No. 1276*d*

DISCUSSION ON ELECTRIC DRIVING IN MACHINE SHOPS

The three preceding papers on Electric Driving were presented at meetings of the Society at St. Louis and New York, April 1910, and the discussions at these meetings follows. At the New York meeting the American Institute of Electrical Engineers coöperated and contributed a paper by Charles Fair, Assoc. A. I. E. E. This paper was published in full in the Proceedings of the American Institute of Electrical Engineers for May 1910. It discusses the advantages of the individual electrical drive for machine tools, with special references to tools which are already in service with belt drive. In such cases it is necessary to consider in choosing a motor the nature of the work, the speed changes required, the number of tools thus to be equipped, and the condition of the tools. Even where a motor is applied to a tool designed for belt drive, the new drive should be simple in construction, satisfactory in operation, and sightly in appearance. Numerous methods of attaching motors to old tools are shown and described.

The choice of control, whether it be with old or new tools, is fully as important as the choice of the motor and it is necessary to consider the accessibility of, the controller to the operator, the method of attaching it to the tools, and its position relative to other tools. Accessibility in case of accident is an important consideration and the starting compensator should be placed where the motor or some of the moving parts can be seen by the operator. Wherever possible, both controller and motor should be attached directly to the tool. In the case of portable tools this is an absolute necessity. The effect of convenient control upon the output of the tool is emphasized and various types of controllers and methods of application are shown and described.

A table is attached which is designed to aid in a general way in the choice of motors, and numerous methods used to maintain standard motor shafts are illustrated.

DISCUSSION AT ST. LOUIS

W. F. M. Goss. A few years ago it was commonly believed that the electric motor could be used only under certain favorable conditions. If there are any today who hold such an opinion, they should visit the great steel works at Gary, Ind., where not only machines but compressors and roll trains are electrically driven, to be convinced that there is nothing in machine driving that can not be done by the electric motor.

A modern machine shop, whether for repairs or manufacture, presents an equipment of specialized machines. The capitalization which underlies the operation of the shop has been extended enormously in these later days, and the added cost of a motor to drive an individual machine is now more easily met than formerly. If the layout of the shop is properly balanced and if there is business sufficient to keep the machines going, an individual motor for each machine will increase the output and improve the efficiency of the shop.

I do not believe that there are many cases where it will pay to fit motors to old machines. There may be individual cases where this may profitably be done, but the new motor and the old machine will always be less efficient than a complete new outfit. If a point is reached in the development of a shop where electrification is in order, it will generally pay to provide new machines which will be up to the standard of the motor.

I am convinced that the machine tool of the future is to be an individual motor-driven machine, a machine in which we shall not see pulleys, belts, or gears. Such a machine will not only be powerful, ready for instant service and easy to maintain, but it may be taken from its station if desired and moved to its work. It will be an instrument which, because of these facts, can be used in the development of a much larger output than will ever be possible from machines of the ordinary characteristics.

E. R. Fish.[1] There are probably few manufacturing plants designed at present which do not provide in a greater or less degree for electric transmission of power. In many instances provision is made for a generating plant, but sometimes it is more economical to purchase current from a central station. My own experience has been in connection with a shop for the manufacture of boilers. In plants of this kind several methods of power transmission are required, but a great many of the tools can best be driven by motors. In fact the use of motors permits the only rational layout of a shop of this sort for economical production. Any other form of motive power can be used only at great inconvenience, with poor economy, and with large maintenance charges. With motor drives the machines can be located exactly where they are wanted and where the successive operations will progress without unnecessary handling or delay. We use the 220-volt, 3-phase, 60-cycle current and have found it entirely satisfactory. It drives plate-working tools of all sorts through individual

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motors, drives a small machine shop through a lineshaft, and operates a 25-ton traveling crane. In our case it was quite impracticable to use power from a public-service station because our processes required a power house of our own. We did want an emergency connection from the outside in order to provide against possible failures of our own generator but the ready-to-serve charge was quite prohibitive. A large portion of our work is done by hydraulic and pneumatic tools, so that even though the generator should fail, the works would not be entirely shut down. It was therefore unnecessary that this charge be incurred. It is undoubtedly true that in many instances a protection against break-downs which would completely close the plant would justify the cost of such an outside connection.

A. H. TIMMERMAN.[1] The choice of direct or alternating current for machine shop drives depends largely upon whether there is a possibility of throwing over to a power company's circuit. If the ready-to-serve charge is not too great, the alternating-current distribution is by far the best, because in case of failure of supply the alternating current of the power company can be relied upon.

In the case of an individual installation in which the amount of power required is large and there is no public service corporation to rely upon, the question of direct or alternating current is largely a question of the area covered by the plant. Alternating current is satisfactory for both small and large plants; but direct current is hardly suitable for a plant extending over a considerable area, because of the large drop in voltage due to the long lines required.

Six or eight years ago a great deal was heard about adjustable-speed motors for all forms of machine-tool drive, but machine tool builders have found it necessary to build their tools so as to get the necessary changes in speed mechanically.

I was rather surprised that emphasis was placed on the squirrel-cage polyphase motor. There is an increasing demand on the part of the power companies for the wound-rotor type. The squirrel-cage draws a very heavy current at starting, in comparison with that used by the wound-rotor type. With the latter type full-load torque is obtained with full-load current, or double torque with double current. The squirrel-cage type requires for full-load torque from two to four times full-load current, depending upon the design of the motor.

In this connection it is also of interest to note that the single-

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phase alternating-current motor can be used just as well as the polyphase motor for tool drive. In fact in many installations it is much better because a single-phase motor, starting on the repulsion principle, has an exceedingly high torque and draws very much less current from the line for a given torque, than is drawn by any other type of motor.

The amount of power drawn for any tool varies from one-tenth full load to a load and a half, and the motor on an individual tool must be able to take care of the largest load that the tool is liable to have. On the other hand, if five or ten tools are grouped together, a motor that has perhaps a quarter of the sum of the individual horsepower capacities required on the different tools may be installed. This is shown by the fact that even where a group drive is used, the actual power drawn from the generator is very often not in excess of 40 to 60 per cent of the total horsepower connected to the generator.

In the installation of alternating-current motors care should be taken that motors not too large for the work are chosen. The alternating-current motor has a very much heavier overload capacity than the direct-current type, and since the power factor at fractional loads is rather low, it is better to have alternating-current motors overloaded than underloaded.

P. A. Morse.[1] If it is necessary to use alternating current from the source of power it is very frequently advisable to put in motor-generators, to take care of machine tools or of hoist motors in such a way that a much better power factor is obtained, thereby decreasing the watt load and increasing the capacity of the generating units. The Grand Trunk shops have some large motor-driven compressors to which are coupled synchronous motors. At a plant in St. Louis in which the power factor was very low, the slip-ring type of alternating-current motors was used for certain work. When these were changed recently to direct-current, it increased the power factor and the capacity of the generating plant.

While alternating-current motors, both single-phase and polyphase, have in recent years been adopted very widely as sources of power in the machine shop, the fact still remains that with a class of work which calls for mechanically different sizes of material to be passed through, and where the processes on a given machine tool

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are not the same from day to day, it will be almost imperative to use the direct-current motor.

Recent practice is to furnish direct-current motors with inter-poles to improve the commutation and the advantage claimed for the alternating-current motor, that it gives less trouble, should not be as much of a factor hereafter.

The alternating-current motor, of course, has practically only the bearings to be looked after, but the narrow air-gap, which is necessary in order to correct certain other things which would make the motor undesirable, must be balanced against commutator trouble. Within the last few years considerable work has been done in bettering the commutation of motors. This fact has not been generally recognized but will have its bearing on future installations.

H. H. Humphrey.[1] In connection with stand-by service from a public utility company, it is often an advantage to be able to start part of the plant before the power plant is ready. I know of one case where the entire plant ran for about three months on central station power. This service has been abandoned this year because it was found that the isolated plant is much more reliable than the central station service in this particular case.

A growing industrial plant is generally provided with reserve power capacity, while on the other hand the central station companies are generally overloaded. If they are not this year, they will be next, for the reason that they connect more customers than their total capacity.

O. Stephensen.[2] Regarding the relative merits of direct and alternating-current motors, there are many cases in which a constant-speed motor can be used, especially for quantity manufacture. Only where the work changes from one job to the next or from moment to moment is an adjustable-speed motor required.

I also take issue with the objection made to the alternating-current motor because of the small air gap. Even with an air gap of only a few thousandths of an inch, proper care, which means nothing more than the right kind of oil in the bearings and the right amount at the right time, will prevent the rotors wearing on the stators, if the

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[2] Electrical Engineer, Wagner Electric Manufacturing Co., St. Louis, Mo.

bearings are designed liberally enough. The latter point is therefore a very important one to the purchaser of an alternating-current motor.

William H. Bryan. The State Railway Commission of Wisconsin has been doing some admirable educational work towards a better understanding of the ready-to-serve charge. It is fixing rates for all the utilities in that state, and doing it very thoroughly and well.

I do not like Mr. Robbins' method of charging depreciation as outlined in Appendix No. 4 of his paper. This method, which he says is in general use in appraising shop tools, is to charge off a certain percentage each year. He gives it as 10 per cent, which I find very common figure. A tool may thus be thirty or forty years old and still have book value. The more modern way of handling depreciation is the sinking-fund scheme, by which the probable life of the tool is first estimated, by a study of its service, and then an amount is set aside each year, which will, with interest compounded annually, at the end of the assumed period of life, have replaced the full value of the tool. To ascertain the value at any intermediate date the amount of the accumulation in that fund is deducted from the cost of duplicating the tool.

