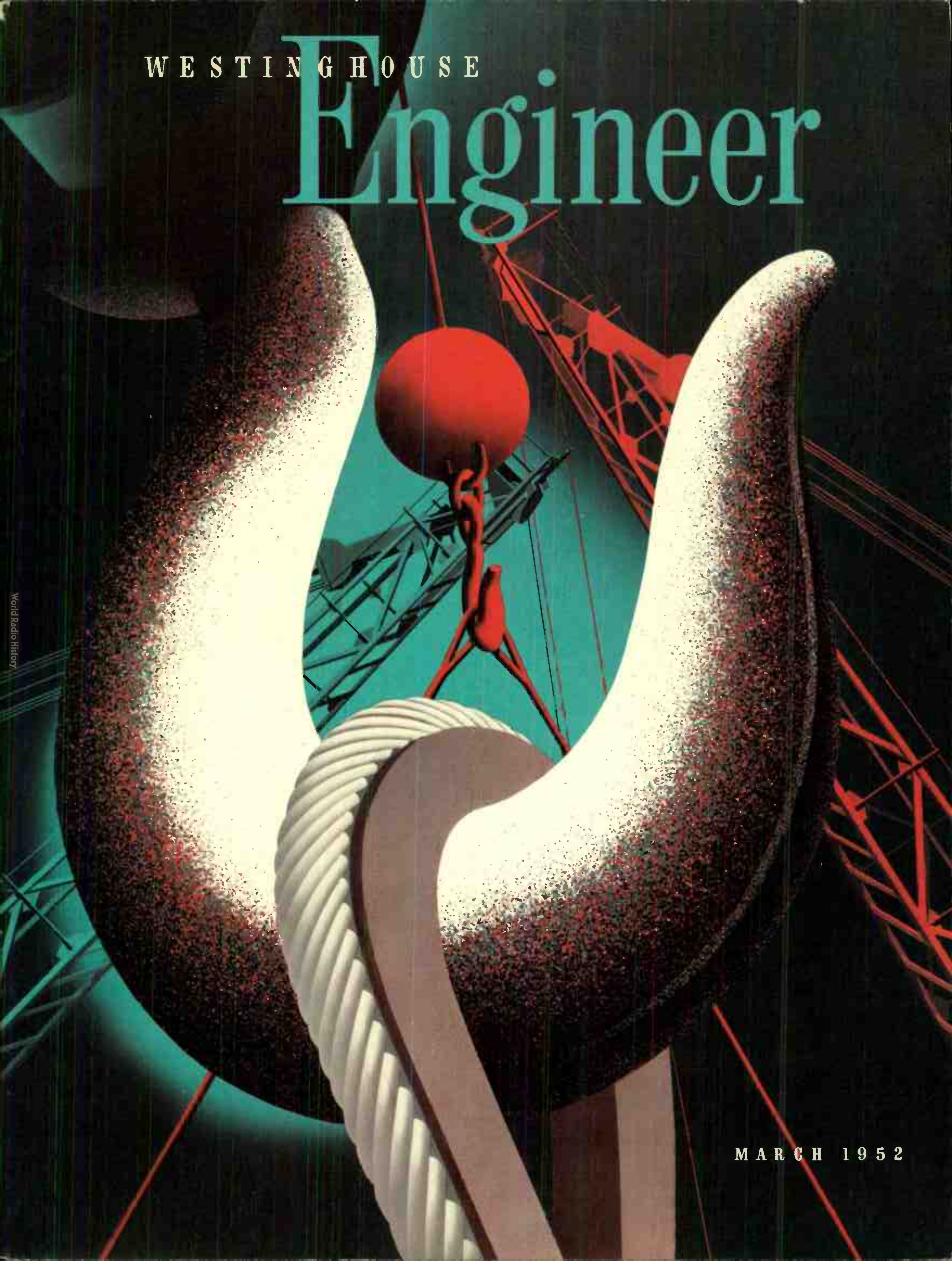
WESTINGHOUSE Engineer



MARCH 1952

SERVICE....*with a Slide Rule*

Excellent performance is not obtained from industrial equipment merely by providing well-designed apparatus. The equipment first must be properly applied, and properly installed. After installation, correct, careful maintenance and operating procedures must be followed if continued satisfactory performance is to be obtained.

Engineering assistance from the manufacturer in the application and operation of equipment can be of great help to the purchaser in achieving these goals. In Westinghouse, field service of this kind is provided by the District Engineering and Service Department. The many ways in which field engineers can assist customers are best illustrated by typical examples of the work they have done recently.

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Two new slasher drives for textile mills are examples of Westinghouse engineering service resulting in a valuable new product. During planning and negotiation with textile manufacturers one of the application engineers in the New England district learned of the need for an improved slasher drive for woolen mills. He assigned himself the task of designing one. Working between jobs and at home when he had spare time, he eventually came up with a design that was acceptable. It was then applied to an actual installation. The routine post-installation engineering follow-up disclosed some weaknesses. Changes were made to eliminate these and an improved design was obtained. Since then the same basic slasher drive has been modified for use in cotton mills. Both drives are now being placed in production as standard products.

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Service engineers are always ready with prompt, effective action when emergencies arise. When the Crossett Paper Mill in Little Rock, Arkansas, was struck by lightning last summer, eight specialists were rushed to the scene to get damaged equipment back in operation.

The damage was extensive. A 7500-kw turbine was seriously damaged, and switchgear, busbar circuits, and other electrical distribution and control equipment were ruined. Crossett engineers estimated a mill shut-down of from four to six weeks would be necessary. Despite the extensive repairs, Westinghouse and Crossett engineers and repair crews had the mill back in full production in a little over four days.

The quick return to full production was made possible through the cooperation of the Arkansas Power and Light Company which supplied 3500 kw of emergency power to make up for the damaged turbine.

Once the mill was back in operation an Engineering and Service field office was maintained at the site until permanent repairs could be completed and new equipment installed.

• • •

Engineering and Service engineers can double as manufacturing engineers when necessary. At Grand Coulee Dam, all of the big Westinghouse waterwheel generators were completely assembled in the field. Waterwheel generators usually must be partially disassembled after testing at the factory and shipped in pieces. The only other alternative is to ship out the parts as they are manufactured and assemble the machines completely in the field. That was done with the 108 000-kw machines for Grand Coulee. Electricity from those generators was needed badly in the Pacific Northwest; so, to reduce the time lag between manufacture and operation, parts for the Grand Coulee machines were shipped directly to the job site, where they were assembled and thoroughly tested before being placed in operation.

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Resourcefulness and ingenuity are the stock in trade of service engineers. The "South Chicago Shaft" illustrates this. A failure occurred in the wobbler coupling of a tandem reversing mill. The tremendous forces that were built up bent the 36-inch drive shaft, and damaged the drive motors. A Westinghouse service engineer was rushed to the job to get the equipment back in operation. He immediately set his crew to work removing the rotors of the 5000-hp tandem motors so that they could be repaired. Some rewinding was necessary and the commutator had to be re-turned and reground. Meanwhile the shaft had to be straightened. Ordinarily, this would necessitate sending the shaft to a repair shop or to a factory. But shut-down time is expensive in a steel mill and sending the shaft to the factory would take time. The service engineer decided to straighten it on the spot. He clamped one end of the shaft securely and supported the other on jacks. A fire-brick furnace was then built around the middle where the shaft was bent. With the middle heated, the shaft was straightened by raising the jacks. The entire repair job was completed and the mill was back in service 17 days after the failure.

• • •

Furnishing engineering help and service on all Westinghouse equipment—old and new—requires a large engineering organization with lots of resources. Over 1200 people—engineers, technicians and craftsmen—are currently on the payroll of the District Engineering and Service Department. Proper installation and servicing of every piece of apparatus manufactured by Westinghouse requires half a million dollars worth of special equipment in addition to obvious tools like meters, wrenches, soldering irons, etc. A few examples illustrate the variety and complexity of these special tools. Included are oscillographs, sound level meters, slot-discharge analyzers, cameras, brazers, r-f heating units, boring rigs for old reciprocating engines, noise meters, equipment used in reblading turbines. There are hundreds more.

The most important resources, however, are intangibles: engineering know-how, ingenuity, resourcefulness. The service described on this page requires a large measure of all three.

WESTINGHOUSE Engineer

VOLUME TWELVE

MARCH, 1952

NUMBER TWO

On the Side

The cover—Lifting hooks are fundamental to mechanical lifting operations. So, to symbolize three articles dealing with crane-hoist control, Dick Marsh has made a massive heavy-duty crane hook the center of interest.

• • •

Expansion of manufacturing facilities throughout American industry has been making headlines for several years, with little notice being taken of expansions of scientific research facilities. Such expansion is no less important than the building of new and larger manufacturing plants. The many new factories being built must be adequately supplied with new ideas and techniques—products of the research laboratory—if expansion of our industrial potential is to continue.

To keep research facilities at Westinghouse in step with the expansion recently announced, plans are now being laid to build larger, more modern research laboratories. Westinghouse is now negotiating the purchase of 72 acres of land in Churchill Borough, a suburb of Pittsburgh about five miles from the location of the present laboratories. The land is adjacent to the Penn-Lincoln Parkway, a new, modern freeway that is being built to connect Pittsburgh with leading East-West traffic arteries. This location has been chosen only after careful consideration of many possible sites.

The new laboratories will be designed to provide an ideal locale for thoughtful research effort. It will be screened by trees and shrubs and will be free from smoke, odors, and noise. Measures will be taken to comply with zoning restrictions to insure the desirability and beauty of the borough as a residential area.

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In This Issue

Packaged power for rolling mills—Improved x-ray tube stand—Deodorizing lamp—Power supply for tong-type brazing—Self-contained Precipitron—Electrical equipment for sintering plant—Improved low-current performance for air circuit breakers—High-speed ironing of photographic paper—Electronic control of textile beam letoff—Automatic capacitor switching for distribution circuits—Largest single-motor paper machine.

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The *Westinghouse* ENGINEER is issued by the Westinghouse Electric Corporation six times a year (January, March, May, July, September, and November). Annual subscription price in the United States and possessions is $2.50; in Canada, $3.00; and in other countries, $3.00. Single-copy price is 35c. Address all communications to *Westinghouse* ENGINEER, P.O. Box 1017, Pittsburgh (30), Pa. The contents of the *Westinghouse* ENGINEER are regularly indexed in Industrial Arts Index. Reproductions of the magazine by years are available on positive microfilm from University Microfilms, 313 N. First Street, Ann Arbor, Michigan.

THE WESTINGHOUSE ENGINEER IS PRINTED IN THE UNITED STATES BY THE LAKESIDE PRESS, CHICAGO, ILLINOIS

Which Crane-Hoist Control?

There are almost as many ways to move things up and down as horizontally. Which has given rise to many different systems for controlling lifting machines. The question is, Which one is best suited for a given job? The answer is not easily obtained; it involves an analysis of the operating requirements of the hoist and the advantages and disadvantages of available control systems.

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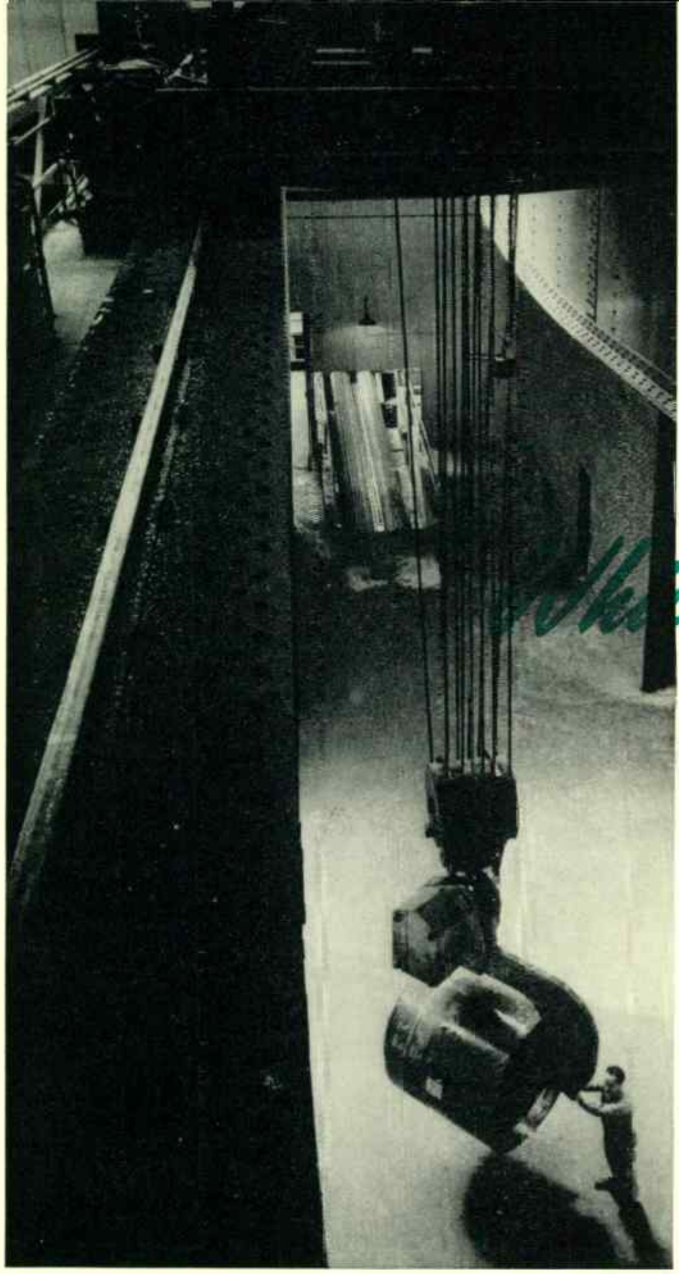

Crane-hoist performance depends not only on adequate mechanical design and proper selection of motor and brakes, but equally on a suitable electrical control system. A variety of control systems is available for use on crane hoists, and no simple tabulation indicates the best controller for every crane application. For most applications, there are two or more controllers that will provide satisfactory operation. The problem lies in choosing the one control system that is most suitable.

Among the factors that influence the choice of a controller are: the type of service and severity of duty likely to be encountered, the sizes and types of loads to be handled, the handling speeds desired, and safety considerations.

Crane-Service Classifications

Overhead traveling cranes usually are separated into five general service classifications: standby, intermittent, regular, continuous, and steel-mill service. The characteristics necessary for each of these are listed in table I.

Standby service requires light-duty cranes for infrequent service such as encountered in pumping plants, generating stations, wind tunnels, and lock and dam projects. They are used steadily during installation of machines and equipment, and infrequently thereafter for maintenance. A regular crane operator is usually employed only during the erection period when full-time operation is involved. The speeds typical of standby service (see table II) can be considered "slow."

Intermittent-service cranes are operated more frequently but are not used continuously. Typical applications are found in warehouses, material stockyards, small foundries, fabricating and assembly areas, etc. No specific operator is assigned, and the crane can be controlled from either a cab or the floor. Occasional precision handling of the load may be required. For intermittent service "slow" speeds are used.

Regular service requires medium-duty cranes such as used in railroad shops, heavy machine shops, assembly shops, fabricating plants, medium-size foundries. Loads vary in size, shape, and weight, and require different degrees of precision in control. Speeds typical of regular service fall between those for standby service and the fast speeds required in continuous service.

Continuous-service cranes operate throughout the day, usually handling bulk materials on a preselected duty cycle. Examples include unloading, stocking and reclaiming materials like coal, ore, and sand. A fixed load is always present, the maximum being set by the capacity of the bucket, magnet, etc. Speeds are fast and selected to suit the cycle requirements. Precise handling of the load is not required. Simplicity, ruggedness, and continuity of service are essential.

Steel-mill service is encountered in open-hearth and rolling-mill applications. Such cranes are production units and must be liberally designed to prevent crane failures.

The Association of Iron and Steel Engineers has prepared "Specifications for Electric Overhead Traveling Cranes for Steel Mill Service" which incorporates the mechanical and electrical designs normally required. Some mills prepare their own specifications for special-service cranes.

Load and Speed Considerations

When selecting a crane hoist, future as well as present lifting requirements must be considered. Excessive capacity results in high initial cost; and the extra equipment weight is "dead load" that wastes energy and slows down the overall performance of the crane. However, where occasional overloads are handled, particularly if they are 125 percent or more of rated capacity, the mechanical and electrical design must be adequate to handle such loads safely. The rated capacity, as recommended by the Electric Overhead Crane Institute, is based on the maximum load to be handled.

Hoist speed goes hand in hand with lifting capacity in determining the practicability of a crane, and the overall usefulness, efficiency, and safety of operation. The heavier the load and the higher the speed, the larger the motor, brakes, and associated electrical equipment must be.

Care in selecting hoist speeds is of particular importance where potentially dangerous loads, e.g., molten metal, corrosive chemicals, or very heavy loads, must be handled. Extremely slow, controlled speeds are necessary for hoists used to assemble precision machinery where smooth, accurate spotting and soft landing are frequently essential.

For precise handling, load movement should be controllable within 1/32 inch on a main hook, and within 1/4 inch on an auxiliary hook. Such precision can be obtained best by handling the load at smooth, very slow, creeping speeds. However, with most controllers a precision load must be inched into position by jogging the master or drum switch between "off" and the first or second running position. On long lifts—say 40 feet or more—satisfactory inching is difficult because of the spring action of the long supporting cables. Creeping speeds not only make positioning easier, but also impose less severe duty on the controller.

Since the loads to be handled by a crane are fixed by the process or application, speed is selected to suit. It is most often a compromise and the rated hook speed is usually specified to come within the speed range established by industry. The standard speeds recommended by crane manufacturers are listed in table II. If no standard speed is suitable, the operating requirements of the crane should be analyzed to determine what speed is necessary. Non-standard speeds may require special crane design to accommodate larger motors for higher hook speeds or additional gearing for reduced speeds; this increases the cost of the hoist and crane.

TABLE I—TYPICAL HOIST CHARACTERISTICS FOR OVERHEAD TRAVELING-CRANE SERVICE

Type of Service	Typical Applications	Duty	Speed*	Degree of Precision	Power Supply	Type of Motor	Type of Controller[1]	Operation
Standby service	Pumping plant Generating station Locks and dams	Light	Slow	Extremely slow, accurate positioning required	A-C	A-C Crane Motor (type CI) or D-C Mill Motor (type MC)	Magnetic for ratings above 30 hp	Cab (no full-time operator)
Intermittent service	Warehouses Assembly areas	Light	Intermediate	Most loads do not require precision handling	A-C	A-C Crane Motor (type CI)	Magnetic for all floor-operated cranes and for ratings above 30 hp	Cab or floor (no full-time operator)
Regular service	Railroad shops Heavy machine shops Fabricating plants Foundries	Medium	Intermediate	Accurate handling	A-C	Sameas Intermittent	Sameas intermittent	Cab (full-time operator) or floor (no full-time operator)
Continuous service	Bulk material hdlg. Bucket cranes Magnet cranes Metal-scrap hdlg.	Heavy	Fast	Gentle handling not required	A-C or D-C	A-C Crane Motor (type CI), or D-C Mill Motor (Type MC)	Magnetic for ratings above 15 hp	Cab (full-time operator)
Steel-Mill service	Ingot Ladle	Heavy	Fast	Accurate handling	D-C or A-C	D-C Mill Motor (type MC)	Same as continuous	Cab (full-time operator)

[1] Semi-magnetic controllers are used on a-c hoists that do not have mechanical load brakes and that require motors of 30-hp or less.
*For typical hoisting speeds see Table II.

Types of Controllers

Three general types of controllers are used on crane hoists. They are: drum, full-magnetic, and semi-magnetic. Drum controllers are most frequently used on a-c-powered cranes requiring motors of 30 hp or less and on systems using mechanical load brakes. The advantages of a drum controller are low first cost and simplicity. A minimum amount of detailed apparatus is required and all controller items are mounted inside the cab.

Full-magnetic controllers are especially desirable for cranes to which no regular operator is assigned and for floor-operated cranes with a pendant pushbutton station. With a full-magnetic controller, acceleration is partially automatic. Operation, therefore, is extremely smooth. In addition, less physical exertion is required to operate the master switch; and since the switch handle is easily positioned, more accurate positioning and spotting of the load or hook is possible. In steel mills, full-magnetic controllers are used almost exclusively, especially for cranes requiring motors larger than 15 hp. Continuous-service bucket and magnet cranes can justify a similar procedure.

Semi-magnetic controllers are seldom justified except for a-c systems with electric-brake lowering where the duty is not severe and the added expense of a full-magnetic controller not warranted.

Control Systems

A speed-load diagram is helpful in determining the most suitable control system for a particular hoist application. The general arrangement of such a diagram is shown in Fig. 1. Hoisting and lowering characteristics of a controller are determined by the location of speed-load curves.

D-C Systems

The *d-c constant-potential* hoist controller (discussed in greater detail in an article on page 62) is the oldest of the crane controllers—and is still quite popular. The series-wound d-c motor that is almost universally used inherently provides high speeds for raising light loads and slow speeds for raising heavy loads. The motor is operated as a shunt machine in lowering, because the speed of a series-wound motor is not stable with an overhauling load. Dynamic braking, used in lowering an overhauling load and in stopping

TABLE II—REPRESENTATIVE HOIST SPEEDS FOR OVERHEAD TRAVELING CRANES

Rated Lifting Capacity (Tons)	Range of Hoist Speeds in Feet per Minute				
	Standby and Intermittent Service	Regular Service*	Continuous Service	Steel Mill Service	Auxiliary Hoists
5	15–26	20–50	85–100	55–80	35–50
7½	15–20	20–45	75–100	50–75	30–45
10	15–20	20–40	60– 80	50–60	25–40
15	10–18	15–30	45– 75	40–45	25–40
20	10–15	12–25		40–45	20–35
25	10–15	12–25		30–45	20–35
30	8–10	12–20		26–30	20–30
40	6– 8	10–15		16–20	
50	5– 6	8–12		13–20	
60	5– 6	8–12		10–18	
75	4– 5	7–10		10–18	
100	4– 5	6– 8		6–15	
125	3– 4	6– 8			
Over 125	3– 4				

*Speeds for ratings up to 50 tons taken from Appendix B, Spec. 49, "Standard Industrial Service Electric Overhead Traveling Cranes," as published by the Electric Overhead Crane Institute, January 1949.

the hoist, provides inherent protection from dropping the load. The speed-torque characteristic of the d-c constant-potential system is shown in Fig. 2.

The *d-c adjustable-varying-voltage** controller combines the advantages of an a-c supply and a d-c driving motor. It is used in applications that require very high light-hook speeds and slow creeping speeds. Speed-torque curves for this controller are shown in Fig. 3.

D-c power is supplied to the hoist motor from a motor-generator set. An a-c squirrel-cage induction motor drives a differential-compound d-c generator, which supplies excitation to the hoist motor, a compound-wound d-c mill motor. Field excitation to the d-c generator is supplied by a compound-wound d-c exciter.

For lowering, the differential series field of the generator is short-circuited and the current to the series field of the hoist motor is blocked by a rectifier. Thus, both generator and motor function as shunt machines.

