

SYMPOSIUM ON ELECTRIC DRIVING IN MACHINE SHOPS

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ECONOMY OF THE ELECTRIC DRIVE IN THE MACHINE SHOP

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It is proposed to show in this paper the most salient points which affect the economy of the electric drive in the shop, and also, in a general way, the proper relation between the motor and the driven machine.

2 When the electric motor was first used in the shop, practically no other claim was made for it than that it saved power by obviating the losses in line and countershafts. Exaggerated statements were made of savings to be effected; and though it was proved later that many of these claims should be divided by a large factor, and that some should even be provided with the negative sign, these statements did a great deal of good by calling attention to the fact that great losses existed.

3 The writer knows of no way to determine the exact amount of these losses, but wishes to call attention to the fact that a method which has been employed quite frequently is entirely misleading. The method referred to is, to measure electrically or by indicator card the amount of power required to run all or a part of a shop with and without machine load. The difference between the two readings is supposed to be the loss. That this is wrong becomes obvious as soon as one considers that the frictional load of every bearing changes with the amount of the load, and that the belt pull sets up bending and torsional strains in long lengths of shafting, which may cause losses much greater than the losses by journal friction.

4 The method of taking separate measurements of the work done by each machine individually, and totaling the result, is also

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wrong, as all machines do not require the maximum amount of power at the same time. To multiply the total by some fractional coefficient is merely a refined way of guessing. Statements have from time to time appeared, as to the amount of saving effected by the substitution of motor drives for lineshaft drives, but never with the positive statement that at the same time other changes were not made which might have some effect on the situation. This absence of reliable data is apparent all over the field of this subject, and it will therefore be impossible to say beforehand with any fair degree of certainty how much, if anything, can be gained by the conversion of a shop from shaft to motor drive. It will be possible, however, to indicate points which should be kept in mind, and which are the controlling factors.

5 Economy is the art of obtaining the greatest output with the smallest outlay. To strike a balance between these two elements, outlay and output, is the work of the industrial engineer. In a great many cases, perhaps in the majority, there are not sufficient data to enable him to do this; his work then becomes hazardous and is on a level with that of the prospector. Many reputations are based on a stroke of luck and many have been lost by a single wrong guess. On the other hand, many hundreds of thousands, or more likely, millions of dollars have been lost to shop owners by listening to the lure of the enthusiastic engineer with more faith than data.

POINTS TO BE CONSIDERED

6 In considering the economical features, when converting a shop from shaft to motor drive, the following points should be kept in mind:

- a* The nature of the shop.
- b* The possible economies which may be effected by the installation of electric drive.
- c* The first cost of such an installation.
- d* The cost of its upkeep.
- e* The cost per unit of power.

Though these are the main points to be considered in a preliminary investigation, they are by no means the only ones. They are specially mentioned here because their contemplation will naturally lead to the consideration of other points as well.

7 As the electric drive for the machine shop alone will be considered here, it may seem that the nature of the shop might have been

left out of consideration. In the great majority of cases, however, a machine shop is of a dual nature. A foundry or blacksmith shop, or perhaps a plating shop is connected with the establishment; or warehouse and yard service may form a considerable portion of the operations. The yard service of a plant may be of an elaborate nature, while the machining operations are of a simple nature. It may be that the machine-shop operations cannot be improved enough by the change to electric drive to warrant its installation, yet the gains to be made by converting yard cranes and other similar apparatus to electrically-driven apparatus may be so great as to make it advisable to change the mode of driving of the entire plant.

8 As to the possible economies which may be effected by a change of drive, this involves so many considerations that nothing but an exhaustive study of the entire plant in all its aspects will clearly show what may be accomplished. Though at one time the only economy considered was the saving of power, it is now well recognized that this is by no means the only or the most important economy resulting from a conversion to electric drive, and that such a conversion may even be highly economical, though there be an actual loss in power consumed.

9 To illustrate: practically all of the work done in a machine shop, or which power is used, is the removal of chips. The writer has in mind a shop where an average of 9 tons of metal is daily fed through the shop, to be made up into high-grade machinery. This metal is for the greater part cast iron, with a minority of steel and a small percentage of bronze and other metals, just as in most machine shops. The total of chips removed amounts to less than 15 per cent or 2700 lb. of metal in a nine-hour day, making 300 lb. per hr., or 5 lb. per min. This shop uses an average of 225 h.p., which is 45 h.p. per min. for each pound of chips removed. Figuring that all the chips are steel, this would mean that the shop requires about 12 h.p. per cu. in. of steel removed. It should be noted that this shop is to a large extent electrically driven, and otherwise as well or better equipped than the majority of machine shops. The power costs about \$40 per h.p. per year, or a total of \$9000, which includes steam for heating, however.

10 Figuring that all of this amount is spent for power, and that half of it could be saved by some other mode of driving, then the total possible gain would be \$4500 per year. This shop employs about five hundred men, so that the gain would be \$9 per man per year. An establishment of this kind and size delivers a product of

about \$2000 per man per year. If the installation of a new mode of driving could increase this output only 5 per cent, then the gain per man per year would be \$40, or more than four times the gain which can be made by cutting the power consumption in two. Obviously then, the problem is to increase the amount of chips made in a given shop, and not to diminish the amount of horsepower for a given amount of chips. This phase of the subject will be treated more extensively later.

11 As to the first cost of installation, though it may be beyond doubt that a change in the mode of driving might effect economies, yet it remains to be shown that these economies will give a good return on the investment, and further, that this same investment could not be used in another direction to better advantage. What is true when a shop is to be converted from one drive to another, is also true when a new plant is to be built. Directors of industrial undertakings have frequently been criticised for apparent lack of progress, when a close analysis might have shown other more crying needs for the investment of the capital at command. Though the shop of an industrial undertaking may be the only place where its product is made, it may not be the only place where its money is made. And even should the shop be beyond doubt the best place to invest the money on hand, it remains to be shown that the proposed change of drive will bring better returns than improvements along other lines. This question will also be dealt with later.

12 The probable cost of upkeep must also be thoroughly investigated, especially as it is likely to be under-estimated unless one goes fully into details. In considering the probable economies, this cost of upkeep has to be estimated and deducted from the gross gains; but the same item appears again in the form of disturbance of operation, when it is much harder to estimate it. This must be done as well as possible, however, before reaching a final conclusion. These disturbances make themselves felt, especially the first few years after making the change.

