ELEMENTS OF ELECTRICAL ENGINEERING.—III.

THE ARC-LIGHT DYNAMO.

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Continued from Supplement No. 1658, page 230.

A MORE familiar designation would be "series arc dynamos." It is now hard to realize how meager were artificial illuminants before the advent of electric lighting. Streets were dimly and even dangerously dark; halls, stores and factories served with gas and oil illustrated unhealthful and dangerous conditions. There was, therefore, great incentive to produce the arc light on a practical scale, and the spectacle of Gramme's magnificent lights, in Philadelphia in 1876, first revealed to the public that electricity had other commercial uses than to operate telegraph instruments. Though some timid people seemed to be frightened by the otherwise prophecies of physicians as to the dangerous effect of intense brilliancy upon the optic nerves and brain, evidence was not lacking, that with economical apparatus at hand to produce the arcs in sufficient numbers, there would be plenty of customers.

Two men stand out conspicuously as having solved the problem. They were Charles F. Brush, of Cleveland, Ohio, whose principal work was done between 1876 and 1880, and Elihu Thomson, early of Philadelphia, Pa., and then of Lynn, Mass., who made valuable improvements and extensions in the early '80s. Brush's machines were of much better mechanical design than Thomson's, but the latter had the more effective regulator. The personality of the men, the successive steps in the development of their "systems," the competition between the two manufacturing companies that were organized, the loyalty of the employees at the Cleveland and Lynn factories, are matters of historic interest to those who were associated in the work in those stirring times, but their narration need not cause a diversion in this article. It is interesting to note that Prof. Thomson originally sold his patents to the Brush Company, then with the assistance of Prof. Houston, bought them back and organized his own company; after interesting further capital and removing to Lynn, this "Thomson-Houston Electric Company" obtained a controlling interest in the Brush Electric Company, and later, in the days of the General Electric Company—formed by the consolidation of the Thomson-Houston and Edison interests—the pioneer company was wholly absorbed and disappeared from active existence. Brush himself, however, had prospered richly from his inventions and has had the satisfaction of seeing the distinctive construction of Thomson abandoned, and his own, with the addition of the Thomson regulator, substituted for the recent largest sizes of arc dynamos. A personal article by Brush himself regarding his early experiences forms highly interesting reading in the Century Magazine for May, 1905.

Without stopping to follow the successive steps in the early development of the two systems of these inventors, it will be well to explain what necessity exists for constant current working, what are the electrical and magnetic conditions that will allow a dynamo to supply such a current, and then to observe how these conditions were met in the Brush and Thomson apparatus.

If two or more lamps are to be operated from the same dynamo, economy of wiring would dictate that they be connected in series with each other; each

lamps ordinarily supplied from a central station many independent dynamos would be needed. With lamps or other devices connected in multiple, or parallel, the potential is limited to that demanded by one unit, each customer is wholly independent of others, and there is no limit yet reached in the size in which the generators may be built. For this reason interior arc lamps are now commonly connected in multiple, the

Fig. 11.—Connections of 16-Light Brush Arc Dynamo.

expense of the copper being justified by the use of lamps requiring small currents and by the more general demand for all-day service.

In the early days, however, street lighting was of the first importance, and private customers were considerably scattered, so the series connections of arc lamps were very properly considered to be necessary. Street lighting alone is likely to comprise the sole use of such circuits in the future. With this idea in mind, of operating lamps in series, demanding extreme variations in voltage, the hardest problem was the first to be presented; even now, the theory of arc dynamos is not very well understood and their operation is still attended with adverse conditions.

The requirement of constant current and variable voltage is just the opposite of the natural capability of a dynamo. A field magnet is ordinarily designed of a certain size to carry a definite flux of force, and would not be considered as giving good returns if operated at much above or below that amount; the number of conductors on an armature is obviously fixed; the speed of rotation, for practical reasons of good engineering, is maintained very uniform. Upon these three quantities—the field flux, the number of armature conductors, and the speed, as explained in a preceding article—depends the value of the electromotive force, and if they are fixed, the electromotive force is necessarily constant; then, dependent upon the resistance of the circuit, current of greater or less strength will flow. This condition of operation is sought and attained in machines now used for general purposes of electric supply; they are classed as "constant potential" generators, and will form the topic

more expensive to construct, the more satisfactory would be the behavior. By such proportions, three essential factors were presented—a highly saturated field magnet, strong armature reactions, and much self-induction. The effect of these three will be separately considered.

