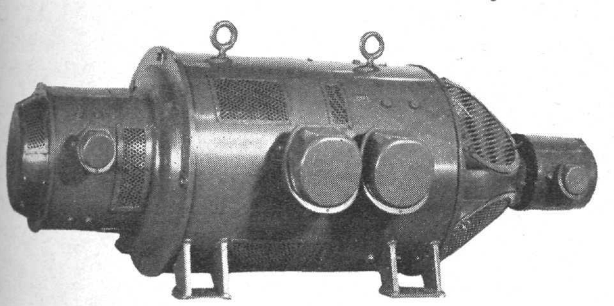
CONTROL GENERATORS

JERE BROPHY, Engr. I



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Dynamoelectric Amplifier—Rototrol

Ever since power has been used intelligently it has been harnessed. This has been the duty of the control equipment designed by the control engineer. Control engineering grew up simultaneously with power engineering, as is clearly demonstrated in electrical engineering. Among the various control devices developed for use in this field are rheostats, starting boxes, contractors, relays, regulators, controllers, and, recently, control generators.

Most of these methods of control have a low speed response to any sudden change, however, the control generator may have both a high speed response and the ability to control large amounts of power with a small input.

For this reason many machines using large amounts of power were operated by mechanical, steam or hydraulic devices until recently. This is particularly true of the industries engaged in the manufacture of heavy products. Steel mills formerly used steam power for reversing, flipping and rolling their blooms and operating the flying shears in the finishing mill. This was done to save time on each operation in starting, stopping, reversing and accelerating equipment and work which had a high moment of inertia. Today much of this work is being performed by large electric drives since the large amounts of power required can be quickly controlled by small, almost minute, amounts of power. The output of a photo-electric cell can be made to control the operation of a four stand mill, if necessary.

The machine which makes this possible without undue complexity is the control generator. It is essentially a motor-driven generator with an extra set of brushes for each set of poles. Any variation in the input to this generator is greatly amplified in the output across the load brushes. This is the machine which amplifies a bit of control power of about one watt to a controlling power of 2000 watts, 10,000 watts or more, if necessary, with a high speed response.

In external appearance, this dynamoelectric amplifier, or "amplidyne" or Rototrol as it is commercially known, does not differ from the conventional generator. Internally, it contains a set of short-circuited brushes in quadrature to the set of load brushes in the conventional generator.