13 It is further true that radical changes are usually made at a time when there is a heavy demand on the shop, either because it is thought that the output can be increased by the contemplated changes, or because the size of the power plant has not kept step with the growth of the rest of the plant, or because at such times of business prosperity, money can be easily obtained for such changes. Whatever the reasons, the fact has been fairly well established; and a change at such a time must be doubly hazardous, not only

because it may fail to accomplish the desired increase of output, but because it may actually prove to be a source of disturbance, and reduce the output instead of increasing it.

14 The cost per unit of power should enter into the preliminary considerations, as it will determine to a large extent the kind of current to be used, and this may have a decided effect on the final economy of the system as applied to the shop. Attention will again be directed to the foregoing items later in the paper.

SAVINGS EFFECTED BY ELECTRIC DRIVE—INCREASED OUTPUT

15 The savings effected by driving the shop electrically may be classed under two heads: increased output and less expense. Whether savings can be effected by increasing the output depends on so many and such varied items that it seems best to show them first in an elementary way, by considering a single machine under a set of assumed conditions.

16 Let us take for example a 12-ft. boring and turning mill, used in a shop devoted to the manufacture of a single line of product and having enough machines of each kind to allow each machine to be devoted to a very limited line of operations. Suppose the machine under consideration to do nothing but turn up large rings, ranging in diameter from 12 ft. to 8 ft.; and further, that a great number of rings of each size are to be turned up in each lot, so that the amount of time lost in setting the machine for the different kinds of work becomes negligible. Let it be further supposed that the machine is provided with a number of speeds in geometrical progression, with steps of 25 per cent, and that there is one speed which happens to correspond to the proper speed for the material used and for a diameter of 12 ft. This is supposing a set of conditions as good as can be expected in the ordinary commercial machine.

17 Under these conditions, the low speed must be used for all rings from 12 ft. down to 9.6 ft., and the next higher speed for all rings ranging from 9.6 ft. down to 8 ft. Supposing that the number of all rings of the same size is the same, it follows that the machine runs $\frac{6}{10}$ of the year on the lower speed, and $\frac{4}{10}$ of the year on the higher one. Allowing $\frac{1}{4}$ of the total time for chucking work, removing it, changing tools, etc., there remains $\frac{3}{4}$ of the year spent in removing chips. The machine removes chips, therefore, at the lower speed during $\frac{9}{20}$ ($\frac{6}{10}$ of $\frac{3}{4}$) of the year, and $\frac{6}{20}$ ($\frac{4}{10}$ of $\frac{3}{4}$) of the year at the higher speed. This higher speed might be called 12, and the

lower speed 9.6. A measure for the amount of chips removed, and, therefore, for the number of pieces turned up, would then be the amount of time multiplied by the linear speed of the tool. This is not exactly correct, but near enough for a mere illustration.

18 So far, however, an expression has been found only for the number of revolutions of the machine. In order to reduce this to linear speed, we must consider the fact that the higher speed is the proper speed for a diameter of 9.6 ft., and the lower speed for a diameter of 12 ft. If the machine were to run all the time at the speed corresponding to the diameter to be turned up, the total output for the year could be expressed by the time the machine is actually removing chips, which is $\frac{3}{4}$.

19 When running at the lower speed, however, the machine has the proper speed only when the diameter to be turned up is exactly 12 ft. At all other diameters, the speed is too low. The effect is the same as if the machine were running all the time at the lower speed, and all the work were of a diameter of the mean between 12 and 9.6, or 10.8. Therefore, when running on the low speed, the output runs down from $\frac{9}{20}$ to $\frac{8.1}{20}$. Similarly, the output of the machine, when running at the higher speed, has been reduced from $\frac{6}{20}$ to $\frac{5.6}{20}$, and the total from $\frac{3}{4}$ to $\frac{13.6}{20}$, or a reduction of nearly 10 per cent. Now if this machine were driven by a variable-speed motor, it would be possible to find a proper speed for every size of ring to be turned up, and the production might be increased from 136 to 150, or a gain of nearly 11 per cent.

20 Merely to say that there is a gain in production of 11 per cent is perhaps sufficient to prove that under certain conditions a change from belt to motor drive may be profitable, but it is in no way a measure of the amount of profit. If, for instance, the machine is capable of taking care of all the work in the shop, then the only gain is in the wages of the operator; if, on the other hand, there is more work than the machine can take care of, then the increased production of the machine may mean a corresponding increase in the production of the entire shop, improved deliveries, and the avoidance of a great deal of confusion, of which the money value may be many times greater than the mere saving in wages.

21 In the foregoing example, the advantage gained is entirely due to the fact that a variable-speed motor was attached to the machine. This is by no means, however, the only reason why the change to electric drive may increase the efficiency of a machine. The electric drive may enable one to place the machine in a more

convenient position, or bring it under a crane; or it may be the means of giving the machine more power than it could have with a belt drive; or again, it may be the means of doing away with some harmful conditions which have diminished the machine's efficiency. Among such circumstances may be mentioned the variation in length of belts due to weather conditions, or to varying loads on an upper floor, making the belts from pulleys attached to the under-side of this floor either too loose, having been adjusted at a time when the load on the upper floor was light; or too tight, owing to adjustment at a time when the load on the upper floor was heavy. Then there is the convenience of altering speed if a machine has a motor or a convenient gear drive, when the operator might forget that there is such a thing as a change of speed for varying conditions of work, if he had to shift a belt. An almost unlimited number of considerations affect the result to be obtained from the application of a motor to a machine tool; so that it is almost impossible to forecast the economy which will result from such a change, though it may be perfectly possible to say that the change will be beneficial to some extent.

22 The fact that the change from one style of drive to another is practically always accompanied by some other changes, either in addition to, or as a result of the change of drive, makes it impossible to show by data how much gain is the result of this change. Under very definite conditions, such as were supposed in the example given, it may be possible to calculate these gains beforehand, and even to verify the calculations by the actual results, but in the vast majority of cases neither calculation nor verification is possible. For this reason, this paper is confined to pointing out in which respects and under which conditions profits may be expected. Such profits will appear either in increased output or in the curtailing of expenses.