A numerical example will assist in making apparent the value of a magnetically saturated condition of the iron of the field. Suppose a dynamo is supplying a circuit of 40 lamps in series; the voltage needed would be about 2,000, and the current, presumably, 10 amperes; let half of the lamps be turned off, by short-circuiting them; then only about 1,000 volts would be needed. If no other changes took place in the circuit, the 2,000 volts would still continue to be generated, and therefore result in sending 20 amperes instead of 10 through the lamps; with unsaturated field magnets in series with the same circuit, there would then be nearly twice as much magnetism produced, and this in turn would elevate the potential still higher, so that at the time when a half potential was desired, it would be much more than doubled. The result would be no saving in the driving power, and disaster to the windings of the machine and lamps. If, instead, the normal 10 amperes so highly saturated the field magnet that an increase in the current produced appreciably more magnetism, no actual rise in the voltage could accompany diminished load. Again, if the proper conditions for half load were attained, and full load was thrown on, the dynamo should at once increase its potential from 1,000 volts to 2,000; if there was any delay in reaching this value, the current would momentarily fall to 5 amperes; if this resulted in lessening the magnetism to one-half, the voltage would of course fall, and the current in turn be further reduced, but if the taking away of 5 amperes from the circuit did not proportionately affect the magnetism, no such exaggerated lapse would occur. If a 10 ampere dynamo is desired, it should be so designed that 3 or 4 amperes will about saturate the field, then slight variations in the current above and below normal will be nearly ignored.

The production of magnetism is an invariable result of current flow; even if the inclosed iron is in the form of a ring or drum armature core, the introduction of current at one point of the winding, and its exit at another, will produce definite poles in the circular faces; within the limits of saturation, the larger the number of turns, and a given current, the greater the amount of magnetism. An arc dynamo is a high potential machine, and to generate the requisite number of volts, many turns of wire are needed on the armature, and a high degree of magnetization results. To minimize sparking in a generator it is found necessary to move the brushes forward, in the direction of rotation, and the greater the armature magnetization the more must be this displacement from the mean position. Diagrams could be drawn to show that under these conditions there is a compo-

Fig. 10.—40-Light Brush Arc Dynamo. Type of 1881.

Fig. 12.—50-Light Thomson-Houston Arc Dynamo. Type of 1886.

lamp would then be sure to receive the same current; the dynamo should then be designed to supply a voltage proportional to the number of lamps, but a current invariable in value. A given circuit would, therefore, be generally associated with some one dynamo, and any one customer could not be served without energizing the entire line; for even a hundred lamps in one circuit, the requisite voltage might be dangerously high, consequently for thousands of

of the fifth article. Early dynamos were rather lean in their magnetic circuits, and considerable copper wire was used in order to bring their magnetism to its full value; these proportions are now known to be far from the proper conditions for constant potential working, so unwittingly there was a contribution in the right direction to assist the early seekers after constant current machinery; they quickly found that the less iron and more copper in a dynamo, though

ment produced that acts directly against the field flux. It will be at once recognized that such an action is highly helpful in maintaining the current constant, for with the value normally at 10 amperes, a rise to 11 would at once increase the armature demagnetizing component, and reduce the effective field flux, and a fall to 9 amperes would so reduce this reaction as to permit an increase in the flux. Too large a current would therefore tend to reduce the voltage, and too

small a current to increase it. Self-correcting influences would thus be at work at every incipient change of the current.