Before approaching the subject of motor control

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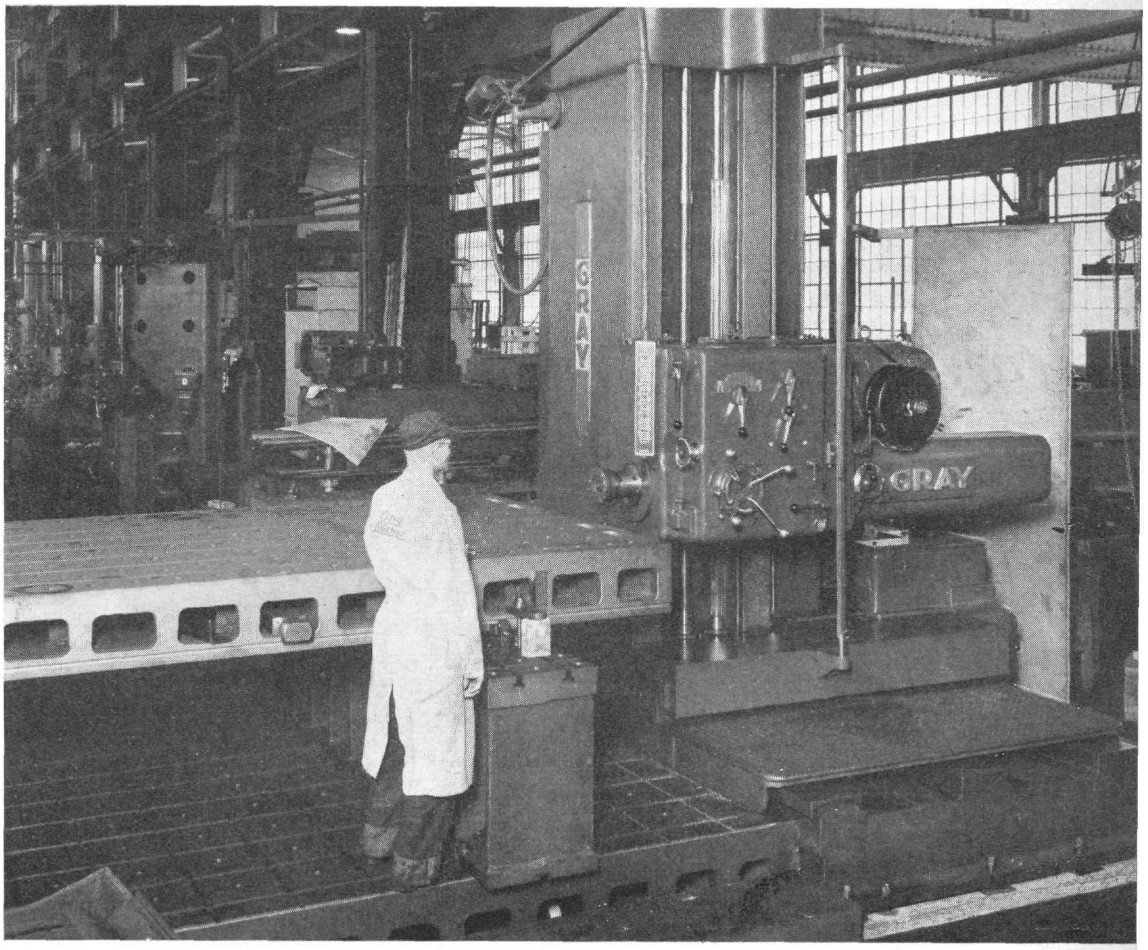
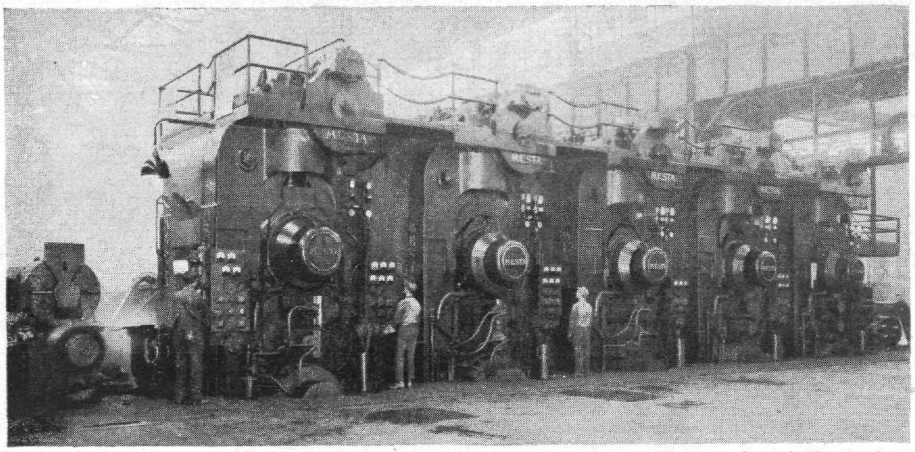


Rototrol applied to a planer.

Rototrol Control on a Planer



Courtesy General Electric Co.

Fig. 6. Hot-strip mill installation using amplidyne exciter for constant-tension control of strip tension at reel

with the dynamoelectric amplifier, a bit of review of some of the characteristics of the direct current motor might not be amiss. The torque produced by a motor is a function of the product of the field flux and the armature current. Thus, $T = KfIa$. Also, the speed of a motor is directly proportional to its counter e.m.f. and inversely proportional to its field flux. Thus,

$$S = K\frac{E}{f} \text{ or } S = K\frac{V - IaRa}{f}$$

where T is torque, K is a constant, f is field flux, E is counter e.m.f., Ia is armature current, Ra is armature resistance, V is externally applied voltage across the armature and S is speed. As may be readily seen from the above formulae, if the field flux is increased by increasing the field current the torque is increased and the speed is decreased.