Most of the braking effort is obtained from the machines themselves. When an overhauling load is being lowered, regenerative braking takes place. With the master switch handle in the "off" position, a generator "killer" field is connected and dynamic braking retards the hoist and load. The magnet-released shoe brake does not set until speed has dropped to a low value. If the brake is not functioning properly, or a-c power fails, or both, the load is not dropped because lowering speed is limited by regenerative braking.

The maximum load that can be lifted is inherently limited by preselecting the stalled-torque value (usually about 200 percent of the full-load rating of the motor). This keeps the stress in the hoist and crane below a safe value and insures maximum protection to both men and equipment.

A-C Systems

Two limitations are fundamental to all a-c hoists. First, full speed is essentially the same for all loads, both hoisting and lowering, because of the constant speed-torque characteristic of a wound-rotor induction motor. Also, for a process crane handling many light and medium loads, the motor rating of an a-c hoist may have to be 25 percent greater than that required with a d-c system, because the rated speed must be greater to provide the desired high speed for handling light loads.

The Load-O-Matic system (described in detail in an article on page 56) provides positioning and creeping speeds and smooth, safe performance comparable to that of the d-c adjustable-varying-voltage controller. It is capable of load-handling refinements not possible with any other controller.

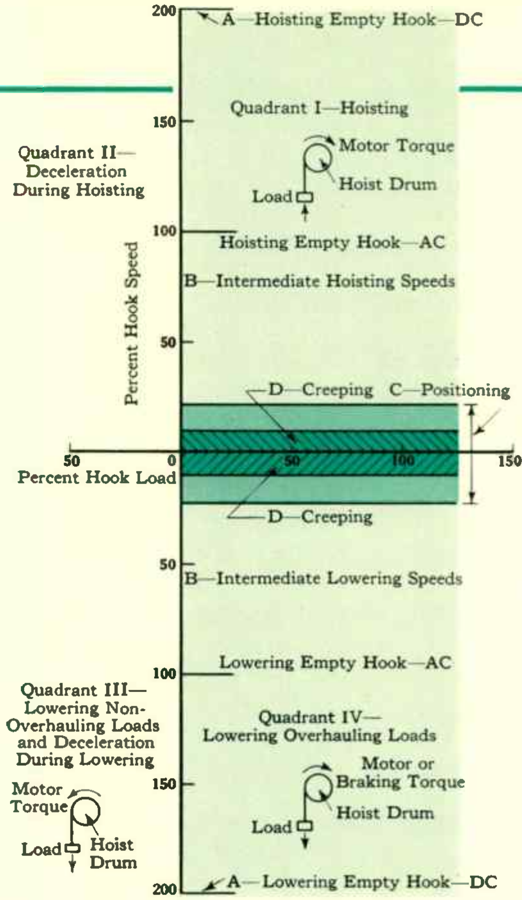

Fig. 1—This is the basic form of a speed-load diagram. The principal operating areas are shown in color. Curves in quadrant I would indicate hoist performance during lifting operations. Extensions of these curves into quadrant II are important when a load must be slowed down during hoisting. Curves in quadrant III indicate performance when light, non-overhauling loads are lowered and also when a load must be retarded. Quadrant IV indicates performance with overhauling loads.

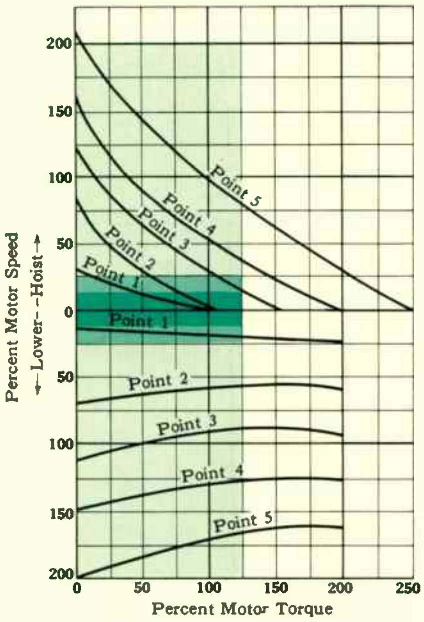

Fig. 2—Speed-torque diagram of the d-c constant-potential control system.

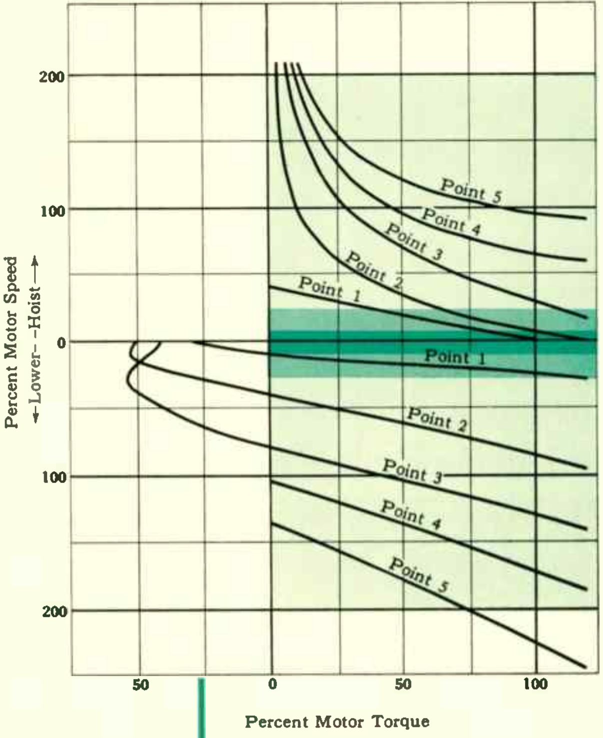

Fig. 3—Speed-torque diagram of the d-c adjustable-voltage controller.

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*For detail description see "A Simple Adjustable-Voltage Cargo Hoist," by Walter Schaelchlin and H. L. Lindstrom, Westinghouse ENGINEER, November, 1951, p. 173.

Emergency dynamic braking guards against dropping a load. For further safety, the maximum load the hoist will raise can be limited to a safe value by means of a limit switch that functions in response to load on the hook. If the *up* limit switch should fail to function, the load detector acts to stop upward travel of the hook, thus protecting the crane from dangerous stresses.

The response of the hoist to any movement of the master-switch handle is immediate and positive, but extremely smooth. Stabilized creeping speeds are provided for both hoisting and lowering. For extremely accurate and precise positioning, the creeping speed can be reduced further, by means of a vernier control, to any value between zero and about seven percent of rated speed. This superior performance is obtained with a minimum of contactor operations. The master-switch adjustment affects only the reactor excitation; secondary contactor operation is eliminated during positioning and spotting. Since motor input current is low, an oversize motor or high-temperature insulation is not required.

The speed-torque curves, shown in Fig. 4, can be adjusted easily in the field to tailor the response to the application.

The *electric-load-brake* controller provides good speed-torque characteristics (shown in Fig. 5). The primary function of the electric load brake is to eliminate the friction losses and the adjustment and maintenance of a mechanical load brake. The braking torque used to control the speed is obtained from eddy currents developed in the d-c-excited stator of an a-c machine having a squirrel-cage rotor. A source of d-c power is required for excitation purposes, in addition to the usual electric holding brake, control board, etc.

The motor is required to provide driving torque in both directions for control points using the load brake. With suitable combinations of rotor resistance and brake excitation, a wide range of hoist speeds is available.

Care must be exercised in selecting the load brake, since it not only must exert the required retarding torques, but, to assure satisfactory winding life, must also adequately dissipate the heat generated. Due to the additional duty imposed upon it, the motor may require special high-temperature insulation (class B or H), or may require an oversize frame.

An emergency source of d-c power, such as a direct-connected generator, can be supplied to energize the load brake if a-c power should fail. This also provides a restraining torque and keeps the load from dropping if both the a-c power and electric holding brake fail simultaneously.

The *d-c-dynamic-braking-lowering* controller furnishes a good set of lowering characteristics for overhauling loads but leaves something to be desired in spotting light hooks. (See Fig. 6.) Inching is necessary for raising a load and there may be a tendency for a heavy load to settle slowly on the first hoisting-control point.

This control requires a separate source of low-voltage d-c power for exciting the stator of the a-c wound-rotor hoist motor. D-c power may be obtained from either a motor generator set or rectifier. Motor heating is about normal with rated loads; however, it increases if overloads are handled because the excitation must be increased. Power for the d-c electric brake is usually supplied from this same d-c source

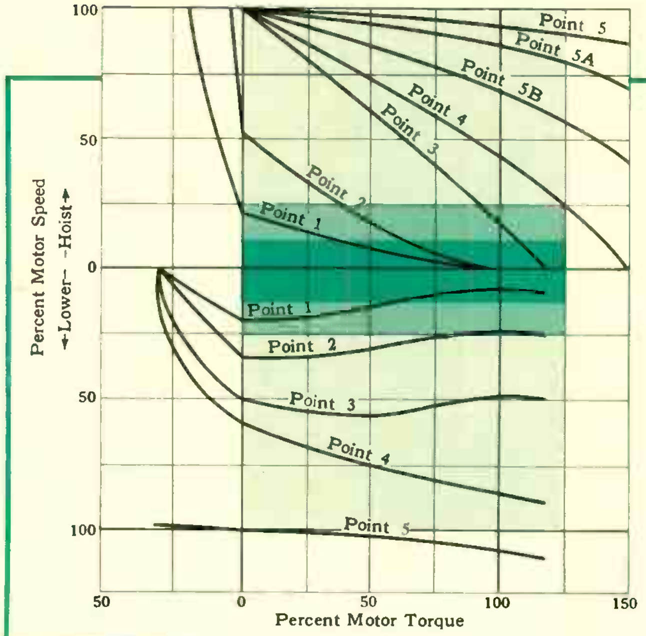

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Fig. 4—Speed-torque diagram for a full-magnetic Load-O-Matic controller provides excellent slow-speed control. With vernier control, speeds between zero and seven percent are available (these are not indicated on the curves). The maximum load limit can be adjusted between 150 and 275 percent of full-load torque. The Load-O-Matic is also available as a semi-magnetic controller.

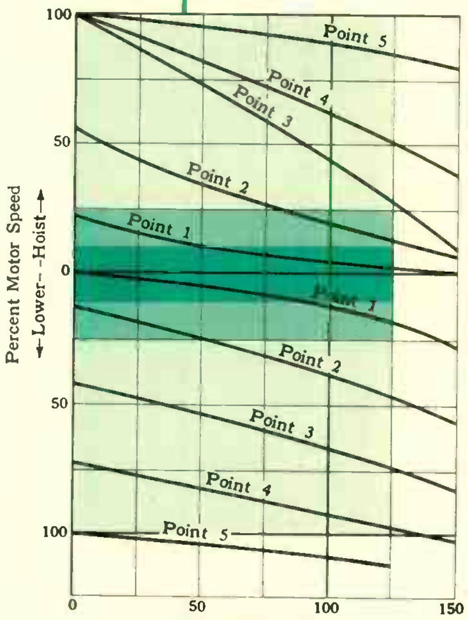

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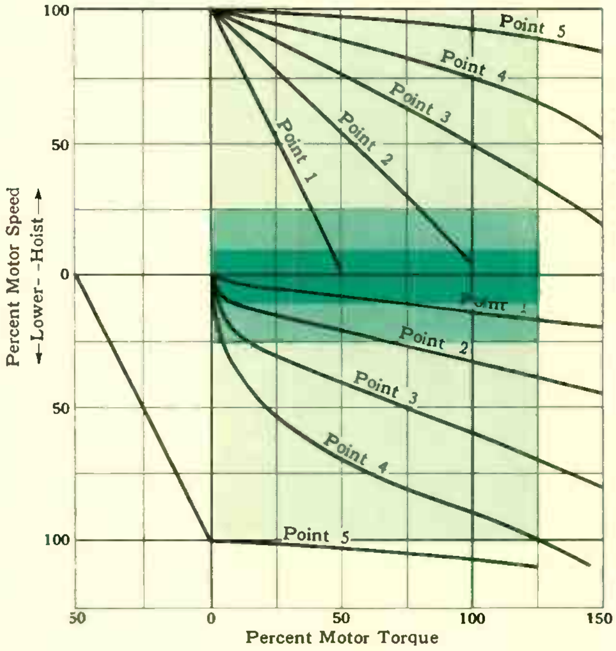
Fig. 5—The speed-torque diagram of the electric-load-brake controller, which provides slow speeds for precision handling.

Fig. 6—These speed-torque curves, for the d-c-dynamic-braking-lowering controller, are satisfactory for lowering. Hoisting precision is limited.



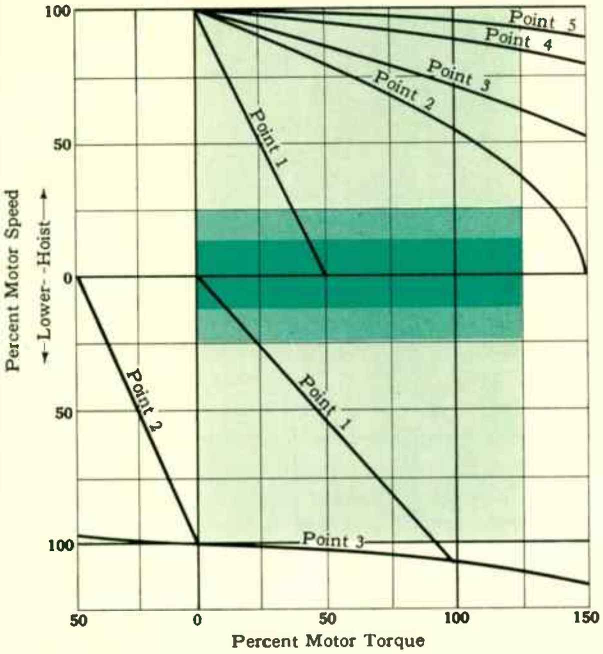


Fig. 7—Speed-torque curves of the a-c-dynamic-braking-lowering controller. This control is not suitable for precision crane hoists.

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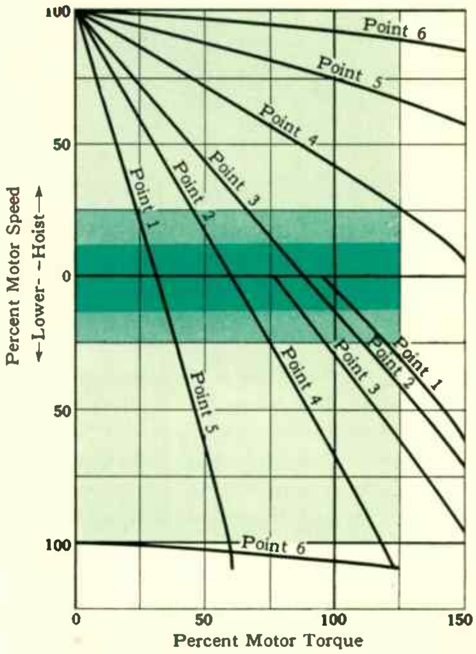
Fig. 8—Speed-torque curves of the a-c counter-torque controller, which is used only where rough handling is not objectionable.



to assure positive interlocking between the a-c and d-c supplies. Emergency dynamic braking is not normally supplied.

The *a-c-dynamic-braking-lowering* controller is simple and rugged. It is best suited for light, intermittent duty where precision handling is not necessary. Single-phase power is applied to the stator of an a-c wound-rotor motor with two terminals shorted. Speed-torque characteristics are adjusted by varying the motor secondary resistance. The curves in Fig. 7 are for a motor having a pull-out torque of 275 percent of full-load torque (NEMA standard). The maximum braking torque at synchronous speed is approximately one third of the pull-out torque. With rated load on the hook, the best lowering speed is approximately 70 to 75 percent of the rating, depending upon the mechanical efficiency of the hoist. Limitations for hoisting and for lowering light loads are similar to the d-c-dynamic-braking-lowering controller.

The motor primary is unbalanced with the single-phase excitation; therefore, higher currents and motor heating result. An oversize motor or special insulation, or both, may be necessary if the duty is severe.

The electric brake must do considerable retarding as well as holding the load. It alone keeps the load from dropping if a-c power should fail.

The *counter-torque* controller employs simple resistance control and has steep speed-torque curves, as shown in Fig. 8. The principal drawback to this system is speed instability. A change in the weight of the load causes a great change in speed. For this reason it is limited primarily to rough hook service, where the load is heavy and usually the same.

The *mechanical-load-brake* system utilizes a plain reversing controller and an a-c wound-rotor motor. The motor must develop both hoisting and lowering torque; however, in the lowering direction it develops only enough torque to overcome the locking effect of the mechanical load brake. The torque must be sufficient to lower the load under direct control of the motor and at a speed dictated by the position of the control switch. Typical performance is shown in Fig. 9.

This is the simplest and least expensive of all a-c systems. The brake is a frictional device and is subject to considerable maintenance. Operation is apt to be erratic in lowering, especially at slow speeds. The load brake is released during hoisting, but acts as a holding brake if a-c power and/or the electric brake should fail.

Where the Systems Fit

An analysis of the characteristics of the various types of crane-hoist controllers must be made before one is chosen. A comparison of crane-hoist controllers is given in table III.

Light Loads

It is often desirable to raise and lower light loads or empty hooks at speeds above the rated speed. This is especially true where lifts of 40 feet or more must be made. Then, fast speeds save valuable production time. Such applications occur in all types of crane service, but especially in steel mills and on standby cranes in large powerhouses and pumping stations. Where d-c power is available, such as in steel mills, d-c constant-potential control is used universally, because it inherently provides high speeds for light loads. Where only a-c power is available, similar performance is obtained from the d-c adjustable-varying-voltage controller. The lack of this inherent performance is the basic limitation of a-c systems because the a-c wound-rotor crane motor is a constant-speed machine. Full speed is approximately the same for any load within its capacity. Somewhat higher lowering speeds are obtained with overhauling loads by running the motor in the final controller position with some permanent secondary resistance left in the rotor circuit. This is done in the Load-O-Matic system. The higher speed, however, must not exceed the maximum safe speed recommended by NEMA for wound-rotor motors (125-150 percent of synchronous). If speeds higher than this are required, motors of special mechanical design should be specified.

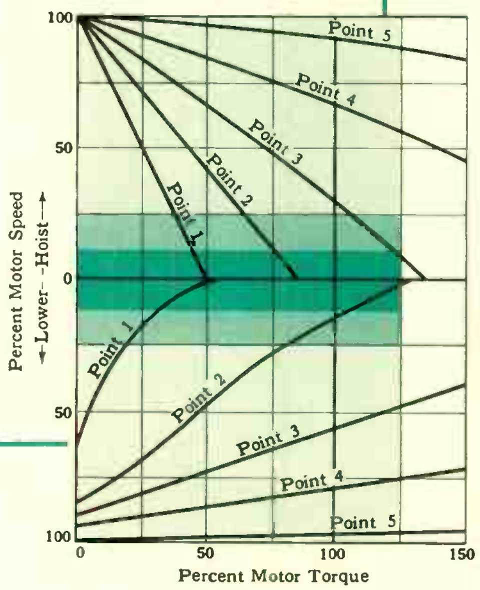
Any controller must provide good inching or creeping speeds for both lifting or lowering. The best performance of this type is obtained with the d-c constant-potential and adjustable-varying-voltage systems, and the a-c Load-O-Matic and electric-load-brake systems.

TABLE III—COMPARISON OF WESTINGHOUSE CONTROL SYSTEMS FOR OVERHEAD CRANE HOISTS

No.	System	*Spotting Speeds—%			Precision Handling	Motor	Safety Features	Comments
		Light Hook	75% Load	Full Load				
1	D-C Constant Potential (Class 9635)	10	20	25	Good	Standard	Very good	Used where direct current is available
2	D-C Adjustable Varying Voltage (Class 9675)	12	15	20	Hoisting—Excellent Lowering—Very good	Standard	Good	High light-load speed Precision handling Smooth operation Load limit
3	A-C Load-O-Matic Varying Unbalance (Class 13625)	0–7	0–7	0–7	Excellent	Standard	Good	Precision handling Smooth operation Load limit
4	A-C Electric Load Brake (Class 13600)	2	10	12	Hoisting—Excellent Lowering—Very good	High-temperature insulation or oversize frame may be required	Good (If dynamic braking is provided)	Special motor for long lifts and medium to severe duty
5	A-C with D-C-Dynamic-Braking Lowering (Class 13630)	5	10	13	Hoisting—Fair Lowering—Very good	Standard	Fair	Limited precision for hoisting
6	A-C-Dynamic-Braking Lowering (Class 13640)	10	80	110	Fair	Oversize motor required unless duty is light and intermittent	Fair	Limited to light intermittent duty unless special motor is used. Speed reduction limited in lowering
7	A-C Counter-Torque (Class 13610)	100	25	10	Hoisting—Fair Lowering—Poor	Standard	Fair	Used only in rough hook work for predetermined loads
8	A-C Plain Reversing with Mechanical Load Brake (Class 13600)	50	30	15	Hoisting—Good Lowering—Poor	Standard	Excellent	Limited to medium duty Lowering speeds erratic due to varying friction of load brake

*Spotting speeds, obtained from speed-torque curves, are given for lowering direction only.

Fig. 9—Speed-torque curves of the mechanical-load-brake controller. Good positioning speeds are available for hoisting but the lowering precision is poor.



Medium Loads

Hook cranes operate most of the time with loads less than 75 percent of the hoist rating. In this load range any d-c or a-c system may be acceptable; however, systems with reasonably flat speed regulation throughout the load range obviously are preferable. The operator, experienced or otherwise, enjoys a better feel of the hoist, since, for a given position of the master-switch handle, approximately the same speed is obtained regardless of the load being handled.

Positioning

Some loads are not readily subject to damage; and precision handling is not required. In such applications the "landing" and "pick-up" speeds can be relatively high, and "inching" the load when necessary is acceptable practice. Controllers providing approximately 25 percent speed or less on the first speed point are applicable. Any of the available control systems, both a-c and d-c, satisfy this requirement.

Extremely accurate spotting finesse, both lifting and lowering, is required for assembling and disassembling machinery. Such performance is provided by the d-c adjustable-varying-voltage and the a-c Load-O-Matic and electric-load-brake control systems.

Safety

Safety is of paramount importance. In crane operation, two hazards are especially serious: dropping the load due to failure of power or brakes, and handling loads beyond the safe limit of the crane.

The hoist with a reliable mechanical brake and a spring-set, electrically released brake is protected from dropping a load if for any reason the power supply fails. Then, too, the failure of either brake, with or without simultaneous power failure, is not serious, since either brake can hold the load.

Where d-c power is available, the d-c constant-potential hoist controller has long been in favor. This system, which has dynamic braking, eliminates the need for a mechanical load brake to supplement the electric brake for holding. If power or the electric brake fails with the control switch in the "off" position, the load is lowered at a safe speed by dynamic braking. The d-c adjustable-varying-voltage controller also provides protection against dropping the load and overspeeding of the motor-generator set.

Unfortunately, the a-c wound-rotor motor cannot brake itself electrically without some form of stator excitation. For protection against power failure, a-c systems require an independent source of excitation. The Load-O-Matic controller provides this feature by exciting the stator with d-c supplied by the pilot generator.

Crane overload protection is desirable. This feature is provided on the a-c Load-O-Matic system by the load detector. Power to the crane can be cut off completely or the operator can be signaled if the load is excessive.

Other a-c and d-c systems are dependent upon the use of some form of torque (current) relay system, and this type of protection is not normally provided.