The third factor, self-induction, is one that has momentary influence only; it is electromagnetic inertia of a very transient sort. Its analogy to the mechanical inertia of a flywheel is helpful toward a clear understanding of its influence, and though ordinarily associated with the working of alternating currents, a brief explanation will be made at this point. A fly wheel tends to keep the motion uniform; it resists acceleration and retardation alike; the numerical value of the energy resident in the mass of the wheel varies as the square of the angular velocity. Likewise, when a diminution of the current from a dynamo is attempted, the reduction in the number of lines of force at once generates an electromotive force to prolong the current; in case of an actual break in the circuit the high self-induced voltage may produce a visible or even disastrous flash, just as the sudden stopping of a fly wheel may mean ruin to the connected machinery; a rise in the current immediately produces more lines of force, and they generate an electromotive force in the direction to check the current. To compensate for fluctuations in the driving of the engines, and irregularities in the burning and feeding of the carbons in the lamps, self-induction is a force for instantaneous remedy. Still resembling the mechanical case, the value of self-induction varies as the square of the number of turns in the coils, and as the arc dynamo has many turns it has very high self-induction.

Were these three qualities alone present in the dynamo, it would still be unsatisfactory in its operation; the current would have no particular value, and in spite of helpful influences, considerable variations would result from extreme changes of load. It is like a steam engine with heavy flywheel, long crank, and restricted steam ports; with steam supplied, it would run at some speed, though indeterminate, and vary with every change of load; even though the load were entirely removed the engine might not race on account of the protective effect of the narrow ports. Though the arc dynamo might supply too weak a current at extreme loads, the factors just explained might prevent a ruinous one on short circuit. For uniform engine speed over appreciable lapse of time the flywheel is helpless, and a "governor" is attached, so the arc dynamo needs the additional help of a mechanically operated "regulator." The voltage of a dynamo has been shown to be dependent upon the field flux, number of armature conductors and the speed. Just the right potential could always be secured by driving the dynamo at a suitable speed, but such a method would involve impracticable engineering. Of the two remaining chances, control by varying the field strength would involve departure from the desirable condition of high saturation, and varying the number of armature conductors from one moment to the next looks impossible. Brush actually adopted the method of varying the field strength, and thereby introduced the only weak point of his system; while Thomson, by varying the position of the brushes, changed the effective if not the real number of armature conductors, a device of marvelous sensitiveness and reliability.

Shunt-wound fields have been used on a small scale for series-connected arc lamps. Edward Weston, afterward the maker of electrical measuring instruments, adopted this kind on some 20-light dynamos; a mechanical governor was attached to vary the field rheostat, but the action was too sluggish to be satisfactory, and the current was apt to surge through wide variations. For extreme variations in the number of lamps a shunt winding could not possibly be

Fig. 10 shows the appearance of the Brush machine for 40 lights; the integral casting of base and magnet yokes with their bearings for the shaft was an English construction; in Cleveland, two channel bars running lengthwise to which the upper castings were bolted made a lighter yet rigid construction, and one not likely to be broken in shipment; also for transportation to difficult locations, the machine could then be dismembered. Though comprised in four separate parts the field magnet has essentially only two poles, for those facing each other are of the same polarity, and except for interference with access to the armature might be joined together. In some of his dynamos for electroplating Brush actually made the iron continuous, as did Gulcher and some others who copied freely from the Brush design. The location of the commutator brushes at lines 180 deg. apart in-

Fig. 13.—Thomson-Houston Ring Armature.

