all power must be transmitted from the surface. Transmission itself means loss of power varying from 10 to 60%, depending upon the medium used. It is therefore the choice of transmission medium that largely governs the mechanical efficiency.

Systems of Drainage.—The ideal pumping system for metal mines would be one which could be built in units and could be expanded or contracted unit by unit with the fluctuation in volume; which could also be easily moved to meet the differences of lifts; and in which each independent unit could be of the highest mechanical efficiency and would require but little space for erection. Such an ideal is unobtainable among any of the appliances with which the writer is familiar.

The wide variations in the origin of power, in the form of transmission, and in the method of final application, and the many combinations of these factors, meet the demands for flexibility, efficiency, capital cost, and reliability in various degrees depending upon the environment of the mine. Power nowadays is generated primarily with steam, water, and gas. These origins admit the transmission of power to the pumps by direct steam, compressed air, electricity, rods, or hydraulic columns.

Direct Steam-pumps.—Direct steam has the disadvantage of radiated heat in the workings, of loss by the radiation, and, worse still, of the impracticability of placing and operating a highly efficient steam-engine underground. It is all but impossible to derive benefit from the vacuum, as any form of surface condenser here is impossible, and there can be no return of the hot soft water to the boilers.

Steam-pumps fall into two classes, rotary and direct-acting; the former have the great advantage of permitting the use of steam expansively and affording some field for effective use of condensation, but they are more costly, require much room, and are not fool-proof. The direct-acting pumps have all the advantage of compactness and the disadvantage of being the most Page 141inefficient of pumping machines used in mining. Taking the steam consumption of a good surface steam plant at 15 pounds per horse-power hour, the efficiency of rotary pumps with well-insulated pipes is probably not over 50%, and of direct-acting pumps from 40% down to 10%.

The advantage of all steam-pumps lies in the low capital outlay,—hence their convenient application to experimental mining and temporary pumping requirements. For final equipment they afford a great deal of flexibility, for if properly constructed they can be, with slight alteration, moved from one horizon to another without loss of relative efficiency. Thus the system can be rearranged for an increased volume of water, by decreasing the lift and increasing the number of pumps from different horizons.

Compressed-air Pumps.—Compressed-air transmission has an application similar to direct steam, but it is of still lower mechanical efficiency, because of the great loss in compression. It has the superiority of not heating the workings, and there is no difficulty as to the disposal of the exhaust, as with steam. Moreover, such pumps will work when drowned. Compressed air has a distinct place for minor pumping units, especially those removed from the shaft, for they can be run as an adjunct to the air-drill system of the mine, and by this arrangement much capital outlay may be saved. The cost of the extra power consumed by such an arrangement is less than the average cost of compressed-air power, because many of the compressor charges have to be paid anyway. When compressed air is water-generated, they have a field for permanent installations. The efficiency of even rotary air-driven pumps, based on power delivered into a good compressor, is probably not over 25%.

Electrical Pumps.—Electrical pumps have somewhat less flexibility than steam- or air-driven apparatus, in that the speed of the pumps can be varied only within small limits. They have the same great advantage in the easy reorganization of the system to altered conditions of water-flow. Electricity, when steam-generated, has the handicap of the losses of two conversions, the actual pump efficiency being about 60% in well-constructed Page 142plants; the efficiency is therefore greater than direct steam or compressed air. Where the mine is operated with water-power, purchased electric current, or where there is an installation of electrical generating plant by steam or gas for other purposes, electrically driven pumps take precedence over all others on account of their combined moderate capital outlay, great flexibility, and reasonable efficiency.

In late years, direct-coupled, electric-driven centrifugal pumps have entered the mining field, but their efficiency, despite makers' claims, is low. While they show comparatively good results on low lifts the slip increases with the lift. In heads over 200 feet their efficiency is probably not 30% of the power delivered to the electrical generator. Their chief attractions are small capital cost and the compact size which admits of easy installation.