Protection against overtravel of the hook can be incorporated in all controls. Overtravel in the hoist direction is guarded against by using either a series limit switch (in motor leads) or a shunt limit switch (in control circuit). Usually the limit switch is operated by the hook block.

The Future

As crane hoist drives and controller systems are further developed, major improvements probably will be simplifications of present equipment. The number of motors required may be reduced by combining hoist and trolley drives in one motor; control schemes should be less complicated and require less apparatus; the size and operating effort required of manual drum switches and master switches should be decreased; and smaller control devices that can do the same or a better job than present control equipment are needed. Meanwhile, there is a drive with adequate performance and control for any application.

Load-O-Matic

A-C Crane-Hoist Control

Last fall a more precise a-c crane-hoist control system became available. Giving performance that can be surpassed only by some d-c adjustable-voltage systems, it provides extra-slow creeping speeds, decrease in speed with increased load, and safety features that are not available on other crane-hoist controllers.

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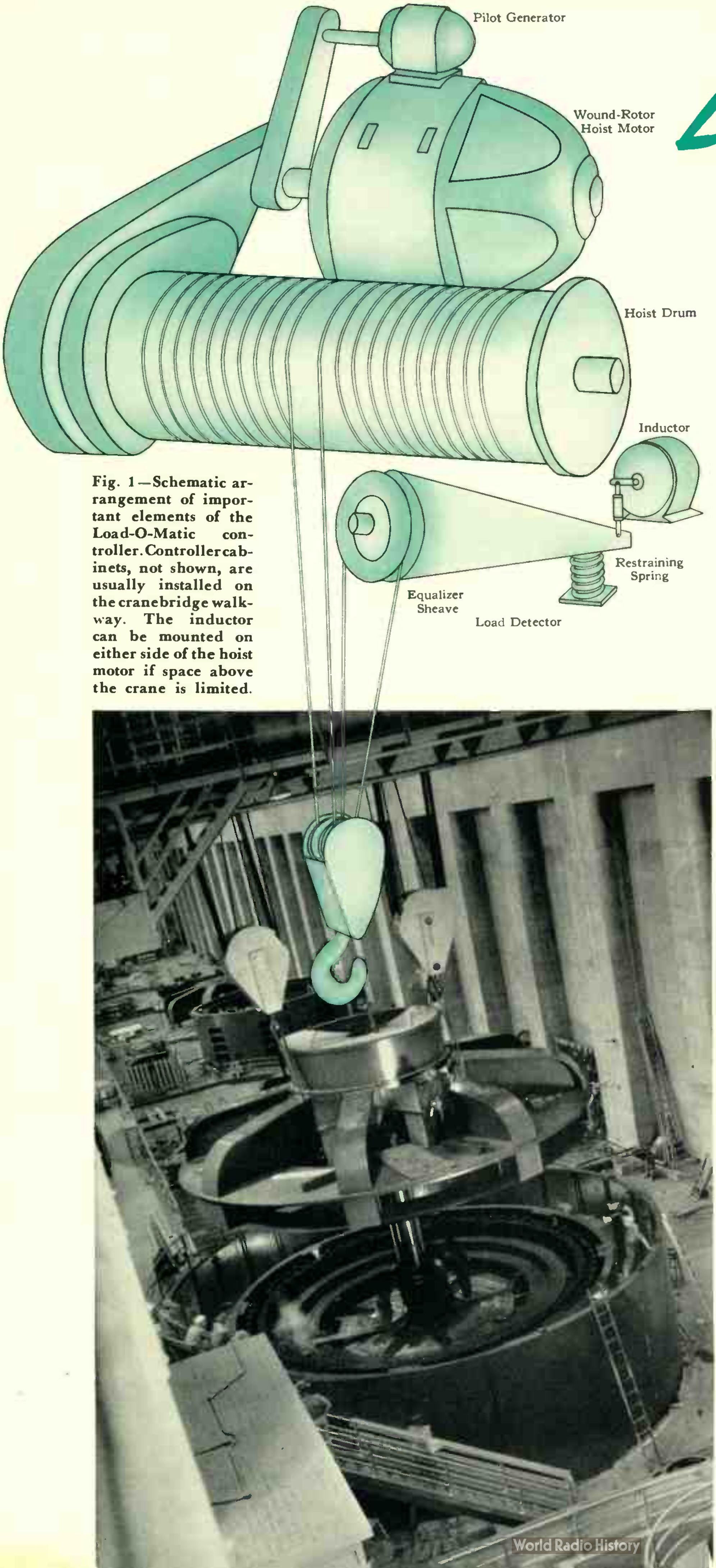


Fig. 1—Schematic arrangement of important elements of the Load-O-Matic controller. Controller cabinets, not shown, are usually installed on the cranebridge walkway. The inductor can be mounted on either side of the hoist motor if space above the crane is limited.

Because a-c power is usually more readily available than d-c power, crane hoists powered by a-c motors are preferred for most applications. Consequently, engineers have worked continuously to improve the performance of a-c hoists, which are inherently more difficult to control than d-c powered hoists. Various a-c crane-hoist systems have been used, but none has furnished completely satisfactory performance in precision hoisting operations.

A new a-c crane-hoist controller, termed Load-O-Matic, has been developed especially for those applications that require precise control. A precision crane should be able to handle light as well as heavy loads at slow speeds. The lack of good slow-speed performance, particularly in the lowering direction, is the principal drawback of most a-c systems. Usually the crane operator must resort to inching or jogging to position a load. Load-O-Matic offers advanced refinement in low-speed control for both hoisting and lowering; it provides slower positioning speeds than any previous a-c system and does not require inching or jogging. By means of a load-measuring device, most of the upward pull of the motor for both hoisting and lowering is in direct response to the weight on the crane hook. Speed is also used to adjust the motor torque; however, it accounts for only a small part of the total pull, and is dominated by the load signal. This permits the selection of any reasonable speed for a given load.

The Load Detector

The key item in this control system is the load detector, shown in Figs. 1 and 2. This mechanism causes a lever to deflect in proportion to the load on the hook. The lever rotates the shaft of an inductor which produces an electric current proportional to the load. This current is then used to control the excitation of the driving motor.

The lever mechanism is built into the rope system of the hoist and can be readily adapted to the mechanical layout. Most cranes require a special equalizer sheave like the one shown in Fig. 2. The lever arm has a hub on one end, on which the equalizer sheave is mounted. The hub, in which an off-center hole is bored, is supported by a shaft inserted in this hole. Antifriction bearings are used between the sheave and hub and between the shaft and hub. Any load on the crane hook exerts a downward force through the center of the hub. Since the hub is free to turn only around the supporting shaft, and since the shaft is off center, the force acting through the center of the hub causes the lever arm to rotate clockwise. This rotation is restrained by a spring and usually does not exceed two or three degrees. The lever arm has a throw of about one inch at the point where the inductor is coupled. The rotor of the inductor never moves more than 45 degrees from its position with no load on the hook.

The only installation adjustments are mechanical. The linkage to the load inductor must be adjusted to give the amount of "throw" necessary to provide the desired full-load operating speed.

In addition to load intelligence supplied by the load detector, a limited speed intelligence is also required. This is supplied by a pilot generator furnished integral with and driven by the hoist motor, as shown in Fig. 1.

Unbalanced Voltage Utilized

The speed of the driving motor is controlled by varying the torque developed by the motor. This is accomplished in the Load-O-Matic system by applying variable unbalanced voltage to the stator windings. By controlling the degree of unbalance, the torque and thus the speed developed by the motor can be regulated.

Adjustable, unbalanced voltage is obtained from what might be called a "duplex, interconnected three-phase" source. The conventional vectors of a three-phase system in which the rotation is clockwise, $L1$ to $L2$ to $L3$, are shown in Fig. 3. The primary and secondary of a transformer can be connected so as to set up a fourth phase $L4$. In relation to $L1$ and $L3$ this fourth phase forms, in effect, another three-phase system. The vector rotation is again clockwise, but in the sequence, $L1$, $L3$, $L4$, which is opposite to the conventional rotation of a three-phase system.

If the terminals of a motor are connected to $L1$, $L2$, and $L3$ respectively, the terminal voltage sequence is $T1$, $T3$, $T2$. With this sequence, the hoist motor of the Load-O-Matic system tends to run in the hoist direction. If terminal $T2$ is removed from $L2$ and connected to $L4$, the phase created by the addition of the transformer, the terminal voltage sequence of the motor is reversed. The motor therefore tends to run in the opposite or lowering direction.

When lowering or hoisting at reduced speed, motor terminal $T2$ is not connected directly to either $L2$ or $L4$. Instead, it is connected between two saturable reactors which are connected in series from $L2$ to $L4$. This is shown in Fig. 4. By varying the excitation to these two reactors the unbalance in the voltage applied to the primary of the motor is changed. This shifts the vector position of motor terminal $T2$, thus changing the direction and amount of torque developed by the motor. Terminal $T2$ can be made to take any vector position along the locus between $L2$ and $L4$.

It can be explained mathematically that, as the unbalance is increased, the rotating magnetic field of the

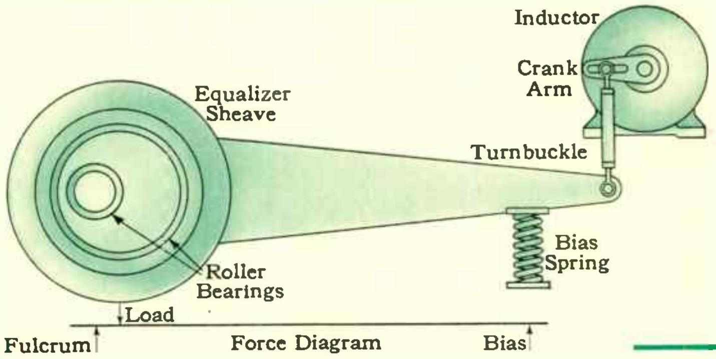


Fig. 2—The essential parts of the load detector showing the special equalizer sheave required when the sheave is part of the trolley structure of the crane.

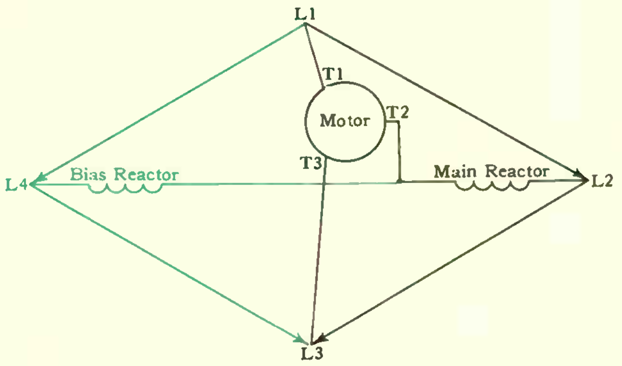


Fig. 3—The three-phase network system created by the addition of the transformer is shown in color. It causes the motor to rotate in the lowering direction. Normal three-phase vectors for hoisting are in black.

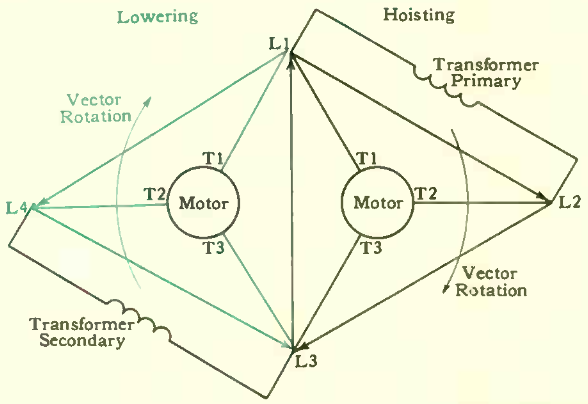


Fig. 4—By connecting one motor terminal between two reactors, as shown, unbalance can be varied by changing the excitation to the reactors. Thus, motor torque can be controlled to give any desired speed.

motor becomes, in effect, elliptical; and the net torque therefore becomes less. This is illustrated in Fig. 5 where the area within the ellipses indicates the magnitude of the torque developed at various degrees of unbalance. The transition from full torque clockwise (hoisting) to a specified torque counter-clockwise (lowering) is gradual.

In Fig. 6 the position of motor terminal *T*2 with respect to phases *L*2 and *L*4 is expressed as percent of unbalance. With no load on the hook, and with the motor at rest, the unbalance is always more than 100 percent and might be 120 percent as shown. If lowering speed or the load on the hook is increased, the unbalance decreases. This is accomplished by arranging the electrical signals from the pilot generator and load detector to increase the excitation of the motor. As excitation increases, the vector position of terminal *T*2 moves away from *L*4 toward *L*2. As this happens, the down torque of the motor decays to zero, then reverses and starts to increase in the hoisting direction.

Circuit Operation When Lowering

No Load—The three sources of main-reactor excitation—the pilot generator, the inductor, and the vernier excitation circuit—are connected in series as shown in Fig. 7. (This can be seen by tracing the circuit, starting at motor terminal *T*2, through the bias reactor, through points 4, 5, 2, 3, 40, 92, 91, then back to *T*2.) At the instant the drum switch is moved to the first point lower, contactors 1*H*, 1*BR*, and 1*DB* close. With no load on the hook and with the motor at rest, the unbalance is 120 percent and the motor torque is *T*1 in Fig. 6, because no voltage is being produced at any of the three sources. As torque *T*1 accelerates the motor in the lowering direction, voltage from the pilot generator increases excitation, which reduces the unbalance. When speed *D*1 is reached, the unbalance has been reduced to 100 percent. The torque at that point is zero; therefore the motor stops accelerating and speed *D*1 is maintained.

Half of Rated Full Load—With 50 percent of full load suspended on the hook and the drum switch in the off position, the reactor is pre-excited by the inductor and the unbalance is about 72 percent. At the instant contact is made on the first point lower, torque *T*3 is produced. This is less than *T*4, the downward torque caused by the load. Therefore, the motor is overhauled and accelerates in the lowering direction. As motor speed increases the pilot generator adds exciting current to that already being generated by the inductor. The increase in excitation results in a decrease in unbalance to 57 percent, which corresponds to speed *D*2. When the speed reaches *D*2, the motor torque balances the load torque, and there is no further acceleration of the load.

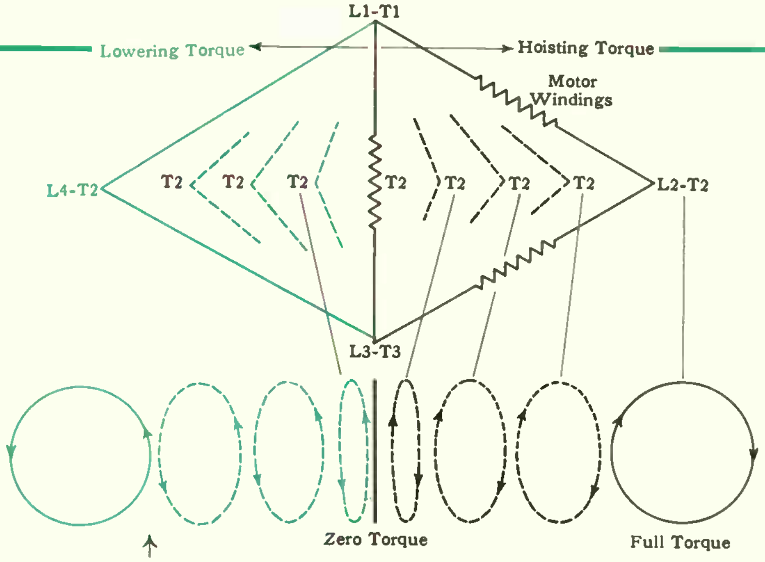


Fig. 5—The ellipses represent the shape of the magnetic field of the motor for various degrees of unbalance. The area within each one indicates the relative magnitude of torque developed for each degree of voltage unbalance.

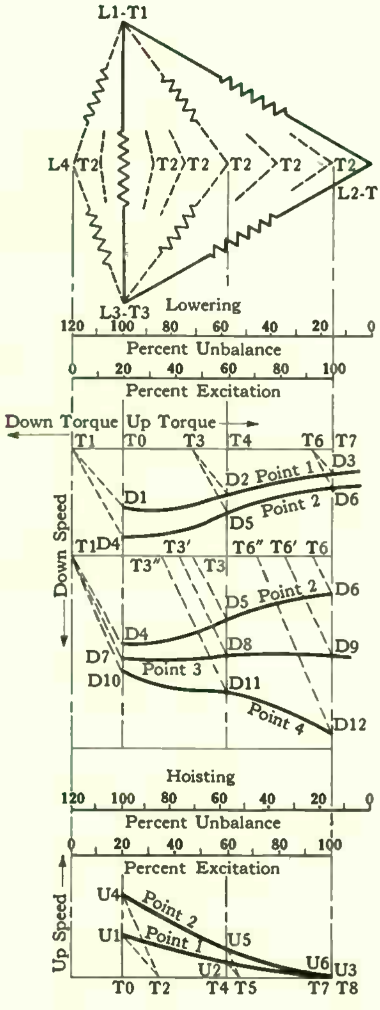


Fig. 6—Speed-load loci for various control points on the drum or master switch.

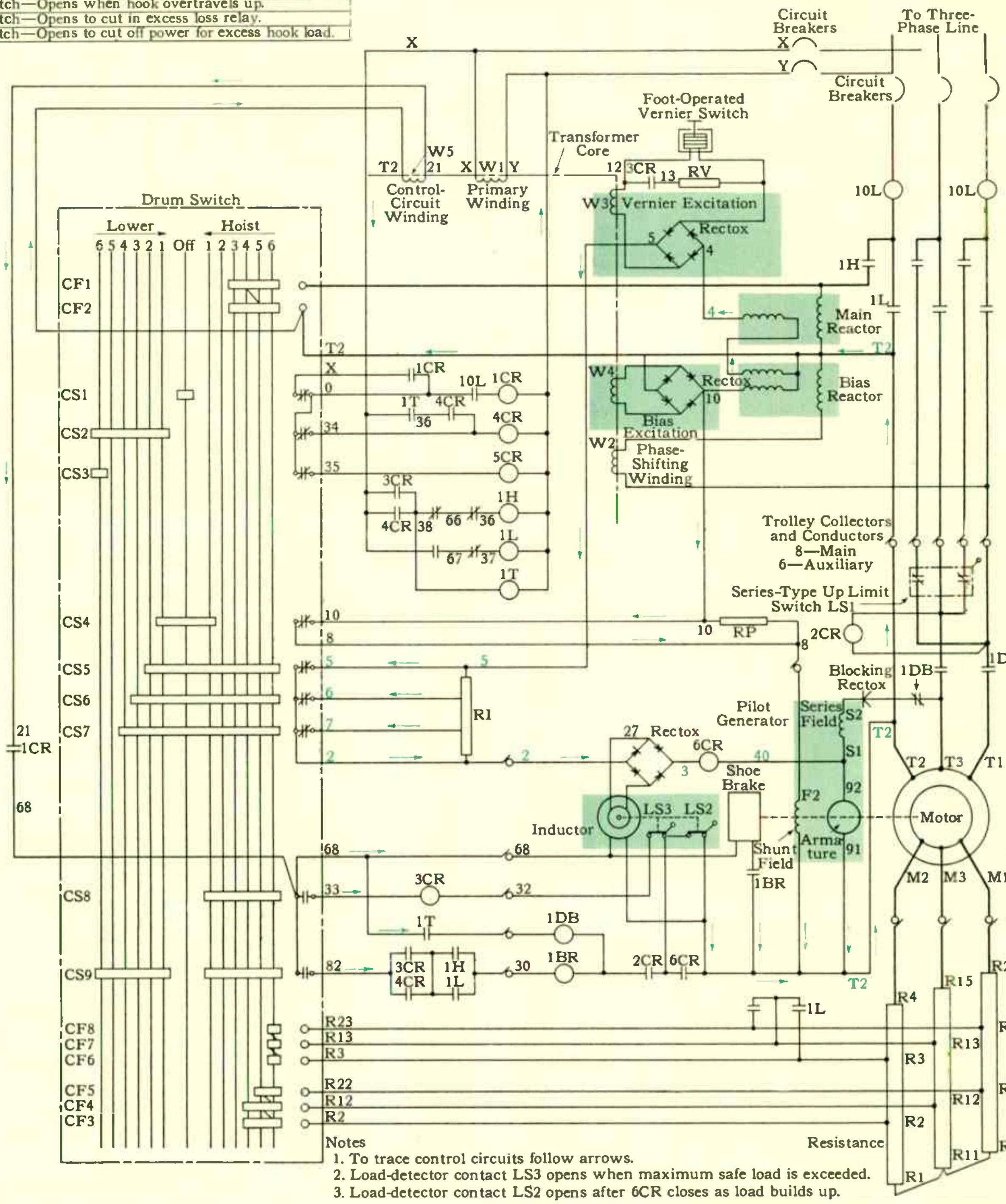
Full Load—With full load on the hook, the output of the inductor raises the excitation to about 92 percent and reduces the unbalance to about 24 percent. The motor then delivers torque *T*6, which is less than the torque *T*7 being exerted on the motor shaft by the load. Hence, the motor is overhauled. At speed *D*3 the motor and load torques balance so that there is no further acceleration and speed *D*3 is maintained with the drum switch on the first point.

A curve passing through *D*1, *D*2, *D*3 is the speed-load locus with the drum switch set on the first notch in the lowering direction.

Other Lowering Points—With the drum switch on the second lowering point, contact *CS*4 opens to insert a resistor, *RP*, into the shunt field circuit of the pilot generator. (On the wiring diagram this resistor is above the pilot generator.) This reduces the effect of the pilot machine for a given speed. The speed, therefore, must rise higher, to *D*4, *D*5, and *D*6 in Fig. 6, to produce the stabilizing excitation for no load, half load, and

	Controller Points Acceleration ←— Lowering							Hoisting —→						Controller Points Deceleration Lowering —→							←— Hoisting					
	6	5	4	3	2	1	Off	1	2	3	4	5	6	6	5	4	3	2	1	Off	1	2	3	4	5	6
CF1										🟩1	🟩	🟩	🟩									1	🟩	🟩	🟩	🟩
CF2										🟩1	🟩	🟩	🟩									1	🟩	🟩	🟩	🟩
CF3											🟩1	🟩	🟩										1	🟩	🟩	🟩
CF4											🟩1	🟩	🟩										1	🟩	🟩	🟩
CF5												🟩1	🟩											1	🟩	🟩
CF6													🟩1												1	🟩
CF7													🟩1												1	🟩
CF8													🟩1												1	🟩
CS1						1	🟩	1												🟩1						
CS2	🟩	🟩	🟩	🟩	🟩	🟩								🟩	🟩	🟩	🟩	🟩	🟩							
CS3	🟩1													🟩	1											
CS4					1	🟩	🟩	🟩	1										🟩1	🟩	🟩1					
CS5				1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩					🟩1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
CS6			1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩				🟩1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
CS7		1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
CS8								🟩1	🟩	🟩	🟩	🟩	🟩							1	🟩	🟩	🟩	🟩	🟩	🟩
CS9	🟩	🟩	🟩	🟩	🟩	🟩1		🟩1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	1	🟩	🟩	🟩	🟩	🟩	🟩
1CR	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
2CR	🟩	🟩	🟩	🟩	🟩	🟩4		🟩4	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	5	🟩	🟩	🟩	🟩	🟩	🟩
3CR								🟩2	🟩	🟩	🟩	🟩	🟩							2	🟩	🟩	🟩	🟩	🟩	🟩
4CR	🟩	🟩	🟩	🟩	🟩	🟩2								🟩	🟩	🟩	🟩	🟩	🟩	2						
5CR	🟩2													🟩	2											
1T	🟩	🟩	🟩	🟩	🟩	🟩4		🟩4	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	3	🟩	🟩	🟩	🟩	🟩	🟩
1H	3	🟩	🟩	🟩	🟩	🟩3		🟩3	🟩	🟩	🟩	🟩	🟩		🟩3	🟩	🟩	🟩	🟩	4	🟩	🟩	🟩	🟩	🟩	🟩
1L	🟩3													🟩	3											
1BR	🟩	🟩	🟩	🟩	🟩	🟩5		🟩5	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	2	🟩	🟩	🟩	🟩	🟩	🟩
1DB	🟩	🟩	🟩	🟩	🟩	🟩5		🟩5	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	6	🟩	🟩	🟩	🟩	🟩	🟩
6CR	Series Relay—Opens in event of excitation failure.																									
LS1	Limit Switch—Opens when hook overtravels up.																									
LS2	Limit Switch—Opens to cut in excess loss relay.																									
LS3	Limit Switch—Opens to cut off power for excess hook load.																									