stead of 90 deg., as required with four poles, is proof of the existence of two poles only. The armature is a cast iron ring of short axial, but considerable radial length. Twelve deep and wide slots hold the coils of copper wire wound in a manner apparently resembling Gramme's; it differed from his, however, in the essential respect that adjacent coils were not connected together, and to a multiple segment commutator, but opposite coils were joined in series, and to a two-segment commutator; other opposite coils were also connected in similar manner, each pair having a two-segment commutator of its own. Coils occupying positions 90 deg. apart could momentarily be put in multiple with each other by the bridging action of the brushes, but the separate groups of commutators were connected in series, while the coils passing through the neutral line were completely cut out of circuit. A diagram of the circuits of the 8-coil 16-light machine is given in Fig. 11. The wires that connect the opposite coils in series are not shown, but they do not take the S-shaped path, as erroneously given in some text books; the true directions of the current result in producing consequent poles in the armature core, not in driving the magnetism in the closed circular path. The curved pole pieces seen in Fig. 10 are omitted from the diagram; their real effect along with the great distortions produced by the armature reactions will explain the extreme shifting of the brushes from their expected position. Imagining the current to start at the negative brush A, it enters the coils numbered 3, then out of the brush A' to B; coils 2 and 4 are for a moment in parallel, and the current unites again at brush B', and passes around the field coils, then through the lamp circuit and back to A. Brush suspected a fault in the ordinary Gramme winding, thinking that under some conditions there was a chance for the current to go backward through the closed circuit. This idea was of course not well founded, and it is curious to notice that the condition which he wrongly suspected in the other armature, he actually introduced in his own. The two coils which he allowed to be put in parallel have equal electro-

the method was obviously inappropriate, and compelled him to adopt the simple Gramme connections. The "open-coil" arc dynamos at once won popular favor, and made public lighting on a large scale possible. The inventor is now recognized as the "Father of Arc Lighting."

The regulator devised by Brush consisted in creating a variable by-pass, or shunt, to the field winding. A doubly wound solenoid was arranged, so that the movement of its core, acting through a lever, would vary the pressure on a column of carbon plates; the greater the pressure, the lower their resistance, and more of the current would pass through them instead of flowing through the field windings. The main current, which it was desired to keep constant, passed through one of the windings of the solenoid, and the field current passed through the other. A slight variation in the main current would thereby be reinforced by the considerable change in the field current to assist in the necessary action. The regulator was adjusted for any desired value of the current by assisting or opposing the pull of the solenoid by an adjustable spiral spring. Between half and full load the regulator acted very well, but on very light loads, the solenoid, though checked by a glycerine dash pot, made altogether too erratic movements, and allowed the current to surge through extreme ranges. The reason lies in the qualities of the iron of the field for holding "residual" magnetism; taking away a desired portion of the exciting current does not necessarily take away the magnetism, and increasing the current a little does not at once increase the magnetism. When considerable change of current is made, the magnetism does alter, but by altogether too much in value. By use of wrought-iron cores and laminated pole pieces in the latest machines, this tardy and extreme action is considerably lessened.

Within a few years after making the first dynamos Brush replaced the solid armature cores with laminated ones. Their higher permeability allowed a greater magnetic flux, and their cooler running and greater tensile strength permitted higher speeds, so that the 16-light size became of 25, and the 40-light of 65 lights capacity. "Half-arc" machines for $6\frac{1}{2}$ amperes instead of 10 were constructed, the machines being wound with more turns of finer wire, and would light 40 and 85 lamps respectively. An idea of the winding of the armature of the 40-light $6\frac{1}{2}$ -ampere is given by stating that each of the eight coils consists of 48 turns per layer and 22 layers of No. 15 wire, weighing about 15 pounds.

The Thomson-Houston dynamo is of peculiar construction. Its armature is spherical, and when the drum type was used was certainly difficult to wind; the field magnet is prodigal of wire, and access to the armature is awkward. With two field poles, the three commutator segments and four brushes, the machine stands unique among dynamos. Its one qualification is that it works marvelously well under all changes of load; the full number of lamps can be turned on and all but one suddenly turned off, and that one will "shine on" with almost imperceptible change. Even on a short circuit the current will not rise to a ruinous value. The regulator is perfect. It consists in automatically moving the brushes to such positions as enable just the right potential to be available; the full current always flows around the field, a feature unduly wasteful at light loads, but keeping the iron saturated. By arranging the main brushes to be capable of considerable movement, and the second set—in multiple with the other—to have a coincident movement about one-third as far in the opposite direction, Prof. Thomson was able to add the electromotive of two coils together to get a maximum, or to oppose them to each other to get a minimum, intermediate values being obtained by intervening positions of brushes. A surprisingly small movement is all that is needed to compensate for ordinary changes in the circuit. With only one commutator and that consisting of but three segments, there was sure to be considerable sparking, but the 3- and 6-light machines were able to withstand it. Beginning with the 12-light size, the current would flash around the commutator in preference to lighting the lamps. The inventor proceeded heroically to blow out the sparks, and the centrifugal blower mounted on the shaft just back of the commutator became at once a distinctive and necessary adjunct; it was highly effective even in the 50- and 65-light sizes of machines, but not reliable for potentials much over 3,000 volts. Most of the noise attending the operation of these dynamos comes from the angry snapping or rupturing of these incipient arcs. Movement of the brushes to follow the demands of the circuit is furnished by a direct-acting electromagnet mounted on one corner of the machine.