H. Wade Hibbard. I recently visited the St. George Street plant of the American Car and Foundry Company in St. Louis, where electric driving is applied to a wide range of work. That plant, engaged in the manufacture of steel cars, is very large and compact. Since it is engaged in the manufacture of a large number of parts that can be produced on a factory basis, they have adopted alternating-current motors. The large machines are individually-driven, and the small machines are group-driven.

Henry Hess. I cannot agree that the direct-connected motor drive is always and everywhere the only correct thing; nor do I reject it absolutely and utterly for every shop, place and tool. Both attitudes are too radical and sweeping; truth will be found as usual between the extremes.

The direct-connected motor drive is distinctly preferable where any advantage in quantity of output results from its use, or where a machine is to be portable, or is so located that it can be reached only by long or awkward lineshaft and belt drives. Under every other condition the individual motor drive is more expensive in initial installation and upkeep, and more complicated to maintain in the average shop.

The absence of overhead and vertical belting is an advantage that appeals to the extremist. The amount of light obstructed is inappreciable, be the shop of the modern well-lighted type or one of the older dark interior. The horrible example which Mr. Riddell shows (Fig. 21) is most carefully selected; but is not necessarily representative. In contrast note Figs. 37 and 38 herewith. Here are six parallel rows of lathes in a shop bay 50 ft. in width. The two side rows are driven from lineshafts carried on the crane columns. The four central rows are driven from two lineshafts that are mounted on cast-iron columns standing free of the building. Cross-arms from these support longitudinal channel beams to which the countershaft hangers are attached. The lineshafts are driven by alternating-current motors back-geared to the shafts. Note also the utilization of the crane-track girders for carrying the lineshaft that drives tools close to the crane columns. These lineshafts are also direct motor-driven. There is no interference with the overhead traveling crane. Not the most rabid advocate of light has ever been able to criticise this installation for lack of it. Nor is there any noticeable interference with lighting when there is an overhead ceiling as in Fig. 39. Here again the lineshaft is driven by a motor attached to the ceiling.

Even eliminating all of the many establishments that could not fairly be classed as progressive, provided the test of progressiveness is not based on the direct-connected idea, an examination of the machine shops in a given city will fail to show the prevalence of the direct-connected individual drive, whether the comparison be based on the number of shops, the number of machines, or the power transmitted. The conditions found in one city will be found true of others and of the country districts as well. The lineshaft and belting manufacturers are not yet losing sleep or going into the hands of receivers.

Whenever increase in capacity is directly attributable to the individual motor drive, that should be installed; but in each case it should be carefully considered whether the same increase in capacity cannot be secured without it. Then the relative cost of initial equipment and maintenance should be the deciding factor.

The shop manager not interested in what his operation costs is likely soon to receive emphatic reminder that his lack of interest is not shared by those whose dividends are affected. Every possible saving should be taken advantage of, every element of cost should be reduced if possible.

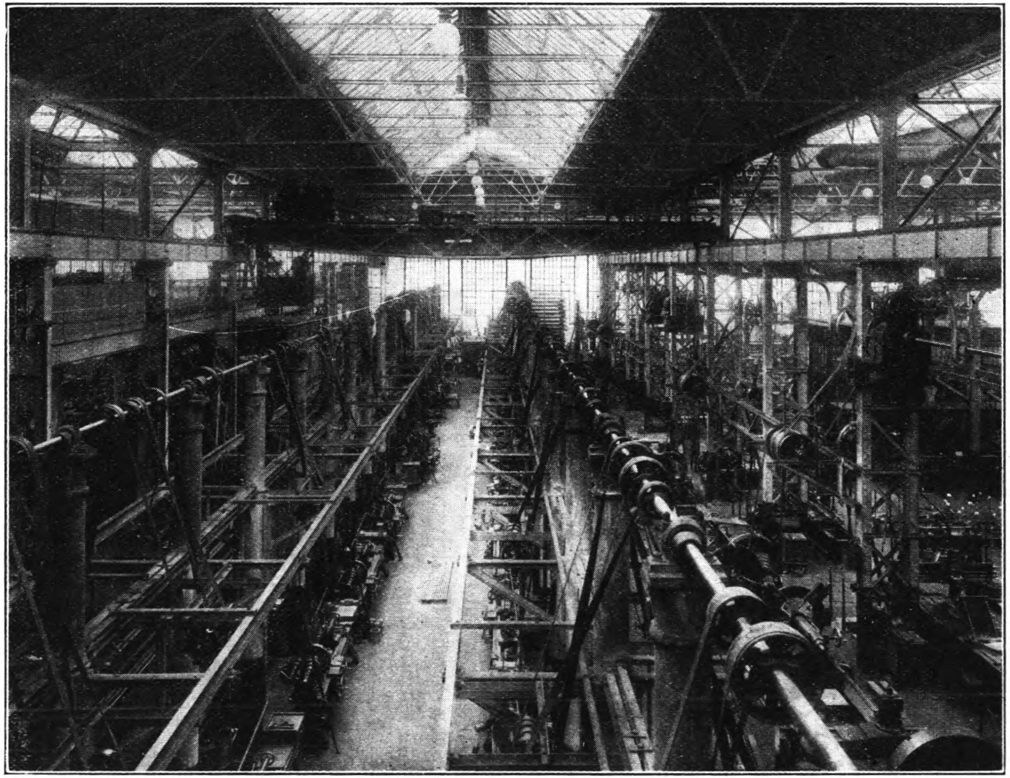

FIG. 37 BELT-DRIVEN MACHINE SHOP FROM ABOVE

Fig 38 Same as Fig. 37 from Below

As producing engineers, we are all necessarily interested in advocating the particular thing we produce or help to produce. So far as my advocacy of the ball bearing is concerned, however, that does not predispose me toward the ball-bearing lineshaft, for the simple reason that the ball bearing is quite as widely employed on electric motors as on lineshafts.

Can the most thorough-paced advocate of the electric motor claim for it that it delivers more power than may be transmitted through a belt? Should one be found possessed of sufficient temerity, then what explanation has he to offer for that species of direct-connected motor drive in which a belt is interposed between the motor and the machine? Many such are to be found in the shops of the best-equipped motor manufacturers, who, believing in the most thorough way in adopting what they advocate for others, equip throughout with motors to the exclusion of all lineshafts. Certainly these manufacturers and their shop managers do not go to the length of sacrificing capacity merely to be consistent, but they get that result in many cases through belts, and even through belts plus the despised countershaft, with the motor thus twice removed from the direct connection (see Figs. 25 and 29, of Mr. Riddell's paper).

Moreover, with belt drive the machine-tool manufacturer can build his machines in large lots without having to individualize for the almost endless diversity in electric motors. Attention has been called to the difficulties in reconciling the diametrically opposed needs of the electric motor and the machine tool. All of these difficulties are solved by the gear box already in more or less general use by many machine tool builders. It may be driven by either a direct-current or an alternating-current motor or by a belt from a lineshaft or countershaft. All it asks is that the motor or belt be of sufficient size to satisfy its hunger for power.

A motor is many times more costly than a belt, wastes far more power in journal friction and windage alone than the belt uses up, and in addition has great electrical losses. Mr. Robbins, in advocating the motor, admits a motor waste of one horse-power to every three usefully delivered. What belted drive can be accused of similar wastefulness and inefficiency? Remember also that the belt drive does not vary in speed even by a few per cent. Can that be said of the electric motor? Even its advocates have admitted the contrary.

Great credit is due the manufacturers of electric machinery for having given an impetus to the art of economical machine production. They have not only stimulated the advance through constant demand on the machine tool builder but they have also shown him the way by example. Naturally they have made the widest possible use of that means of power transmission which constitutes one of their staples of manufacture. That has focussed attention on the methods they advocate. Other methods no less meritorious, or even superior, with no such strenuous and interested advocates have not been similarly brought to public attention, and possibly have not felt the need.

The essential matter which the man responsible for final costs must weigh is not that of direct-connected individual motor drive, or of any other drive, but that of final total cost as influenced by all factors. So far as the transmission and application of power are concerned, it is a matter of largest output at least cost. It must be by motor if that gives more output than can be realized by shaft and belt. It must be by shaft and belt if that can give as great an output as the motor. The decision must so fall, simply because of lower first cost and lower upkeep cost.

Stress has been laid in the papers on the economical features of the direct electric motor drive. Whenever such application results in increased output, due to qualities inherent in the electric motor, then the direct motor drive is in order. Whenever the direct motor application does not inherently reduce operating time, then investigation is in order to determine whether the line-shaft drive is not more economical and the direct motor application a compliance with a fad to be dearly paid for.

The impression given by the papers is one of the all-round superiority of the direct-connected motor. It is only in the following instances, however, that the individual motor drive overbalances the economic features of the lineshaft:

a Where machine portability is important.

b Where relative under-equipment with large machines makes their overtime operation necessary, while the balance of the plant is idle.

c Where occasional machines can be reached only by long lines of shafts or are inconvenient to drive from the lineshaft.

d Where the direct motor application results in increased productive output not otherwise obtainable.