Fig. 7—Circuit diagram for a semi-magnetic Load-O-Matic controller. Circuit operation can be followed by using the sequence table above the diagram. Contactors are closed where blocks are colored. The numbers inside the blocks indicate the sequence in which the contactors operate when the drum switch is moved to a new position. For example, when the drum switch is moved from point two to point three hoisting, the only new thing to happen is the closing of reactor-shorting contactors CF1 and CF2. They close simultaneously. All other contactors remain as they were. When the drum switch is moved from point three to point two in decelerating (right side of table) the new operation is the opening of contactors CF1 and CF2. Contacts CF3 to CF8, when closed, short-circuit secondary resistance. Devices CS1 to CS9 are auxiliary contacts operated by the drum switch. Contacts 1CR to 5CR are control-relay contacts.



Notes
1. To trace control circuits follow arrows.
2. Load-detector contact LS3 opens when maximum safe load is exceeded.
3. Load-detector contact LS2 opens after 6CR closes as load builds up.

full load. The second locus is of the same general slope as the first, because the "speed signal" from the pilot generator is about equally effective at all loads.

For succeeding lowering points of the drum switch, contacts *CS*5, *CS*6, and *CS*7 open to insert increasing amounts of resistance in series with the main-reactor excitation circuit. This resistance weakens the effect of both the inductor and the pilot generator. The weaker load signal from the inductor causes the motor torques, *T*3 and *T*6, to be less than before. However, load torques *T*4 and *T*7 are the same for half- and full-load conditions since these are direct mechanical torques transmitted to the motor shaft through the rope system. Hence for a given load, with the drum switch on one of the last three lowering points, there is a greater difference between the load torque and the motor torque caused by the inductor. Therefore, the speed signal required to obtain the stabilizing speed must be proportionately greater, and the speed must rise higher to enable the pilot generator to produce the required signal.

Circuit Operation When Hoisting

No Load—When the drum switch is moved to the first point in the hoisting direction, contact 3*CR* (between points 12 and 13 of the vernier excitation circuit in Fig. 7) immediately closes to excite the main reactor and reduce the unbalance to about 85 percent. With this condition motor torque *T*2 is produced at once; and since it is unopposed by any load on the hook, acceleration takes place in the hoisting direction. The pilot generator is driven by the hoist motor; therefore, it rotates in the hoisting direction also. With this rotation, the voltage produced by the pilot generator opposes the excitation initiated by the drum switch. As the speed increases, raising the output of the pilot generator, the net excitation to the reactors decreases and unbalance increases. The unbalance reaches 100 percent when speed *U*1 is attained. At that point, the torque developed by the motor is just enough to maintain speed *U*1, and acceleration stops.

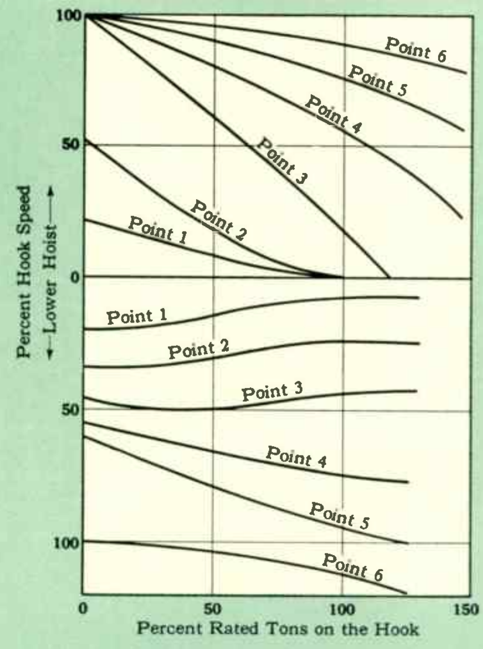


Fig. 8—Estimated speed-torque characteristics of the semi-magnetic Load-O-Matic controller shown in Fig. 7. The lower creeping speeds available with vernier control are not shown.

Half of Rated Full Load—With 50 percent of full load on the hook and the master switch on the first point hoist, the excitation from the inductor plus that produced by the drum switch reduces the unbalance so that motor torque *T*5 results. This is greater than torque *T*4 which is exerted on the shaft by the load, hence the motor accelerates to speed *U*2. At that point the motor torque has fallen off so that it balances *T*4 and no further acceleration occurs.

Full Load—With full load on the hook, motor torque *T*8 will equal or slightly exceed load torque *T*7. The motor may not be able to accelerate the load in the hoisting direction, but it cannot be overhauled in the lowering direction. The hoisting speed will be low, or zero.

A curve drawn through *U*1, *U*2, *U*3 is the hoisting speed-load locus for the first controller point. For the second controller point, hoisting, the shunt field winding of the pilot machine is weakened so that the speed must rise higher to stabilize the load and motor torques. Succeeding points provide for acceleration by the removal of reactors from the motor-primary circuit and the removal of resistance from the secondary circuit.

Speed-Torque Characteristics

The curves in Fig. 8 are estimated for the six-point controller shown in the wiring diagram. Since they show hook speed versus tons on the hook, they include the effect of crane friction. Frictional torque always opposes the existing motion, hence it aids the motor in supplying the necessary retarding torque for lowering. The magnitude of the torques indicated by these curves does not represent the ultimate obtainable, but rather, magnitudes that are practical from the standpoint of current input for crane-hoist applications. The ultimate is the maximum that the motor can deliver; the reactor system imposes no appreciable limitations.

Performance Curves

A comparison of no-load and full-load speeds of a 15-ton, 40-feet-per-minute crane hoist is shown in Fig. 9. As these oscillograms show, there are no transients produced in starting and stopping the hoist, nor when the switch is moved from point to point. The no-load lowering speed for the first point is about 20 percent of rated full speed, while with full load the speed for the first point is only about 10 percent. The spread in speed between no-load and full-load hoisting is a little greater on the first point hoist; no-load speed is about 20 percent, full load is about five percent.

Advantages of the Load-O-Matic System

The load detector and the pilot machine of the Load-O-Matic system make possible features that are not usually available on a-c cranes, some of which are possible only with the Load-O-Matic. Some of these advantages are:

Very Slow Creeping Speeds—Extreme slow-speed maneuvering well beyond ordinary requirements for occasional operations is possible. When full-magnetic control is used, this performance is obtained by means of an auxiliary squeeze lever on the master-switch handle. Squeezing this auxiliary lever slows down the lowering motion or speeds up the hoisting in proportion to the pressure applied. For the semi-magnetic controller shown in the wiring diagram of Fig. 7, this performance will be provided by application of pressure to a foot-operated vernier switch. Thus, with the switch in position one, the lowering speed of the load can be reduced to any low value down to and including zero, or *load floating*. No other system,

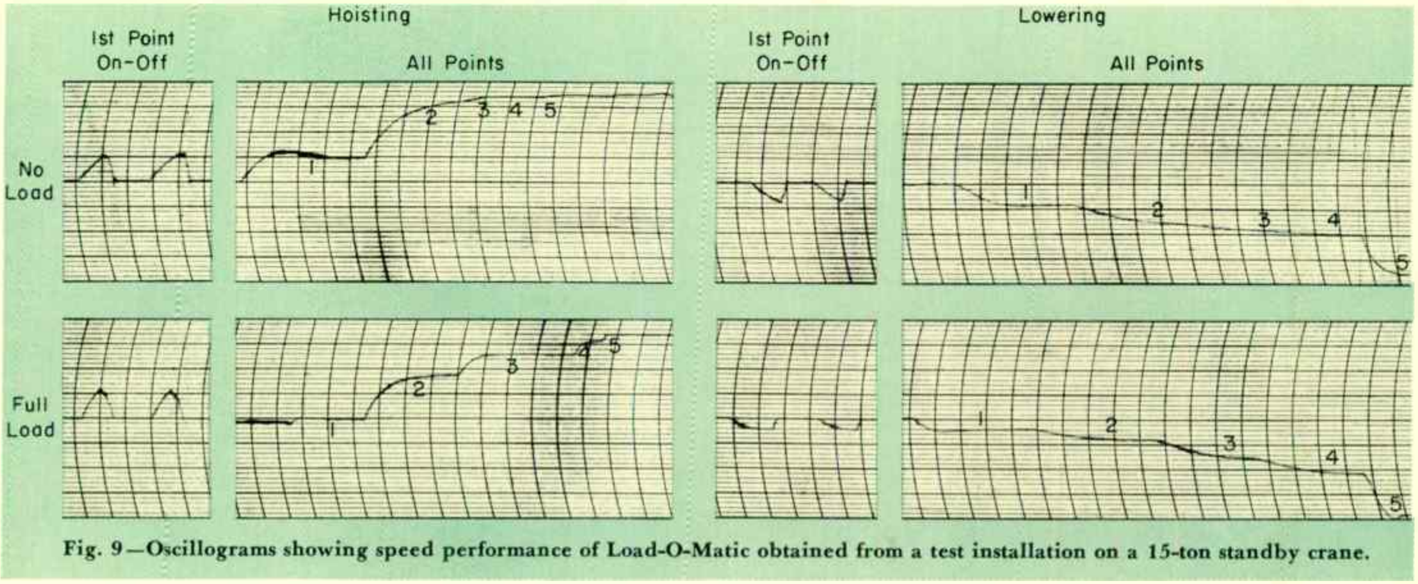


Fig. 9—Oscillograms showing speed performance of Load-O-Matic obtained from a test installation on a 15-ton standby crane.

except perhaps d-c adjustable voltage, is capable of such a refinement.

Lower Speed for Heavy Loads—On the first two points of the controller, when hoisting or lowering, speed decreases as the load increases. This makes possible safer and more precise handling of heavy loads. This performance is obtained without excessive input current to the motor, because there is little voltage unbalance with heavy loads. The current input is little more than would be required with orthodox balanced voltage. Heavy currents (150 percent of normal) occur only when the crane is overloaded.

Protection from Overloads—The load detector can be used to warn the operator when there is an overload on the crane and to limit the maximum load that can be lifted.

Provision can be made to warn the operator when the load on the hook is greater than the crane rating. Since the mechanical part of the load detector deflects in proportion to the load, a limit switch, set to operate when the deflection corresponds to the desired maximum load, can be arranged to operate a visual or audible signal.

The maximum load on the hoist can be limited. This is accomplished in a manner similar to that used to warn the operator of an overload. A contact on the load detector stops the hoist if the load is excessive. The cut-off is instantaneous and direct acting, and occurs before, not after, the crane is subjected to dangerous strains.

The load detector will perform as a back-up to the up limit switch, if the latter should fail to function, to stop upward travel when the hook is raised to the maximum permissible height. If this should happen, the cables tighten because of jamming of the blocks and cause the load detector arm to be depressed as if the load were excessive. This deflection operates the overload cut off to stop the hoist, and may under certain conditions prevent serious damage to the crane.

Protection in Case of Power Failure—Dynamic braking, to be applied in case of power failure or other emergency tripping, is provided. This is achieved by selecting the size of the pilot generator to give it an intermittent rating that is three to five percent of the rating of the hoist motor. The generator armature is connected across two motor terminals through a series field and blocking Rectox unit. If the hoist is lowering at the time of emergency, the d-c machine builds up as a series generator to excite the motor primary for ordinary d-c dynamic braking. If the motion is hoisting when the emergency occurs, the Rectox prevents demagnetization of the d-c machine while the motion continues and assures build-up when the motion reverses due to overhaul.

Dynamic braking also provides protection in case the magnetic brakes fail to hold the load with the drum switch centered. When electric braking is removed, shortly after the switch has been centered, the dynamic-braking circuit is established and prevents dropping the load.

If the pilot generator fails to function, the speed will merely rise higher than ordinary. If there is light or no load on the hook, the speed may eventually reach synchronism. For heavy loads the rise will vary depending on conditions, but with the controller on the first or second point, it should be less than synchronism. For the third and fourth points it should be less than the allowable limit of 150 percent. Rate of acceleration will be slow.

Protection Against Loss of D-C Excitation—The inductor originates most of the d-c excitation for the Load-O-Matic system. If this excitation is lost, a contact on a series current-type relay (6*CR* in Fig. 7) opens to cut off the power, set the holding brakes, and apply dynamic braking. However, the relay contact closes to allow normal operation only when the load is heavy enough to cause overspeeding. For light loads that do not produce enough excitation to actuate the relay, the relay contact is by-passed by a light-load contact (*LS*2) on the inductor. The light-load contact opens when the load is great enough to insure operation of relay 6*CR*.

Summary

Load-O-Matic is no panacea for every crane-hoist application. It was developed especially for precision-handling crane operation. Creeping speeds can be reduced to any value between zero and about seven percent of rated speed. This exceptional performance is obtained with a standard motor. In addition, safety features not available with any other controller are provided by means of the load detector. Load-O-Matic is especially applicable in generating stations, pumping plants, foundries, machine-assembly areas, and other types of crane-hoist service that require accurate handling of varied loads. In such applications it provides safe, reliable handling of all loads with precision comparable to that obtainable from d-c controllers.

Constant-Potential D-C Hoist Control

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Simplicity and safety are advantages of the d-c constant-potential crane-control system. While it cannot do some of the tricks possible with d-c adjustable-voltage and certain a-c systems, those tricks aren't necessary for most lifting. The d-c constant-potential system—oldest of all—is still the most frequently used. And old as it is, its design and operation are still being improved.

For more than 40 years, d-c constant-potential crane-hoist controllers have been favorites, especially where hard service is encountered. The principal reasons for this popularity are the basic simplicity of such a system and the excellent speed-torque characteristics that are obtainable. In addition, only standard electrical components are required and these are types that are built especially for hard service. A standard mill-type d-c motor, mill-rated contactors, and heavy-duty resistors are used.

The d-c constant-potential hoist control system is unchanged fundamentally from the one originally used 40 years ago. Before that a simple reversing controller had been used. A d-c series motor was reversed for lowering, with speed control provided by a mechanical load brake. The mechanical brake had several disadvantages: it required a great deal of adjustment and maintenance and did not provide accurate control of lowering speed.

In the d-c constant-potential system, a standard, series-wound d-c motor, controlled by a resistance controller, is used for hoisting. But for lowering, dynamic braking is provided by operating the motor as a shunt machine.

The speed-torque characteristics of a series-wound motor are basically different from those of a shunt machine. On a series motor, load is an important factor in determining speed: as the load on the motor increases the speed decreases. This inherent characteristic makes the d-c series motor especially suited for hoisting operations, since it automatically provides high speed when hoisting light loads, and slow speeds when hoisting heavier loads that must be handled more carefully. However, the series motor has a major disadvantage. At no load, or with an overhauling load, the speed rises uncontrolled and may become destructive.

In contrast, the speed of the shunt-wound d-c motor is reasonably constant over the entire load range, even at no load or with an overhauling load. Since overhauling is encountered in crane applications when a load is being lowered, a shunt machine is preferable for lowering.

In the d-c constant-potential system the advantages of both machines are utilized. The series motor is operated in the usual way for hoisting. To obtain more desirable speed characteristics for lowering, however, the series field is connected across the line in parallel with the armature. The motor then functions as a shunt-wound machine. Light hooks are lowered by making the motor turn in the lowering direction. Overhauling loads are retarded by means of dynamic and regenerative braking.

Circuit Operation

Although the performance of the d-c constant-potential system has been eminently satisfactory, a study of this control was made recently in an effort to find the simplest circuit that would give the desired hoist performance. The main-circuit schematic diagram of the resulting control is shown in Fig. 1.

The simplicity of the circuit can best be appreciated by following the operation of the circuit for all positions of the controller in both hoisting and lowering operations.

Hoisting—With the master switch on the first hoisting point, contactors 2M, 4M, and 5M are closed to connect the motor for series operation. Resistor R1 is connected as an armature shunt by the closing of contactor 1M; and R7 is connected across motor armature and field by a spring-closed contactor. The armature shunt increases the current in the field coil of the motor, thus limiting the motor speed. Motor shunt, R7, in conjunction with resistor R3, which is in series with the motor, limits the armature current. This combination makes possible a very slow, first-point hoisting speed that remains fairly steady throughout the load range, as shown by the speed-torque curves of Fig. 2.

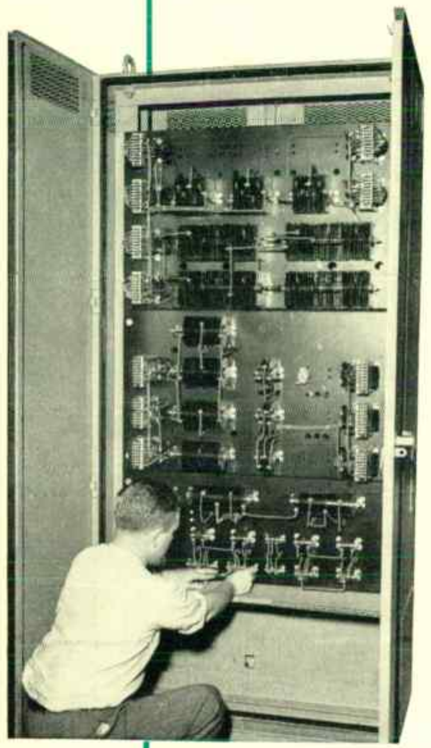
Speed is greater for the second controller point because contactor 1M opens, removing the armature-shunting resistor from the circuit. On the third point, speed increases further when the motor shunt is removed from the circuit. For the fourth point, an additional rise in operating speed is obtained by connecting resistor R4 in parallel with R3, the series resistance. This is accomplished when contactor 6M closes. Full speed is attained on the fifth point, because the motor is connected directly across the line when contactors 7M and 8M close.

Lowering—For lowering, the series field is connected across the line in series with resistors when contactors 1M and 8M close. The armature circuit is connected in parallel with the field when contactor 3M closes. With these connections, the motor performs as a shunt machine.

For the first-point lowering, the speed-torque curve is flat and provides slow speeds to facilitate accurate handling of light hooks and for positioning loads. The field excitation is at a maximum value, limited only by resistor R1. With this high motor flux, a counter electromotive force equal to or greater than line voltage is developed at a relatively low motor speed. Therefore, speed is kept low. This is true throughout the load range because load has only a minor effect upon speed.

To obtain higher lowering speeds for succeeding controller points, resistance is added to the field circuit of the motor. This reduces the flux, and therefore the counter emf devel-

Output stage of Magamp regulator. Magamps for control and IR-drop compensation are on the opposite side of the cabinet.



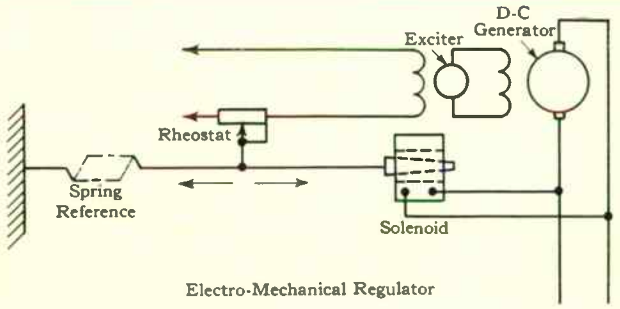
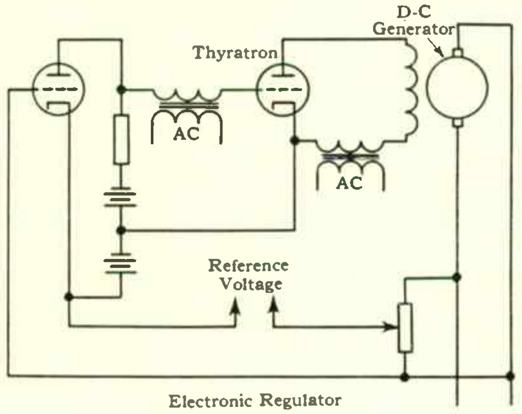
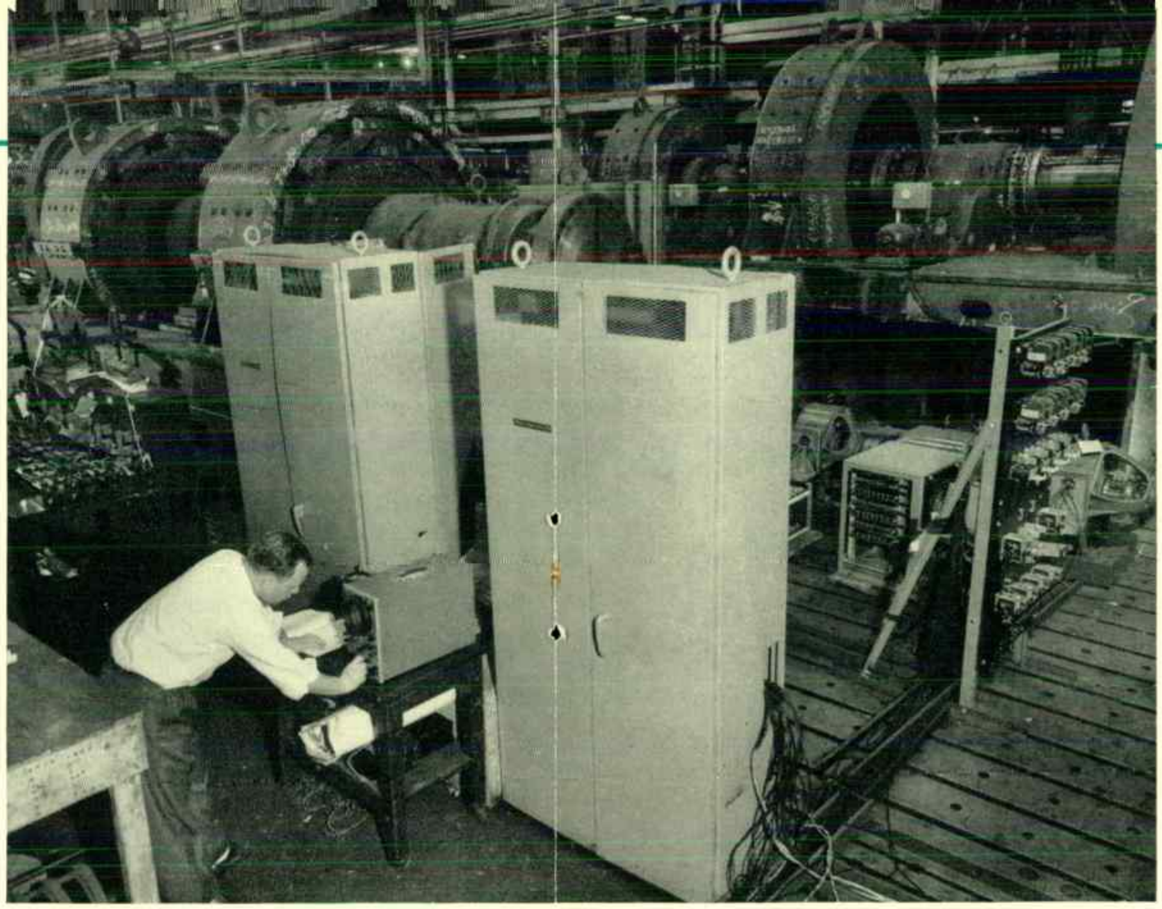


Fig. 1—Schematic diagram of electro-mechanical regulator.