The control generator takes advantage of this fact in its regulation of the desired motor action. The control generator is used to supply the current necessary to produce the field flux required by the motor. Therefore, any variation in the control generator's output directly affects the operation of the motor.

In the conventional generator a voltage is produced in the armature conductors by their cutting of the field flux. The current in the armature is proportional to the armature voltage and the armature circuit resistance. Cryptically, $E = KfS$ and $Ia = \frac{V - E}{R + Ra}$ where R is the load resistance. Another phenomenon which also occurs in the armature is the armature reaction. It is the flux produced by the armature current flowing in the armature and is, of course, proportional to the armature current. It is easily proved that this flux is in quadrature, or at right angles, to the field flux and is stationary even though the armature is constantly revolving. This armature reaction is a nuisance in conventional generators since commutating field poles have to be provided to compensate for it. In the case of the control generator this field is used advantageously.

If the armature of a conventional generator is short-circuited the load resistance is almost negligible. Since the armature current is inversely proportional to the armature circuit resistance it can reach a very high value with only a very small field flux. The high armature current produces a large armature reaction or high armature flux. If a set of brushes and poles are added to this short-circuited generator the armature reaction will produce an e.m.f. at these new brushes. This is a cross-axis excited generator.

Schematic Development of a Control Generator from a Conventional Generator

If a load is connected to the new set of brushes the load current will, in turn, set up an armature flux which will oppose the primary field flux since the load flux is in quadrature to the short-circuited armature reaction. Another field is added to the circuit to neutralize the new load flux by placing a field coil in series with the load and winding it so that its flux bucks the load current flux. Thus, the initial control field is unaffected and has only to form sufficient flux to produce enough e.m.f. for the short-circuited armature. Since this is almost pure resistance and of very low value the speed response is great. When the cross-axis excited generator has the load-compensating field added to its other fields it is known as a dynamoelectric amplifier. This unit is

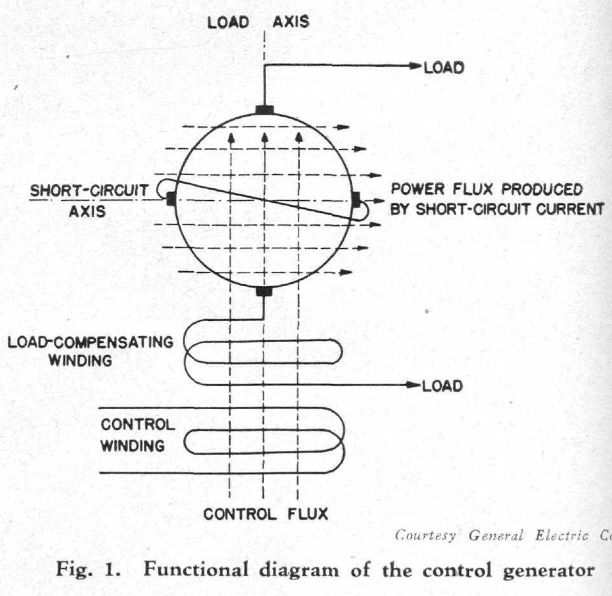


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Fig. 1. Functional diagram of the control generator

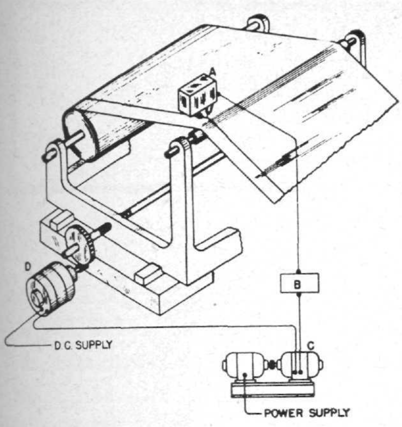

Fig. 10. Photoelectric register equipment using the control generator for power supply to Servo-correcting motor
A: Scanning head.
B: Electronic amplifier.
C: Amplidyne generator.
D: Control motor.