In every other case the lineshaft has the advantages of lower first cost, lower cost of maintenance, smaller depreciation, less power waste and less grand total of annual costs.

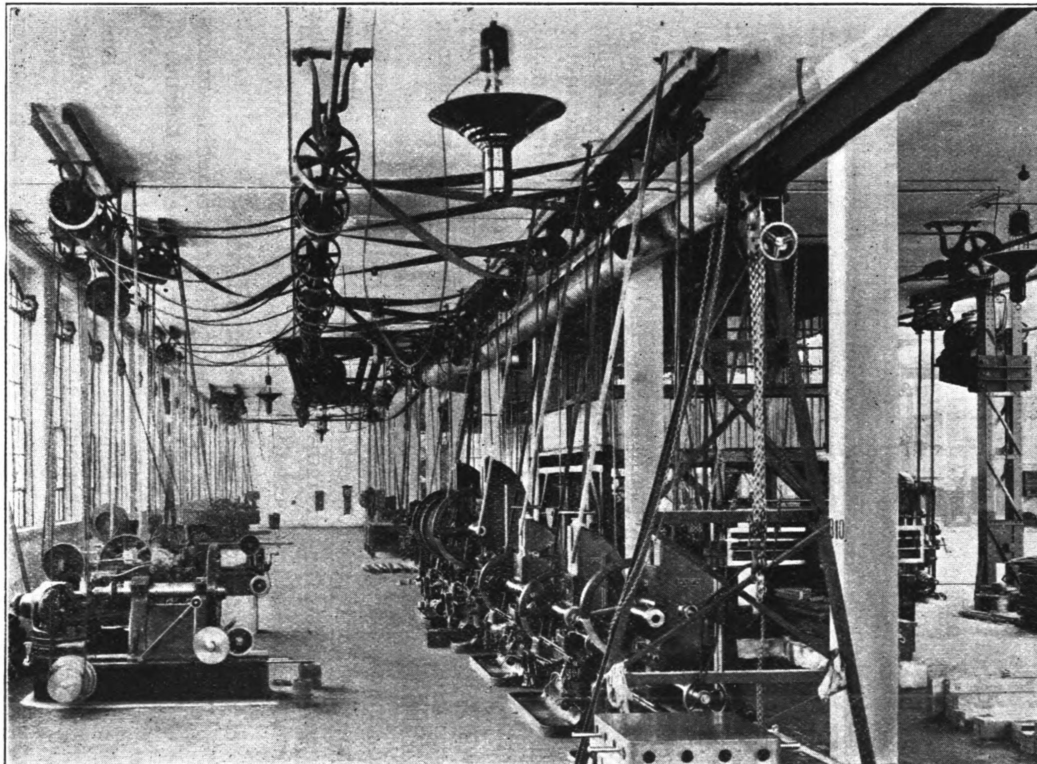

FIG. 39 BELT-DRIVEN MACHINE SHOP WITH CEILING

Moreover, the differences are very decided. This is true even when the lineshafts are mounted on plain bearings, with their large friction wastes. It is still more true when these friction losses are reduced by mounting the lineshafts on ball bearings of a durable type. The difference is still further increased in favor of the lineshaft when it is run at the high speed that ball bearings make feasible. High speed decreases weight of shafting, weight of pulleys, weight of belts, and with these the journal loads and losses, as well as the first cost of every element in the system.

Realizing that definite figures rather than general statements are wanted, I have made direct quantitative comparisons, using as a base an existing, well-arranged plant of direct motor-driven machine tools. For this purpose our former president, James M. Dodge, placed the data and experience of the Link Belt Company's works at my disposal.

Fifteen representative machine tools cost for motors $4920; for power annually at $0.03 per kw-hr. $2930; for depreciation at 10 per cent and maintenance at 5 per cent $492 and $246 respectively. The total annual cost is $3668

A lineshaft installation at 200 r.p.m. on plain bearings would cost only $520 initially and take $170 less annually for power, with a total annual cost of only $2838, or $830.00 less.

The same lineshaft, but carried in ball bearings, would cost only $790 initially, save $330 in power annually and involve a total annual cost of only $2718, or $950 less.

Increasing the lineshaft speed to 600 r.p.m. and carrying this in ball bearings gives the most economical arrangement at an initial cost of only $460, an annual power charge reduced by $750 and a total annual cost of but $2249, or $1419 less.

Such a high-speed ball-bearing lineshaft system costs less than one-tenth as much to purchase as a direct-connected individual motor system, while involving less than two-thirds the latter's annual charges. Even this can be bettered materially by the employment of ball bearings in the countershaft and loose pulleys.

The data on which the foregoing is based are given in detail in the Appendix herewith, based on the tabulation, Table 19, of direct-connected machine tools in the shops of the Link Belt Company's plant, at Philadelphia.

APPENDIX TO DISCUSSION BY HENRY HESS

REFERENCES TO TABLE 19

As the total load factor in Table 19 is 17.0 per cent of the total motor rating, the total useful power delivered is 167 × 0.17 = 28.4 h.p.

In Par. 126 of his paper Mr. Robbins allows for the low load factor of direct-connected motors by assuming an average motor efficiency of 75 per cent. But this is not the whole story. Some prime mover, as a steam engine, must first drive an electric generator and the current must then be conveyed to the motor by wires. The generator efficiency will average 92 per cent and the line transmission 95 per cent. This makes a combined average efficiency for the generator, line and motor of 0.92 × 0.95 × 0.75 = 0.65.

Using this value gives $\frac{28.4}{0.65} = 43.6$ h.p. as the average total power consumption.

The cost varies with local conditions, but will rarely be less than 3 cents per kilowatt-hour, making the power cost for a year of 300 days at 10 hours = 0.03 × 43.6 × 0.746 × 3000 = $2930.

TABLE 19 DIRECT-CONNECTED MACHINE TOOL DATA

Motor No.	Motor Rating Horse-Power	Load Factor Per Cent	Motor Cost Dollars	Machine
43	25	14.4	583	120-in. vertical boring mill
42	25	12.0	588	84-in. vertical boring mill
76	9	16.6	268	37-in. vertical boring mill
99	9	16.6	268	30-in. vertical boring mill
100	9	15.6	250	Keyseater
61	3	20.0	159	Drill press
60	8	27.5	303	Keyseater
72	8	21.3	237	Keyseater
46	18	20.0	477	20 in. × 49 ft. lathe
44	12	8.3	440	30 in. × 27 ft. lathe
62	3	16.7	159	Cut-off lathe
104	12	14.2	440	Milling machine
39	9	36.5	263	Planer
59	8	18.8	237	Side planer
66	9	15.5	250	Screw cutter
Total	167	17.0	$4922	

REFERENCES TO TABLE 20

The lineshaft and countershaft journal losses in Table 20 are based on a ratio of 1.94 to 1, in accord with Flather's findings of average machine shop conditions as quoted in Kent's Pocket Book, 4th edition, p. 965.

REFERENCES TO TABLE 21

The loss of 13.2 h.p. on plain bearings in Table 20 is incurred by the line-shaft journals and the countershafts; it is reasonably accurate to apportion

TABLE 20 LINESHAFT DATA AT 200 R.P.M. WITH PLAIN RING-OILING BEARINGS

Shaft diameter $2\frac{15}{16}$ in. safe for 100 h.p. usual catalog rating	Cost
Shaft length 100 ft.	$65.20
Main drive belt 14 in. by 30 ft.	90.62
Main pulley 56 in.	26.77
12 hangers, 26 in. drop with ring oiling bearings	81.60
15 double pulleys on lineshaft	37.25
15 sets of belts to drive countershafts	217.71
Total	$519.15
Useful power delivered to the machines, as with the motors	28.4 h.p.
Lineshaft and countershaft journal losses	13.2 h.p.
Total	41.6 h.p.
Total annual payment for power at $0.03 per kw-hr. and 3000 hours = 0.03 × 41.6 × 0.746 × 3000 =	$2700.00

TABLE 21 LINESHAFT DATA AT 200 R.P.M. WITH BALL BEARINGS; OTHERWISE AS IN TABLE 20

Shaft	$65.20
Main belt	90.62
Main pulley	26.77
2 D Hangers, with medium weight ball bearings next to main pulleys	80.34
10 C Hangers, with light weight ball bearings	269.90
15 pulleys on lineshaft	37.25
15 sets of belts to drive countershafts	217.71
	$787.79
Useful power delivered to the machines, as with the motors	28.4 h.p.
Lineshaft and countershaft journal losses	10.9 h.p.
Total	39.3 h.p.
Total annual payment for power at $0.03 per kw-hr. and 3000 hours = 0.03 × 39.3 × 0.746 × 3000 =	$2600.00

TABLE 22 LINESHAFT DATA AT 600 R.P.M. WITH BALL BEARINGS

Shaft diameter $2\frac{15}{16}$ in. safe for 96 h.p. usual catalog rating	
Shaft length 100 ft.	$ 48.00
Main drive belt 10 in. by 30 ft.	64.80
Main pulley 36 in.	10.19
2 B hangers 18 in. drop with medium-weight ball bearings next to main pulley	34.68
10 B hangers 18 in. drop with light-weight ball bearings	150.00
15 double pulleys on lineshaft	19.41
15 sets of belts to drive countershafts	129.52
Total	$456.60
Useful power delivered to the machines as with the motors	28.4 h.p.
Lineshaft and countershaft losses	4.1 h.p.
Total	32.5 h.p.
Total annual payment for power at $0.03 per kw-hr. and 3000 hours = 0.03 × 32.5 × 0.746 × 3000 =	$2180.00

this equally between the two. Ball bearings will save, under average conditions, if other conditions remain unchanged, about 35 per cent of the lineshaft journal loss. In this case, therefore, taking the 13.2 h.p. from Table 20, $\frac{1}{2} \times 13.2 \times 0.35 = 2.3$ h.p. This leaves a loss of $13.2 - 2.3 = 10.9$ h.p., as given in Table 21.