Fig. 2—Schematic diagram of an electronic regulator.





The test equipment used to check the performance of the Magamp regulator. Speed of the 4000-hp, double-armature motor, behind the control panels, is controlled by adjusting the voltage of the 3600-kw d-c generator in the right background. Generator voltage is adjusted by changing the excitation supplied by the power Magamp.

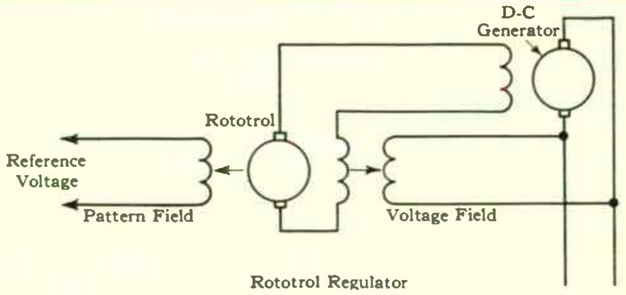
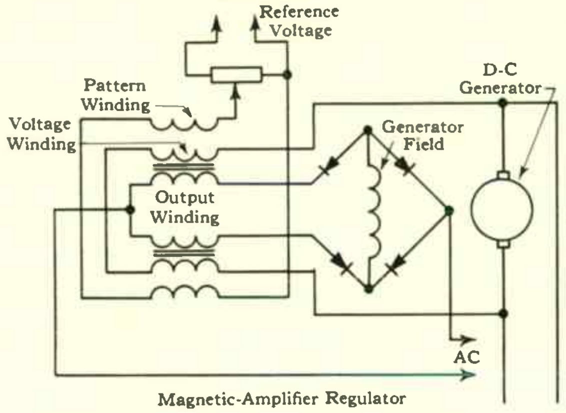
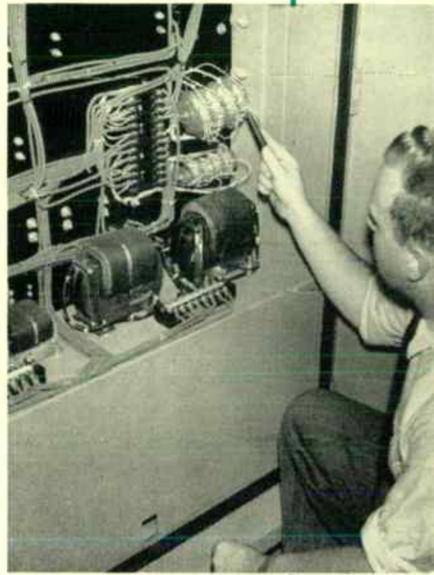


Fig. 3—Typical schematic diagram of Rototrol regulator.

Fig. 4—Schematic diagram of Magamp regulator. The voltage winding measures reference voltage. Any error in generator voltage produces a change in excitation.



Below, an engineer is pointing to control Magamp. Directly below it is IR-drop-compensation Magamp.



Magamp Regulation of a Tandem Cold-Reduction Mill

For many years little attention was paid to the magnetic amplifier, while the vacuum tube performed a variety of control tricks for a vast and admiring audience of control engineers. But the Magamp, with the help of better core materials, now has stepped forward into the limelight, demanding its share of attention—and getting it. One of many new Magamp applications is the control of drive equipment on tandem cold-reduction steel mills.

THE MAGNETIC amplifier—using saturable-core reactors—is a device that employs a small direct current to control a large amount of power. Saturable-core reactors have been used for many years as current-limiting devices in which the a-c impedance of a reactor is changed by exciting the core with d-c. Since World War II the use of self-saturating magnetic amplifiers—Magamps—has been extended to all types of control circuits. Now they are being used for voltage regulation of d-c generators on cold-reduction steel mills.

There are several reasons for the increased use of Magamps. First, the self-saturating circuit is now more completely understood and the great amplification possible can be utilized to better advantage.

Second, core materials and rectifiers, which largely determine the performance of a self-saturating magnetic amplifier, have been greatly improved so that Magamps are now more useful to industry. Improvements in alloy steels such as Hipersil and Hipernik, and development of new ones such as Hipernik V, make possible higher amplification and greater linearity. The improved characteristics that can now be provided in dry-type rectifiers are equally important, because imperfections in rectifier characteristics adversely affect the operation of an amplifier.

Third, there is an increasing need for Magamps. Foremost among their advantages as regulators are reliable maintenance-free operation and ease of installation. There are no tubes, brushes, or commutators that need regular attention, and units can be panel mounted and wired, thus reducing installation expense. These are particularly important features in heavy industries like steel. The steel industry is using more automatic regulating equipment on drive systems than before, and there is a need for a regulating device that is static, simple, and relatively maintenance-free—requirements that the Magamp fits to a T.

Control Systems for Cold-Reduction Mills

There has been a marked increase in the speed and power of drives for cold-reduction mills in the last 20 years. The first tandem cold-reduction mill, installed in 1928, was a four-stand, 32-inch mill with a maximum rolling speed of 340 feet per minute. A total of 1020 hp was required of the mill-drive and reel motors in that installation. Today, a rolling speed of 5000 fpm is not uncommon on five-stand tandem mills. One such mill, with a top speed of 4950 fpm, requires 17 550 hp.

As speed and horsepower increased, improved control systems were needed to regulate properly the faster, more powerful mills. Until 1938 all stand motors and generators were tied to a common d-c bus. Mill speed was adjusted by varying the bus voltage. To accommodate different rolling schedules, the speed of individual motors was controlled by changing the excitation to the shunt field of the motor.

About 1938, IR-drop compensation came into use for speed regulation. As the rolling load in a mill increases, the motor IR drop also increases, and speed drops. By compensating for the IR drop, speed can be controlled.

About 1945 a further improvement in mill regulation was made when the individual generator system was introduced. In this system driving equipment is not tied directly to a common bus. Each drive motor is supplied from an individual generator and all stands are matched to a d-c reference bus through a precise control system.

In an individual generator system, IR-drop compensation is obtained by controlling excitation to the individual generator fields. This eliminates expensive IR-drop boosters previously required on every stand.

Types of Regulators

Four types of regulators are in general use on industrial drive systems. They are: electro-mechanical, electronic, Rototrol, and magnetic-amplifier regulators. Each of these compares the quantity being regulated with a reference standard. If there is any difference, the excitation of the regulated machine is automatically adjusted to correct its output.

Typical operation of an electro-mechanical regulator is shown in Fig. 1. A spring is used as a fixed reference. Bucked against the pull of this spring is a solenoid excited by the output of the generator. Any unwanted change in the generator voltage upsets the balance of solenoid and spring forces. This mechanical unbalance changes the setting of a rheostat connected in the generator excitation circuit, and causes the generator output voltage to be corrected.

In the other systems, a d-c voltage is the reference standard. In the electronic regulator shown in Fig. 2, generator excitation is controlled by a thyratron tube. The grid bias of the thyratron depends on the output of a triode vacuum tube, which is determined by the difference between the reference voltage and the generator output voltage. If the generator voltage is incorrect, the output of the triode changes and adjusts the firing point of the thyratron. The new thyratron output produces the generator-field excitation necessary for the desired output voltage.

In the Rototrol system shown in Fig. 3, a d-c reference voltage is applied to the pattern field of the rotating regulator. The voltage field measures the generator output voltage and opposes the pattern field. If the two voltages differ, the output of the Rototrol, which controls generator excitation, is changed so that the output voltage of the generator is corrected.

Operation of a Magamp regulator is similar to that of Rototrol. A typical application is shown in the diagram in

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This article was prepared by W. R. Aul of the Westinghouse ENGINEER staff from information supplied by Mr. W. R. Harris, Industry Engineering Department, East Pittsburgh Works and Mr. R. W. Moore, Control Engineering Department, Buffalo Works of Westinghouse Electric Corporation.

Fig. 4. The d-c generator being regulated is matched to a common reference bus. The pattern winding measures reference voltage; the voltage winding measures generator voltage and opposes the pattern winding. Any difference between the generator and reference voltages changes the permeability of the core, hence, the output of the Magamp. This output is rectified and applied to the field of the generator. Any error in generator voltage thus causes a change in field excitation which forces the generator voltage back to the desired value.

Magamp Regulator for a Steel Mill

As part of a broad regulating-system development program, the potentialities of a Magamp regulator for use on a four-stand, tandem cold-reduction mill were investigated last year. To determine which of several systems offered the best possibilities, extensive studies were conducted on the Anacom computer. The aim was to design a regulator that would at least equal the excellent performance of Rototrol rotating regulators. To accomplish this, a Magamp regulator must provide the following:

1—High amplification to assure the extreme accuracy necessary for proper tracking of all stands from threading to maximum rolling speeds.

2—Very fast and well damped transient response to assure optimum mill performance during acceleration, deceleration, and emergency stops.

3—Fast regulation without overshoot.

4—Simple design and operation with a high degree of reliability.

With these criteria a complete Magamp regulating system was designed. Then it was tested on full-scale steel-mill equipment set up in the shop.

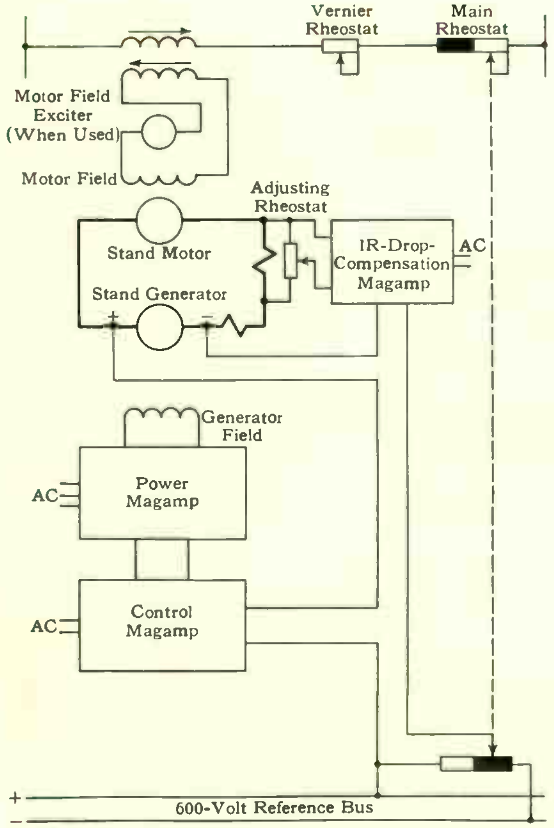


Fig. 5—Schematic diagram of the regulating system for one stand of a four-stand, tandem cold-reduction mill.

Since the response of a Magamp is inversely proportional to the frequency of the a-c power supply, the system finally chosen was tested with both 60-cycle and 400-cycle Magamps. The 400-cycle system provides the ultimate in accurate response and ease of damping.

Operation

A schematic diagram of the 400-cycle system is shown in Fig. 5. The output voltage of the stand generator is compared with a d-c reference voltage. This occurs in the control Magamp, which regulates the output of a second Magamp. This second output Magamp furnishes excitation to the generator field. Thus, any error in the generator voltage is used to adjust the field excitation to give the correct voltage. The amplification of the error voltage through the Magamps causes a large momentary change in the generator excitation voltage which corrects the output voltage.

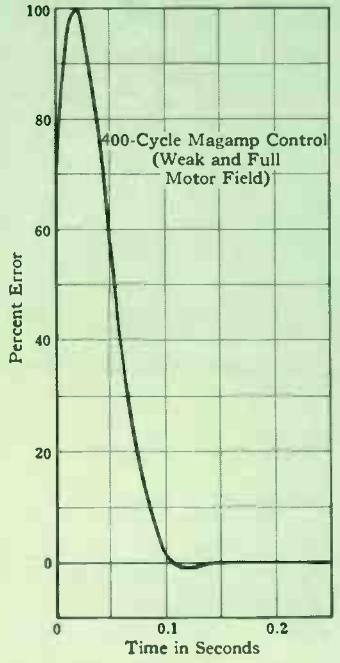
IR-drop compensation is applied by a separate Magamp, and adjustment is independent of other system components.

Tests and Results

To test the performance of the Magamp regulator, a typical mill installation was simulated on the test floor. The equipments used are a stand motor and a power-supply generator built for use on a tandem rolling mill. The stand motor is a 4000-hp, 200/485-rpm, double-armature machine, with each armature rated for 2000 hp. In an actual installation, both armatures are used to drive the mill. They obtain excitation from the same source. However, in the tests, one armature was used to simulate half of the inertia load of an actual mill stand. This armature was driven by the second, which would normally supply half of the total driving power to the stand. In this way the performance of the regulator on an actual mill installation was simulated. The stand generator is a 3600-kw, 360-rpm machine. The reference-bus system and control devices are the same as those used in tandem-mill service. The shop installation is shown in the pictures on pages 64 and 65.

Test results on this equipment are reproduced in Fig. 6. The error is the difference between reference and generator voltages.

Fig. 6—Transient response at 50 percent of rated voltage of the 400-cycle Magamp.



The response of the Magamp control system is extremely fast. With 75 percent IR-drop compensation, full voltage correction is accomplished in about 0.1 second and is not greatly affected by motor field strength.

Other Applications

Many other applications of magnetic amplifiers are now apparent. Paper machines, textile-finishing ranges, slashers, and warpers, like tandem steel mills, must operate over wide ranges of speed. Magamp regulating systems provide exceptional performance in such applications.

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oped, requiring the speed to rise higher. On the second point lowering, resistor R2 is added when contactor 5M opens. On the third point, 6M drops out placing R3 in the circuit. On the fourth point, contactor 4M is de-energized, making R4 effective. On the fifth point, R5 is connected in series with the motor field when contactor 7M opens. Field excitation is then minimum and the motor speed rises to its maximum value.

Braking

Several desirable safety features are inherent in the d-c constant-potential system. The brake coil is in series with the motor field. During hoisting, when the armature, field, and brake coils are in series, the brake releases only when power is available to the motor. It does not release until the current builds up to a point that insures motor torque great enough to prevent dropping the load. If power to the motor fails, the series brake sets and dynamic braking is established.

Conditions are somewhat different during lowering. Then, the armature is in parallel with the field and brake coils, and armature current does not pass through the brake coil. On the first point lowering position the current in the brake coil is sufficient to release the brake quickly; however, for higher lowering speeds, motor field current is insufficient to assure rapid brake release. Under some circumstances it may not release the brake at all. To circumvent any possible trouble from this source, the magnetic controller is designed to hesitate automatically on the first point lowering before going on to higher speed points. This insures proper brake response even if the master-switch handle is moved rapidly to the full-speed lowering position.

Dynamic braking for normal stopping or for emergency conditions is supplied by resistor R7 when the spring-closed contactor closes. The armature, motor-field, and dynamic-braking resistors are so arranged that when the armature is rotating in the direction to lower the load, the motor builds up as a self-excited series generator, thus providing dynamic braking action whether external power is available or not. If power fails, the spring-closed contactor closes, dynamic braking is established and the load is retarded. When speed has been reduced to a predetermined low value, the brake is applied to stop the load. If there should be a simultaneous failure of the brake, the load is lowered at a controlled rate by means of dynamic braking.

Speed-Torque Characteristics

In addition to the basic simplicity and inherent safety features of the d-c constant-potential controller, this system provides good slow-speed performance and smooth operation.

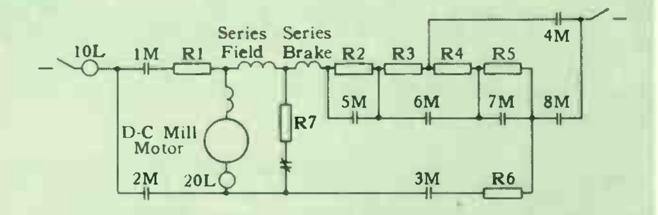
As shown by the speed-torque characteristics in Fig. 2, slow-speed response is relatively flat on the first control point for both hoisting and lowering. Slow-speed hoisting is possible even with an empty hook. The extension of the first-point hoisting curve out to 100 percent of rated torque assures enough motor torque to prevent a heavy load from drifting downward when an attempt is made to raise it with the drum or master switch on the first hoisting point. Empty hooks and light loads are lowered by driving the hoist drum in the lowering direction.

The characteristic curves are uniform in shape and equally distributed over the operating range. This enables the crane operator to select a speed suitable for the job at hand, with assurance that a specific movement of the master switch will initiate a specific response from the hoist. Smooth operation of the hoist when the master switch is moved from point to point is accomplished by properly proportioning the speed increments between operating points of the master switch.

The slope of the speed torque curves helps to limit the transient current peaks encountered in moving the master switch from one operating point to another. This prevents excessive wear of commutator and brushes and assures long reliable operation from the contactors.

An independent adjustment of the high-speed lowering curve can be made. The speed on the last point lower can be as high as is consistent with safety.

The d-c constant-potential crane-hoist controller provides a desirable combination of good speed characteristics, simplicity, and sturdiness. Excellent overall performance plus a simplified circuit and safe operation place it at the top of the list of hoist controllers where d-c power is readily available.



Device	Lower					Off	Hoist				
	5	4	3	2	1		1	2	3	4	5
1M	🟩	🟩	🟩	🟩	🟩		🟩				
2M							🟩	🟩	🟩	🟩	🟩
3M	🟩	🟩	🟩	🟩	🟩						
4M			🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩
5M					🟩	🟩	🟩	🟩	🟩	🟩	🟩
6M				🟩	🟩					🟩	🟩
7M		🟩	🟩	🟩	🟩						🟩
8M	🟩	🟩	🟩	🟩	🟩						🟩
B						🟩	🟩	🟩			

Fig. 1—Main-circuit schematic diagram of constant-potential d-c control. In the sequence diagram, colored blocks indicate closed contacts.

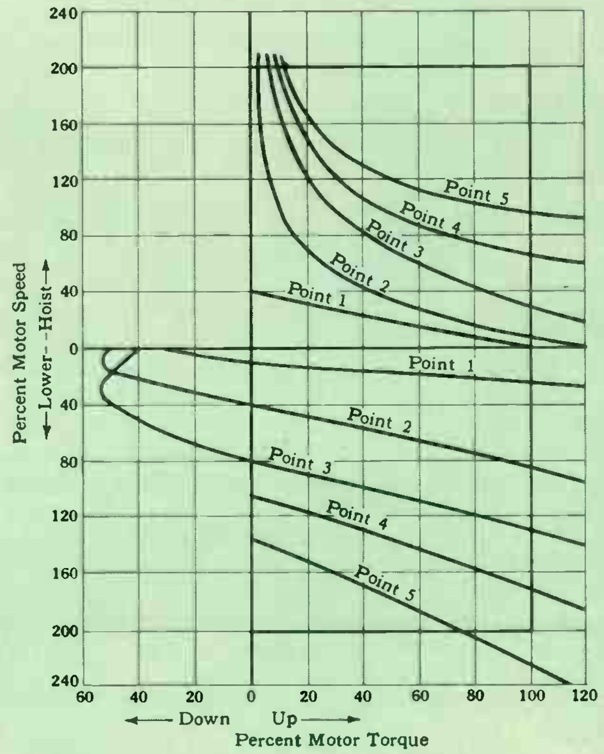
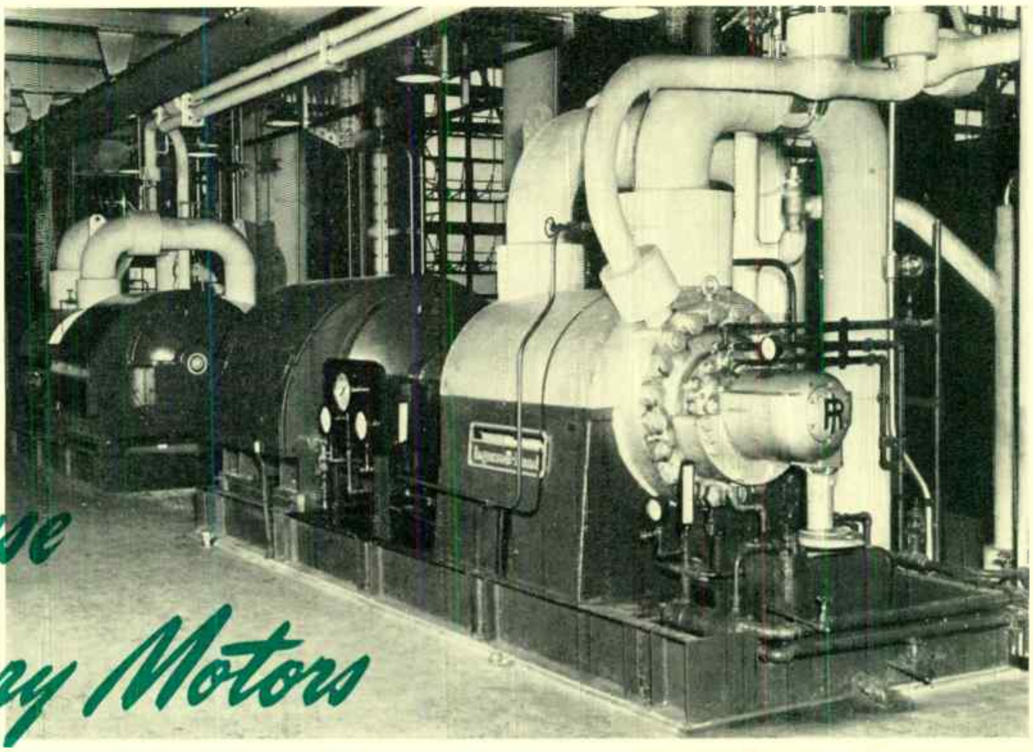


Fig. 2—Speed-torque curves.

One of the largest customers of any steam generating station is its own auxiliaries. Furthermore, no customer presents more exacting or more varied operating requirements; and nowhere is reliability more important. Consequently, selection of powerhouse auxiliary motors constitutes a specialized field of motor application.

Powerhouse Auxiliary Motors



Two 700-hp, 3600-rpm induction motors driving boiler-feed pumps in a steam generating station.

