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THREE-WIRE SYSTEM FOR VARIABLE SPEED MOTOR WORK.

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A description of the operation of variable speed D.C. motors on the three-wire system. Illustrated.

At the present time, when the possibilities of the electric motor are being realized and it is everywhere taking its place in factories, machine shops, steel mills and in practically every kind of industrial enterprise, the type of motor to be used and the best method of applying its power are much discussed topics in engineering circles. In deciding the type of motor to be used it is generally recognized that the alternating current induction motor has its own particular field; the D. C. and A. C. motors have a common field, and the D. C. motor in turn has its own special field. In deciding the method of applying the power, the choice lies between a separate motor for each machine and group driving of machines from counter-shafts driven by constant speed motors. If individual motors are selected, when variable speed is desired, there is the further choice between the constant speed motor with mechanical speed changing devices and a variable speed motor direct connected to the machine. In this latter class of work is found the special field for the D. C. motor.

Omitting cranes, street railways, hoists, and other classes of service where the series motor with rehostatic control is used, we find that variable speed motor work may be divided into three classes:

(1.)—Machines requiring a torque increasing with the speed. Blowers and fans belong in this class. The power required for the machine increases very rapidly as the speed increases and great care should be exercised in selecting motors for such service. However, as the variation required is usually small, the requirements can be met with standard motors on a single voltage system. Motors should preferably be compound wound and the speed should be varied by means of a resistance in the shunt field.

(2.)—Machines requiring a constant torque. In this class pumps and air compressors are the most conspicuous examples. The speed variation required for such service is usually small and it is generally best and most economical to supply compound motors and to vary the speed by means of the shunt field rheostat, as in the case of the fans and blowers. A series winding is especially beneficial for this class of work in preventing the heavy fluctuations of current that would take place with a constant speed motor in passing through the different parts of the cycle. A compound motor may be used for this work because a constant speed at any point on the controller is not necessary.

(3.)—Machines requiring approximately the same maximum output at any speed, or a torque varying inversely as the speed. This class includes most of the machine tool work where automatically constant speed regulation on any notch of the controller is especially desirable. It is, therefore, necessary to use a shunt motor having good inherent regulation.

It is the last named class of service that has caused the most discussion. Several companies have entered this field with different systems of variable speed motor control. Some of these companies are able to place their motors on the standard and well known systems of power distribution, while others seek to introduce special systems. The writer has been interested in the development of the three-wire system for this class of work, and it is the purpose of this paper to describe its operation and advantages.

The Generator:—The standard Edison three-wire system for general power distribution is so well known that it is unnecessary to describe it. The power station equipment, consisting of two 125 volt generators connected in series with the neutral wire brought out between them, is also well known and the single voltage generator with a motor-generator set of sufficient capacity to carry the unbalanced current, is used in many places. But the type of generator which is rapidly attaining prominence is the so-called three-wire generator, consisting of a standard D. C. generator designed for the maximum required e.m.f. having collector rings connected to the armature winding like a two-phase rotary converter. The leads from these rings are connected to auto-transformers or balancing coils, the middle points of which are connected to the neutral wire. With no external devices whatever, the neutral wire is thus maintained at a voltage midway between the outside wires of the system (see Fig. 1). These generators may be operated in multiple with any standard three-wire system, whether it consists of two machines operated in series, a single voltage generator with a balancing set, or a