The loss could be reduced by another 2.3 h.p. by mounting loose pulleys and countershafts on ball bearings; but as these parts are generally furnished with the machine it is relatively difficult to secure them so mounted. It must be remembered that it is the user and not the builder of the machine who secures the benefits of the ball bearing mounting and it behooves the user to specify accordingly and to insist on compliance.

REFERENCES TO TABLE 22

Referring to the useful power delivered to the machines, the total lineshaft load is now only

$$\frac{1\frac{15}{16} \times 7110 \times 600}{12 \times 33{,}000} \times 0.0015 = 1 \text{ h.p.}$$

owing to the reduction in weight of the shaft, pulleys and belts and also the reduction in pull of narrower high-speed belts to 7110 lb.

The countershaft total load is 5000 lb., speed 400, but the friction is high at about 0.08 as conditions are not as good for the plain journals of the countershafts. This gives a loss of

$$\frac{2\frac{7}{16} \times 5000 \times 400 \times 0.08}{12 \times 33{,}000} = 3.1 \text{ h.p.}$$

Total loss $= 3.1 + 1 = 4.1$, as in Table 22.

L. R. Pomeroy. In Par. 95 of his paper, Mr. Robbins states that the alternating-current motor is essentially a constant-speed machine. The variable-speed alternating-current motor, possessing series characteristics, is not adapted to general machine tool driving, but it can be used to more or less advantage to perform operations to which a series motor is adapted, such as driving bending rolls, cranes, etc. In a number of tools it is advantageous to vary the speed, to stop, start and reverse quickly in order to facilitate lining up the work, to take a trial cut, to adjust counterbore, etc. After such adjustment the open or synchronous speed can be used for cutting and the tool then becomes, through its working cycle, essentially a constant-speed machine. The additional speed changes, as outlined, are valuable as time savers and are justified from this standpoint, yet it is not necessary to drive with a direct-current motor.

The references in Par. 96 and Par. 149 to geared-head machines or tools equipped with mechanical speed variation hardly do justice to these tools, as the speed-changing mechanism in many of them is as available and handy as if obtained electrically and, therefore, removes the necessity for individual drive for a tool located in a department group. There is no question that, from a commercial viewpoint, the alternating-current motor is preferable for constant-speed work, on account of economy of transmission, ease of obtaining proper voltage for lighting, and the general cost of upkeep of motors. As an example of this latter point, the case of a large manufacturing concern in the Middle West is pertinent. The shop is provided with both direct and alternating-current motors, and the cost of upkeep is $2 per month more for the 600 h.p. in direct current than for the 4000 h.p. in alternating current.

For railroad shop conditions 75 per cent of all requirements can be fully met by constant-speed motors and as the necessary 25 per cent of direct-current motors for the variable-speed machines can be obtained by the use of a motor-generator, it would seem that this is the most desirable combination to use. By providing a synchronous motor for driving the motor generator, an excellent opportunity is given to adjust or to increase the power factor, thereby eliminating the low power factor and its consequent disadvantages. The synchronous motor, besides delivering leading current and neutralizing a low power factor, has 70 per cent of its capacity available for mechanical load, and as this part of the load can be utilized to supply the necessary direct current for variable-speed tools, the combination becomes an efficient one. Alternating-current motors are especially economical and advantageous in wood-working shops on account of the presence of dust and flying particles. If direct-current motors are used, the fire hazard necessitates the use of enclosed motors, which are much larger for a given output, on account of the restricted ventilation due to enclosing.

As an illustration of the advantage of reckoning with the intermittent duty of a given machine in determining the size of motor to select for a given service, suppose the requirements are 50 h.p. for five minutes, 10 h.p. for ten minutes, the cycle to be repeated every 15 minutes with speed constant. The speed characteristics of the motor require a shunt excitation, i.e., a definite exciting current in the fields regardless of the load on the armature. The average motor load is

$$
\begin{aligned}
50 \text{ h.p.} \times 5 \text{ min.} &= 250 \text{ h.p. min.} \\
10 \text{ h.p.} \times 10 \text{ min.} &= 100 \text{ h.p. min.} \\
\text{Total, } &350 \text{ h.p. min.}
\end{aligned}
$$

$$\text{or, } \frac{350}{15} = 23.3 \text{ h.p. average.}$$

The average load will not produce the heating that the cycle will, for the reason that the copper loss varies as the square of the current. The root mean square or equivalent heating will be produced by the following:

$$\begin{aligned}(50)^2 \times 5 \text{ min.} &= 12{,}500 \text{ (h.p.)}^2 \text{ min.}\\ (10)^2 \times 10 \text{ min.} &= 1000 \text{ (h.p.)}^2 \text{ min.}\\ \text{Total, } &13{,}500 \text{ (h.p.)}^2 \text{ min.}\end{aligned}$$

Dividing this power by 15 minutes gives the average square as 900, the square root of which is 30 h.p.

$$\sqrt{\frac{13{,}500}{15}} = 30 \text{ h.p.}$$

This is the root mean square load, or a load which will produce the same heating if applied continuously as would the intermittent work.

Group driving, employing relatively short main and counter-shafting, is not an unmixed evil for the reason that the aggregate stored energy of pulleys, due to flywheel action, is advantageous where slotters, shapers, drills, planers, etc., are present, counteracting in a large measure the shaft friction losses. Very often a better load factor is obtained from the group motors than from the aggregate intermittent service of the individual-drive motors. The repairs on individual-drive motors are heavier than for the same number of group-drive motors. As an illustration, a certain shop has the same number of motors as one of 70 per cent greater capacity located in another city, both shops producing the same kind of output. In the former case individual drive is the rule; in the latter group driving prevails. The repairs per unit of output are larger in the former than in the latter.

7 It is also quite necessary to consider the work to be performed by a given tool in a given department, rather than the range of the tool. For example, a 72-in. boring mill has an ultimate range of work from 72 to 3 in., and with various materials a cutting-speed range of 15 to 25 ft. per min. The total speed range therefore becomes

$$\frac{72 \times 25}{3 \times 15} = 40 \text{ to } 1$$

Where the variety of work a tool will perform is the determining factor a wide range of speed quickly obtained is desirable, but under ordinary machine shop conditions, volume of output is the standard governing the selection of a tool, requiring in many cases constant speed.

The ideal condition is when the work is so classified and arranged that the machine is performing practically the same work all the time, i.e., duplication of parts. This condition requires the minimum amount of speed manipulation, at least that which is electrically obtained. The more variable speed is sought for, the further we are getting from ideal conditions. This should promote judicious conservatism and careful analysis to make sure of definite reasons for departure from the ideal standard. A careful study of each tool, with reference to the work to be performed, will establish definite ranges of speed, which will be found quite narrow, and which automatically determine the power requirements. The selection of the driving motor would be governed by the foregoing conditions, and might not apply to the same kind of machine in another shop or even in another department of the same shop, where a different output prevailed.

Mechanical changes of a simple character, not covering a very wide range but grouped about the zone of work for which the tool is generally intended or selected to perform, giving changes within comparatively narrow limits, provide variations that are useful and advantageous. This avoids the necessity of using motors with large speed ranges and very often admits of the application of a constant-speed motor, where otherwise a variable-speed motor might be required, all of which tends towards economy in first cost and repairs.

The results of comparison vary, depending upon whether the tool output is based on performing stunts or ordinary commercial shop operations. In forge shops at steel plants, where no attempt is made to forge close to size and the machine tools are relied on quickly to reduce the forgings to rough-finished sizes, or where motor shafts are rough-forged and then finished on machines, the question of high-speed cutting tools and powerful machines is of the greatest importance. But in railroad shops where the companies purchase driving axles, crank pins, piston rods, etc., rough-turned with a flat-nosed tool to within one-eighth or one-sixteenth of an inch of finished dimensions, an entirely different standard necessarily governs the rating of tools, both as to power and speed requirements. For instance, in a list of parts, 23 in number, scheduled for manufacture at the central or main shop of a large railway, the arrangement is such that the minimum amount of machine work has to be performed at the local or division shop where the repairs are to be made. Piston rods are finished except piston and crosshead fits, crank pins are finished complete except for wheel fit, etc., all of which goes to show that a large quantity of work, at least in railroad shops, requires minimum rather than maximum machine tool duty.

The heavy type of so-called high-speed lathe is practically built for forging lathe conditions and under these conditions requires high power to drive it, but when, as is frequently the case, this same tool is installed in a railway shop where much smaller cuts are the rule, it is not necessary to provide for such great power, as the full capacity of the tool is never utilized.