Courtesy General Electric Co.

the machine which was developed under the supervision of Dr. E. F. W. Alexanderson.

The adding of the load-compensating field and its balancing to neutralize the load flux is a delicate task since any change in the control flux may cause changes 10,000 times as great in the output circuit. Moreover, the current flowing in the load circuit is many times as great as the current in the control field. This makes the coil adjustment difficult.

The amplification of a dynamoelectric amplifier may be defined as the ratio of its output to its input to the control field. This value usually ranges between 2,000 and 10,000 but may go considerably higher.

The dynamoelectric amplifier may be likened to a two stage radio amplifier. The small current sent to the control field sets up a small flux which causes a small voltage in the armature conductors. As the armature is short-circuited the current which flows in it is very high. Thus, a small current with its individual idiosyncrasies has transmitted those peculiarities on a larger scale to a larger current. This might be considered as the first stage of amplification. The amplification in the succeeding stage is smaller.

In the second stage, the armature current produces a large flux called the armature reaction. This flux causes a high e.m.f. at the load brushes. Both stages of amplification are now complete.

In a typical machine the short circuit voltage is low, about two volts. Very little control field flux is needed to produce this low voltage. The low resistance of the shorted armature permits a high armature current as a result of the low short circuit voltage. This current will produce an armature reaction sufficient to produce an e.m.f. of 250 volts at the load brushes. The current in the shorted armature is approximately equal to the available load current. Since the short circuit voltage is so small the extra set of brushes introduces no additional problems of communication.

Amplification in a four kilowatt machine is approximately 175 in the first stage and 40 in the second stage. The total amplification is the product of the two stage amplifications, approximately 7000.

In another respect the dynamoelectric amplifier is analogous to a radio amplifier; very high amplification can be secured at the expense of the time response. The sensitivity of the operation may be increased in the ratio of 100 to 1 by permitting the cycle to take 100 times as long to complete itself.

Amplification can be further increased by introducing a primary stage with "hard" vacuum tubes. The output from such a stage is sufficient to control the generator since its power requirement is about one watt. A high gain would result here since the control energy of the vacuum tube amplifier is measured in microwatts and its output is measured in watts. Thus minute forms of energy such as a beam of light, can be utilized to control accurately and quickly large amounts of power.

More amplification can be achieved by cascading the power from the dynamoelectric amplifier into a conventional generator or another dynamoelectric amplifier whose output is used to excite and control the final drive motor.

The amplification of the control generator may also be increased by increasing the short circuit armature flux. This may be done by adding field coils which aid the already existing flux. These coils may be excited by shunting them across the load, by placing them in series with the short-circuited armature or both methods may be used simultaneously when necessary. At times it may prove advantageous to use one of these methods to buck the primary control flux and thus reduce the amplification.

Since the control field needs a very small current

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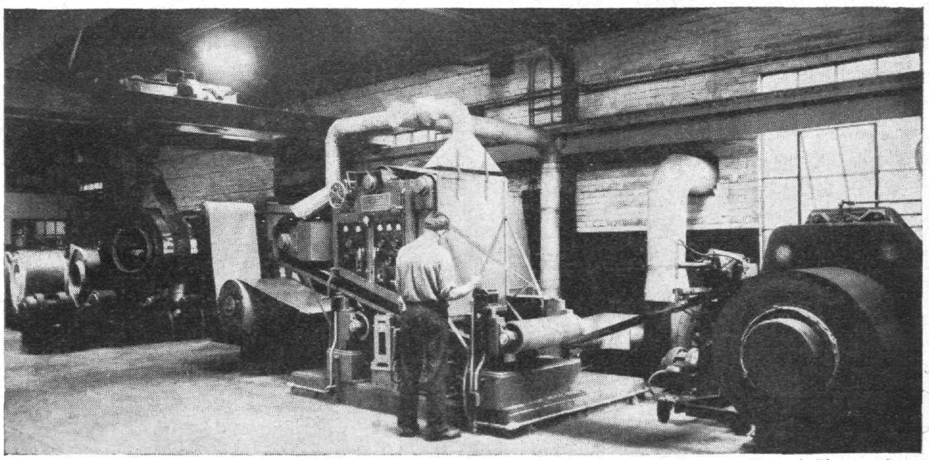


Courtesy General Electric Co.

