strength of the field; by varying the voltage applied to the armature terminals.

These characteristics make the shunt-wound motor most suitable of any for the purposes of machine-tool driving, and by means of these methods of control, either singly or in combination with each other or in combination with gearing, most of such work is now accomplished.

Speed Control.

A discussion of the principal methods of speed control may be of interest. If the armature current in a shunt-wound motor be decreased by inserting resistance, the field remaining constant, the speed of the motor will decrease. But when this method of control is used the motor loses one of its most valuable qualities. It will no longer run at constant speed under varying load. Besides, this method of control, like that of the series-wound motor, is very wasteful, and the controller must likewise be large and complicated to handle the large current which must be broken. This method, therefore, has ceased to be used to any great extent.

If the field strength of the shunt motor is varied the speed will vary accordingly, and in this method of control the bad features of the above method do not appear. The field current is small, and therefore the resistance loss small and the controller simple and cheap. The motor, likewise, retains its good quality of steady running. The power, however, falls off, for now the commutating ability of the field has decreased, so that less current can be passed through the armature. In order, therefore, to get a given output at higher speed with field control the motor must be larger than one built for the same output at the normal fixed speed.

To illustrate: A 4 h.p. motor at 400 revolutions per minute will give only 1 h.p. at 1,600 revolutions per minute with field control. It will be seen at once that in order to get a large range in this manner the motor must be very large. It will be noticed, however, that the characteristic of the motor fits the requirements of tools in class b, and it is therefore much used for driving this class.

Theory and Practice.

If the field strength is kept constant and the impressed volts at the armature terminals be varied, the speed of the shunt-wound motor will vary accordingly. Theoretically, this is a most excellent method of speed control, as it allows the use of a smaller motor than in the method of field control, and the efficiency of the motor at the various voltages is high. In practice, however, the number of voltages that can be supplied, is limited, and therefore in its simplest form the system has the same defect as the method of controlling alternating induction motors by changing the frequency. It is usual, therefore, to make the motors large enough to have field control sufficient to reach between voltages, which makes a system that completely covers the range between voltages and extends the range beyond the speed normal at highest voltage.

The Four-Wire System.

To illustrate: Suppose the range is 4 to 1, as before, and let the voltages be 60, 80, 110, 140, 190, 250, as used by the Bullock Co. in its four-wire system. Let the minimum rate at which power is required be 1 h.p. as before. Neglecting losses, this range of voltages alone would give six fixed speeds, and if, as before, the lowest is 400, the fastest would be about 1,600 or directly proportional to the voltages applied. The motor for this system would only need to be 1 h.p. at 400 revolutions per minute, instead of 4 at 400 revolutions per minute, as in the case of shunt field control. If now the motor is made large enough to stand an increase of speed by field control of about 33 per cent., it can be speeded up in that way from voltage to voltage, and the whole range covered. Further, when running at 1,600 revolutions per minute at 250 volts, it can still be speeded up to 2,133 revolutions per minute, making the total theoretical speed range 5 to 1.

Multiple Voltage Peculiarities.

Undoubtedly this system works well, but like all the others it has its defects. It is not desirable to carry high voltage round manufacturing plants, for obvious reasons, so that in order to get a large range in this manner the lowest voltage must be very low. To obtain the full output at low speed—and it has been seen that generally the greatest output is required at the lowest speed—the current must be increased; so that the expense of wire runs up rapidly for wiring the low voltages, or if the mains are kept down in size, the line losses are heavy, and the impressed volts drop off, the motor slowing down accordingly. Further, the obtaining of only six voltages by a four-wire system introduces considerable complication, as is easily seen, besides the extra expense for controllers, wiring, and the machines for giving the various voltages. A description of the latter is beyond the scope of this article. Generally a motor generator set of some form is run from the main series of the principal generating set which splits the voltage of these mains. Thus a 250-volt circuit can be divided by two wires from such a set into 60, 80 and 110 volt steps, and the combinations of these give six voltages. (See illustration.)

A Three-Wire System.

If a three-wire system, giving, say, 110 and 220 volts, as available, a speed range of 4 to 1 can be obtained in the following manner: Let the data be the same as above, and then for this case the motor will be a 2 h.p. motor at 220 volts and 800 revolutions per minute. When running on 110 volts and full field it will develop 1 h.p. at 400 revolutions per minute. Since the motor is running below normal speed it can be speeded up through a considerable range and still commutate well. By this means probably 60 per cent. increase can be obtained with the ordinary motor, when the voltage must be changed to 220 and full field applied for any further increase. On the higher voltage the field can be again weakened till the speed is doubled, and at 1,600 revolutions per minute, as the motor is now large for the work to be done, it will commutate all right.

In order to make a close comparison with the other systems this motor should be somewhat larger, say 3 h.p. at 220 volts, or $1\frac{1}{2}$ h.p. at 110, so as to cover by field control the whole range from 400 to 800. In such a case, however, a further increase in speed could be made when running on 220 volts, thereby extending the range somewhat.

Gearing with Field Control.

If it is not desired to use the excessively large motor resulting from entire field control or the complication of multi-voltage, a combination of field control and gearing can be used. Using the same data as before, the motor could be designed for a field control of 2 to 1, and a single set of change gears used in combination with it. Here the motor would be a 2 h.p. at 800 revolutions per minute, giving 1 h.p. at 1,600, and not exceeding the speed limit originally assumed. This method, which is a compromise between the other systems, has many good points. The wiring and generating systems are simple, as only a single voltage is necessary, and the motor need not be excessively large for the work, as it can be worked at the maximum range of speed which is allowable for gear connection. The voltage is always the highest permissable, hence the wiring is small; and while the multi-voltage system gives somewhat quicker change of speed, the difference in well-designed machines will not be very great.

In the writer's opinion it is a logical system, and will be very widely used in machine-tool work, mainly on account of its electrical simplicity. The efficiency of such a system is good, and if the gearing is properly designed the range covered by the motor alone need not be great enough to make it large and clumsy.

Sizes of Motors.

Table 2 shows the relative sizes of motors which must be used in the systems described, to cover the range from 400 to 1,600

System	400 Revs. per Minute			800 Revs. per Minute			1600 Revs. per Minute		
	Maximum H.P.	Current for H.P.	Volts	Maximum H.P.	Current for H.P.	Volts	Maximum H.P.	Current for H.P.	Volts
4 to 1 field control.....	4	3	240	2	3	240	1	3	240
4-wire multi voltage ...	1	12	60	2	6	120	4	3	240
3-wire multi-voltage ...	$1\frac{1}{2}$	6	120	3	3	240	$1\frac{1}{2}$	3	240
2 to 1 field control, with 2 to 1 gearing.......	2	3	240	2	3	240	1	3	240

Column 1 under each speed gives maximum horsepower motor will give.
Column 2 gives the ampere per horsepower.

Table 2.