In order to utilize the full power of such a machine, it is necessary to raise the cutting speed in the same proportion as the area of the cut is reduced, but this is not always possible. For example, a $\frac{3}{8}$ in. by $\frac{1}{8}$ in. cut was taken at 38 ft. per min., while with a cut of $\frac{3}{16}$ in. by $\frac{1}{8}$ in. only 52 ft. per min. could be obtained. With one-half the area of the cut, the cutting speed could be increased only one-third, resulting in the removal of only 57 per cent as much metal. If the full capacity of the machine is not possible, why pay the price for a high-power motor when a saving in first cost is possible by the selection of a motor more suitable and a better efficiency can be obtained by running the motor more nearly up to its normal capacity? A 10 per cent loss in efficiency on a 15-h.p. motor capitalized at 10 per cent per annum would amount to $750. The same policy carried out among a large number of machines would result in a considerable saving.

The formula in Par. 185 can be simplified and made more workable if stated as

$$\frac{\text{diameter} \times \text{r.p.m.}}{3.82}$$

This affords a very expeditious method of finding by the slide rule the cubic inches of metal removed per minute, which equals diameter $\times$ r.p.m. $\times$ 3.15 depth by feed. Substituting the values given by Mr. Robbins, we have $5.5 \times 45 \times 3.15 \times 0.45 \times 0.06 = 21$ cu. in.

Gano Dunn.[1] It is not a question of whether or not we should have electric motor drive in a machine shop, but what kind of drive. If what Mr. Hess said is true, most of us are wrong, yet I think I am within the facts when I say there are very few machine shops built today that are not electrically driven. If we adopted Mr. Hess's methods of equipping a factory, we should have the conditions shown in Fig. 21 of Mr. Riddell's paper. It is obvious that his form of machine shop is obsolete.

After all, the cost of power in our plants is not the principal ques-

[1] Vice-President, Crocker-Wheeler Co., Ampere, N. J.

tion. Some years ago I gathered figures which showed that the cost of power in the average machine shop was only about two per cent of the value of its product. That indicates that questions of saving in power are of minor importance.

With Mr. Hess's suggestion, where should we come out on the other vital part of the question, the capacity or output? The day of the electric motor in a machine shop is the day of the red-hot chip. It has driven out belts in the same way that it has driven horses from the front of street cars. It is successful, it is practical, and it is the one thing that fills all our wants, because it gives us all the power we want, where we want it, when we want it, and as we want it.

Mr. DeLeeuw's paper and Mr. Robbins' paper are dictionaries of the art of electric driving. In connection with the classic paper of Mr. Taylor, On the Art of Cutting Metals, we now have a reference library to which we can turn for almost any question likely to come up.

I do not believe there is any specific rule that can be laid down to guide an engineer in the layout of a machine shop. Each case must be decided on its own basis. My view of how much power it takes to run a particular machine tool is that it depends on who is the superintendent of the shop. The problem is principally one of capacity. The enormous capacity we can put into a tool by means of the electric drive, to say nothing of all the other advantages that have been rehearsed, it seems to me not only settles the question now, but will continue to settle it.

In the very early days, when it was hard to get the attention of manufacturers to the subject of the electric drive, we had to use the argument that it saved power. Then there came a time when it was admitted that electric motors were good for ordinary work, but could not drive rolling mills. And now the climax of rolling-mill development is capped when we see a 6000-h.p. induction motor driving the mill at Gary. I feel that we have now closed the first chapter on the art of the electric drive in machine shops.

FRED. L. EBERHARDT, Vice-President of the National Machine Tool Builders' Association, gave a summary of the progress made toward the standardization of motors for machine tools by a committee from his association in conference with one appointed by the American Association of Motor Manufacturers. Fifteen points were proposed for discussion by the former committee, of which seven were agreed upon and have since been adopted by the motor manufacturers. The remaining eight are still being studied and discussed. The following quotations from the report of the committee on standardization of motor drives for machine tools to the Rochester convention of the National Machine Tool Builders' Association, May 24, 1910, outlines the present situation:

1 *Horse-Powers.* It is thought that the following horse-powers will meet practically all the requirements of electric drives for machine tools: 1, 1½ (for D. C. only), 2, 3, 5, 7½, 10, 15, 20 and 25. Though it was agreed that horse-powers more than 25 and less than 1 are used, it was not thought advisable to embody them at the present in the attempted standardization.

2 *Voltage.* It is recommended that for D. C. motors 115 and 230 volts be adopted as standard, and for A. C. motors 110 and 220 volts. There is now a good deal of confusion as to voltages for D. C. motors. The motor manufacturers have reached an agreement among themselves as to these voltages, and the 115 and 230 voltages recommended by them represent the nominal voltage of the system, and not the real voltage at the motor.

3 It is recommended that the horse-power ratings for machine-tool drives be the standard ratings of the American Association of Electric Motor Manufacturers, i.e., (*a*) that motors be given the continuous constant horse-power rating where approximately standard load conditions exist; (*b*) for adjustable-speed motors used for intermittent service the standard two-hour continuous-duty rating be used for ordinary shop conditions and that the name plates of such motors indicate the time as well as horse-power ratings of the motor, and further that the horse-power be figured at the high as well as the low speed for adjustable speed service.

4 *D. C. Motors.* It is the recommendation of the joint committee that constant speed motors, adjustable speed motors with a range of 2 to 1, and adjustable speed motors with a range of 3 to 1, be included in the attempt at standardization. This does not exclude the occasional use of motors with a different speed range, such as 4 to 1, or even more; but it was the opinion of the committee that motors with a higher range of speed than 3 to 1 are not used to a sufficient extent and are not so absolutely necessary for machine-tool construction as to include them among the standardized motors.

5 The following table of speeds is recommended as the standard for adjustable speed D. C. motors:

h.p.	2 : 1	3 : 1
25	900—450	900—300
20	900—450	900—300
15	1200—600	1200—400
10	1200—600	1200—400
7½	1200—600	1200—400
5	1200—600	1200—400
3	1500—750	1500—500
2	1500—750	1500—500
1½	1500—750	1500—500
1	1500—750	1500—500

6 *A. C. Motors.* It is recommended that the following table of polyphase 60-cycle A. C. motors be adopted:

25 h.p.	900 and 600	5 h.p.	1200
20 h.p.	900 and 600	3 h.p.	1200
15 h.p.	900 and 600	2 h.p.	1200
10 h.p.	1200 and 600	1 h.p.	1800 & 1200
7½ h.p.	1200 and 900		

7 For the consideration of the constant-speed A. C. motors, 60 cycles is to be used as the basis.

8 *Shaft Diameter.* It is recommended that the shaft diameter be figured according to the formula $D=C\sqrt{\frac{\text{h. p.}}{S}}$ in which C is a constant to be agreed upon by motor manufacturers, D the diameter, and S the speed; it is further desired that all diameters up to and including one and one-half inches be given in one-eighth of an inch, and all diameters above one and one-half inches be given in one-quarter of an inch.

9 *Length of Shaft.* It is recommended that there shall be a fixed proportion between diameter and length; the constant to be determined by the motor builders. Further, that the shaft be rounded at the end.

10 *Keyways.* It is recommended that keyways be made for square keys and that the key be equal to one-fourth the diameter of the shaft.

11 *Driving Fit.* It is recommended that there be added to the standard dimensions of the shaft 0.0005 in. for every half-inch diameter of the shaft or fraction thereof.

12 *Variation.* It is recommended that shafts shall not be under the specified size, but may exceed same by 0.0005.

13 *Height of Centre.* The height of center to be given in full one-fourth inch, and shall not be less than figured dimension, but may exceed this dimension by one thirty-second.

14 *Clearance Circle.* It is recommended that the clearance circle around the motor shall have a diameter of one-half-inch less than twice the centre height.

15 *Base.* All motors to be held down by four bolts. Bolt holes to be drilled one-sixteenth above size of bolt required. Bottom of motor to be planed parallel with the shaft of motor. It is further recommended that the bolt holes be placed in a configuration of constant proportions, preferably in a square, and that the dimensions of this configuration be made a function of the horse-power divided by the speed, and further that all dimensions be given in the nearest higher one-fourth inch. The feet of the motor should extend beyond the body sufficiently to allow for drilling and reaming of dowel pin-hole while motor is in place.

DISCUSSION AT NEW YORK

CHARLES FAIR.[1] It is disappointing that so many of the tool builders fail to take advantage of the increased production which would result from proper attention to convenience of control. There are many cases where the tools are so arranged that the control

[1] General Elec. Co., Schenectady, N. Y.

might easily be damaged by trucking, etc., and sometimes the control is placed 40 or 50 feet away from the motor, necessitating considerable useless wiring. Others often place the operating handle in such a position as to make a back-breaking job for the operator.

For electrical reasons it is of course not practical to build motors with a ratio so great as 15 to 1, nor can I agree with Mr. Eberhardt that such a large ratio would be desirable or necessary for a large majority of the work. The standardization of speeds and principal dimensions is not impossible, but that the tool builders would be satisfied with any standard is not at all probable, inasmuch as there is a decided difference of opinion among them as to both speeds and shapes of motors.

An unfortunate circumstance which often surrounds discussions relating to electrical apparatus for tools is a lack of knowledge on either side of the limitations and requirements of the other. Much of the trouble which tool builders are experiencing today could be eliminated were they to discuss their difficulties more freely with men who are conversant with both sides of the subject.