Fig. 7. Steel-strip polishing apparatus using amplidyne exciter for reel motors to control speed and tension.

CONTROL GENERATORS

(Continued from Page 11)

the physical size of the field poles and coils can be very small. This permits several different control fields to be placed on the same amplifier. It is readily apparent that one field could be used as function of speed; another of voltage, current or phase relationship.

At present, most dynamoelectric amplifier are being used as exciters for final drive units in the heavy industries. They are being used on synchronous motors to maintain leading components and on steel mill, low inertia motors and generators to secure a maximum reversal speed within proper limits of the current rise.

Army mechanics may soon get to know the intricacies of the control generator from first hand experience. Some of the new tanks will have dynamoelectric control. An airplane type motor will act as the prime mover to drive a large, amplidyne-controlled generator which furnishes the power for the amplidyne-controlled driving motors.

A large twin-head vertical boring mill in the Schenectady Works of the General Electric Company has a simple but unique application of the dynamoelectric amplifier. There is a motor for each head which controls its horizontal and vertical motion. Either motion may be selected by using the conventional mechanical two-way clutch for operating either lead screw.

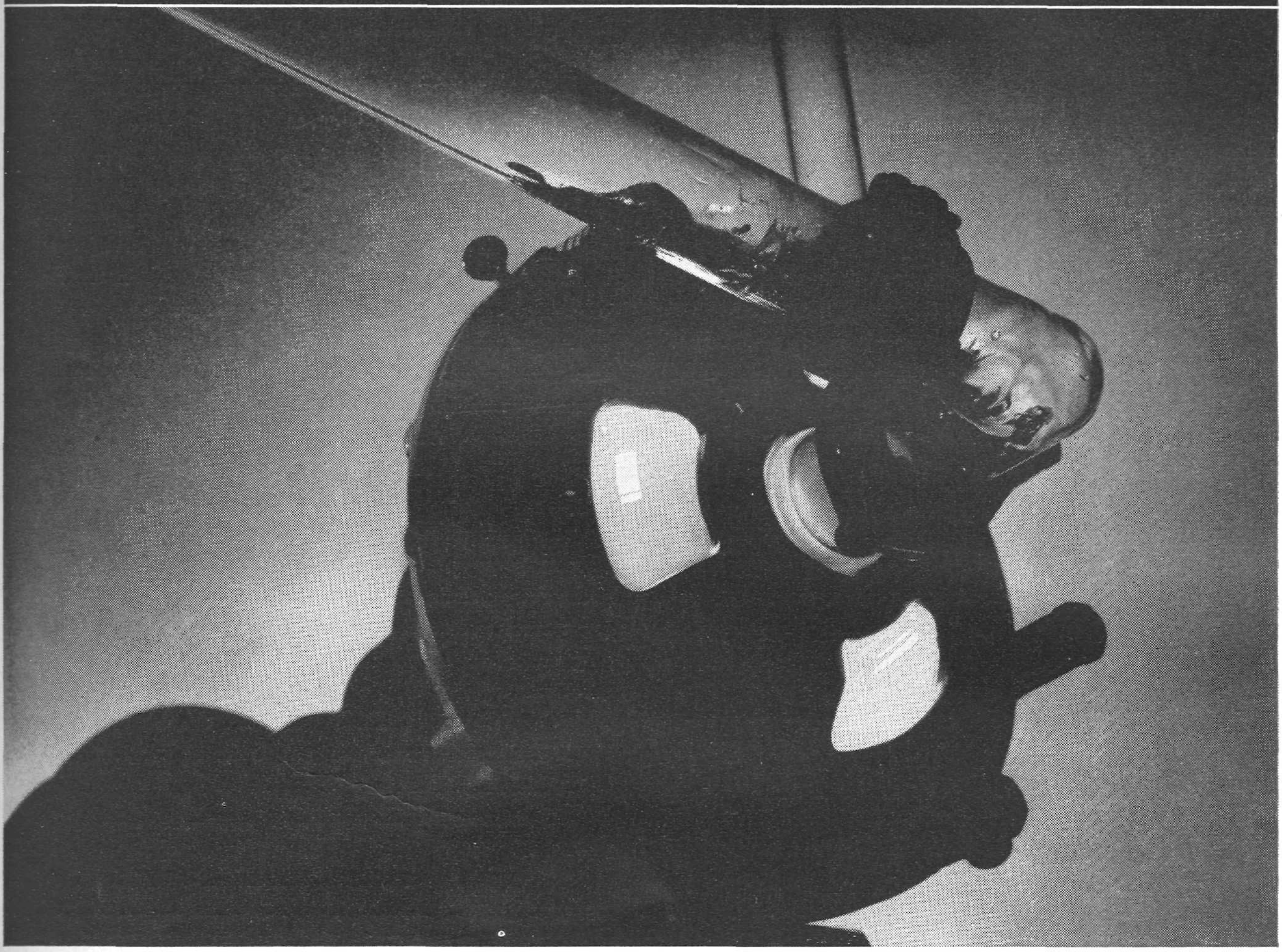
To start a cut the operator has only to engage the proper motion for the head with the clutch and press a button. The head automatically moves to the correct position for the cut and begins when the feed is engaged.