Rod-driven Pumps.—Pumps of the Cornish type in vertical shafts, if operated to full load and if driven by modern engines, have an efficiency much higher than any other sort of installation, and records of 85 to 90% are not unusual. The highest efficiency in these pumps yet obtained has been by driving the pump with rope transmission from a high-speed triple expansion engine, and in this plant an actual consumption of only 17 pounds of steam per horse-power hour for actual water lifted has been accomplished.

To provide, however, for increase of flow and change of horizon, rod-driven pumps must be so overpowered at the earlier stage of the mine that they operate with great loss. Of all pumping systems they are the most expensive to provide. They have no place in crooked openings and only work in inclines with many disadvantages.

In general their lack of flexibility is fast putting them out of the metal miner's purview. Where the pumping depth and volume of water are approximately known, as is often the case in coal mines, this, the father of all pumps, still holds its own.

Hydraulic Pumps.—Hydraulic pumps, in which a column of water is used as the transmission fluid from a surface pump to a corresponding pump underground has had some adoption in Page

143 coal mines, but little in metal mines. They have a certain amount of flexibility but low efficiency, and are not likely to have much field against electrical pumps.

Bailing.—Bailing deserves to be mentioned among drainage methods, for under certain conditions it is a most useful system, and at all times a mine should be equipped with tanks against accident to the pumps. Where the amount of water is limited,—up to, say, 50,000 gallons daily,—and where the ore output of the mine permits the use of the winding-engine for part of the time on water haulage, there is in the method an almost total saving of capital outlay. Inasmuch as the winding-engine, even when the ore haulage is finished for the day, must be under steam for handling men in emergencies, and as the labor of stokers, engine-drivers, shaft-men, etc., is therefore necessary, the cost of power consumed by bailing is not great, despite the low efficiency of winding-engines.

Comparison of Various Systems.—If it is assumed that flexibility, reliability, mechanical efficiency, and capital cost can each be divided into four figures of relative importance,—*A*, *B*, *C*, and *D*, with *A* representing the most desirable result,—it is possible to indicate roughly the comparative values of various pumping systems. It is not pretended that the four degrees are of equal import. In all cases the factor of general power conditions on the mine may alter the relative positions.

	Direct Steam Pumps	Compressed Air	Electricity	Steam-Driven Rods	Hydraulic Columns	Bailing Rods
Flexibility	*A*	*A*	*B*	*D*	*B*	*A*
Reliability	*B*	*B*	*B*	*A*	*D*	*A*
Mechanical Efficiency	*C*	*D*	*B*	*A*	*C*	*D*
Capital Cost	*A*	*B*	*B*	*D*	*D*	—

As each mine has its special environment, it is impossible to formulate any final conclusion on a subject so involved. The attempt would lead to a discussion of a thousand supposititious Page
144 cases and hypothetical remedies. Further, the description alone of pumping machines would fill volumes, and the subject will never be exhausted. The engineer confronted with pumping problems must marshal all the alternatives, count his money, and apply the tests of flexibility, reliability, efficiency, and cost, choose the system of least disadvantages, and finally deprecate the whole affair, for it is but a parasite growth on the mine.

MACHINE DRILLING: POWER TRANSMISSION; COMPRESSED AIR *VS*. ELECTRICITY; AIR DRILLS; MACHINE *VS*. HAND DRILLING. WORK-SHOPS. IMPROVEMENT IN EQUIPMENT.

For over two hundred years from the introduction of drill-holes for blasting by Caspar Weindel in Hungary, to the invention of the first practicable steam percussion drill by J. J. Crouch of Philadelphia, in 1849, all drilling was done by hand. Since Crouch's time a host of mechanical drills to be actuated by all sorts of power have come forward, and even yet the machine-drill has not reached a stage of development where it can displace hand-work under all conditions. Steam-power was never adapted to underground work, and a serviceable drill for this purpose was not found until compressed air for transmission was demonstrated by Dommeiller on the Mt. Cenis tunnel in 1861.