A. L. DeLeeuw. Generally speaking, the machine tool builder does not know to what purpose his product will be applied by the consumer. It is true he knows in a general way that a lathe will be used for turning and a drill press for drilling, but he has no knowledge of the methods employed in the shop where his product is to be used, nor whether his machine will be used for general work or for some special operation. The machine may never be called upon to work up to its maximum capacity, and yet it may be called upon to do this all the time. If the machine is to be supplied with a motor, the only safe thing is to attach a motor of sufficient capacity to run the machine all the time up to its maximum output. Even if it is known that the machine will be used for light work by the man who buys it, yet it may some time come into other hands and be used for entirely different purposes. Hence, unless the machine is supplied with a sufficiently large motor, the design may be condemned at some time.

It is true that in general machine tools do not operate at their maximum capacity or even at the rated capacity of the attached motor more than one-third to one-fifth of the time, so that in the majority of cases a much smaller motor can be used than would be required if the machine were constantly working at full capacity. However, the machine tool builder has no guarantee that this general rule will apply to his machine. The tendency nowadays is to specialize in the use of machine tools and to subdivide operations in the shop. Whereas a few years ago it was the custom to give a shaft to some lathe hand to be turned and let him finish all operations on this shaft, preferably in one setting, now it is more common practice first to rough a lot of shafts, then finish them in a subsequent operation, and then perhaps grind them for a final finish. Wherever it is possible to do so, these operations are again subdivided.

The subdivision of operations, when carried out to its limit, makes operations in the shop extremely simple, requiring no adjustments of feeds or speeds while a lot is run through the machine, and calling for only a single tool. Where operations are carried through in this manner it is often possible to make them continuous. By this is meant that the process is so arranged that both machine and man are working all the time, or at least practically so. The vertical milling machine, for instance, in milling flat surfaces, may do so with the use of a rotary table and a multiple fixture mounted on this table, whereby it becomes possible for the operator to load and unload one piece while the cutter is acting on another piece. In this case the feed is adjusted to such a rate that the operator has just time enough to load and unload while the cutter passes over one piece. Where the piece is so small that the time for cutting is materially less than for loading, more than one operator may be used on such a machine; where it is much more than for loading, one operator may attend to two or three machines. In all cases the highest attainable economy is reached when both operators and machines are working all the time, and the rate of work should be such that the machine can keep it up without breakdown, and the tool not need an excessive amount of regrinding, nor the operator be fatigued by too rapid work.

Though the example given above is perhaps the most perfect application of this system of continuous operation and though rotary fixtures cannot always be applied, there are various means by which this same degree of efficiency can be approximated. The table of the milling machine may be given a reciprocating motion, either automatically or by the hand of the operator, at the end of each cutting stroke. In this case two fixtures are used. Again, a single fixture may be used with two loading fixtures, which can readily be clamped in the stationary fixture on the table of the milling machine, so that only a very small amount of time is lost between cutting operations. The relative cost of labor and machine burden would determine whether it would be better to slow the feed down so as to give the operator time to load a fixture or whether two operators should be employed for one machine.

The same degree of efficiency can often be reached in lathe operations by providing the operator with two mandrels and dogs and shading the cutting operations down to a point where the time of cutting is just slightly longer than the time for removing a piece from one mandrel and loading a new one. Here again two operators may be employed or one operator may run two machines. There are many cases where the time of the cutting operation is considerably longer than the time required for preparing a new piece for the machine. In such cases it may often be found advantageous to divide the cutting operation into two parts so as to have the time for cutting more nearly equal to that for loading. In a similar way, efficiency on the grinding machine can often be reached by grinding in two operations, one rough and the other for finish. Drilling also lends itself in many cases to the application of this plan, especially where gang drills are used.

The application of this principle of keeping both machines and operators busy all the time at their maximum efficiency leads to many interesting problems in the machine shop and could be carried very much further than is done at the present time. The application of this system, however, imposes much heavier duty on the machine tool, and would not allow, therefore, of applying to such tools motors which have been rated on the assumption that they will not be called upon for more than two hours continuous service.

Carl G. Barth. The various advantages of motor drives over belt drives have been thoroughly and ably set forth, but I cannot let go unchallenged the claim of closer speed regulation.

While speed controllers of motors are frequently arranged to give successive speeds varying nominally by as little as 5 per cent, the variation in speed consequent on a variation in load is so great as to make it practically impossible to tell beforehand what controller point must be used to insure a predetermined cutting speed for a given piece of work, as required by the most advanced shop management of today.

As an exponent of such management I have therefore been forced to remain an advocate of belt drives in preference to individual motor drives; for if a belt is properly cared for and not required to transmit an undue amount of power, its speed variation with load variation is only a fraction of that of an individual motor under the same conditions.

This does not mean that I never advocate individual motor drives, for frequently the real advantages of such drives are so great as to outweigh entirely the consideration of the greatest constancy of speed. I hope the time is not far away when motors will be built at a reasonable cost that will be so nearly constant in speed at all controller points, regardless of load, that they will possess incontrovertibly all the advantages claimed for motors in the papers before us.

In fact, I have recently learned of a company that expects soon to put on the market a line of 3-to-1 adjustable-speed motors with no greater variation then 4 per cent in any part of the entire range of speeds and loads. If these motors actually materialize, a great step will have been taken towards the millenium of the machine shop engineer vitally interested in cutting speeds. But nothing is yet in sight that promises entirely to replace the belt.

John Riddell. Ball bearings are undoubtedly very valuable, but nothing has been said about the quantity of belts required to go with lineshafting in an establishment like the General Electric Company. I pointed out in my paper by very conservative figures that had we continued putting in lineshafting, countershafts, hangers and belts, we would use approximately 6½ miles of lineshafting, about 4¾ miles of countershafts, 21,225 hangers, and about 80½ miles of belts. These figures were based on 8500 machine tools. We have in addition to this number possibly 2000 other machines, most of which are driven by motors. These would require many additional feet of shafting and belts, and a great many more hangers or roller bearings. We know from many years experience that the upkeep and attention required by such material are very great.

Machine tool builders seem to think that every electric motor is made for some machine tool, whereas less than 3 per cent of the motors turned out by the General Electric Company are used for this purpose. If the tool builders would standardize their tools so that the same motor would do for the same nominal size of lathe, milling machine, or any other machine tool, the results would be more satisfactory. It would be useless for us to undertake to standardize 70,000 or 80,000 motors when only about 2000 of them would be used for machine tools and these widely distributed over many types. It would not pay any concern turning out electric motors to attempt to standardize for machine tools, especially since they are rapidly being changed and developed. Many machine tools are made to double the work today that they did a few years ago, and had motors been standardized then they would have undergone constant changes. I speak from the standpoint of the middleman, being partly an electrician and partly a mechanician, and knowing the difficulties from both sides.

H. A. Hornor.[1] In a plant which requires a number of tools of large size for operating blacksmith, plate, angle, forge, pattern and joiner shops, the machine shop bears a less important relation to the total power consumption. For the operation of this class of tools constant-speed motors with heavy starting torque, capable of withstanding prolonged overloads, are satisfactory, as the work does not require close adjustment of speed. With an ample power supply of alternating current the losses are reasonably low and are due in large part to the variation of the product. Under these circumstances the induction motor can be used with great economy. It is thrown on the line and reversed with a simple knife switch, requiring no starting compensator and permitting quick stopping and reversing. The induction motor, if substantially designed, will withstand all the shocks which severe duties demand and will cause little trouble or expense. A 50-h.p. squirrel-cage induction motor has operated a jogging machine for ten years with no other attention than the oiling of the bearings. The plant with which I am connected was equipped with induction motors at the time when the individual motor drive was an experiment and it may be conservatively stated that after a decade it has fulfilled every promise which its advocates claimed at its installation.

W. S. Chase.[2] With reference to the statement in Par. 82 of Mr. DeLeeuw's paper that variable-speed motors should always be used with screw machines, our company has had on the market for two years an automatic screw machine, usually driven by a single belt, all the speeds necessary for the production of any part being controlled within the machine beyond the point of application of power. For electric drive it is merely necessary to supply a motor instead of a belt and the motor may be of any type, alternating or direct-current, of any standard make, and of constant speed. We believe that we were the first to adopt this self-contained single drive on the automatic screw machine, although similar machines have recently been placed on the market.

[1] New York Shipbuilding Co., Camden, N. J.
[2] Manager of Sales, National-Acme Mfg. Co., Cleveland, Ohio.

Clarence L. Collens, 2d.[1] I will limit myself exclusively to adjustable-speed direct-current motors and certain phases of their use in manufacturing machine shops, where the variable-speed machine tool plays an important part in the process of manufacture.