23 We will now consider more in detail the economic advantages mentioned in the foregoing paragraphs. Fig. 1 shows the main points in which an increase in output may be expected from the substitution of electric drive for shaft drive. The electric drive will show its effect on individual machines (provided they are individually motor-driven), on the handling of the work in the shop, on the light and cleanliness of the place, on the possibility of making changes in the arrangement of the shop when needed, and last, but not least, on the individual effort of the operator.

EFFECTS OF ELECTRIC DRIVE ON INDIVIDUAL MACHINES

24 *More power.* The greater output of individually motor-driven machine tools is due to a number of items, shown in the diagram. The first item, more power, is especially prominent in heavy tools. The power of cone-driven machines is limited by the belt speed, and by the width possible, considering that the belt has to be shifted. It might be said that a single-pulley drive has no such limitations;

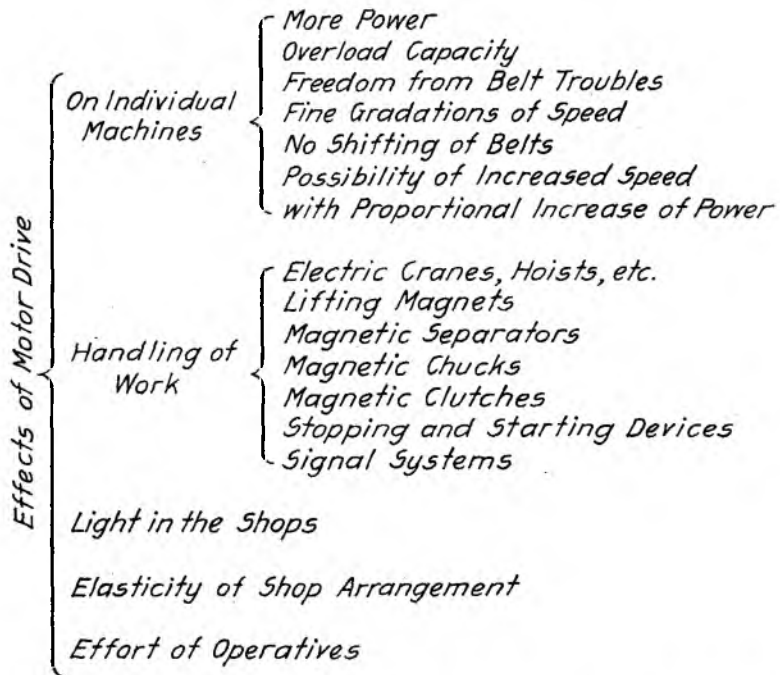


FIG. 1 DIAGRAM SHOWING THE ADVANTAGES OF ELECTRIC DRIVE

but on the other hand the single-pulley drive does not lend itself to fine gradations of speed, especially in heavy machinery. Further, such a drive would take up a great deal of space, would be very costly, and would be extremely awkward to handle, unless auxiliary mechanism were provided to do the shifting of the heavy gears, which is a further source of expense. The electric drive, on the other hand, would allow of a motor with a certain amount of variation of speed, which, combined with a few gears, would give all the variation

obtainable with the cone pulley, and by much finer gradations. This is so well recognized at the present time, that very few heavy machines are built to order with a cone drive.

25 High-speed steels made an increase of power imperative for some of the heavy machines, and for some of the lighter ones as well. In a number of cases, it was found that the frame of the machine, as well as most of its mechanism, was strong enough to stand this increase of power, but that it was practically impossible to substitute larger cone pulleys without rebuilding the entire machine; in all such cases, the electric motor has proved to be the solution of the problem.

26 *Overload capacity.* The electric motor not only makes it possible to give more power to the machine, but it gives it a reserve capacity that a belt-driven machine cannot have. For instance, a casting has to be turned up: it has a swelling where the seam of the parting is, and the amount of metal at this one point is too much for a single cut; the machine stalls. If the machine were motor-driven the overload capacity of the motor would carry the cut past this point, without harming the motor. In other words, a motor acts on a machine tool somewhat as a flywheel acts on an engine. Before electric drives were known, the power of the machine tool was almost always its weak point; after electric motors were applied to existing machines, it was the frame of the machine which had to be treated with consideration.

27 *Freedom from belt troubles.* The elimination of belt troubles is one of the strongest points in favor of the electric drive. During an investigation of a large Western railroad shop by the writer, this point was shown with exceptional clearness. Practically all machine operators "nursed" their jobs because they had to wait too long for the chief millwright, who thought he was the only man capable of putting on or correcting a belt in the proper manner. Out of consideration for the machine tools, this man would put on belts from $\frac{1}{2}$ in. to 1 in. too narrow. The combination of these two pieces of foolishness reduced the output of the belt-driven machines fully 50 per cent where heavy cuts had to be taken, and reduced the output of the entire machine department at least 10 per cent. It might be said that the management should have corrected this evil, and so it did, but only after the evil had existed for a great many years. Conditions such as these are the outcome of growth, and are generally not found out until the shop becomes too small for the work to be done and the management begins to cast around for means to increase the output.

28 **Belt troubles** are caused by so many conditions that a shop is rarely free from them. It was observed at the shops of a machine-tool concern in the Middle West, that the output of their milling machines was increased 25 per cent by driving them by electric motors, though no further changes were made. This instance deserves attention, because while some of the machines were changed to electric drive, other similar machines were left with belt drive, and there is a clear chance for comparison. The main reason for the increased output was supposed to be the avoidance of belt trouble. These milling machines were located on the first floor. The second floor was also used for a machine shop, and was at times heavily loaded with finished and unfinished stock; this variation in loading causing a variation in the deflection of the upper floor that made it necessary to keep the belt very slack, for fear it might be too tight when the upper floor was not loaded. Weather conditions have a similar effect; especially where there are rapid changes in humidity. The effect is to lower the capacity of the machine by a large percentage.