R. W. Ferguson, *Central Station Engineering, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania*

A COMPLETE description of the many and varied motor applications found in a modern steam station is almost a description of the station itself. Every phase of power generation requires some closely associated auxiliary equipment, which, in a modern power plant, is driven almost exclusively by electric motors. Indicative of the large number of motor applications in a steam station, a recent power plant comprising two 75 000-kw turbines required over 700 auxiliary motors. In a typical plant the auxiliaries consume approximately 6 percent of the total power output and have a total horsepower rating of from 12 to 15 percent of the kilowatt rating of the main turbine generators. The initial investment required for the auxiliary motors can amount to from $2.00 to $2.50 per kilowatt of generator rating.

The cross section of a typical steam plant shown in Fig. 1 illustrates some of the duties performed by auxiliary motors. In addition to the motor applications shown, numerous special applications such as water and chemical pumps, elevators, and machine-shop tools also require motor drives.

No two generating stations are identical. It is impossible to state exactly the motor sizes and types that will be present in a steam generating station of a particular size. The requirements are governed by such factors as type of fuel, heat cycle, source of water, and anticipated station loading cycle.

Approximate sizes of the major auxiliary motors are given later as percentages of the nominal rating of the turbine-generator unit. The figures are average values based on a survey of steam stations with turbine-generator units of 100 megawatts and below.

Characteristics of Powerhouse Auxiliary Motors

The primary characteristics to be considered in selecting auxiliary motors are size, speed, motor type, torque requirements, operating conditions, class of insulation, and type of enclosure. In addition, motors for central-station service must have special features that insure reliability and ease of operation, features such as special moisture-resistant insulation, adequate provision for oil-ring inspection on motors with sleeve bearings, easy accessibility of the bearings and windings for servicing and inspection, and adequate terminal boxes. The reliability, efficiency, and simplicity of installation and control of the squirrel-cage induction motor have made it the almost universal choice for powerhouse applications.

Powerhouse auxiliary motors range in size from less than one horsepower, used to open and close valves, to several thousand horsepower, used to pump water into the boiler. They usually have drip-proof enclosures with class A insulation, and are designed to have low starting current and normal starting torque. However, some auxiliaries require special torque or speed characteristics, or present unusual service conditions such as excessive dirt, moisture, abrasive flyash, or high temperature; or the plant may be an outdoor installation. Motors for such applications must have special characteristics to satisfy these requirements.

Pump Motors

Pumping is one of the major duties performed by powerhouse auxiliary equipment, and usually the largest motors in the station are those that drive the boiler-feed pumps. In a typical station the total horsepower rating of the boiler-feed-pump motors is between five and six percent of the kilowatt rating of the associated turbine. At least two and usually three boiler-feed pumps of equal rating are used. These pumps operate against a very high head of water and require 3600-rpm driving motors.

The output of the boiler-feed pumps is controlled by throttling or by varying the speed of the pump. The latter method is attractive because of reduced operating cost. Variable-speed control, when used, is achieved with a variable-speed coupling or by using a wound-rotor motor and a liquid rheostat.

The torque requirements of boiler-feed pumps and most other pumps are satisfied by motors with low starting current and normal starting torque. Most boiler-feed-pump motors are rated for a temperature rise of 40 degrees C above ambient and have class A insulation. Where the ambient temperature is above 40 degrees, class B insulation is used.

Although drip-proof construction is usual, special enclosures are sometimes used to reduce the noise level of the motor or to protect the motor from flyash and other unfavorable atmospheric conditions. Noise can be reduced by using pipe- or base-ventilated motors in which the inlet and exhaust for cooling air are at a remote location. In particularly dirty locations enclosed motors are used. Air for such motors is cooled by either an air-to-air or an air-to-water heat exchanger. Since outside air is never drawn into the motor, the windings are protected from contamination.

In addition to boiler-feed pumps, numerous other pumps are associated directly with the water cycle of the plant or perform auxiliary functions. These include pumps for handling circulating water, condensate, drain water, raw water, water-purification chemicals, ash, flood water, water for fire protection, sump water, lubricating oil, and station water supply. Usually the largest of these are the circulating-water pumps. In a typical station, there are two circulating-water pumps per turbine with a total horsepower slightly less than one percent of the turbine rating. The remaining pumps range in size from a fraction of a horsepower for small chemical-feed pumps to 100 to 300 horsepower for some raw-water, ash, and fire pumps. The size of the driving motor in a particular application is determined by the head and capacity requirements, which are influenced by the nature of the water source.

The location, and the speed and torque requirements of these pumps usually allow the use of standard drip-proof, squirrel-cage induction motors with low starting current and normal starting torque. Most pump motors have a synchronous speed of 1200, 1800 or 3600 rpm; however, some motors, such as the circulating-water pumps, may require speeds as low as 277 rpm. Vertical motors are frequently used for pumping service because they require much less floor space.

Air- and Coal-Handling Motors

Fans supplying air for combustion are usually driven by squirrel-cage motors. Where variable speed is desired for control and to reduce fan wear, wound-rotor induction motors or squirrel-cage induction motors with hydraulic or magnetic couplings are used. Frequently, two-speed squirrel-cage induction motors are used to take advantage of the reduced fan wear at the slower speed permissible during light-load periods.

In a typical station, induced-draft fans have a total horsepower of 2.5 percent of the turbine rating, while forced-draft fans have a total horsepower of approximately 1.2 percent. Usually two forced-draft fans and two induced-draft fans are used per boiler. Forced- and induced-draft fans are often installed in locations with abnormally high ambient temperatures. For such applications the motors must have class B insulation. With unfavorable atmospheric conditions, totally enclosed, fan-cooled motors are used for the fan drives.

Most stations using coal for fuel burn the coal in pulverized form. Pulverizers present the problem of a high starting torque, high-inertia load. The starting-torque requirements

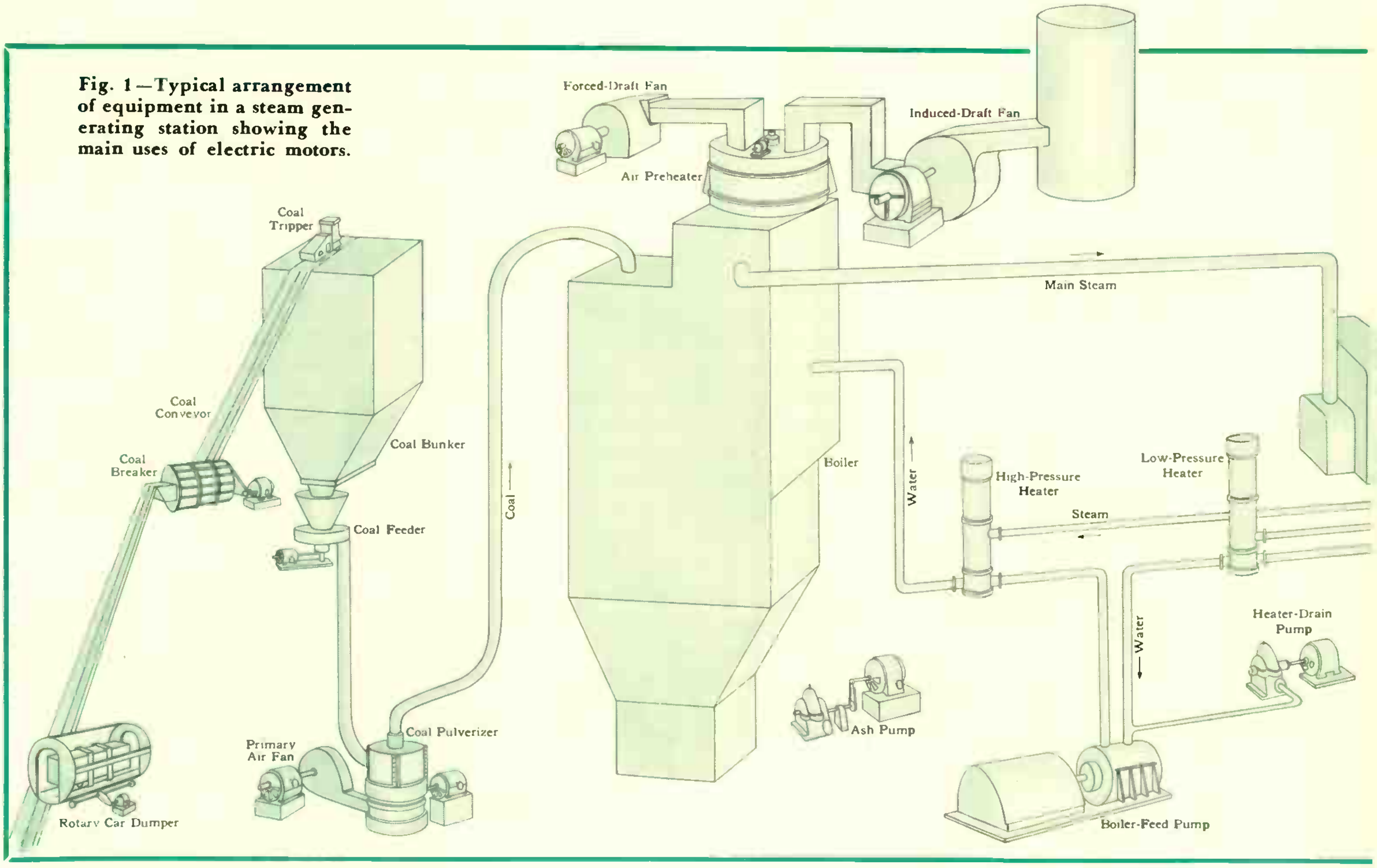


Fig. 1—Typical arrangement of equipment in a steam generating station showing the main uses of electric motors.

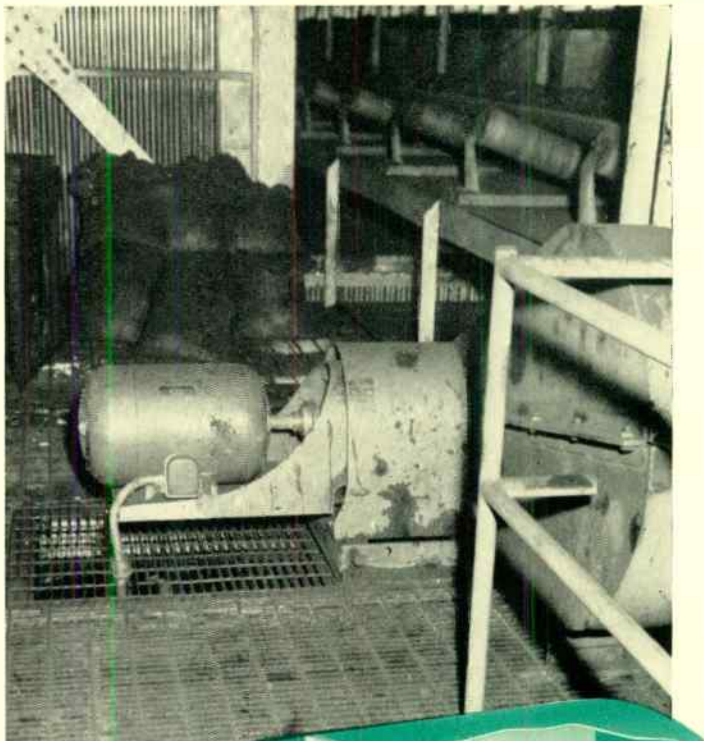
vary with the type of pulverizer, the amount of moisture in the coal, and the duration of shutdowns. Motors are selected that can start the mill with favorable coal conditions after a momentary shutdown and have sufficient thermal capacity to allow two consecutive normal starts at full voltage. The motors are either high-torque or low-torque, drip-proof, squirrel-cage induction machines with class A insulation.

Motors driving coal-handling machinery are subjected to particularly severe operating conditions and must possess special characteristics. They operate in dust- and moisture-laden areas; therefore, totally enclosed or totally enclosed fan-cooled motors are necessary. Some coal-handling auxiliaries require special torque characteristics. For example, coal-conveyor motors must have high starting torque. Other motors, such as coal-bridge motors, are rated for cyclic or short intermittent duty. Hoist motors with high starting torque and high slip are used for drag scrapers and similar coal-moving equipment. Gearmotors are frequently used to satisfy the slow-speed requirements of conveyors.

Types of Motors for Powerhouse Applications

Motors for powerhouse auxiliaries are available in three standard constructions: drip-proof, splashproof, and totally enclosed fan-cooled. The correlation between type of enclosure, temperature rise, ambient temperature, and type of insulation is shown in table I. All motors rated for a temperature rise of 40 degrees C will carry a 15-percent overload continuously with a safe temperature rise when operating in an ambient temperature of 40 degrees C.

In addition to the three standard enclosures, special ones are necessary for unusual operating conditions. These enclosures include self base-ventilated, self pipe-ventilated



Above. A totally enclosed, fan-cooled motor driving a coal conveyor.

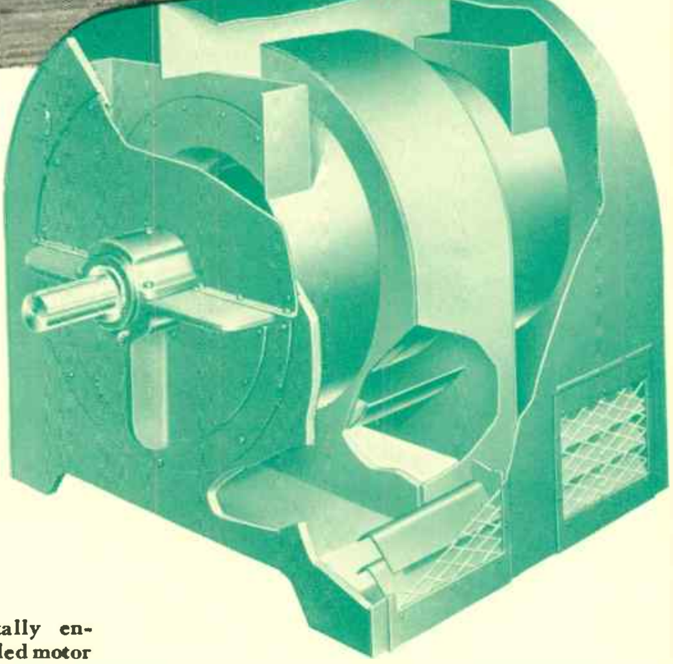


Fig. 2—This cutaway view of the outdoor motor shows the construction features that provide extra protection against the effects of weather.

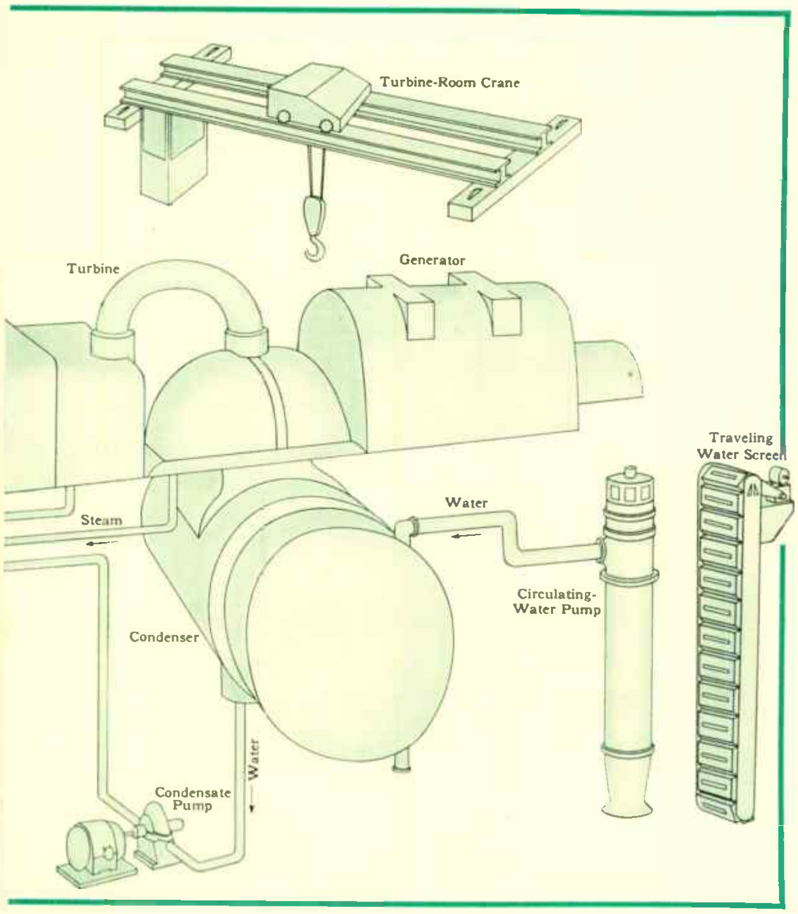


TABLE I—TYPES OF MOTORS MOST USED ON POWERHOUSE AUXILIARIES

Type of Enclosure	Temperature Rise Above Ambient Degrees C	Ambient Temperature Degrees C	Class of Insulation	Service Factor
Drip-proof	40	40 max.	A	15%
		41 to 50	A	None
		41 to 60	B	15%
		61 to 70	B	None
Splashproof	50	40 max.	A	None
		41 to 60	B	None
Totally Enclosed Fan-Cooled	55	40 max.	A	None
		41 to 60	B	None
	75	40 max.	B	None

forced-ventilated, explosion-proof, and outdoor types. Self base- and pipe-ventilated motors are totally enclosed and cooled by air circulated through ducts or pipe. The air intake and discharge are located in areas remote from the motor. This reduces the noise at the motor location and, where the air around the motor is dirty, makes it possible to obtain cleaner air from another location. Base-ventilated enclosures have openings at the floor line for connection of air ducts. Duct work to the source of air can then be installed underneath the floor if more space is available there. Pipe-ventilated motors have openings above the floor line.

There is a growing trend toward outdoor or semi-outdoor installation of new steam stations. Motors in such applications must be capable of providing reliable operation during all types of weather. A motor designed for outdoor service is shown in Fig. 2. On each side are two inlet-air openings protected by screens and louvers. From these inlets, air passes upward through a low-velocity space where the movement of the air is slow enough that air-borne particles of water and dust drop out and do not enter the motor. When the air reaches the top of this space, it is circulated through the motor and leaves at either end between the motor feet. A straight-through path is provided in both the inlet and discharge passages so that winds of hurricane velocity will not blow water into the motor.

This outdoor enclosure is also available for vertical motors. Again two inlet and two discharge openings are provided. These are alternately spaced at 90-degree intervals around the circumference of the motor. The inlet openings are at the top of the motor; the discharge openings are at the bottom. Low-velocity air passages are provided to remove entrained water from cooling air and straight-through passages for winds of hurricane velocity.

Many motors, even in a modern steam station, are located in extremely unfavorable atmospheres. Frequently moisture, coal dust, oil, weak acid fumes, and other elements that im-

Personalities IN ENGINEERING

This will be the story of John F. Peters. It will be replete with laudatory adjectives and nouns. But this is no idle eulogy. These words will be chosen with careful consideration for their meaning.

Not all stories of great men can best be told chronologically. But this one must be. John F. Peters, with two brothers and three sisters, grew up on a farm near Chambersburg, Pa. Money was not available to give all six a good education. John's portion ended with the grade school—and a one-room one at that. But he wasn't satisfied to stop there—and therein lies the secret of a matchless career of technical accomplishment. Although it was not feasible for John to attend high school, much less college, he could study at home. He read every technical book he could borrow or buy. He taught himself mechanical drawing. What he read, he remembered.

In 1904 Peters left the farm and came to Pittsburgh, looking for a job—any job if it had any direction toward engineering. He was able to convince the Pittsburgh Steel Company at Monesson that he could be the night electrician, presumably by force of enthusiasm as no direct qualification was in sight.

In a few months Westinghouse advertised for an armature winder. John and a couple hundred other applicants appeared at the employment gate. Somehow he was singled out of the crowd and given a job, which turned out to be not armature winding, but work on induction motors. Because he could read drawings better than most he was soon placed in charge of assembly of special induction motors.

Then—fateful day for John and engineering—he learned of an opening in transformer engineering—and engineering was where John was determined to be. Without any transformer background he applied for the job, offering to work without pay. Brash? Self-confidence and keen interest are better terms. Because of his lack of transformer experience, he was given an oral quiz. He had the answers. This was no fluke. A steady diet of reading and study far into the night paid off.

This was in 1906. His course was now set—a course to be followed arrow-fashion for almost a half century with the same determination that was displayed in establishing it. Progress now was steady. He began with transformer insulation and in a very few years was designing the big power transformers (4000 and 5000 kva,

pair motor insulation, are present. For such applications, special protection must be given the motors. Totally enclosed, fan-cooled motors are especially applicable where large amounts of flyash and dust are present, or in outdoor installations where salt spray is a problem. In the tube-type, totally enclosed, fan-cooled motor, air from the atmosphere is not used inside the motor for cooling. A copper-tube heat exchanger is used to cool the motor. Air contained inside this enclosure never comes in contact with the atmosphere.

If totally enclosed motors are not justified, but extra protection of the motor insulation is needed, special moisture-resistant insulation should be specified to insure reliability. This insulation consists of additional dips and bakes of the motor winding.

If open-frame motors are to be subjected to unusually abrasive flyash the coils should be given the additional protection of a Neoprene coating. The abrasive particles bounce off the Neoprene and thus do not become embedded in the insulation where they might ultimately cause failure.

Extra Precautions Taken During Manufacture

Motors for powerhouse auxiliary drives must meet a wide range of requirements. All motors must provide the maximum possible reliability even under severe operating conditions. To assure that this requirement is met, Westinghouse motors earmarked for powerhouse auxiliary service are labeled as such from the time the order is received until they are shipped. Motors with this label are given special attention during manufacture, including special inspections and other precautions to insure reliability. In the larger sizes, motors with this label are automatically provided with special moisture-resistant insulation.

Motors for central-station use are frequently purchased by the manufacturer of the auxiliary equipment. To assure special treatment, it is essential that the manufacturer be notified that the motors are going into power plants. For complete assurance of the best insulation, the purchaser should specify special moisture-resistant insulation for all motors to be installed in powerhouses.

which were big for their day). During this period he created some of the rational bases for transformer design still in use.

The first 150-kv single-phase transformer for California, built in 1913, was Peters' design. By 1917 he was technical assistant to the manager of transformer engineering. When World War I arrived Peters was assigned to help B. G. Lamme develop a means of submarine detection (using the principle of distortion of the earth's field). This was the beginning of the many special engineering assignments that so characterize his technical career. Never again was he to undertake routine design or administrative duties.

The war was followed with studies of bus structure for electric furnaces, special electric railway problems, current-limiting reactors, and stability of a-c arcs.

Peters is today recognized as one of the half-dozen best applied mathematicians in all Westinghouse history. Even so, his part in the development and initial application of symmetrical components is not generally known. The initial public presentation of this now universally used form of mathematics was made by Dr. Fortescue in 1918. Peters was one of the few who understood the subject well enough to interpret it to others, which made its application possible. He wrote a classic interpretative paper on it in 1920, which was used for instruction within Westinghouse. Had it been widely distributed, Peters' name would be ranked with Fortescue and Slepian as the founders of symmetrical components.

In this postwar period, Peters was becoming the first Westinghouse-employe consulting engineer. This was formally recognized in 1926, which title he held until his retirement in 1950. As Peters tells it, he has always been let alone, never has had to make routine reports, has had no budget problems. A credit to wise management, we'd say.