A view of the standard 50-light size of the Thomson-Houston dynamo is given in Fig. 12. The field cores are hollow in order to concentrate the magnetism in the remaining portion; polar faces are cup-shaped so as to act properly on the spherical armature. Levers for actuating the brushes are readily recognized, the electrical connection between two brushes being main-

Fig. 14.—Thomson-Houston Connections for Dynamo, Regulator and Lamps.

effective, for the 50 volts required for one lamp might not be sufficient to enable the dynamo to start at all, and the several thousand volts acting at full load might burn out the winding. With the added expense of the fine wire for such coils, and the danger of rupture of the insulation, there is now no likelihood of considering other than the eminently satisfactory series winding.

motive forces for the merest instant only; before and after that instant, they are by no means equal, and one coil becomes a short circuit for the other; the high self-induction of the coils, however, prevented the fault from doing harm, and the connection gave momentarily the benefit of a reduced armature resistance. When, later, Brush tried the same device on low-potential machines with negligible self-induction,

trained by tubular sliding contacts; the two blower nozzles are seen at top and bottom of commutator just ahead of the secondary set of brushes. A view of the ring armature adopted in 1888 is given in Fig. 13. The narrow units into which the winding is divided are to enable the individual coils to be wound in forms and slipped in place on the core through a narrow crevice. This opening is finally filled and locked with a T-shaped laminated wedge. The original drum armature could be wound by experts only; the ring had the qualifications of higher self-induction and better insulation, and could be repaired or entirely rewound by any clever station attendant. The scheme of connecting the coils imitates Brush's armature; five coils in one group are connected in series with each other and then in series with the opposite group; one of the final terminals is led to the hoop on the wooden ring in the front of the figure and the other end to a commutator segment; two other groups are similarly formed and symmetrically connected to hoop and segments.

Fig. 14 shows a diagram of connections of dynamo, regulator, controller and lamp circuit. Before starting, the armature is normally short-circuited by means of the small switch just above the commutator. If revolving, the armature generates some current, for

the residual magnetism of the field may be considerable. The regulator arm is then lifted to the highest point, that of minimum potential; then the switch is opened. The small current that was flowing in the highly inductive armature continues to flow, but is compelled to traverse the entire circuit; the field is excited, the lamps start, and brushes fall to the position to fit the demands. Two paths are observed as possible from the left-hand side of dynamo to the "controller" that may be located conveniently near the machine; one of these paths includes the regulator magnet; the other does not. A solenoid is included in the main circuit; a current above normal lifts the core, breaking the short path from the dynamo, and compelling the current to traverse the regulator magnet. The brushes are thereby lifted to a position of lower voltage and consequently less current; when below normal current, the solenoid will drop its cores, and short-circuit the regulator; by force of gravity the heavy armature of the regulator will then fall and move the brushes to a position of higher potential. A dash-pot prevents too sudden or wide movements. The attempt is not made to hold the current at an absolutely constant value, but to admit the inevitable, and confine the variations to narrow limits. A variation of half an ampere really suffices to operate

the controller, while the actual power to move the brushes comes from the energetic electromagnet. The simplicity, reliability and "fool-proof" qualities of the Thomson-Houston regulator accounted for its commercial popularity over the more "finicky," though more economical Brush construction. Added to the inherent good working qualities of the machines the aggressive activity of the company's management, and some reason for the phenomenal success of the "T-H" system is accounted for.