29 *Fine gradations of speed.* Another reason for the greater economy of motor-driven machines is that finer gradations are obtainable with a motor drive. Of course, this benefit is derived only from a variable-speed motor. When attention was called to this feature earlier in the paper, nothing was taken into consideration except the fact that it would be possible with the variable-speed motor to obtain a speed in accordance with the material to be cut, and with the diameter of the work or of the cutter. However, there is more than this to be considered. A lot of castings are seldom or never of uniform hardness. This being the case, it is quite natural for the operator to set his machine for the hardest piece in the lot, and it may well happen that he strikes the hardest piece first. Where he has simple means for varying his speed, he will be governed entirely by the hardness of the piece on which he is doing work.

30 *No shifting of belts.* The fact that no belts have to be shifted is another cause of increased efficiency. The machine operator who shifts belts for pleasure has yet to be found. Besides, where the ceiling is high, it is not easily possible to shift a belt without the aid of a long stick; and this stick is generally somewhere else. The amount of time lost in hunting for the stick, and in the operation of shifting the belt, may be quite considerable in itself, especially in shops where small lots are the rule and where it does not pay to perform only one operation at a time, so that a single piece must

receive all the operations of a certain machine before it is taken out of it.

31 But worse than the loss of time in shifting belts is the fact that this shifting is generally entirely neglected, and all the various operations are carried on at the speed of the slowest. There are cases where the gain due to this feature of the motor drive may be negligible and there are other cases where this gain may be a large percentage.

32 *Increase in power with increase in speed.* Another point in favor of the motor drive, is the fact that it is possible to speed up a machine with a proportional increase in its power. This problem appears whenever a change is made from carbon to high-speed steels; and though most shops at the present time are provided with high-speed cutting tools, this is by no means true to such an extent that this point may be overlooked. There are few, if any shops where some operations are not done with carbon-steel tools, sometimes because high-speed steel has been overlooked, but more often because no benefits would be derived from it, as the machine could not be run at a higher speed without cutting down the depth of cut or feed. In some cases, this can be corrected by putting a larger pulley on the lineshaft; but in the majority of cases which have come to the attention of the writer, this could not be done without more elaborate changes.

33 Generally speaking, it is a small thing to increase the speed of a motor-driven tool without cutting down its torque. Not long ago a number of cases came to the attention of the writer, which put this matter to him in a very clear light. Some boring machines, used for boring holes out of the solid in steel bars, and using twist drills for this purpose, were supplied with high-speed drills; but it was found that the feed could not be increased, as the machine was run to the limit of its capacity. It was further found impossible to shift the belt to a larger step of the cone, thus giving more torque, as it was not practical to increase the speed of the machine without making extensive changes in the arrangement of the lineshaft. A motor drive would have solved the problem and would have increased the feed from $\frac{3}{8}$ in. to $1\frac{1}{8}$ in. per minute. Such instances are by no means rare. It is this feature of the motor drive which makes it possible, in many cases, to get the full benefit of high-speed steels with old machines.

HANDLING OF THE WORK

34 *Electric cranes.* Electric current in a shop not only makes it possible to get more production from machines individually, but admits of a number of improvements in the handling of work. The electric traveling crane has become such a common aid in the shop that it is almost difficult to realize that it is only twenty years since it was new. It is also hard to realize that it is one of the possibilities of the electric drive. The effect of the electric crane on the economy of the shop cannot well be over-estimated; though it is difficult to express in figures the amount of this economy. So much can be said, that only a few shops are over-supplied with cranes, while in a great number more cranes could be placed to good advantage. The installation of electric cranes or hoists in a shop is somewhat similar to the installation of compressed air. It is generally difficult to estimate beforehand with certainty the amount of savings to be effected, or to realize the various uses to which the apparatus will be put, but once a compressor is installed its capacity is soon exceeded; similarly, the electric crane is soon overworked.

35 The proper choice and installation of electric cranes and hoists is a separate branch of industrial engineering, though not generally considered as such. The best effects can be had only when the apparatus is taken into consideration with the placing of the tools in the shop, and the laying out of the shop buildings. Instances where the exact amount of savings effected was known even after the new apparatus had been installed for some time, are also rare, though not quite to the same extent as data about machine tools. The installation of a yard crane in a flask yard reduced the number of laborers from nine men to two and the crane tender. The installation of a small electric hoist, on a small traveler worked by hand, increased the output of a milling machine, besides doing away with the help of a laborer. It should be remarked here that the weight of the piece to be milled was too much to be lifted by hand, and that the time used for the operation proper was small. Instances of this kind are not rare and have come under the observation of almost every engineer connected with industrial establishments.

36 *Lifting magnets.* In line with electric cranes are lifting magnets, which are to be considered as an adjunct to the crane. They can often be used to good advantage for lifting plates, for loading and unloading pig-iron and scrap, for hauling small castings in quantities,

and even larger castings, provided their shape and the distribution of metal makes them adapted to this mode of handling, for lifting drop weights, and for a number of other purposes. Though no instances are at hand, it seems to the writer that a small lifting magnet could be used to good advantage for collecting chips at the various machine tools in a shop.

37 *Magnetic separators.* Magnetic separators, though more commonly used in the foundry, are used also in the machine shop for the complete separation of the chips of various metals. However, they seem to be more of a luxury than of a necessity.

38 *Magnetic chucks.* This cannot be said of magnetic chucks, which make it possible to do quickly, conveniently and accurately a great many jobs which would be very difficult, if not impossible, without this piece of apparatus. Magnetic chucks are of special merit in combination with small planers, shapers, milling machines, lathes and grinders. Their economical value may range from that of a mere aid to the operator, to the means of doing a job which could not otherwise be done at all. It is generally easy to estimate the savings to be effected, as the time for ordinary chucking methods is well known, and the time for chucking by means of the magnetic chuck is practically negligible; further, the amount of power used for the chucks does not need to be taken into consideration. They have their limitations and are not adapted to all or even to a great number of operations; but where they are applicable at all, they are of great value.

39 *Magnetic clutches.* Magnetic clutches seemed at one time destined to play a great part in shop economy. So far, however, they have been a disappointment. This seems to be partly due to inherent weaknesses of the magnetic clutch, but perhaps more to faulty construction, and especially to the fact that those who designed and developed the magnetic clutch did not quite clearly understand the requirements of the machine tools to which they were to be applied, and further, that those who had to apply the clutch to machine tools did not understand the peculiarities of a magnet. There never was the hearty coöperation that would make the magnetic clutch a success.