The ideal requirements for a drill combine:—

a. Power transmission adapted to underground conditions.
b. Lightness.
c. Simplicity of construction.
d. Strength.
e. Rapidity and strength of blow.
f. Ease of erection.
g. Reliability.
h. Mechanical efficiency.
i. Low capital cost.

No drill invented yet fills all these requirements, and all are a compromise on some point.

Power Transmission; Compressed Air *vs.* **Electricity.**—The only transmissions adapted to underground drill-work are compressed air and electricity, and as yet an electric-driven drill has not been produced which meets as many of the requirements of the metal miner as do compressed-air drills. The latter, up to date, have superiority in simplicity, lightness, ease of erection, reliability, and strength over electric machines. Air has another advantage in that it affords some assistance to ventilation, but it has the disadvantage of remarkably low mechanical efficiency. The actual work performed by the standard 3-3/4-inch air-drill probably does not amount to over two or three horse-power against from fifteen to eighteen horse-power delivered into the compressor, or mechanical efficiency of less than 25%. As electrical power can be delivered to the drill with much less loss than compressed air, the field for a more economical drill on this line is wide enough to create eventually the proper tool to apply it. The most satisfactory electric drill produced has been the Temple drill, which is really an air-drill driven by a small electrically-driven compressor placed near the drill itself. But even this has considerable deficiencies in mining work; the difficulties of setting up, especially for stoping work, and the more cumbersome apparatus to remove before blasting are serious drawbacks. It has deficiencies in reliability and greater complication of machinery than direct air.

Air-compression.—The method of air-compression so long accomplished only by power-driven pistons has now an alternative in some situations by the use of falling water. This latter system is a development of the last twelve years, and, due to the low initial outlay and extremely low operating costs, bids fair in those regions where water head is available not only to displace the machine compressor, but also to extend the application of compressed air to mine motors generally, and to stay in some environments the encroachment of electricity into the compressed-air field. Installations of this sort in the West Kootenay, B.C., and at the Victoria copper mine, Michigan, are giving results worthy of careful attention.

Mechanical air-compressors are steam-, water-, electrical-, and gas-driven, the alternative obviously depending on the source and cost of power. Electrical- and gas- and water-driven Page 147compressors work under the disadvantage of constant speed motors and respond little to the variation in load, a partial remedy for which lies in enlarged air-storage capacity. Inasmuch as compressed air, so far as our knowledge goes at present, must be provided for drills, it forms a convenient transmission of power to various motors underground, such as small pumps, winches, or locomotives. As stated in discussing those machines, it is not primarily a transmission of even moderate mechanical efficiency for such purposes; but as against the installation and operation of independent transmission, such as steam or electricity, the economic advantage often compensates the technical losses. Where such motors are fixed, as in pumps and winches, a considerable gain in efficiency can be obtained by reheating.

It is not proposed to enter a discussion of mechanical details of air-compression, more than to call attention to the most common delinquency in the installation of such plants. This deficiency lies in insufficient compression capacity for the needs of the mine and consequent effective operation of drills, for with under 75 pounds pressure the drills decrease remarkably in rapidity of stroke and force of the blow. The consequent decrease in actual accomplishment is far beyond the ratio that might be expected on the basis of mere difference of pressure. Another form of the same chronic ill lies in insufficient air-storage capacity to provide for maintenance of pressure against moments when all drills or motors in the mine synchronize in heavy demand for air, and thus lower the pressure at certain periods.

Air-drills.—Air-drills are from a mechanical point of view broadly of two types,—the first, in which the drill is the piston extension; and the second, a more recent development for mining work, in which the piston acts as a hammer striking the head of the drill. From an economic point of view drills may be divided into three classes. First, heavy drills, weighing from 150 to 400 pounds, which require two men for their operation; second, "baby" drills of the piston type, weighing from 110 to 150 pounds, requiring one man with occasional assistance in setting up; and third, very light drills almost wholly of the Page 148hammer type. This type is built in two forms: a heavier type for mounting on columns, weighing about 80 pounds; and a type after the order of the pneumatic riveter, weighing as low as 20 pounds and worked without mounting.