A full account of Peters' many special-problem assignments would far outrun the space available. But one of the early ones is as illustrative as any.

One day in 1921, Walter Rugg, who was soon to become Vice President in Charge of Engineering, called him to his office. The one-sided conversation went something like this: "John, we have got to do something to get a better understanding of lightning. I want you to develop an instrument to measure lightning voltages. Take $3000 and make one. When that is spent come back for more." John departed, without the faintest notion of how such an assignment was to be satisfied. In a few months he returned with the klydonograph, which gave the initial impetus to a quarter century of lightning study and for which he later received the Franklin Institute Edward Longstreth Medal.

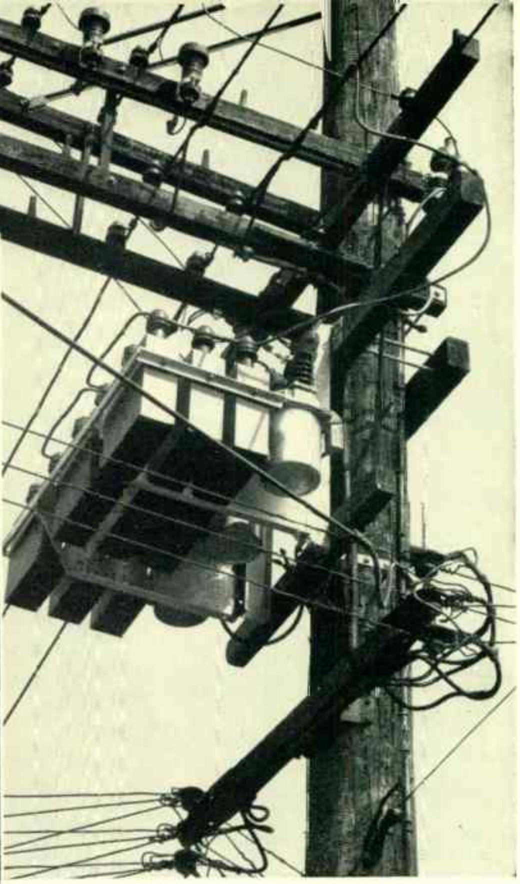
An amazing range of tasks has befallen problem-solver Peters. He worked out the design of a single-phase capacitor-type induction motor (which proved to be ten years ahead of its day). He proved mathematically that heating of steel billets electrically was impractical. He showed by analysis why cast-concrete piles were proving unsatisfactory. He analyzed unbalanced currents in a large rotary converter. All sorts of transformer problems were routine, such as the cause of failure of one of the first 220-kv units. He was a major participant in the application of the world's biggest homopolar generator for pipe welding.

Finally came World War II, with a host of new and stubborn problems. John essentially went into seclusion—to work on secret controls for gun-fire control for planes, on gun-fire computers that are so complex as to cause many engineers to shudder. And now in post-retirement he is engaged in a variety of defense projects. The newest is a secret device related to nuclear-energy development. Thus far it has "stumped the experts." John wanted to rest—but the challenge of this "impossible job" is more than he can resist.

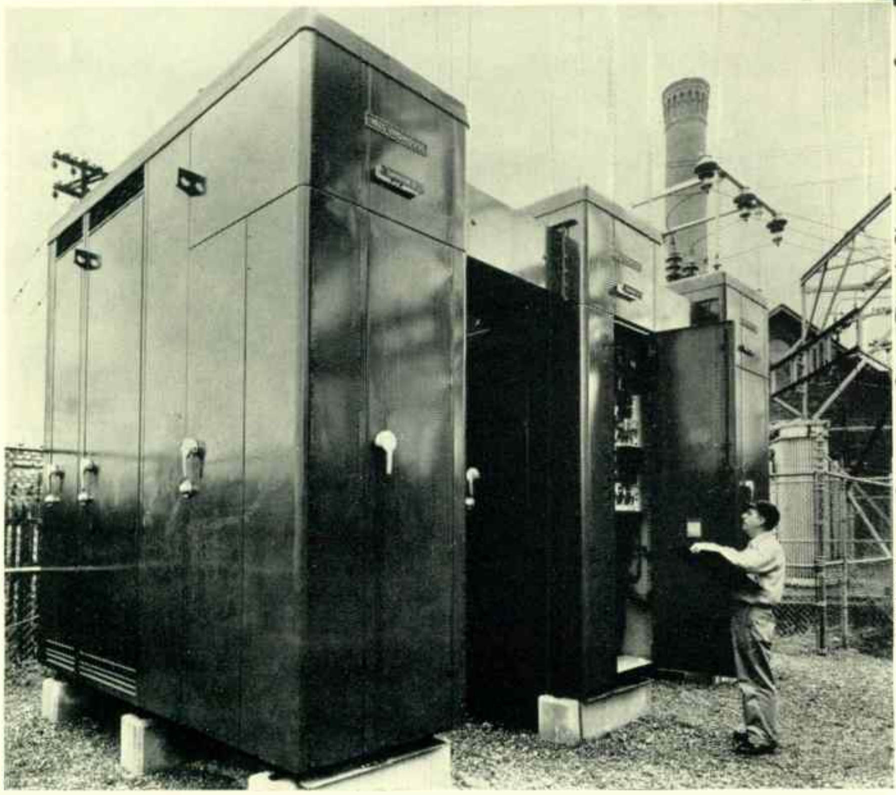
Not all of John's work has been with inanimate things. For years most inventors or would-be inventors calling at Westinghouse to sell their ideas were turned over to John to locate the flaw—if any—in their proposals.

Because of his clear conception of engineering fundamentals, he has been an excellent teacher. For years he sat in the Company's engineering and design schools to give counsel and experience to the young engineers. In the Company design sections, it has been common practice for experienced engineers stumped with some technical problem to "take it to John." He listens patiently, unassumingly, and usually winds up making suggestions so quietly, so semi-apologetically that the questioner does not realize the full merit of the advice until after he has departed.

John's is a story-book story. His has been a long career rich in technical accomplishment, accomplishment achieved the hard way without the aid of a formal engineering education. It must be viewed in the light of his personal characteristics. John Peters is modest almost to the point of shyness. He is mild of manner, soft of voice, a patient teacher, a kindly critic, yet his words carry the quiet force that springs from the powerful determination characteristic of his life. His career is the envy of his associates. It has been said of him that, near the close of an illustrious career, he can claim everyone who knows him as a friend. Contrariwise, few have ever spoken ill of him. That tribute comes to few men.



→ Fig. 1—A factory-assembled, pole-mounted, switched-capacitor bank with CSO-1 switches for use on distribution circuits. This unit was hoisted and connected without disturbing other circuits.



← Fig. 2—When installed at substations, switched capacitors may be metal-enclosed type as in the installation shown here.

Control of Switched Capacitors

Many methods can be used to initiate the switching of capacitors. In choosing one, the signal available for initiating the operation and the coordination of the control device with other equipment are important factors that must be considered.

R. L. Tremaine, *Central Station Eng., and* W. H. Cuttino, *Capacitator Eng., Westinghouse Electric Corp., East Pittsburgh, Pa.*

Today capacitors are used extensively on utility systems to control the flow of kilovars to the load. Capacitors provide an economical solution to the problems of voltage regulation, reduction of I^2R losses, and maximum utilization of power-transmission equipment, and are becoming as much a necessary part of a system as transformers, distribution lines, and watthour meters. As their cost has been reduced and their benefits appreciated, they have been more generally applied on utility systems.

In the last 20 years, the kilovars of installed capacitors on utility and industrial circuits in the United States have increased from an average of 0.01 to 0.25 kilovar per kilowatt. This ratio is expected to double in the next 15 years.

Usually, the minimum kilovars required by the load—on the average about 0.3 kilovar per kilowatt—can be supplied to distribution feeders from fixed capacitors. Above this minimum, additional kilovars must be supplied from switched capacitors. Since many utilities have already completed their fixed capacitor program, greater emphasis is being placed on the use of switched capacitors.

Fixed capacitors are usually installed in pole-top banks on feeder circuits operating at voltages between 2.4 and 13.8 kv. Switched capacitors are mounted on poles, in easily installed units, as shown in Fig. 1, or are located in substations as shown in Figs. 2 and 3. Installations of switched shunt capacitors range from 2400-volt distribution circuits to 115-kv transmission circuits, and they can be directly connected to 230-kv transmission lines.

Selection of a Control Method

The selection of a method for controlling switched capacitors should be based on the combination of possible benefits desired from the capacitors and on the intelligence that is available for use as a control signal. Theoretically, any intelligence that can be measured and that changes only when an operation is desired can be used to switch capacitors. Generally, voltage, current, time, kilovars, or various combinations provide the basis of control. Care must be exercised to insure that when the capacitors are switched, the intelligence supplied to the control circuit is not changed so that pumping results. If capacitor operation can affect other devices, particularly automatic voltage-regulating devices, then their control must be coordinated with these equipments.

Voltage Control

Voltage is by far the most commonly used signal for controlling capacitor switching. When voltage control is used, a contact-making-voltmeter type of voltage relay initiates the switching operation. In addition to the voltage-sensitive element, time delay must be incorporated in the control circuit to prevent excessive operation of the capacitor switching equipment.

Four voltages have an important bearing on the setting of most voltage-regulating relays. These are the voltages at which the raise and lower contacts open and close. In order of increasing magnitude, they are: the "raise-make," "raise-break," "lower-break," and "lower-make" voltages, and are illustrated in Fig. 4. The difference between the raise-make and lower-make voltages is called band width. The difference between the raise-make and raise-break voltages, and between the lower-make and lower-break voltages, is the compounding or seal-in voltage. The difference between the raise-break and lower-break voltages is the dead band.

Several factors must be considered in selecting band width. The most fundamental is that *the voltage change produced by one switching step must not exceed the dead-band voltage.* If the voltage change caused by the capacitor exceeds the dead-band voltage, inertia overswing can cause excessive operation of the switching devices. To illustrate, assume that the raise-make contact has closed, and that during the time delay, the system voltage has increased to a point just below the raise-break voltage. Then the voltage step plus the overswing might cause the lower-make contact to close. The sys-

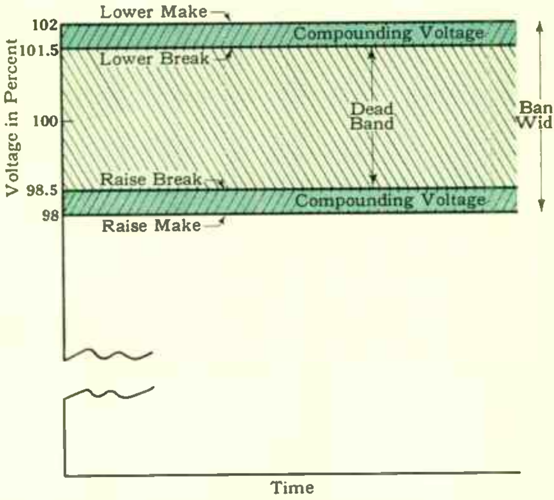


Fig. 4—The relationship of the four voltages and the voltage bands that are important in setting voltage-regulating relays.

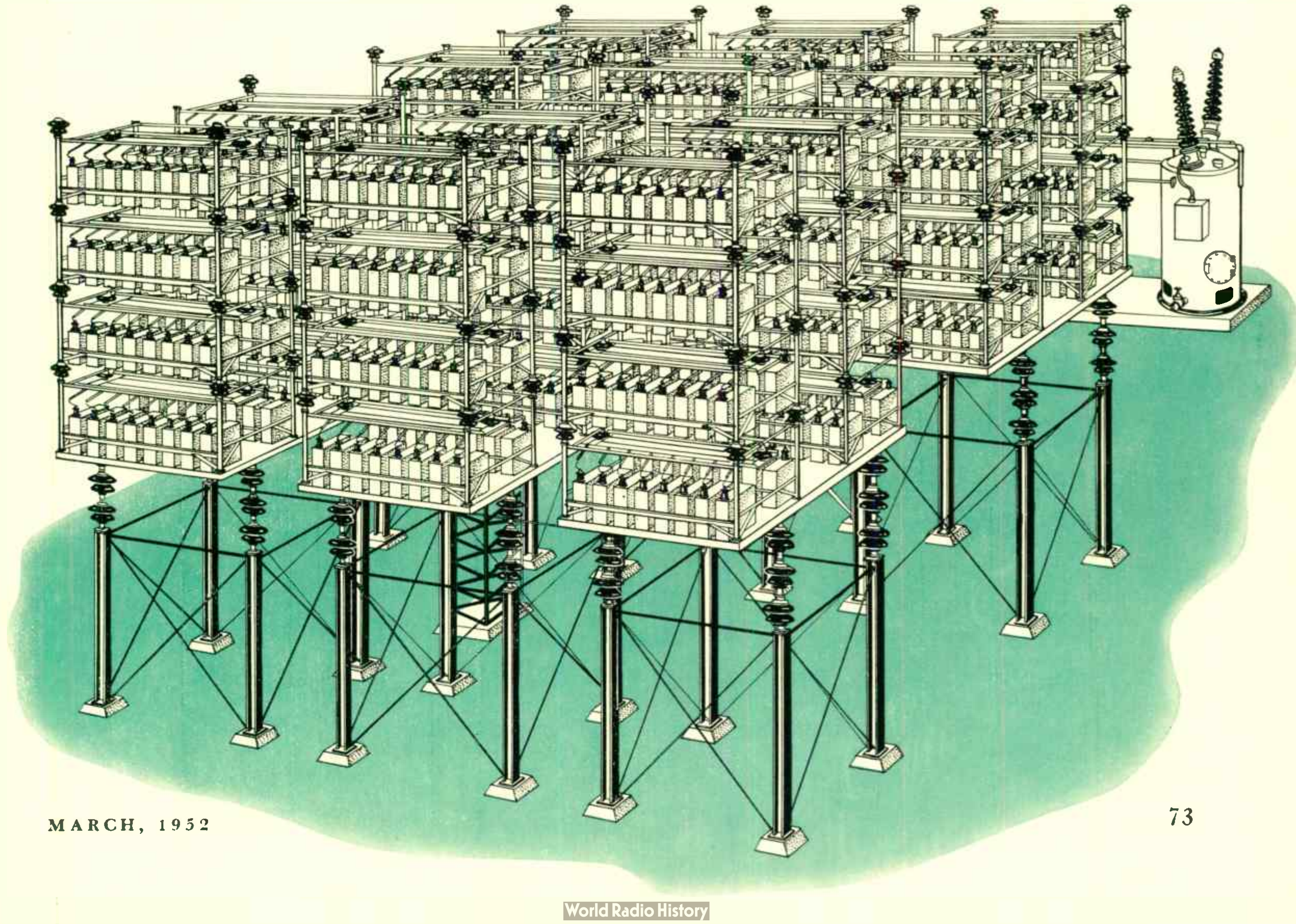


Fig. 3—Sketch of a new direct-connected, 19 200-kvar, 110-kv, three-phase shunt-capacitor bank composed of factory-assembled racks. The bank is switched by a type GM-5 oil circuit breaker. The new racks save installation time and expense, since they can be shipped ready for mounting with capacitors and fuses in place.

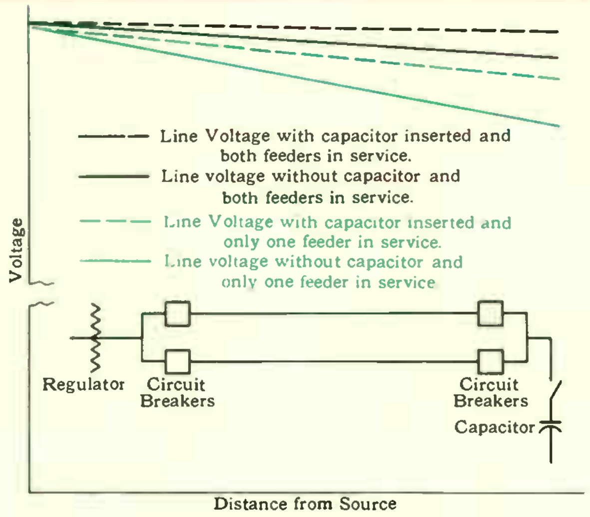


Fig. 5—The effect of source impedance on the voltage change produced by switching one capacitor step. The vertical distance between solid and dotted lines of the same color represents the change in voltage caused by one switching step. In this example the voltage step is doubled if one feeder is lost.

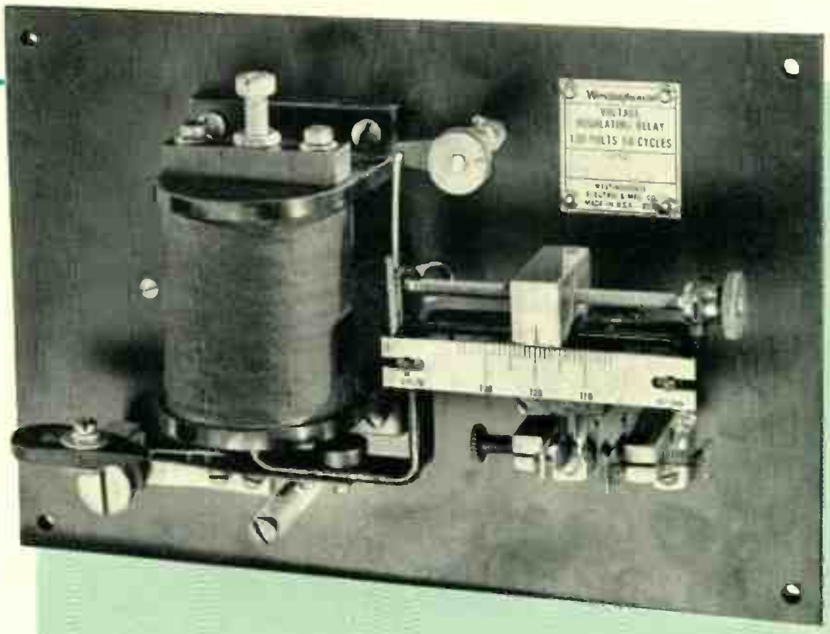


Fig. 6—The type SU voltage-regulating relay, with cover removed. The type SU is a solenoid-operated, balanced-beam voltmeter relay and requires a separate time-delay device. This relay is suitable for double-band-width applications if an electromagnet is substituted for the permanent magnet.

tem voltage then is higher than the lower-break voltage, the relay times out, and an extra operation occurs. Such an operation is prevented by making the dead-band width greater than one voltage step.

Another factor to consider in selecting band width is the variation in source impedance caused by switching. This affects the voltage change produced by a given capacitor bank. For example, if one of two parallel feeders is lost, the voltage change caused by one switching step can double, as shown in Fig. 5. The band width of a voltage relay is normally based on the voltage change under the worst probable switching condition. If this consideration results in an excessively wide band width, and system switching intelligence can be supplied to the control circuit, a voltage-regulating relay with two band widths can be used. The relay shown in Fig. 6 can be modified for this application by replacing the permanent magnet with an electro-magnet in which the current is varied by the switching intelligence to obtain two band widths.

Compounding voltage should also be considered in setting a relay. The desire to obtain narrow band width should not result in reducing the compounding voltage below a safe value. Sufficient compounding must be provided so that good contact pressure is obtained, otherwise radio influence and burning or frying of contacts might result. A factor sometimes overlooked is that when the lower-make contacts close some drop in voltage always occurs at the relay terminals due to the load of the auxiliaries. Compounding must be greater than this voltage drop to prevent oscillation of a relay. This is important only when the leads are unusually long.

The desire to provide minimum voltage regulation usually conflicts with the desire to reduce switching operations. A compromise must be made, weighing improved voltage regulation against increased switching operations. In this problem, voltage charts taken at the proposed capacitor location are helpful. It is also desirable to record voltage and switching operations after installation to insure that a satisfactory compromise has been obtained.

A simple, inexpensive form of voltage control is shown in Fig. 7. This relay (type CJ-2) is suitable for switching a single capacitor step. It is unique in that both the voltage relay and the auxiliary close-trip relay are mounted in a single weatherproof socket-type case similar to that used with watthour meters. If this relay is used with an oil contactor or an electrically operated oil switch, such as the CSO-1, no additional devices are required. The contact-making voltmeter in this relay is a modified induction-disk relay element (type CV). Necessary compounding is built into the relay and is not adjustable. Time delay is provided by the inherent inverse time-delay characteristic of this type of relay, and is a function of the change in voltage and the relay setting. Curves for determining time delay are shown in Fig. 8.

This device is applicable to feeder circuits where narrow band widths are not required. Before applying the CJ-2 relay, a graphic record of the voltage at the proposed location should be taken. By comparing the operating time of the relay for its contemplated settings and the voltage changes recorded on the graph, the expected number of operations can be estimated to determine whether or not the application will be a satisfactory one.

Solenoid-operated, balanced-beam, contact-making voltmeter relays are also used as voltage-regulating relays. This type of relay is suitable for multiple-step banks, and can be used also on single-step banks. Two typical examples are shown in Figs. 6 and 9. These relays are alike in that the moving contact is attached to the balanced beam, which moves up or down in response to a change in circuit voltage, and that travel of the moving contact can be varied by adjusting the two stationary contacts. They differ in the means used to adjust compounding and band width. Separate time-delay devices must be used with balanced-beam relays.

In the relay in Fig. 6 (type SU) band width is adjusted by varying the magnetic pull on the beam when the beam is in the neutral position. Compounding is changed by adjusting the stationary contacts.