40 It would not be surprising to see the magnetic clutch come to the foreground once more and claim its own. There seems to be a field for this kind of apparatus in controlling mechanism of all kinds, as well as for braking the movement of a machine or a part thereof. Its peculiar value in this respect would be to give the

operator the means for controlling his machine by merely touching a button or turning a small switch. The magnetic brake is employed now, especially in cranes, indicating that there is nothing inherent in the magnetic clutch which makes it unfit for application.

41 Attention might be called here to the possibilities of the application of the magnet in its various forms to operations in the shop, and to the performance of certain functions in a machine tool. Magnets now are employed for holding small portable tools in position, and might be used for vises and other handling devices. Further attention should be called to the possibility of using the motor itself as a brake, by short circuiting the armature on a given amount of resistance.

42 *Stopping and starting devices.* In the previous paragraphs, mention was made of the possibility of applying the electric magnet for the purpose of controlling a machine. This might be called control from a distance, though, in the applications hinted at, the distance would be very small in most cases. There is no reason, however, why this distance could not be increased at will. As a matter of fact, a number of installations are in existence where electric devices (though not necessarily electro-magnets) are in use for this very purpose. They will be found especially in rolling mills, and other plants where given amounts of material have to be handled continuously. These devices enable the engineer to minimize manual labor, besides making the plant safer and the action more continuous.

43 *Electric signals.* Electric signal service in shops was well known before the electric drive was thought of, but it can be greatly improved where electric power is at hand, as lamps of different colors, placed in the shop, will transmit intelligence better and with less confusion than electric bells. The telephone would come under the head of electric signals, but it is not dependent on the use of current in the shop.

OTHER BENEFITS FROM ELECTRIC DRIVE

44 *Lighting.* One of the greatest blessings of the electric current in the shop is electric lighting. This is so generally acknowledged, and so universally employed, however, that it would be a waste of space to go further into this matter here.

45 *Elasticity of shop arrangement.* Another great benefit of the electric drive is elasticity of arrangement. Growing establishments

have had to be satisfied with arrangements of machinery which had no other point in their favor than that they were the only possible ones. It was often necessary to place departments where they should not be, simply because it was not possible to drive the machinery in them if they were placed elsewhere. The electric drive makes it possible to change the arrangement of the machinery, and the relative location and size of the different departments, according to the changing needs of the shop. This principle of changing the shop according to the work to be done, is carried to its logical limit in the system of floor plates and portable tools.

46 Besides making alterations in an existing arrangement possible, the electric drive also allows departments to be placed far enough from each other so that each may be extended separately, without interfering with the other departments. This was generally not possible with belt drive, as the distances became entirely too large. It was generally found necessary for large plants to have a multiplicity of engines. A number of the best known modern shops are witnesses to the advantage of electric drive in the matter of arranging buildings and departments. It is hardly necessary to mention that the established ideas in regard to shop arrangement had to be largely revised and that there is even now considerable uncertainty as to what is the best possible arrangement, but it is safe to say that there is little divergence of opinion as to what kind of drive will give the greatest possible elasticity, if elasticity is required or deemed advisable.

47 *Effect on operatives.* It was mentioned before that the variable-speed motor, applied to a machine tool, induces the operator to experiment with the best possible speeds. There is, however, another way in which the electric drive affects the efforts of the men. It is nowadays well recognized that favorable conditions in regard to light, heat, sanitary conditions, etc., have their immediate effect on the output of the shop. These conditions cannot be ideal with a confusion of belts obstructing light and gathering and distributing dirt. Though in most electrically-driven shops belts are not entirely absent, they are so few that their evil effects are reduced to a minimum.

RELATION OF FIRST COST TO DECREASED EXPENSES

48 Whether savings are effected by lessening expenses depends on the nature of the old installation and that of the new one.

49 The writer was at one time connected with a large manufacturing plant, spread over a large tract of ground, which in its general layout and operations is fairly representative of a great number of existing manufacturing plants. It was at that time steam-driven, as the motor had not been sufficiently developed for a complete electrical drive to be considered. However, the management being progressive, partial conversion to electric drive was considered even at that time. The plant included two multiple-story buildings used as machine and erecting shops, a forging shop, a building used for some machine operations, for dropping malleable castings and for a warehouse, a wood-working shop and warehouse, another warehouse, and a malleable and a grey iron casting foundry. There were in all five engines driving these different shops, with the necessary transmissions from one building to another. In a few cases, quite elaborate systems of shafting were installed to drive a single piece of machinery; such, for instance, as the elevator in the warehouse. The engines ranged from 150 to 500 h.p. It was not possible at that time to determine accurately the aggregate of power consumed in that plant, but it was estimated that a single 1500-h.p. engine would carry the entire load. In the light of later developments, this amount now seems excessive, as a number of shops have since found that the amount of loss by friction in the transmission is greater than was estimated at that time, namely 30 per cent. The single engine could have been run condensing, as plenty of water was at hand. The several smaller engines did not pay, of course.

50 The following items would have decreased expenses, if this plant had been driven electrically:

- a* Lower first cost of engines.
- b* Lower first cost of boilers.
- c* Lower cost of piping.
- d* Lower cost of power houses.
- e* Lower cost of stacks.
- f* The omission of all transmission machinery.
- g* Greater economy of the engine in its steam consumption.
- h* Economy in oil and waste.
- i* Economy in repairs.
- j* Reduction in the number of engineers required.
- k* Reduction in the number of firemen required.
- l* Saving in the handling of coal and ashes.

m A probable more even load during the day, as the greater number of machines on a single engine has a tendency to equalize the load.

51 A number of these points are of value when a power plant is newly built, but are of no value where an established power plant is to be changed. To offset the above items the following must be considered:

- a* Greater first cost due to the generators.
- b* Greater first cost due to the wiring.
- c* Greater first cost due to the motors.

52 Besides, there are a great number of other factors to be considered. In this plant there were no duplicate engines, so that it would not be fair to figure in the first cost of the electrical installation of a reserve unit; though, of course, good present-day engineering would consider this an absolute necessity. It is true that where there are a number of engines, the breaking down of a single engine does not throw the entire plant out of action; but it is also true that in the plant under consideration the stoppage of a single department would soon have closed the entire plant. Considerations of this kind cannot be generalized, but must be taken up in detail in every specific case.

