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Creators: Spohn, G. A.

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Testing Variable Speed Induction Motor

By G. A. SPOHN, '25

RUNNING tests in the electrical laboratory at school was very interesting, but it is a far call from these to tests conducted during the past summer on electric drive equipment for the rolling mill of a large steel manufacturer, in the Schenectady factory of the General Electric Company.

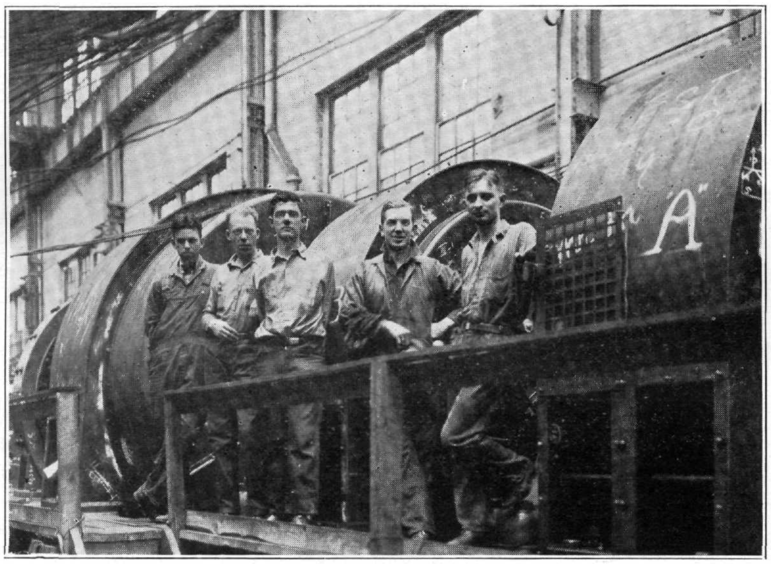
There were five men conducting the test, representing the following school: Oklahoma A. & M.; Carnegie Tech., Univ. of California, Michigan State and Ohio State.

Electric power in steel mills has been found to perform the manufacturing operations in a better, more efficient, and more reliable manner than otherwise possible, and many of these operations and processes would be practically impossible with any other form of power. Hardly any new mills are being equipped with anything but electric motors and older steam driven mills are being gradually electrified for purely economic reasons.

The equipment we tested was built for the Sparrows Point (Maryland) plant of the Bethlehem Steel Company and will drive a continuous rolling mill.

Following is a description of the motors, generators and control apparatus:

An adjustable speed induction motor with its Scherbius equipment consists essentially of two units, the main induction motor direct connected ohmic drop exciter; and the two Scherbius machines with direct connected synchronous exciter, driven by a 6100 k. va. synchronous motor which also drives a 2300 kw. direct current generator for a separate direct current supply.



Testing the Electrical equipment for the continuous rolling mill of the Sparrows Point plant of the Bethlehem Steel Co. G. A. Spohn is shown at the extreme left

THE SYNCHRONOUS EXCITER

The synchronous exciter has three field windings, the first is in series with a rheostat and is excited by means of 250 volts direct current, the second is across the armature of a small direct current generator driven by an induction motor which operates at slip frequency, and the third field winding is in series with the field winding of the above generator. The armature of the synchronous exciter is connected to the slip rings of the ohmic drop exciter. Thus the synchronous exciter supplies a variable voltage, constant frequency excitation to the ohmic drop exciter.

THE OHMIC DROP EXCITER

The ohmic drop exciter is in reality a rotary converter supplying a three phase voltage at slip frequency. The value of voltage obtained at the commutator of this machine is not dependent upon the slip of the induction motor as long as the voltage applied to its collector rings remains constant; however, this voltage will have a frequency the same as the slip frequency of the main induction motor because it has the same number of poles and is driven at the speed of the induction motor which is the synchronous speed plus or minus the slip.

The commutator voltage of the ohmic drop exciter is used to supply a part of the excitation to the field windings of the Echerdius machines. The rest of the excitation current for the Scherbius machines is supplied by means of an auto-transformer which is connected in Y across the slip-ring circuit of the induction motor.

The Scherbius machine is a three-phase commutating motor or generator on whose stator there are three shunt-field windings spaced 120 electrical degrees apart. The brushes in the commutator of the Scherbius machine are connected to the rotor slip-rings of the main induction motor. The two Scherbius machines operate of series to absorb or deliver power to the rotor of the main induction motor depending upon whether it is operating below or above its synchronous speed. There are other windings on the stator of this machine to improve the commutation.

SPEED REGULATION OF THE INDUCTION MOTOR

Since the Scherbius machines are capable of absorbing or delivering power at slip frequency to the ring circuit of the induction motor it is possible to vary the speed of that motor because the speed is dependent upon the voltage applied to the rotor circuit.