Arc dynamos with closed coil ring armatures are made by some firms; the commutators are more expensive in first cost and suffer more from the sparking and burning than the other sort. In case of accidental rupture of the circuit, the flash that results is more dangerous to the winding than the simple "spilling" over the commutator experienced with the open coil winding. In ordinary running, such small differences exist between the two types that it is easy to find those who champion each with equal zeal.

In modern central stations it is common to find arc dynamos driven by electric motors; the appearance of some such "units" along with explanations of the switching and accessory devices will be given in later articles; the next one will be on "Arc Lamps." (To be continued.)

THE ECONOMICAL UTILIZATION OF LABOR.*

CONSIDERATIONS GOVERNING EFFICIENCY.

BY HENRY L. GANTT.

Those who have given even superficial study to the subject of labor are beginning to realize the enormous gain that can be made in the efficiency of workmen if they are properly directed and provided with proper appliances. Few, however, have realized another fact of equal importance, namely, that to maintain permanently this increase of efficiency the workman must be allowed a portion of the benefit derived from it. To successfully obtain a high degree of efficiency, however, the same careful scientific analysis and investigation must be applied to every labor detail as the chemist or biologist applies to his work. Wherever this has been done, it has been found possible to reduce expenses and at the same time to increase wages, producing a condition satisfactory to both employer and employee.

Wherever any attempt is made to do work economically the compensation of the workman is based more or less accurately on the efficiency of his labor. Very fair success in doing this has been accomplished in day work by keeping an exact record of the work done each day by every man and by fixing his compensation accordingly. This method, however, falls very far short of the highest efficiency, for very few workmen know the best way of doing a piece of work, and scarcely any have the ability to investigate different methods and select the best. It often happens, then, that a man working as hard as he can falls very far short of what may be done, on account of employing inferior methods, inferior tools, or both.

We can never be certain that we have devised the best and most efficient method of doing a piece of work until we have subjected our methods to the criticism of a complete scientific investigation. Many people who have been accustomed to seeing an operation performed in a certain way, or even to performing it in that way for a number of years, imagine they know all about it, and resent the intimation that there may be some better way of doing it. Anybody, however, who carefully analyzes the sources of his methods will find that the mass of them are either inherited, so to speak, from his predecessor, or copied from his contemporaries. He will find that he knows but little of their real origin, and consequently has no ground on which to base an opinion as to their efficiency.

Even such a simple operation as shoveling is done very uneconomically in many places. The writer has seen the same shovel used for coal, ashes, and shavings, and this when coke forks were available for the shavings. The foreman had apparently given the subject no study and was content if the men were at work. The idea of working efficiently had never occurred to him. This is, of course, an extreme case, but it is a real one, and all degrees of efficiency exist between this and the case where each workman is provided with the proper implement and given a specific task, for the accomplishment of which he is awarded extra compensation.

Having determined thus the amount of work that a man can do, we can usually get it done if we offer the proper wages for doing it, and furnish an instructor who will teach the workman how to do it. In order to get the best results the following four conditions are necessary: First, complete and exact knowledge of the best way of doing the work, proper appliances

and materials. Second, an instructor competent and willing to teach the workman how to make use of this information. Third, wages for efficient work high enough to make a competent man feel that they are worth striving for. Fourth, a distinct loss in wages in case a certain degree of efficiency is not maintained. These four conditions for efficient work were first enunciated by Mr. Fred W. Taylor, and when they are understood their truth seems almost axiomatic. They are worthy of very careful consideration.

Let us study these steps one at a time. The first is a scientific investigation of how to do the work and how long it should take. The fact that any operation, no matter how complicated, can be resolved into a series of simple operations, is the key to the solution of many problems. Study leads us to the conclusion that complicated operations are always composed of a number of simple operations, and that the number of elementary operations is often smaller than the number of complicated operations of which they form the parts. The logical method, therefore, of studying a complicated operation is to study the simple operations of which it is composed, a thorough knowledge of which will always throw a great deal of light on the complex operation. Also the time needed for performing any complex operation depends upon the time of performing the simple operations of which it is composed. The natural method, then, of studying a complex operation is to study its component elementary operations. Such an investigation divides itself into three parts, as follows: An analysis of the operation into its elements; a study of these elements separately; a synthesis or putting together the results of our study.