53 Another point to be kept in mind is, that copper wire largely takes the place of transmission machinery, and that such wire is an asset with practically no depreciation except that due to fluctuation in price (and this may be up as well as downward). On the contrary, transmission machinery should be considered as an expense, as in most cases it has no value except as scrap iron when no longer in use.

COST OF UPKEEP

54 Still another point, and one which should have most careful consideration, is the value of the time of the plant, and the relative chances of a breakdown. In some plants the process is continuous: that is, the product goes from one machine to another without interruption, and the breakdown of a single machine would cause the stoppage of the entire plant. In such cases the breakdown should be charged with the amount of the productive capacity of the entire plant during all of the time lost. In other plants the various machines balance each other only roughly and often there is a small

surplus of almost all kinds of machines in use, while some of the machinery is used only part of the time. Where these conditions prevail, the loss due to a breakdown of a single machine may be simply the cost of repairing the apparatus. In a majority of cases, neither of these two extremes is the true condition, and the engineer considering the kind of drive to be used must make some estimate of the loss due to a breakdown in any part of the installation. It should be kept in mind that the correctness of his estimate can never be established by positive proof; for, no matter which course he takes, it is impossible to say positively what would have been the result if he had pursued the other.

55 Though all of the points mentioned above affect the ultimate economy of the power installation, their relative importance changes with local conditions. For example, while the saving in the coal bill may be of the greatest importance where coal is high-priced and where the expenses for power are a large portion of the total expenses, this saving may be a vanishing quantity where coal is cheap, and where the expenses for power form but a small fraction of the total expenses of the plant.

56 While in the example cited there was a decided saving in the number of engineers required there may still have been a loss on this score, due to the fact that in some small plants a high-grade engineer must be employed for an electrical installation, whereas a combination engineer and fireman would be good enough for the engine-driven proposition. And so on all along the line: what is a saving in one case may be a loss in another.

COST OF UNIT POWER

57 In practically all cases which have come to the notice of the writer, the cost of power per unit has gone down after conversion to electric drive, but in no case was it possible to point out in what way the saving was effected, as in addition to the substitution of electric drive for shaft transmission there were always other changes which might affect the cost of the power. Such changes were, more efficient engines, better boilers, new auxiliary devices, etc. Also in all these cases, the amount of power required after the conversion was greater than before: this was not proof that the new installation was less effective than the old one, however, the probable cause in all these cases being that the output of the shop increased much more than the amount of power saved would have taken care of. It

is almost to be regretted that high-speed steels made their entrance into the shop almost simultaneously with the electric drive. Though both are good, they have obscured each other to such an extent that it is almost impossible to trace the effects of each item separately.

CHOICE OF THE ELECTRIC SYSTEM

58 If, after considering all these points in a general way, the engineer comes to the conclusion that the electric drive will decrease expenses, then the next step will be to select the nature of the drive. The diagram in Fig. 2 shows the main points to be considered.

59 Whether a central generating station or a multiplicity of smaller plants is preferable, depends again on local conditions. Certain conditions might make a number of generating plants preferable, as, for example, in a plant which consists mainly of a machine shop requiring considerable power, with a smaller wood-working shop located at a considerable distance from the rest of the plant. In this case, the outlay for copper to supply the wood-working shop with power would be considerable; whereas by placing an individual generating plant near the wood-working shop, the shavings might be used instead of coal.

60 Another case would be where a portion of the shop requires a great amount of power, but only for a short time each day, or perhaps at long intervals, thus necessitating a large outlay in generating machinery and copper. By separating this part of the plant, the outlay for copper is avoided and a cheaper class of generating machinery may be used.

61 The writer has in mind a plant devoted to the making of electric generators and motors. By far the greater part of its output is in

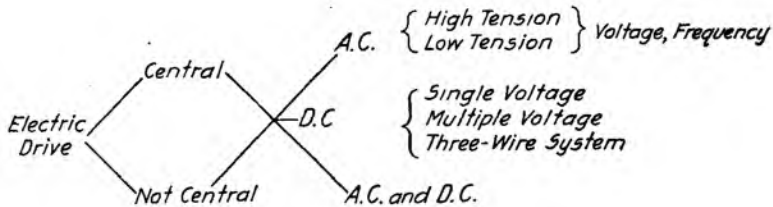


FIG. 2 DIAGRAM SHOWING THE DIVISIONS OF ELECTRIC DRIVE

smaller units, but a certain small percentage is in larger generating units. The power required for testing these large generators exceeds

all the power required for the operation of the entire plant. This plant gets its current from a central station near by, but the amount of copper required for the large testing currents would be more than the cost of installation of a cheap gas engine and generator. Here again the engineer must consider conditions as he finds them and must not be governed by general principles only.

ALTERNATING OR DIRECT CURRENT

62 The question whether alternating or direct current should be used is especially difficult of solution, and there is a wide difference of opinion among engineers as to which is best. It may be that too many engineers look at this proposition only from a power standpoint, without giving due attention to the output of the plant. Commercial reasons also have figured largely in the past, the representatives of companies manufacturing both kinds of apparatus naturally advocating the alternating variety, as by so doing they eliminated some competition. Now that more electrical companies manufacture alternating apparatus, this phase of the matter has almost entirely disappeared.

63 *Alternating current.* It may be said that, all other conditions being the same, alternating current offers an advantage when the distances over which the current must be transmitted are considerable. The fact that current can be generated at high voltage diminishes the amount of copper needed for transmission, but here again the problem is not simple. Attention must be paid to the expenses incurred in step-up and step-down transformers and auxiliary apparatus; and also to the fact that money invested in copper conductors is lost only in part, while money invested in auxiliary apparatus is lost almost entirely in case of a change. There are a number of cases where the installation of alternating current would be the only practical solution, on account of the long distances and the heavy currents to be carried.