This precise control is obtained by the accurate placement of several limit switches which are actuated by the movement of the tool head. These switches govern the control field circuits of the amplifier. The power requirement for the control circuit is very low which permits the use of small accurate switches for the limit positioning. Switches, half the size of a match box, which require only a movement of two thousandths of an inch to operate them are large enough to carry the control power of the amplifier.

The control generator furnishes the armature power for the motor which drives the feed screw for the tool head. The motor field is externally excited. Thus, the control generator may start, stop or operate the motor at any predetermined speed by varying the control excitation to the motor. The excitation of the control field of the amplifier comes from a tiny generator that is driven by the motor for the tool head. The output of this small generator passes through the limit switches and potentiometers to the dynamoelectric amplifier.

(Continued on page 26)

Here's the Glass pump that couldn't be built...



THE ENGINEER from the Chemical Works had one of his usual headaches.

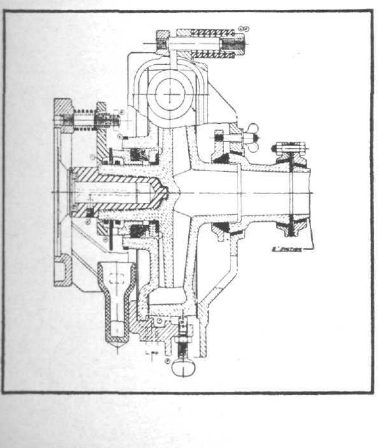
"We're pumping hot corrosive acids through your glass pipe, and it lasts for years," he moaned, "and the works bogs down because the pumps can't take it! Can't you people build a glass pump?"

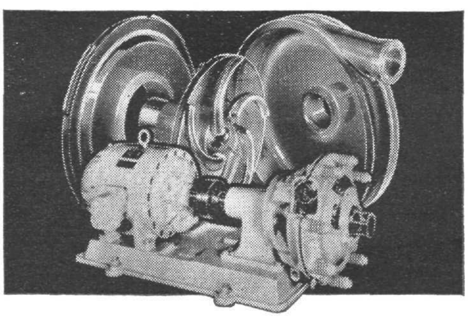
It sounded impossible. Pump makers said it couldn't be done. Such a pump required not only highly resistant glass but also intricate parts, accurate to thousandths of an inch! Even Corning had doubts but decided to tackle the problem.

Pooling its ideas with Nash Engineering Company's knowledge of pumps, Corning devised new methods of glass manufacture, even a new type of glass for certain parts.