In all Scherbius equipment previously built the excitation voltage of the ohmic drop exciter was constant, and therefore the only way to vary the field strength of the Scherbius machine was by means of the taps on the auto-transformer excited

(Continued on Page 6)

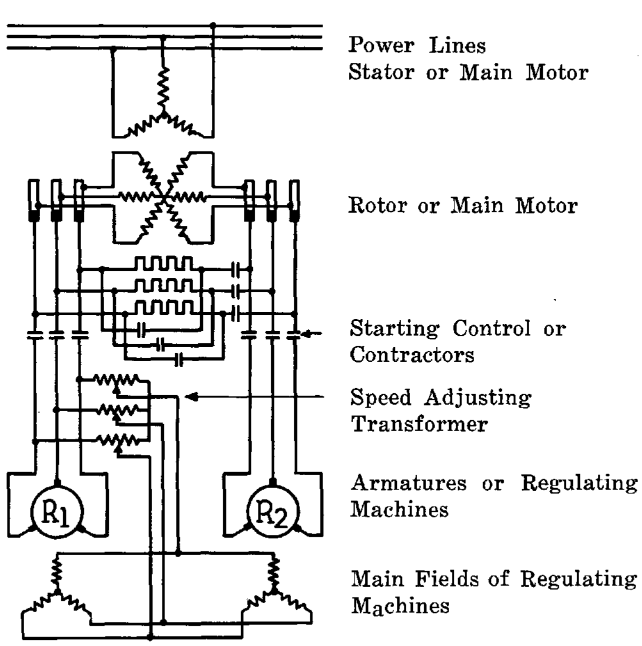
from the clip-ring circuit. Thus the main induction motor would have a series of definite speeds corresponding to the tap setting of the auto-transformer. From the preceding discussion of this set it may be seen that by adjusting the excitation voltage of the ohmic drop exciter it is possible to vary the speed between each of the rough points of speed caused by varying the voltage by tapping off from the auto-transformer.

Thus it is possible to get any speed desired between 250 and 500 r. p. m., and where fine control of the speed is necessary—as in some rolling mills—this feature is very important.

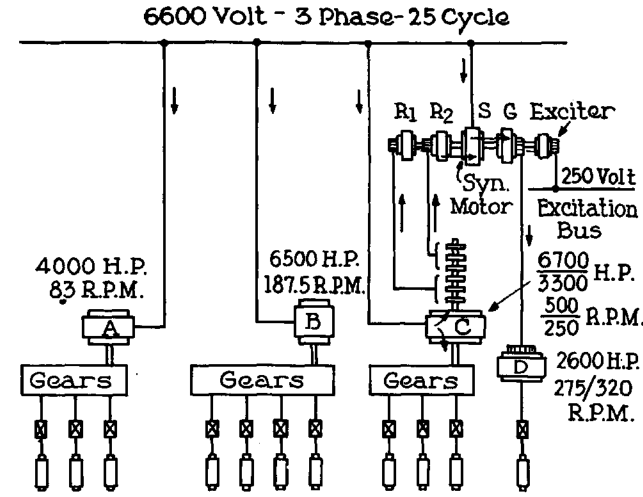
TESTING THE APPARATUS

The set was assembled on the test floor of Bldg. 18 and the first job of the testmen was to wire it up just as it would be wired if it were being actually installed for use. This was quite a task for it is no easy matter to drag thousand ampere cables around and to make connections in places where it is almost impossible to squeeze the human body.

But finally all the connections were made and everything was ready to put the set into operation. The induction motor was first operated and a great many readings taken at various speeds to be sure that it was working properly. It was found that some minor adjustments had to be made and so all of these readings had to be taken over again. Although I never heard anyone complain, I can imagine that many of the men were reading meters in their sleep. At last it was working properly, so it was mechanically connected to a three-phase alternator, the power from this alternator being pumped into a three-phase water rheostat. Thus by varying the resistance of the water rheostat or by varying the armature voltage of the machine it was possible to get any load on the induction motor that was desired. Again we took innumerable readings of all the currents and voltages until finally the set was running perfectly, from the top to the



Elementary diagram of electrical connections of a Scherbius adjustable speed drive with two regulating machines connected in series



Arrangement of electric drives for a larger continuous mill

lowest speed: and from maximum load to the point where there was no load on the induction motor at all.

Then came the well known heat run. This was taken at the lowest speed of 250 r. p. m., for it is at this speed that the most severe operating conditions are found. Thermometers were placed on all of the machines and readings of the temperature were taken every half hour until all were constant.

At last all of the operating tests were completed and the set was ready for its real work in the steel mill. The wiring that we had taken so much pains with was soon torn out and the machines were given the hi-potential test and the set passed on to the shipping department.