64 The advantages of alternating current, as well as its disadvantages, are well understood, and it is unnecessary to call attention to these points. It may be well, however, to point out instances where it is easy to make a choice. Given a plant covering a large area and using large amounts of current, of which only a small portion is used for variable-speed machinery, and of sufficient size to permit of the use of a separate unit for lighting current, alternating current would be the logical solution. On the other hand, given a compact plant, using a large portion of the power for variable-speed machinery,

direct-driven by motors, and of which the lighting load is small in the daytime, it would be natural to select direct current. As a rule, however, conditions are not so simple, and it is generally very difficult to prophesy which system will give the best results. Of late the problem has been complicated by the fact that a great many machine tools may be had with single-pulley drive, to which an alternating-current or a direct-current motor is equally applicable.

65 The points in favor of the alternating-current motor are then:

- a High breakdown point; that is, the motor goes on with no material change in speed under very heavy overload.
- b Freedom from commutator trouble. This is especially valuable where fine chips are made, or where compressed air is used in connection with the machine. It is not such a weighty point as it used to be, as the better makes of direct-current motors are now equally free from this kind of trouble.
- c Most cities are now lighted by alternating current, so that city current can be used in smaller plants, provided the machine tools are arranged for this kind of motor.

66 *Direct current.* The points in favor of the direct-current motor are:

- a Wider air-gap, allowing a greater amount of wear in the bearings before the motor has to be repaired.
- b The possibility of power and lighting-loads on the same circuits without the poor regulation due to inductive load.
- c The possibility of using variable-speed motors. This is, perhaps, the greatest argument in favor of the direct-current motor. Though it is possible to run a great many machine tools by a motor, yet one of the greatest advantages of such a drive is not available unless the motor is of the variable-speed variety.

67 *Alternating voltage.* When a decision has been reached as to the nature of the current to be employed, the next step will be to decide as to the voltage. A high voltage is likely to be in favor if distance was a controlling factor in the decision to use alternating current; for it is this possibility of using high voltage, which makes alternating current desirable under those conditions. Where the distances are relatively small, it becomes simply a matter of computation whether low copper cost plus the expenses for transformers, etc.,

will give greater or less economy than high copper cost without auxiliary apparatus. In a great number of cases, current is bought from some power company, and in such cases there is no choice. In any case, however, it remains to be decided to what voltage the current shall be transformed. Few engineers nowadays adopt the 440-volt current, on account of the greater danger, and for the same reason 500-volt direct current is very little used. It should be kept in mind that alternating current is more dangerous than direct current of the same voltage.

68 *Frequency and phase.* Frequency depends on the use to be made of the alternating current. In late years a compromise has been reached, which fills practically all wants of the shop by one single frequency, namely 60 cycles.

69 Though there is still some difference of opinion, the question of the number of phases is now fairly well settled in favor of the three-phase current. It would be difficult, however, to point out the advantage of this system over the two-phase system, or vice versa, as far as use in shops is concerned.

70 *Direct voltage.* The choice of voltage is easier when direct current is used. There was a time when the multiple voltage seemed to take a strong hold on engineers for use in machine shops, and the writer must confess that he had strong faith in the ultimate success of this system. However, the development of the variable-speed motor has made the system somewhat superfluous and it has not been installed in any new shops of late. It might be said that, for all practical purposes, the system is dead.

71 There is, however, a kind of multiple-voltage system in use which deserves even at the present day the serious consideration of the engineer. This is the three-wire system, which allows of the use of 110 and 220 volts in the same shop. The 110-volt system alone would require a large amount of copper for power purposes, while the 220-volt installation leads to some difficulties in regard to lighting. However, there are many installations where the 220-volt system is used throughout, both for power and lighting, while the number of shops where a 110-volt system is used for both purposes is very small.

72 There are a few shops using 500 volts, but the number is very small as compared with the other voltages; and it is generally possible to trace the reason for such an installation to the fact that the 500-volt current is available because used for some other purposes, as, for instance, in the case of a repair shop for a street railway system. This system is not to be recommended for a shop (though it is economical

in the use of copper), for the reason that it is dangerous and where there are a large number of circuits and much metal in buildings and machinery great care must be taken to avoid grounds.

73 *Combined alternating-current direct-current systems.* There is finally the combination of alternating and direct current to be considered. This combination has its advantages, especially where it is possible to purchase current from some large power company, which as a rule delivers its product as alternating current. Transformers reduce the voltage to the proper point at the entrance to the shop, and the low-voltage alternating current can be used for all purposes except for driving variable-speed motors, and perhaps some auxiliary apparatus such as magnetic clutches, lifting magnets, etc. As the cost of installation is generally low in such a case, and the price per unit of power usually less than it could be made for, such an arrangement is so inviting that a number of objectionable features may be overlooked. The most serious objection, perhaps, to this method of driving a shop, is that the shop has absolutely no control over the supply of current, and there is nothing to be done in the case of a breakdown but sit down and wait. This is especially serious, as power delivered in this manner is generally transmitted over a long distance which increases the chance of a break in the wires, especially in bad weather.

METHODS OF APPLYING MOTORS TO MACHINE TOOLS

74 The mode of application of a motor to a machine tool, the selection of the motor, and the lines along which economical results may be expected, are fairly well defined at the present time. The following tabulation shows the present state of the art.

75 *Bench lathes:* To be driven from a countershaft, attached to the wall or bench and driven in its turn by a motor. Any kind of motor, except a series-wound or heavily compounded motor, will do. The object of the motor drive is to get the machine in the best possible location without regard to the location of the lineshafting. A number of these machines may be driven by a common lineshaft, driven by a motor.

76 *Speed lathes:* To be driven from a countershaft, located under the lathe, or by a direct-connected motor. In the latter case, a variable-speed motor is to be preferred, if direct current is available. Motor drive is recommended when the machine is used in the assembling department, as the machine may then be placed where it is most needed, and the assembling department being generally of greater height than

other departments crane service would interfere with countershafts. There will be no material gain, if the machine is to be used for ordinary shop operations.

77 *Engine lathes:* Various modes of motor-driving are in use. Some makers furnish motor-driven engine lathes as standard apparatus. Some have a headstock with a limited number of speeds and depend on a variable-speed motor to fill out the speeds of the lathe. Others apply a constant-speed motor, or one with a limited amount of variation, to an all-gearred headstock. In general the use of this class of machines in the shop would naturally lead to group drive. The advantages of the individual motor drive lie in the possibility of completing a job in one setting. There is no material advantage, if the machines are used for regular manufacturing operations, except where the location demands the motor drive.