This is recognized at once as simply the ordinary scientific method of procedure when it is desired to make any kind of an investigation, and it is well known that until this method was adopted science made practically no progress. If it is desired to obtain the correct solution of any problem, we must follow the well-beaten paths of scientific investigation, which alone have led to reliable results. The ordinary man, whether mechanic or laborer, if left to himself, seldom performs any operation in the manner most economical, either of time or labor; and it has been conclusively proven that even on ordinary day work a decided advantage can be gained by giving men instructions as to how to perform the work they are set to do. When these instructions are the result of scientific investigation, the gain in efficiency is usually beyond our highest expectations.

It is well known that nearly every operation can be, and in actual work is, performed in a number of different ways; and it is self-evident that all of these ways are not equally efficient. As a rule, some of the methods employed are so obviously inefficient that they may be discarded at once, but it is often a problem of considerable difficulty to find out the very best method. It is only by a scientific investigation that we can hope even to approximate the best solution of any problem.

To analyze every job and make out instructions as to how to perform each of the elementary operations requires a great deal of knowledge, much of which is very difficult to acquire; but the results obtained by this method of working are so great that the expenditure to acquire the knowledge is comparatively insignificant.

It has been demonstrated that whether the labor is that of a Pennsylvania Dutch workman in a machine shop, a Hungarian laborer handling stock in the yard of a steel works, or a skilled cloth handler in a bleachery, the amount of work the average workman does under the ordinary conditions is only about one-third of what can be done by a proper workman under the best conditions. In other words, when a man sets his own task, as he virtually does in ordinary day work, he usually does about one-third of what a good man fitted for the work can do under the best conditions.

As a result of our first step or our scientific investigation, we find, in general, that it is possible to do about three times as much as is being done; the next problem is how to get it done. First, I wish to say that no matter how thoroughly convinced we may be of the proper method of doing a piece of work and of the time it should take, we cannot make a man do it unless he is convinced that in the long run it will be to his advantage. In other words, we must go about the work in such a manner that the workman will have confidence in us and feel that the compensation offered will be permanent. When we have established this condition of affairs we are ready to start a workman on the task, which, when properly set after an investigation, is such as can be done only by a skilled workman working at his best normal speed.

The average workman will seldom be able at first to do more than two-thirds of the task, and, as a rule, not more than one out of five will be able to perform the task at first. By constant effort, however, the best workmen soon become efficient, and even the slower ones often learn to perform tasks which for months seemed entirely beyond them.

Buying labor is one of the most important operations in modern manufacturing, yet it is one that is given the least amount of study. Most shops have expert financiers, expert designers, expert salesmen, and expert purchasing agents for everything except labor. The buying of labor is usually left to people whose special work is something else, with the result that it is usually done in a manner that is very unsatisfactory to buyer and seller. It is admitted to be the hardest problem we have to face in manufacturing to-day, and yet it is considered only when the manager "has time" or "has to take time," or on account of "labor trouble." The time to study this subject is not when labor trouble is brewing, but when things are running smoothly and employer and employee have confidence in each other.

Men as a whole (not mechanics only) prefer to sell their time rather than their labor, and to perform in that time the amount of labor they consider proper for the pay received. In other words, they prefer to work by the day and be themselves the judges of the amount of work they shall do in that day, thus fixing absolutely the price of labor without regard to the wishes of the employer who pays the bill. While men prefer, as a rule, to sell their time and themselves determine the amount of work they will do in that time, a very large number of them are willing to do any reasonable amount of work the employer may specify in that time, provided only they are shown how it can be done and paid substantial additional amounts of money for doing it. The additional amount needed to make men do as much work as they can depends upon how hard or disagreeable the work is, and varies from 20 to 100 per cent of their day rate.

* Abstracted from a lecture before the senior class of Stevens Institute of Technology.