Flexibility of Speed Control. In order to deal with definite figures instead of general statements Table 23 is submitted. This table is intended to give an idea of the average speed adjustments possible with belt-driven tools, or with gear-box-driven tools using constant-speed motors. By belt-driven tools is meant tools having

TABLE 23 SPEED CHANGES ON TYPICAL MACHINE TOOLS

	Spindle Speeds or Cutting Strokes Per. Min.		Belt-Driven Cone Pulley Types				Gear-Box Types using Constant-Speed Motors			
			A		B		A		B	
	Total Range	Ratio	no.	per cent	no.	per cent	no.	per cent	no.	per cent
24 in. Engine Lathe	3.5-350	1:100	10	66.8	24	22.2	8	93.0	12	52.0
24 in. Engine Lathe	10-360	1:36	10	48.9	24	16.9	8	66.8	12	38.5
4 ft. Radial Drills	20-320	1:16	8	48.6	16	20.3	12	28.6	24	12.8
No. 3 Plain Miller	12-360	1:30	12	36.2	18	22.2	8	62.6	18	22.2
42 in. Vertical Boring Mills	2- 60	1:30	10	45.9	20	19.6	10	45.9	15	27.5
24 in. Crank Shaper	6- 96	1:16	8	48.6	8	48.6	8	48.6	10	36.1
24 in. Drill Press	12-300	1:25	8	58.4	8	58.4	8	58.4	16	23.9
Average percentage jump at each speed change				50.5		29.7		57.7		30.4
Average percentage which cutting or peripheral speeds must necessarily be below maximum if each tool is doing a large range of miscellaneous work				25.3		14.9		28.9		15.2

cone pulleys for speed control. Six representative tools are shown, with a total range of spindle speeds or cutting strokes, indicated for each, which I believe not only represents a fair average of the speeds for which such tools are now designed, but also fully covers all the requirements of the class of work for which each is intended. In the case of the lathes, two different ranges are shown, as it is hard to give a single ratio which will fairly represent all makes and classes.

[1] President, Reliance Elec. and Eng. Co., Cleveland, Ohio.

Under both the belt-driven tools and the gear-box tools, columns A and B represent, respectively, the minimum and the maximum number of speed changes found in standard tools of the types shown. In each case both the number of changes and the percentage jump in speed at each change are shown, assuming that the speeds are in geometrical progression. The average practice is more nearly represented by column A than by column B. In some cases the maximum number of speed changes for the belt-driven tools is greater than for the gear-box types, due to the use of countershafts arranged for two and in some cases three speeds.

Compare the figures indicated in the table with the results which can be obtained by using adjustable-speed direct-current motors. With the speeds in geometrical progression and a controller having 20 contact points for speed adjustment, the jump in speed between each step for motors with 1:2, 1:3 and 1:4 speed ratios will be 3.7, 6.0 and 7.6 per cent respectively. With the armature-shifting type of adjustable speed-motor there is of course no jump, the speed change being continuous.

From this definite comparison it is almost self-evident that there will be many conditions of work under which the use of the adjustable-speed direct-current motor will result in an increase in the productive capacity of the machine tool of at least 5 per cent, and in many cases 10 per cent, as compared with any form of group or constant-speed gear-box drive. In many cases the greater accuracy of speed adjustment will in itself produce such an increase, and when there is added the greater ease and convenience of making the speed change, the probabilities are more than doubled.

In large manufacturing machine shops using specialized tools and limiting each tool to practically single operations with very little change in the size and character of the work on each tool, the question of accurate speed adjustment is of lesser and in some cases of no importance, but this is not true of the medium-sized or comparatively small plants. In such plants there is not enough work of any one character to justify a specialized tool, and in consequence each tool of the variable-speed variety is called upon to work continuously over a wide and miscellaneous range of work. Does a 5 per cent increase in productive capacity justify for work of this character the use of the individual adjustable-speed motor?

In a small or medium-sized manufacturing machine shop, the average maximum power requirements per tool will usually run well under 5 h.p. Taking 30 cents per hour as the average rate of pay and

30 cents per hour as a fair and probably low overhead charge per tool, the total expense per tool per year of 3000 hours amounts to $1800. Using this figure, 1 per cent increase in productive capacity means an annual saving of $18 per tool.

Even taking into account the much lower capacity per tool of the group-drive motor, the difference between the cost of any form of group-drive installation and the individual-drive adjustable-speed motor, including the cost of mounting on the tool, will in some cases be as low as $200 per tool and will rarely exceed $350 per tool in a plant of the size under consideration. Assuming 15 per cent as the rate of interest and depreciation, an increase in productive capacity of from 1.7 per cent to 2.9 per cent will capitalize the additional investment, and from 11 to 20 per cent will pay for it in one year.

Even assuming that the plant rents power from some central station and is on the outskirts of a city where only alternating current is available, the additional cost of the motor-generator set will run from $30 to $60 per tool, depending on the size of the plant and the number of variable-speed tools. With the 5-h.p. maximum motor capacity per tool, the generator capacity will be about 2 kw. per tool. An increase in productive capacity of from ¼ to ½ per cent will capitalize the motor-generator investment and from 2 to 3 per cent will pay for it in one year.

The total additional cost of the direct-current motors and generators, even taking the maximum figures given, will thus be capitalized by 3½ per cent increase in productive capacity. Five per cent increase in output means a saving equal to practically 25 per cent of the additional cost of the investment, whereas 10 per cent pays for the change in two years.

These figures are well within the possibilities of attainment. It is assumed, however, that the plant is crowded for work and is in a position to sell the additional output. This is a fair assumption, as I believe a plant which is not working full capacity would not be apt to consider any change in its power equipment. As Mr. DeLeeuw has said, an increase in the amount of chips per hour is a more vital factor than any relative saving or loss in different methods of transmitting power.

Speed Ratios for Direct-Current Adjustable-Speed Motors. In Appendix No. 3 of Mr. Robbins' paper, he has in all cases shown 1:3 as the ratio for adjustable-speed direct-current motors. I agree with Mr. Robbins that this will probably become the ultimate standard for many classes of machine tools, but I do not feel that it will ulti-

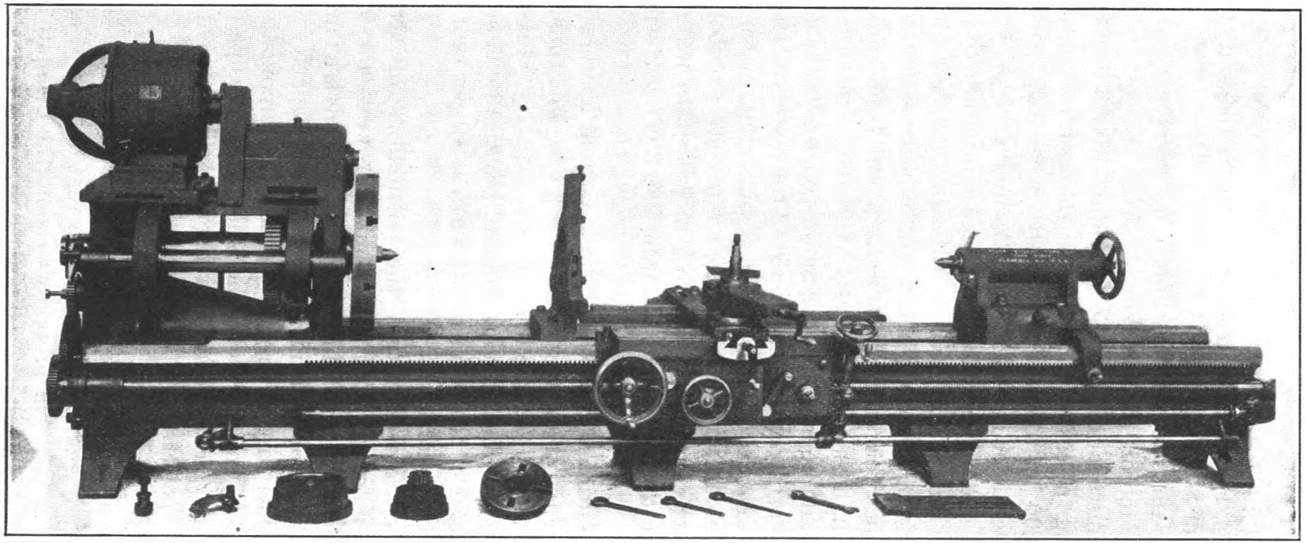

Fig. 40 Application of Armature-Shifting Motor to a Lathe

mately become the standard for all classes, nor does it lend itself entirely to current designs.

The choice of the proper speed ratio for an adjustable-speed motor resolves itself into a very careful study of the ratios of the different gear changes for which the tool is arranged. In the case of engine lathes a motor of 1:3 or even 1:2 speed ratio is usually wholly satisfactory, due to the fact that more attention has probably been given to the application of motors to lathes than to any other tool, and in the designs of motor-driven lathes there are always a sufficient number of gear changes so that the jump in speed between gear changes is rarely more than 200 per cent and is therefore completely covered by an adjustable-speed motor of 1:3 speed ratio. This also applies to millers, radial drills, boring mills, etc., with double instead of single back gears.

There are, however, a large number of tools, including many millers, boring mills, radial drills, drill presses, shapers, etc., which when belt-driven have merely a cone pulley and a single back gear. When an adjustable-speed motor is applied to such a tool, as a rule it merely takes the place of the cone pulley and no change is made in the back-gear ratio, which is seldom less than 1:4 and is in many cases greater than 1:6. In consequence, there are many tools on which the use of motors with 1:4, 1:5, or 1:6 speed ratios is not only wholly practical, but is more economical from an operating standpoint in all cases where accurate speed control is in any way essential. Unless a motor is used whose range of speeds has the same ratio as the back gear, there will be a jump or gap of greater or less magnitude right in the center of the entire range of spindle speeds. It seems illogical to provide close speed adjustment over part of the range and not to provide it over all.