78 *Heavy engine lathes, forge lathes, etc.:* To be driven by a direct-connected motor. The motor should be direct-current, as these machines are too heavy to permit a convenient all-gear drive. If no direct current is available and there is only one machine of its class in the shop, and this is used for an occasional job only, an alternating-current motor could be used, leaving a wide gap in the speeds. If these machines are used for manufacturing purposes, however, it will pay to install a small synchronous connector. The speed range in the motor does not need to exceed two to one, though a wider range is better if obtainable without complications or large expenses. The position of the motor should be low, as the vibrations in the motor-support have a decided influence on the capacity of the machine, as well as on the repair bill. The output of this class of machine may easily be increased from 20 per cent to 25 per cent by motor drive.

79 Further advantages of the motor drive are, the possibility of placing the machine in the line of the routing of heavy work, and of placing it immediately under the traveling crane. This latter object may be reached with a belt-driven machine by placing the headstock under the gallery, if the construction of the shop lends itself to this arrangement, but the same convenience as that of the motor drive cannot be obtained.

80 *Axle lathes, wheel lathes and driving wheel lathes:* It is of the greatest importance that this class of machinery should have the highest possible efficiency, and the most convenient location. These machines are mostly used in railroad repair shops, where time saved does not mean merely the saving of some wages, but each day gained means an added day in the earning capacity of the engine. It is

therefore important that these machines be motor-driven whenever installed in a railroad repair shop, though this does not mean that they should not be so driven if used for manufacturing. Direct current should be used. The economy of the motor drive should not be figured in increased output, but in reduction in time required to repair an engine.

81 *Chuckling lathes*: Generally speaking, there is little reason why a chucking lathe should be motor-driven. Most chucking lathes are provided with the necessary mechanism to shift speeds quickly. A few types handling large work may be motor-driven to advantage, though practically the only advantage lies in the fact that small graduations in speed can be thus obtained. Such machines therefore require a variable-speed motor.

82 *Automatic screw machines*: Small machines of this class are generally group-driven. Large machines may be motor-driven to good advantage. The larger sizes have generally one or two speeds for one piece of work, though these speeds may be varied when the machine is reset for a new piece of work. The speed given to the machine must naturally be proportional to the largest diameter to be turned, or in other words, to the size of stock used. This will reduce the speed for some of the operations, such as drilling and reaming, far below the economical speed. The amount of time saved by the application of the variable-speed motor may be considerable. Where the construction of the machine permits, two motors, one for feed and one for speed, would give still better results. In all cases variable-speed motors should be used.

83 *Sensitive drills*: The only reason why a sensitive drill should be individually motor-driven is, that it is often used in the assembling department, where height of ceiling and crane service would make a belt drive awkward or impossible. Most sensitive drills have in themselves all the speeds required for their work, so that any type of motor will be adaptable. The motor may either be directly applied to the machine or drive a countershaft on a stand, or it may be placed on the floor by the side of the machine in case the machine carries its own set of cones or other variable-speed device.

84 *Drill presses*: Generally speaking, the upright drill is used for manufacturing operations and does not require frequent changes of speed. There are, however, many exceptions, for instance, where upright drills are used to perform all the operations on a piece by means of a jig. In this case frequent changes of tools, and therefore of speeds, are required, and an individual motor drive, whether direct-connected

to the machine or operating on the countershaft, is of the greatest benefit. No great benefit can be derived from a constant-speed motor with this type of machine. Radial drills may be considered the same as upright drills. There is an additional reason why radial drills should be motor-driven—they are often used in the neighborhood of the assembling floor.

85 *Boring machines:* Where boring machines are specialized, performing only one operation, there is no good reason why the motor drive should be preferred to belt drives. Where, however, the machine is used for a multiplicity of operations, such as drilling, boring, reaming and facing, a motor drive is beneficial if a variable-speed motor is used. The range of speed of the motor should be as wide as possible, that no gears may have to be shifted for the entire set of operations on a single hole. Especially where a boring machine is used for facing, this variable speed will be found highly economical.

86 *Grinders:* Grinders in general require so many various movements driven from countershafts that it is hardly possible to apply a single motor directly to the machine. The best that can be done is to attach the countershaft to the machine, and drive the former from a motor standing on the floor or on a bracket attached to the machine. In isolated cases it would be well to have one or more motors, each controlling a single operation, attached directly to the machine.

87 *Planers:* Planers in general are not benefited by the application of a motor, as the motor only complicates the difficulties of a planer drive. However, large planers which must be placed under a crane give better results when motor-driven on account of the facility of handling the work. Another possible advantage when using a variable-speed motor and controlling the speed of the motor at the end of the stroke, is that much higher return speeds can be obtained in connection with any desired cutting speed.

88 *Shapers, slotters etc.:* What is true of planers is also true of these classes of machines. Local conditions may make it advisable to drive them individually by motor, but generally speaking, there is no great benefit from this drive.

89 *Milling machines:* The larger sizes of knee-and-column type machines, if motor-driven, will give the best results if the motor is of the variable-speed type, especially where these machines are used for gang work. This is due to the fact that the speed of the mills is dependent on the largest cutter in the gang, while the feed is dependent on the smallest cutter, not counting the limitations due to the nature of the work. It is therefore important that the speed should be

as close to the permissible limit as possible. When applied to this type of milling machine the motor should be as low down as possible, as vibrations in the machine have a marked effect on the quality of the finish.

90 *Planer-type milling machines:* In practically all cases machines of this type should be motor-driven in order that they may be located under a crane. It is not so very material, however, whether the motor is of the constant-speed or the variable-speed type.

91 *Punches, bending rolls, shears, etc.:* This class of machinery, used largely for boiler, bridge, structural iron and ship-building work, is generally placed in high shops and under cranes, and in locations and directions most convenient for the routing of the work. The shops in which they are placed are generally large and contain a relatively small amount of machinery, so that the amount of transmission gearing required is large in proportion to the amount of machinery. It is for this reason advisable in almost all cases to drive this class of machinery by an electric motor, which, of course, does not need to be of the variable-speed type.

92 It was not the intention to go into detail on the application of the motor to the machine tool, and the above should be considered as merely an enumeration of some of the important points for the most constantly used machines. It is in no way a treatise on motor drive applied to machine tools.