The weight and consequent mobility of a drill, aside from labor questions, have a marked effect on costs, for the lighter the drill the less difficulty and delay in erection, and consequent less loss of time and less tendency to drill holes from one radius, regardless of pointing to take best advantage of breaking planes. Moreover, smaller diameter and shorter holes consume less explosives per foot advanced or per ton broken. The best results in tonnage broken and explosive consumed, if measured by the foot of drill-hole necessary, can be accomplished from hand-drilling and the lighter the machine drill, assuming equal reliability, the nearer it approximates these advantages.

The blow, and therefore size and depth of hole and rapidity of drilling, are somewhat dependent upon the size of cylinders and length of stroke, and therefore the heavier types are better adapted to hard ground and to the deep holes of some development points. Their advantages over the other classes lie chiefly in this ability to bore exceedingly hard material and in the greater speed of advance possible in development work; but except for these two special purposes they are not as economical per foot advanced or per ton of ore broken as the lighter drills.

The second class, where men can be induced to work them one man per drill, saves in labor and gains in mobility. Many tests show great economy of the "baby" type of piston drills in average ground over the heavier machines for stoping and for most lateral development. All piston types are somewhat cumbersome and the heavier types require at least four feet of head room. The "baby" type can be operated in less space than this, but for narrow stopes they do not lend themselves with the same facility as the third class.

The third class of drills is still in process of development, but it bids fair to displace much of the occupation of the piston types of drill. Aside from being a one-man drill, by its mobility it will apparently largely reproduce the advantage of hand-drilling in ability to place short holes from the most advantageous angles and for use in narrow places. As compared with other drills it bids fair to require less time for setting up and removal and for change of bits; to destroy less steel by breakages; to dull the bits less rapidly per foot of hole; to be more economical of power; to require much less skill in operation, for judgment is less called upon in delivering speed; and to evade difficulties of fissured ground, etc. And finally the cost is only one-half, initially and for spares. Its disadvantage so far is a lack of reliability due to lightness of construction, but this is very rapidly being overcome. This type, however, is limited in depth of hole possible, for, from lack of positive reverse movement, there is a tendency for the spoil to pack around the bit, and as a result about four feet seems the limit.

The performance of a machine-drill under show conditions may be anything up to ten or twelve feet of hole per hour on rock such as compact granite; but in underground work a large proportion of the time is lost in picking down loose ore, setting up machines, removal for blasting, clearing away spoil, making adjustments, etc. The amount of lost time is often dependent upon the width of stope or shaft and the method of stoping. Situations which require long drill columns or special scaffolds greatly accentuate the loss of time. Further, the difficulties in setting up reflect indirectly on efficiency to a greater extent in that a larger proportion of holes are drilled from one radius and thus less adapted to the best breaking results than where the drill can easily be reset from various angles.

The usual duty of a heavy drill per eight-hour shift using two men is from 20 to 40 feet of hole, depending upon the rock, facilities for setting up, etc., etc.[*] The lighter drills have a less average duty, averaging from 15 to 25 feet per shift.

[Footnote *: Over the year 1907 in twenty-eight mines compiled from Alaska to Australia, an average of 23.5 feet was drilled per eight-hour shift by machines larger than three-inch cylinder.]

Machine *vs*. **Hand-Drilling.**—The advantages of hand-drilling over machine-drilling lie, first, in the total saving of power, the absence of capital cost, repairs, depreciation, etc., on power, compresser and drill plant; second, the time required for setting up machine-drills does not warrant frequent blasts, so that a number of holes on one radius are a necessity, and therefore machine-holes generally cannot be pointed to such advantage as hand-holes. Hand-holes can be set to any angle, and by thus frequent blasting yield greater tonnage per foot of hole. Third, a large number of comparative statistics from American, South African, and Australian mines show a saving of about 25% in explosives for the same tonnage or foot of advance by hand-holes over medium and heavy drill-holes.