Take a tool with eight spindle speeds in geometrical progression from 20 to 320 r.p.m., obtained with a four-step cone pulley and a single back gear. Without going into the theory of geometrical series, the ratio from the first to the fifth speed in this series is practically 1:5. This fixes the ratio of the back gear for the cone-pulley type of tool. If a 1:3 motor is used with this same back gear, the speeds obtained are 20 to 60 r.p.m. with the back gear in, and 100 to 300 r.p.m. without the back gear, leaving a jump of 67 per cent between the two series. As speeds below 40 r.p.m. and above 200 r.p.m. are probably not used more than 10 per cent of the time, this means an important break in the center of the active range. This jump may not look very serious with a 1:5 back-gear ratio, but in many cases the ratio is 1:6, meaning a jump of 100 per cent.

In this same case a 1:5 motor would give speeds from 13 to 64 r.p.m. with the back gear in, and from 64 to 320 r.p.m. without, leaving no jump or break in the entire range. A still more satisfactory arrangement would be obtained if the tool manufacturer changed the ratio of his back gear from 1:5 to 1:4 when furnishing his standard

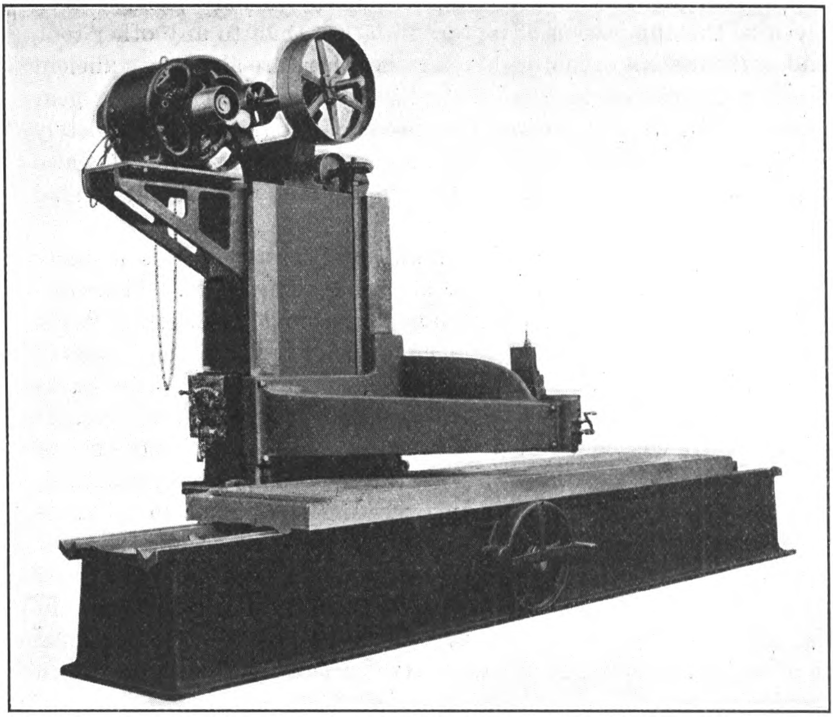

FIG. 41 ARMATURE-SHIFTING MOTOR APPLIED TO A PLANER

tool with motor drive. If this is done, a motor with 1:4 speed ratio is just as satisfactory as the 1:5 motor, gives an unbroken range of spindle speeds, and is less expensive. The range of spindle speeds then becomes 20 to 80 r.p.m. with the back gear and 80 to 320 r.p.m. without.

I would not make this criticism if the machine tool manufacturer made a practice of changing the ratio of his back gear when furnishing certain standard belt-driven types of tools equipped for drive by an adjustable-speed motor. There are many tools with single back gears whose total range of speeds is 1:16 or slightly greater and to which the addition of a second gear change for motor drive would add unwarranted expense. In most cases a change in the ratio of the back gear would add practically no expense, would simply mean a few additional stock gears for the manufacturer, and would make a motor-driven unit which is much more satisfactory to the purchaser. A motor with at least a 1:4 speed ratio should be used on these tools.

A motor of at least 1:4 speed ratio is also desirable on any variable-speed tool which, when belt-driven, is provided with no back gears. Slotters and some types of bolt machinery come in this class.

On certain specialized tools a consecutive range of spindle speeds with graduations not exceeding 5 per cent is not always necessary. Take for instance a driving-wheel lathe, used almost exclusively on two diameters of work, the outer tire and the finished spots on the axle for the bearings. A single back gear, taking into account the difference in the diameter of the axle and tire, as well as the difference in the materials of which these are made, and a motor of 1:2 speed ratio would be wholly satisfactory, even though this left a break of over 200 per cent in the center of the entire range of spindle speeds.

Applying Motors to Old Belt-Driven Tools. Another field for a motor of at least 1:4 speed ratio is in conversion to motor drive of old belt-driven tools. The majority of these have merely single back gears and the ratio is rarely less than 1:6. In changing many such tools for motor drive, especially the smaller and medium-sized machines, it is not only simpler but in many cases less expensive to use a wide-range motor rather than to install additional gear changes.

Types of Adjustable-Speed Direct-Current Motors. There are two distinct types of adjustable-speed direct-current motors used for machine tool work, both operating on the same final principle, namely, the increase in speed of a direct-current motor with any decrease in the strength of the magnetic field within which the armature rotates. In one type the strength of the magnetic field is varied by the use of resistance in the field circuit, and in the other the magnetic reluctance of the magnetic circuit is changed by sliding a slightly cone-shaped armature laterally away from its normal position directly beneath the main poles.

The characteristics and advantages of the armature-shifting type of motor for machine tool work are briefly as follows:

a No resistance controller is required. The speed control is mechanical, obtained by turning a hand wheel, an operation with which the machinist is thoroughly familiar. This hand wheel can be located at any point convenient to the operator.

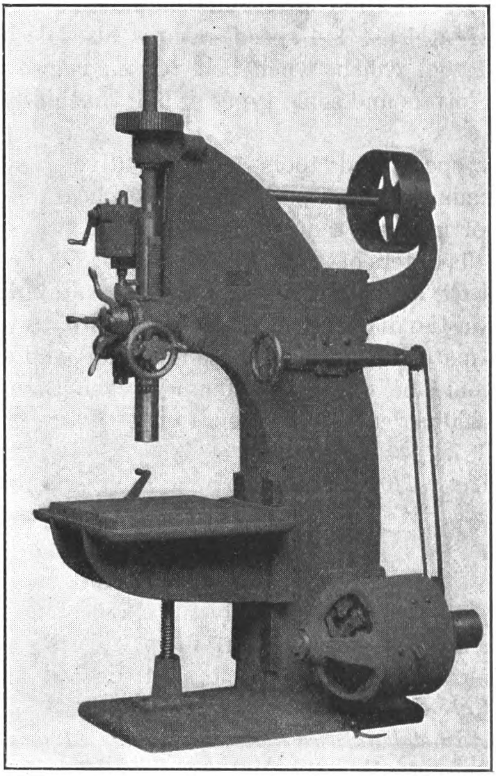

FIG. 42 DRILL PRESS DRIVEN BY AN ARMATURE-SHIFTING MOTOR

b The speed control is a distinct and separate operation from the starting, stopping or reversing of the motor. Two advantages are derived from this: (1) automatic-type starters can be used, taking entirely away from the machine-tool operator all electrical control of the motor and all possibility of abuse to motors, starting equipment or controllers; (2) when the speed is once set, the motor can be started and stopped as often as is necessary to caliper work or sharpen tools without affecting the speed-setting. In the case of unskilled operators, the speed can be set by a speed boss and cannot be tampered with.

c A continuous speed-change is obtained instead of jumping by steps.

d The field distortion due to full-load armature current is practically no greater at high speed under weak magnetic field than at low speed under full magnetic field, due to the fact that under decreasing magnetic field the magneto-motive-force remains constant, the air-gap length is increased and the air-gap area decreased. Satisfactory commutation is therefore obtained over wide speed ranges and is still further augmented for heavy overloads by the use of interpoles.

e Wide speed ranges are secured without excessive cost. These are very often found valuable in applying adjustable-speed motors to machine tools having single back gears, or in converting to motor drive old belt-driven tools.

Methods of Applying Armature-Shifting Motors. The convenience of speed control with a field-resistance drum-type controller has been well illustrated and is always important from an operating standpoint. Equal convenience can also be obtained in the arrangement of the mechanical speed control of the armature-shifting type of adjustable-speed motor. Fig. 40 shows a 30 in. by 24 ft. engine lathe with the mechanical speed control operated from the crank handle at the right of the lathe apron, the connection to the motor being obtained by means of a splined shaft running along the lathe bed. A second splined shaft operated by a hand wheel, also at the lathe apron, controls the full-reverse drum-type starter seen on the right at the end of the lathe bed. The two operations are therefore separate but are both controlled from the same point. Fig. 41 shows a satisfactory and convenient method of controlling the speed where the motor is mounted high on the machine tool. This is done by means of a pendent chain similar to that used on chain hoists. Fig. 42 shows a high-speed drill press with the hand wheel for mechanical speed control brought to a point within easy reach of the operator at all times.

Conclusion. No one type of drive entirely meets all the varying conditions which are found in machine-tool operations. There are many cases where I would recommend belt drive or speed-box drive with either group or individual constant-speed motors. Other conditions require adjustable-speed direct-current motors with field-resistance control, while in many others the mechanical speed control obtained with the armature-shifting type adjustable-speed motor offers advantages which cannot be obtained with any other method of machine tool drive.

The authors desired to present no closures.—EDITOR.