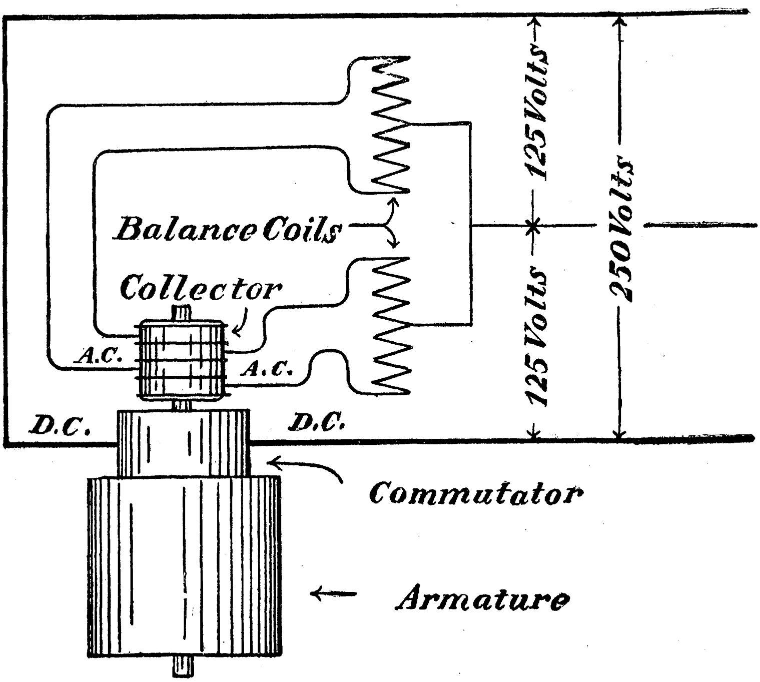

Fig 1.

double commutator generator. Any standard single voltage system may be changed into a three-wire system by adding collector rings to the generator and using balancing coils to supply the neutral wire.

The Motor:—The standard type of motor is used on this system. If only a small variation in speed is desired, as about 2:1 or less, only one voltage is used and the speed variation is secured entirely by changing the shunt field current. If wider variations are required, it is preferable to use the two voltages of the three-wire system. It is necessary simply to make a 220 volt motor connected so that it may be operated on either 110 or 220 volts. The minimum speed is secured on the 110 or low voltage circuit with full field strength. Any other speed less than double the minimum will be secured on the same circuit by decreasing the field current. All higher speeds are obtained on the 220 volt or high voltage circuit in the same manner. Operated in this way the motor is started on the 110 volt circuit, having in series with the armature a resistance, which is cut out for the first running notch. The speed is increased in successive steps by inserting resistances in the field circuit until the maximum 110 volt speed is reached. Then the controller changes the motor to the 220 volt circuit with a resistance in its armature circuit, and at the same time gives the motor a stronger field. The resistance in the armature circuit is used only in passing to the higher voltage, and is immediately cut out for the first runnnig notch. For higher speeds, resistances are again inserted in the field circuit, as before, until the maximum desired speed is reached.

In this manner a variation in speed of 1:6 is easily obtained. Greater variations may be obtained if desired, but are not to be recommended except in special cases, as the size and cost of the motor will be so great that larger variations than 1:6 are hardly to be recommended on any sytem. The size of motor is determined by the output at the lowest speed, so that unless the maximum speed is excessive, the motor size will be very large for the output required if variations even of 1:6 are required

Operation.

Commutation:—The operation of motors on this system is most satisfactory. The fact that the speed is increased so much by weakening the field might lead some to think that the commutation would suffer, but such need not be the case. An example will demonstrate the truth of this statement. A certain machine requires a 5 h.p. motor to operate it with a speed variation of 1:4, say from 375 to 1500 r.p.m. On the three-wire system this motor will be a standard 10 h.p., 220 volt motor operating normally at a speed of 750 r.p.m. Run with full field strength on the 110 volt circuit, it will develop 5 h.p. at about 375 r.p.m. Operating on this circuit, which has only half its normal voltage, the motor will easily stand an increase of speed 60 per cent. to 75 per cent., bringing the speed up to 600 or 650 r.p.m. When it is changed to the 220 volt circuit, it will have its normal capacity for 10 h.p. at 750 r.p.m.; but only half load is required and it will commutate this as easily at a speed of 1500 as it would 10 h.p. at 750, because both field strength and armature current will be divided by two. From this it may be seen that when the motor is running at full armature current, the voltage is only one-half the normal voltage. When the motor is operating at full voltage, the armature current is only one-half the normal current. If speed variations of 1:6 are required, they can be secured by a very slight increase in the normal field strength of the motor.

Regulation:—The performance of the motor in speed regulation on the separate controller points is very good. As the lowest voltage used is 110 volts, the proportion of voltage lost in resistance of motor, brushes, armature, controller and wiring will be very much less than it would be if a minimum voltage of 60 were used, consequently the speed regulation will be much better. On an extremely slow speed motor the resistances of the different parts of the circuit play a very important part in the speed regulation. Where a very low voltage is used the speed variation from no load to full load may be as much as 20 per cent. or 25 per cent.

Controller:—The smoothness of operation in changing from one speed to the next is very noticeable. The field strength changes very gradually no matter how suddenly the field resistance is changed. Consequently, there can be no sudden change in speed. In this respect it is better than a system which changes the speed by changing the armature voltage without a resistance in the circuit. At the only point where the armature voltage is changed on the three-wire system, a resistance is inserted in the armature circuit, which effectually prevents a sudden jump in speed.