And today chemical, food and beverage plants, and other industries handling corrosive solutions have a glass pump that works like a charm. Resistant to corrosion, it eliminates a cause of product contamination and undesirable chemical reactions. Resistant to heat shock, it may be cleaned with hot acids. Transparent, it permits constant visual inspection for cleanliness, color, sedimentation.

In the same way, Corning research for three quarters of a century has licked such glass problems as the bulb for Edison's first lamp, cooking ware for housewives, and tiny glass springs for chemical equipment. And in these days of metal-conservation, Corning ability has reached a new high in usefulness as engineers and production men use glass to solve their new problems. Industrial Division, Corning Glass Works, Corning, N.Y.





The Nash Glass Centrifugal Pump (left — cross section; above —coupled with driving motor, glass pump parts in background) can handle up to 6000 gal. of corrosive acids and chemical fluids per hour against a 65-ft. head.

CORNING

means

Research in Glass

To adjust the position of the limit switches the operator runs the head to its approximate position and sets his first switch, the "slow-down" switch, so that it will be tripped in that position.

This first limit switch changes the potentiometer connections in the excitation circuit. This slows the driving motor to one-fiftieth of its normal speed. The mechanic can then adjust the second limit switch to its proper position at this new speed. With this set-up an accuracy of stopping within two thousandths of an inch in 14 feet is provided.

Excitation for a 5000 horsepower synchronous motor is provided by dynamoelectric amplifier in a steel mill installation.This control was designed to provide high torque for peak loads. The motor is controlled to operate with a leading current up to fifteen per cent of the normal load. The necessary few watts of control excitation are provided as functions of the line voltage and the motor current.

The Wheeling Steel Corporation had a d-c., dynamoelectric amplifier-controlled installation for one of their mills completed in 60 hours which included dismantling time for the a-c. apparatus. With this new apparatus the operators are able to bring the table up to speed in three and one-half seconds and stop the table more quickly than with the old a-c. installation which had frequency control.

The Jones and Laughlin Steel Corporation installed dynamoelectric amplifier control on a 54 inch, four stand, tandem mill producing tin plate. The original production speed on the mill was 905 feet per minute but with new gears and the new control system the speed was raised to over 1650 feet per minute. The value of such equipment at the present is obvious.

The Irvin Works of the Carnegie-Illinois Steel Corporation provides another example of the versatility of the dynamoelectric amplifier. On a hot mill shear high current acceleration for the motor and high acceleration and deceleration with precise stops and smooth control for the shear are necessary. Formerly this was provided by an involved system of contactors, control relays, a counter e.m.f. set and a current regulator. Now an amplifier replaces all of these machines.

Several installations of control generators for motors operating the rewinding and slitting of rolls of paper have been made. To correct the deviation of the actual width of the slit paper from its optimum width (tolerance, 0.005 inch) a d-c. motor placed beneath the machine is geared to move the main roll of paper sideways to correct any error. A photoelectric scanner which registers on either a printed line or the edge of the slit sheet sends its current to a vacuum tube amplifier. The amplifier provides the excitation for the control field of the dynamoelectric amplifier which in turn, controls the d-c. motor for shifting the rolls. To eliminate any tendency for the equipment to lag or hunt, the paper is shifted under the photoelectric cell simultaneous with the movement of the main roll.

Strip grinders which require accurate control of the tension of the winding and unwinding reels are other successful applications of the control generator. Here compensation is also made for the changing inertia of the tension reels. Runout tables require current limit control for their acceleration and voltage control at running speed. Tandem cold strip mills need close interdependent speed regulation. Direct current machines mechanically parallelled demand special load divisions. In all of these situations the control generator has proved itself. Other possible uses for the dynamoelectric amplifier lie in the fields of transportation and combustion control.

In general it may be said that apparatus requiring the swiftly changing field excitation of some large motors or with the highly variable armature demands of some small motors, are well suited for dynamoelectric amplifier control. The control generator is not a panacea for all power control ills and should not be thought of as such; it is a piece of machinery designed to supplement and not supplant any particular piece of existing control equipment. However, in the present situation in the heavy industries it can do a great deal of good in increasing speed and production.

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