The Sparrows Point mill will have a number of stands arranged in tandem. The rolling requirements being different, the first several stands will be driven by constant speed motors. The power supply is 6600-volt, 25-cycle.

The roughing train will take a 4000-h. p., 83.3 rev. per min. motor, A, the intermediate train will be driven by a 6500-h. p., 187.5-rev. per min. motor, B. The following group of stands will be jointly driven through a train of gears by an adjustable speed equipment, C, developing 6700 h. p. at 500 rev. per min. and 3350 h. p. at 250 rev. per min.

The last finishing stand will take a separate direct-connected drive, D, with an output of 2600 h. p. at a speed of 275 rev. per min.; constant horse power output will be maintained for speeds above 275 rev. per min., and reduced output on constant torque basis, for speeds below this value.

These drives will never be required to start their respective mills with metal in the rolls. Mill friction on a cold winter day, after a prolonged shut-down, would be the most severe starting condition. Several tests have shown that a torque of about 25 or 30 per cent normal will start a continuous mill under most adverse conditions.

Under circumstances it was decided to build the drives A and B as synchronous motors and to take advantage of their leading kilovolt-amperes for power factor correction of the steel plant.

(*Continued on Page* 8)

TESTING INDUCTION MOTOR

(*Continued from Page* 6)

The large adjustable speed drive, C, will consist of a 5000-h. p., 375-rev. per min. slip-ring induction motor, the speed of which will be adjusted up to 33 per cent above, and up to 33 per cent below, synchronism (i. e., from 500 rev. per min. to 250 rev. per min.) by means of the two Scherbius regulating machines R1 and R2. With this constant torque layout, the capacity of the drive will be 6700 h. p. at 500 rev. per min. and 3300 h. p. at 250 rev. per min. An A. C. drive of such capacity and speed can be built more economically and with a much higher efficiency than any combination of D. C. machines. The fact that the power supply was 25-cycle gave the Scherbius system an advantage over the Kraemer drive.

The last finishing mill drive, D, will have a wider speed range, is of smaller capacity and runs at a lower speed than the drive C. While a Scherbius equipment for the drive, D, would be fully competitive in first cost, the difference between it and that of a D. C. drive was not as wide as in the case of the drive C. For the sake of greater flexibility of control it was decided to make the drive D of the D. C. type.

A 500-rev. per min. synchronous motor, S, will drive a 2300-kw., D. C. generator G (furnishing power to the motor D) and the two 650-kv-a. Scherbius speed regulating machines R1 and R2 used for adjusting the speed of the induction motor C. When the motor C runs below its synchronous speed, the slip energy flows to the machines R1 and R2; the latter run as motors and assist the synchronous motor S in driving the generator G. In other words, the slip energy does not have to be returned as electric power to the incoming line; instead of this, it may be used for driving wholly or in part, the finishing mill D. The flow of power is indicated by arrows.

When the drive C is running above synchronism, the slip energy becomes negative and arrows shown by the dotted line, will be reversed. The machines R1 and R2 act then as generators, and derive their power from the synchronous motor S.

A direct-connected exciter provides the necessary 250-volt excitation to the synchronous motors A, B and S, and to the D. C. machines G and D.

The use of two regulating machines R1 and R2 for controlling the speed of the Motor C presents some interesting features. The maximum amount of the slip energy to be handled by the speed regulating equipment is 1700-h. p.; it is not practicable to build A. C. commutator machine of such capacity and to run at 500 rev. per min.; a lower speed like 375 rev. per min. or 300 rev. per min. would be required. With the proposed layout such reduced speed would considerably increase the cost of the D. C. generator G and of the motor S. It would be still more expensive to provide a separate low speed drive for the regulating machines R1 and R2, and to drive the generator G by another 500-rev. per min. motor. It was quite advantageous, therefore, to split the capacity of the regulating equipment in two units and to run them at 500 rev. per min.

(*Continued on Page* 28)

TESTING INDUCTION MOTOR

(*Continued from Page* 8)

The connections of the regulating machines to the secondary winding of the induction motor are shown. The 5000-h. p. motor is equipped with six slip-rings, with both ends of each phase of the rotor brought out. Each set of three slip-rings is connected electrically to the commutator of the regulating machines R1 and R2, which thus forms the two Y-points of the secondary circuit. In other words, the two machines R1 and R2 act as if they were connected in series with each other, their e. m. fs. added together. The shunt fields F1 and F2 are adjusted simultaneously by a common speed control apparatus.

By disconnecting one regulating machine and by short-circuiting the corresponding set of slip-rings, it is still possible to operate the drive with the other regulating machine; full torque of the drive will be obtainable, but the speed range will be cut in half; i. e., it will be in this case approximately 312/437 rev. per min.