The duty of a skilled white man, single-handed, in rock such as is usually met below the zone of oxidation, is from 5 to 7 feet per shift, depending on the rock and the man. Two men hand-drilling will therefore do from 1/4 to 2/3 of the same footage of holes that can be done by two men with a heavy machine-drill, and two men hand-drilling will do from 1/5 to 1/2 the footage of two men with two light drills.

The saving in labor of from 75 to 33% by machine-drilling may or may not be made up by the other costs involved in machine-work. The comparative value of machine- and hand-drilling is not subject to sweeping generalization. A large amount of data from various parts of the world, with skilled white men, shows machine-work to cost from half as much per ton or foot advanced as hand-work to 25% more than handwork, depending on the situation, type of drill, etc. In a general way hand-work can more nearly compete with heavy machines than light ones. The situations where hand-work can compete with even light machines are in very narrow stopes where drills cannot be pointed to advantage, and where the increased working space necessary for machine drills results in breaking more waste. Further, hand-drilling can often compete with machine-work in wide stopes where long columns or platforms must be used and therefore there is much delay in taking down, reërection, etc.

Many other factors enter into a comparison, however, for machine-drilling produces a greater number of deeper holes and permits larger blasts and therefore more rapid progress. In driving Page 151 levels under average conditions monthly footage is from two to three times as great with heavy machines as by hand-drilling, and by lighter machines a somewhat less proportion of greater speed. The greater speed obtained in development work, the greater tonnage obtained per man in stoping, with consequent reduction in the number of men employed, and in reduction of superintendence and general charges are indirect advantages for machine-drilling not to be overlooked.

The results obtained in South Africa by hand-drilling in shafts, and its very general adoption there, seem to indicate that better speed and more economical work can be obtained in that way in very large shafts than by machine-drilling. How far special reasons there apply to smaller shafts or labor conditions elsewhere have yet to be demonstrated. In large-dimension shafts demanding a large number of machines, the handling of long machine bars and machines generally results in a great loss of time. The large charges in deep holes break the walls very irregularly; misfires cause more delay; timbering is more difficult in the face of heavy blasting charges; and the larger amount of spoil broken at one time delays renewed drilling, and altogether the advantages seem to lie with hand-drilling in shafts of large horizontal section.

The rapid development of special drills for particular conditions has eliminated the advantage of hand-work in many situations during the past ten years, and the invention of the hammer type of drill bids fair to render hand-drilling a thing of the past. One generalization is possible, and that is, if drills are run on 40-50 pounds' pressure they are no economy over hand-drilling.

WORKSHOPS.

In addition to the ordinary blacksmithy, which is a necessity, the modern tendency has been to elaborate the shops on mines to cover machine-work, pattern-making and foundry-work, in order that delays may be minimized by quick repairs. To provide, however, for such contingencies a staff of men must be kept larger than the demand of average requirements. The result Page 152is an effort to provide jobs or to do work extravagantly or unnecessarily well. In general, it is an easy spot for fungi to start growing on the administration, and if custom repair shops are available at all, mine shops can be easily overdone.

A number of machines are now in use for sharpening drills. Machine-sharpening is much cheaper than hand-work, although the drills thus sharpened are rather less efficient owing to the difficulty of tempering them to the same nicety; however, the net results are in favor of the machines.

IMPROVEMENT IN EQUIPMENT.

Not only is every mine a progressive industry until the bottom gives out, but the technology of the industry is always progressing, so that the manager is almost daily confronted with improvements which could be made in his equipment that would result in decreasing expenses or increasing metal recovery. There is one test to the advisability of such alterations: How long will it take to recover the capital outlay from the savings effected? and over and above this recovery of capital there must be some very considerable gain. The life of mines is at least secured over the period exposed in the ore-reserves, and if the proposed alteration will show its recovery and profit in that period, then it is certainly justified. If it takes longer than this on the average speculative ore-deposit, it is a gamble on finding further ore. As a matter of practical policy it will be found that an improvement in equipment which requires more than three or four years to redeem itself out of saving, is usually a mechanical or metallurgical refinement the indulgence in which is very doubtful.