EFFICIENCY.

Motors:—The efficiency of the motors, as well as of the entire system, is high. Operating on the low voltage, the motor is at all times running under full load conditions with the efficiency increasing as the speed increases, because the field current and core loss are decreased at the higher speeds. When operating at 220 volts at the minimum speed, the efficiency corresponds to the half load efficiency of the standard motor. As the speed is increased, the copper loss in the armature remains constant and the field loss and core loss decrease so that unless the increased friction overbalances them, the efficiency will increase up to the maximum speed. This is in marked contrast to a motor operated on a system supplying a different armature voltage for each speed. To fill the requirements of the above case on the multi-voltage system, a motor of the same weight but normally rated at 20 h.p., 220 volts and 1500 r.p.m. will be required. It will operate at a voltage of about 60 at minimum speed and will there require the normal full load current of the motor to develop 5 h.p. This would be double the current of the motor operated at 110 volts at the same speed; and while the copper loss in the armature and field and the core loss would be about the same as in the other motor, the loss in brushes would be doubled and the loss in controller and wiring very much greater. An increase in the speed will increase the core loss very rapidly, the field will remain constant and the copper loss in the armature will decrease. The efficiency of this motor may be explained by the statement that at the only time the motor is operating under its full load armature current, it is running at 60 volts and the efficiency is necessarily low. At the maximum speed where the normal voltage of the motor is reached, it operates at only one-quarter load and consequently with a low efficiency. At no point on the curve does its efficiency equal that of the motor on the three-wire system.

Transmission:—The efficiency of transmission on the three-wire system is high. Practically all of the current is transmitted at the maximum voltage, as the motors are equally distributed between the two sides of the system for their low speeds. The chances for unbalancing are thus very much less than on a multi-voltage system that requires all of the motors to have corresponding speed notches on the same circuit.

Generating Plant:—The efficiency of the generating plant is also a maximum. The three-wire generator itself has the same efficiency as the standard D. C. generator of the same capacity. The losses in the balancing coils with 15 per cent. unbalanced load will not exceed one-quarter of 1 per cent. of the capacity of the generator. This gives the most efficient type of three-wire generating apparatus. Comparing it with the complicated generating outfit required for a multi-voltage system, shows at once its superiority, both in efficiency and in the amount of attention required in operation.

Economy:—The three-wire system is very economical in the wiring. As practically all of the current is transmitted at the higher voltage, the neutral wire may be very small. In this respect also, it is superior to the multi-voltage system. The latter really has two neutral wires, but as the unbalancing is likely to be much greater, they must necessarily be larger than the neutral of the three-wire system, and all the wires would be larger if the same percentage of line loss were maintained. Branch lines to the motor, forming a considerable part of the total wiring system, must be much heavier than on the three-wire system as there are more wires, heavier currents to be carried and greater losses.

Controller:—The controller of the three-wire system is very simple. It is of the standard drum type, designed mechanically like a street car controller. It has the field and armature resistances in the base, making the whole controller very simple and compact.

The advantages of the system described in the foregoing may thus be summed up as follows:

(1.)—Simplicity, not only in the generating plant, but in the transmission lines, motors and controller.

(2.)—Efficiency in generating plant, transmission line and motor.

(3.)—Economy in first cost of generating plant and transmission lines.

(4.)—Constant speed regulation from no load to full load.

(5.)—Smoothness of operation in changing from one speed to another.

These advantages are all easily apparent for work where the motor output is the same at all speeds. In such work the weights of the motors will be practically the same as those on the multi-voltage system. But it is recognized that in work where a constant torque over a wide range of speed is required the multi-voltage system has certain advantages. The motor required will be smaller, depending on the range of speed to be covered However, for the small amount of such work that is to be done it is better to sacrifice a little in the size of a few motors than to introduce the complicated generating plant and the expensive transmission lines necessary for the multi-voltage system. Motors running on the three-wire system will meet all such requirements. It is only a question of making them large enough.

In cases where it is impracticable to have two voltages, and a wide range of speed is necessary, a double commutator motor may be used with excellent results. This motor may be built with both ends of the armature wound for the same voltage, in which case they will be connected first in series, then in parallel, giving speed changes corresponding to the speed variations on the three-wire system.