The relay in Fig. 9 (type C) has two compounding coils, one in series with the "raise" and one in series with the

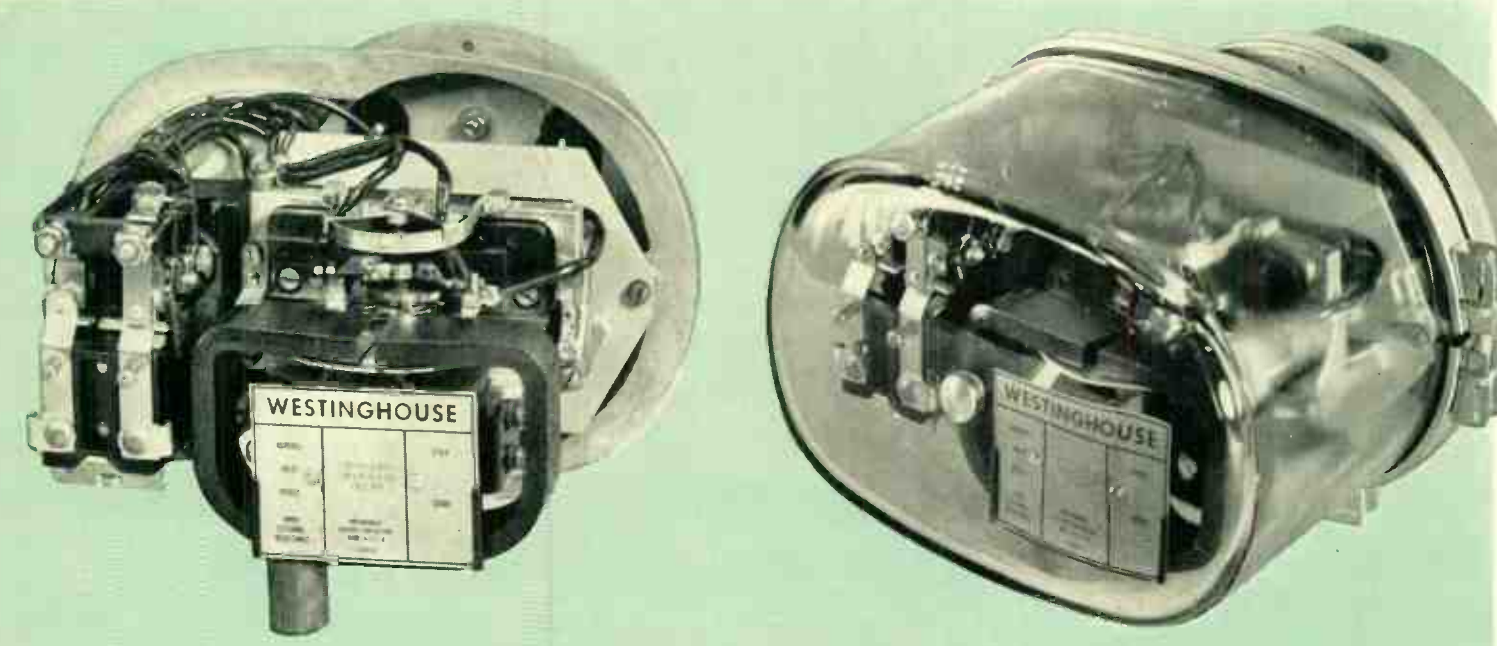


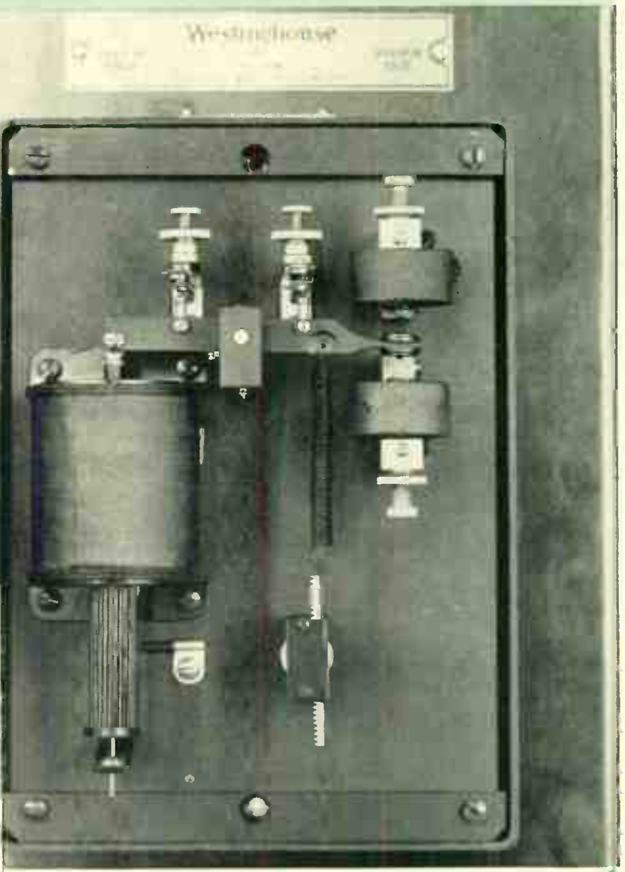
Fig. 7—The type CJ-2 socket-mounted, induction-disk type voltage control. No additional devices are needed when this relay is used with an oil contactor or a CSO-1 switch.

"lower" contacts. As soon as current flows through either contact its compounding coil is energized, and the contact pressure is increased. The amount of compounding is readily adjustable down to a seal-in voltage of less than 0.5 volt. Band width is changed by adjusting the stationary contacts. This relay is more easily adjusted for small compounding on wide band-width settings than the type SU relay and, therefore, is more generally suited for initiating capacitor switching operations.

Time-Switch Control

Frequently, a bus is operated at either of two voltages. This is accomplished with a time switch that changes the voltage setting, or "recalibrates" the voltage relay. This is done by inserting a resistor in series with the relay voltage coil for the higher voltage setting. A timer with a seven-day dial, or one with a 24-hour dial and an omitting device can be used in such an application.

Fig. 9—Type C relay without cover. It is well suited where wide band width and small compounding are necessary.



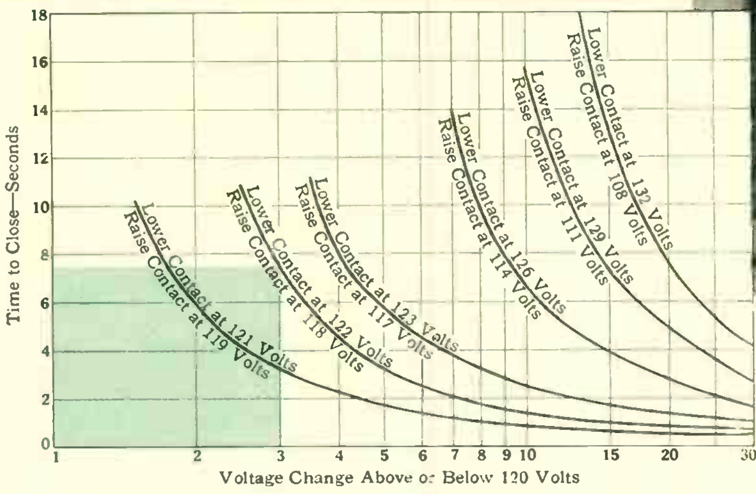


Fig. 8—Typical time-delay curves for the type CJ-2 voltage relay. Each curve is drawn for the indicated settings of the raise and lower contacts. A typical example of their use is shown in color. Assuming the raise and lower contacts to be set at 118 and 122 volts, respectively, and a voltage dip of 3 volts from 120 to 117, the time delay is 7.5 seconds.

One method for controlling the supply of vars is the use of time-switched capacitors. If time control is used alone, switching or unusual load conditions can result in excessive voltage. To preclude this possibility, a wide band-width voltage relay is generally used. If the voltage becomes excessively high or low, the capacitors then can be switched by voltage control. Such a system reduces the switching operations to a minimum and usually can be easily coordinated with voltage-regulating equipment. The band width used is determined by the maximum voltage change that can be tolerated at the capacitor location.

Line-Drop Compensation

Generally the voltage at a feeder bus is not as important as voltage at the customer's location. The load on a feeder usually is either relatively uniformly distributed along the line, or, in the case of more important customers, is at the end of the line. In the latter case, line-drop compensation offers a simple method for keeping the voltage constant (within the limits of band width) at the customer's location. By this method, the voltage at the bus is raised to compensate for line drop in the same manner as line-drop compensation on induction or step regulators. The secondary current from a current transformer in the feeder is passed through a resistor, and the voltage across this resistor is subtracted from the secondary voltage of the potential transformer. In this way, essentially constant voltage can be maintained at the end of the feeder, assuming the power factor to be reasonably constant.

Should the load power factor vary over such a wide range that a resistor is not satisfactory, correct compensation can be obtained with a reactor-resistor combination. This is more expensive and rarely necessary with switched capacitors. On a feeder with distributed load, generally, it is desired to keep voltage constant in the middle of the feeder. The problem is essentially the same as that of a single load, except that the voltages at the ends of the feeder must be checked to insure that they are neither too high nor too low. Reasonable assumptions of the load distribution during heavily and lightly loaded periods must be made in determining the voltage changes at the ends of the feeder.

If the capacitor is applied on a bus that supplies several feeders, the total loading on the bus can be obtained by totalizing the feeder currents, or one feeder can be assumed to be representative. A scheme using only two current transformers to obtain total feeder current is shown in Fig. 10.

Where it is desirable to operate a bus at a higher voltage during heavy load periods, a current relay can be used. A current relay recalibrates the voltage relay when the feeder current exceeds a given value. This system requires an additional relay, however, and does not provide the smoothly varied correction that can be obtained with line-drop compensation.

Current Control

Current control can be used where heavy seasonal or large intermittent loads that are either on or off are encountered. Such a load often requires a single bank of capacitors that must be automatically connected and disconnected with load. In this application, current control can be used to switch the capacitor bank when the current supplied to the load exceeds a given value. Current relays are most commonly used on voltage-regulated feeders, where voltage obviously is not a satisfactory signal.

Current control relays are of the induction-disk, balanced-beam, and solenoid types. In the application of current relays, it must be remembered that they are sensitive only to current. Other factors, particularly voltage, must be examined to insure that the capacitor bank will not be switched improperly. One current relay must be used with each bank of capacitors.

The primary consideration in setting current relays is to insure that proper compounding is obtained. Band width and dead band are not generally important.

Kilovar Control

When it is desired to keep the kilovars supplied over a given line to a minimum in order to reduce system losses and voltage drop and to release generating and transmission capacity, more than one switched capacitor step is generally used. The kilovars supplied to a given point can be measured, and when they reach a given value, the capacitors can be switched to keep the kilovars within prescribed limits. Obviously the kilovars must be measured on the supply side of the capacitors. The relay element shown in Fig. 11 is used for this purpose. This same relay can be connected to measure kilowatts as a signal for switching a single capacitor bank, but this method is not often used.

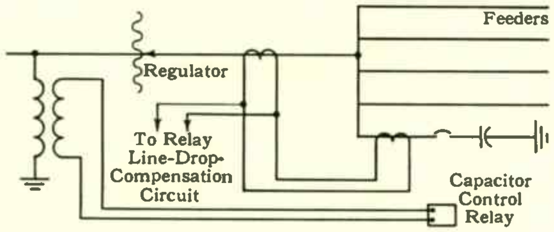


Fig. 10—A method of obtaining total feeder current for voltage-control relays with line-drop-compensation.

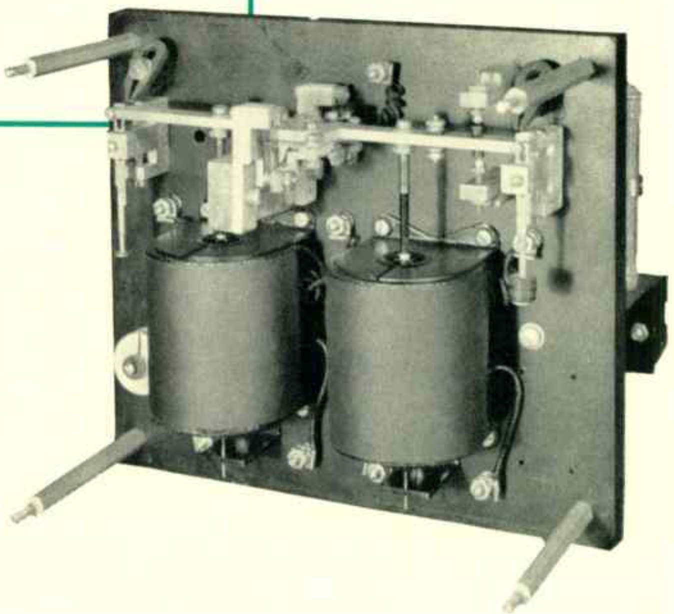


Fig. 11—A kilovar-regulating relay, with the cover removed.

Kilovar relays have four settings analogous to the four voltages listed in the description of voltage-control relays. Considerations in setting a kilovar relay are similar to those in setting a voltage-control relay, and the band width is determined by a method similar to that used with voltage relays. Compounding and dead band must also be considered.

A power-factor relay is not a very satisfactory means of controlling switched capacitors, because a large number of switching steps is necessary and, in addition, a desensitizing device is required at light load to avoid pumping. Kilovar control when properly applied should give the desired results.

Time Delay

Two general means of obtaining time delay are available. The simplest is the inherent inverse time delay in the induction-disk type of contact-making voltmeter relay as used in the CJ-2. The others are non-inverse time-delay relays that are available in the form of thermal, escapement, electronic, and synchronous devices.

The delay used can be any time from a few seconds to a few minutes. It should be greater than the longest momentary voltage change at the capacitor location for which no capacitor switching operation is desired. When other voltage-regulating devices are involved, the time delay should be coordinated with these devices.

In general, the magnitude of the time delay used with switched capacitors is not critical, except that it must be long enough to prevent excessive operation of switching devices and to coordinate with other equipments. Thus, fast-reset timing relays are rarely required, and timers suitable for repetitive impulses should be used.

When more than one switched-capacitor step is used, devices are provided to establish the sequence of the switching operations. Capacitors are normally switched "off" in the reverse order in which they are switched "on." If this results in one switch operating much more often than another, a sequencing circuit can be used to equalize the switching duty.

Coordination of Switched Capacitors with Regulators

The operation of all means of controlling voltage on a system must be checked to insure, first, that they will coordinate properly and, second, that one does not eliminate the need for another. The first results in unnecessary operation of controls or, in extreme cases, cycling, and the second is obviously uneconomical. The operation of a capacitor bank should not cause unnecessary operations of other automatic voltage-regulating devices installed on either the source or load side of the capacitors.

There is a saying among utility engineers that "you cannot get reactive out of a regulator." This refers to the problem of using regulators supplied by relatively thin lines, particularly those supplying loads of low power factor. When the regulator tries to boost voltage, the load takes more current, and the voltage drops; the regulator tries again, and again the voltage drops. Unless anticipated load growth changes the economics, capacitors offer an excellent solution to this problem when their cost is compared with that of reinforcing the supply circuit. Such applications of switched capacitors usually involve rather large voltage steps, and a regulator can be used to limit the voltage change permanently passed on to the customer.

When capacitors and regulators are used on the same bus, the capacitor voltage steps should be as large as practical in the interest of economy and to keep the number of breaker operations to a minimum. A voltage step equal to about half the voltage range of the regulator is desirable, unless this results in temporary voltage changes larger than can be tolerated. If one or more capacitor banks are located near a regulator, and the limit switches of the regulator can be used, or changed so that they can be used, this offers a simple, inexpensive means of controlling the capacitors and there is no problem of coordination. If separate control is required, then current, time-switch, or kilovar control can be used; or voltage control from the supply side of the regulator can be used.

If a regulator supplying several feeders has line-drop compensation, the capacitor current can be combined with the supply current to the bus to obtain total feeder current. This arrangement is illustrated in Fig. 10.

Voltage-controlled capacitor banks can be applied at the end of a feeder supplied through a regulator, provided line-drop compensation is not used. If line-drop compensation is used, then voltage at the end of the feeder is usually not a satisfactory signal. A careful study should be made if voltage control is desired, since capacitors change the power factor of the feeder load, and the effect on the line-drop compensator must be checked to insure that voltage will be satisfactory. Current or time control would normally be more desirable. A resistance-reactance line-drop compensator on a regulator can normally be set to operate satisfactorily with automatically switched capacitors on the end of the feeder.

Conclusions

The methods of controlling capacitors plus the possible modifications of each are numerous. The method used should be tentatively selected on the basis of three fundamental considerations: (1) what is to be accomplished by the application of capacitors, (2) what intelligence is available, and (3) will this method coordinate with other equipments, both existing and proposed. The engineer should ask himself whether all the desired operating characteristics are actually required, and not merely something that would be nice to have. Once he has decided what is needed, then the simplest and most reliable method should be used. The experience of the manufacturer is often valuable in selecting the actual control circuit once its characteristics are determined.

Often it is desirable to select a system that is applicable to several locations, or one that can be modified slightly to suit a number of applications. This philosophy can result in unnecessarily complicated circuits at some locations, but has the advantage of reducing the variety of control circuits on a given system. One solution to the problem of keeping the variety of controls to a minimum is to use the inexpensive CJ-2 to control installations such as shown in Fig. 2, and to use a more complex and flexible control circuit for the larger, more important installations.

Toward a Better Supply of Engineers

This summer between 20 and 40 secondary-school science teachers, recipients of fellowships awarded by the Westinghouse Educational Foundation, will participate in a special six-week program of study at Carnegie Institute of Technology. Purpose of this program is to help science teachers increase their knowledge of the basic sciences so that they will be better able to guide promising students toward appropriate careers in science. It is hoped that by giving such support to teachers, a better supply of engineers and scientists can be maintained.

The special program of study at Carnegie Tech stresses the importance of fundamental concepts in chemistry, physics, and mathematics. Included in the course are lectures on subjects such as radioactivity, nuclear research, and applied mathematics, and a survey of recent scientific developments. The classes also visit industrial plants in the Pittsburgh area.

What's NEW! . . . . in Products

Packaged Power Plants for Rolling Mills

Even rolling mills are packaged as units now. It is possible for a product manufacturer to purchase a small, single-stand mill to roll metal to his particular requirements starting with standard available sheet, or strip. The power supply for such a mill comes packaged, too. In a single metal cabinet 6⅓ feet high, 8⅓ feet long, and 3⅓ feet deep, is a 75-hp motor-generator set to supply power to the main and reel motors, a small booster m-g set to provide IR-drop compensation for the reel motor and to improve regulation, and all the control apparatus. The unit is, in effect, a variation of the AV-drive idea. The power plant uses a selenium rectifier to supply excitation (eliminating one rotating machine). It also uses a magnetic amplifier as a current regulator for the reel motor to enable it to maintain constant tension as the strip builds up on the reel.

The complete power plant is assembled and tested at the factory and shipped as a unit. All parts are in their normal positions, and for installation the unit is set on a prepared foundation and electrical connections made.

A Better Tube Stand Makes a Better X-ray

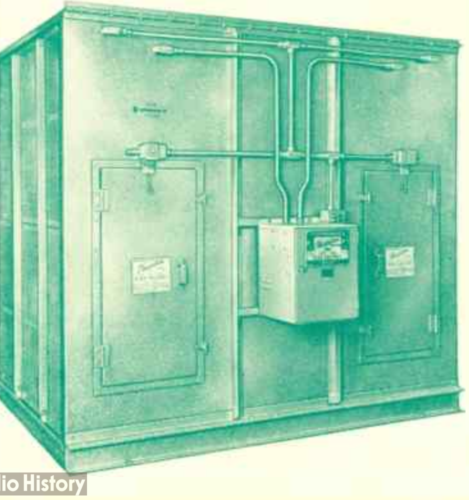
While the tube is the heart of an x-ray equipment, equally important is the associated supporting structure and the table for the patient. General-purpose x-ray equipments in doctors' offices and hospitals require a vertical column extending from floor to ceiling and running on a track. The column gives support to the x-ray tube head and controls mounted on a movable arm, and is precisely counter-balanced so it can be moved into any position or angle and remain there. A new tube stand is a vast improvement over earlier ones in several respects. The tube head can be elevated much closer to the ceiling than before—important because many doctors' offices are in low-ceiling rooms. The floor rail is stronger to prevent tube movement because of "springiness" of the floor. A tube head may have eight to ten locks that must be operated to obtain and hold the universal positioning of the x-ray tube. All those locks not within easy arm's reach of the technician's position are now electrically remote controlled. No more reaching across the patient or

Tong-Type Brazing Equipment

The power supply for incandescent-carbon, tong brazing has been substantially improved. A larger water reservoir is provided and a pump with more positive pressure insures more effective water cooling. Piping is arranged so that water need not be drained when changing tongs. Although both sizes have been increased in capacity—25 and 50 kva, instead of 20 and 40—a more rigorous duty cycle can be safely accommodated. Easy access to the entire working mechanism is possible by removal of one entire side panel. The internal piping is arranged so that brazing tongs can be disconnected at a high point to avoid spilling water.

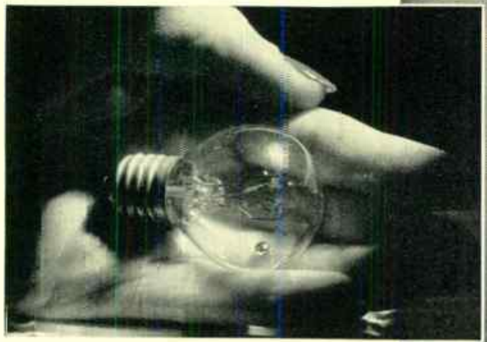
Self-Contained Precipitron

For offices and plants that have a sizable amount of air to rid of dust, but do not need the big, automatic-washer sizes used in large mills, a special encased Precipitron electrostatic air cleaner has been developed. It is completely self-contained; after assembly on the site only duct, electrical, and water connections need be made. The sizes run from 8500 cfm up to 36 000 cfm.



walking around the table to get at locks behind the tube stand. Appearance has been improved by "hanging" fewer devices and controls about the stand. They are made an integral part of it—yet servicing is simpler, such as the changing of the counterbalance should a different weight tube be used.

Electrical Deodorant



In 1945 Westinghouse introduced a deodorizing lamp that utilized ozone to destroy odors. This lamp emits ultraviolet rays with a wave length of about 1850 Angstrom units. These radiations change some of the oxygen surrounding the bulb into ozone, which then oxidizes the odor molecules in the air. Thousands of these ozone lamps are used in clothes dryers, washers, and in beverage machines. Now, as a result of a completely unrelated lamp engineering investigation, a more powerful deodorizing lamp has been developed.

The new lamp, called the Odorout, was developed by F. H. Rixton of the Westinghouse Lamp Division in Bloomfield, New Jersey. As a by-product of research aimed at improving lamp starting, he devised a small lamp that emitted about three times more ozone-producing ultraviolet than the previous deodorizing lamp. Then, all that was needed to make the Odorout lamp was to select a glass bulb capable of transmitting more of the ultraviolet frequencies.

The new lamp eliminates unpleasant odors from cooking, smoking, dampness, mildew, and perspiration more efficiently and quickly than the old lamp. It is recommended for use in the home and in physicians', dentists', and business offices.

This 3½-watt, 12-volt bulb lasts six months when operated 24 hours a day. It can be operated from a standard 110-volt, single-phase, a-c source by using a special fixture containing a built-in control device, such as a transformer, to limit the current and voltage. Suitable wall fixtures are now available.

. . . . in Engineering

Saving Iron-Ore Fines

If iron ore is dust fine it is blown out of the blast furnace, becoming both a nuisance and a loss. This can be overcome by sintering, in which the dust is compacted with a binder into marble-like balls and baked in a continuous furnace. This practice is growing.

An eastern steel company is building a particularly large sintering plant. A conveyor system brings materials from a 270 000 square foot area (300 by 900 feet). To drive the sintering equipment and the many conveyors requires 114 motors, both a-c and d-c, ranging in size from 2 to 1000 hp, as well as rectifier and switching equipment. All apparatus is controlled from a central board on which is a flow diagram with indicating lights to inform the operator of events throughout the plant.

Light-Current Performance of Air Breakers Improved

A "short-snort" is not usually consonant with improved performance. But, an auxiliary air puffer applied to the high-capacity air circuit breaker (DH) provides a "short-snort" of air across the contacts as they separate and thereby decreases the low-current interrupting time. Without puffers, these breakers interrupt large currents more quickly than small ones. At low currents the magnetic forces are too weak to drive the arc into the interrupter; instead the arc floats upward lazily (in a manner of speaking, that is). The puffer hustles the arc along. The puff of air is provided by a piston moving in a cylinder as the contacts separate. The puffer, never used before on this class of breaker, is effective in reducing the interrupting time for all currents from zero to 1000 amperes, and insures interruption for all currents within the standard eight cycles. The breaker is well suited to 2.4- and 4.0-kv distribution circuits, and for powerhouse auxiliaries, particularly those supplied through cables that provide difficult-to-interrupt charging currents.

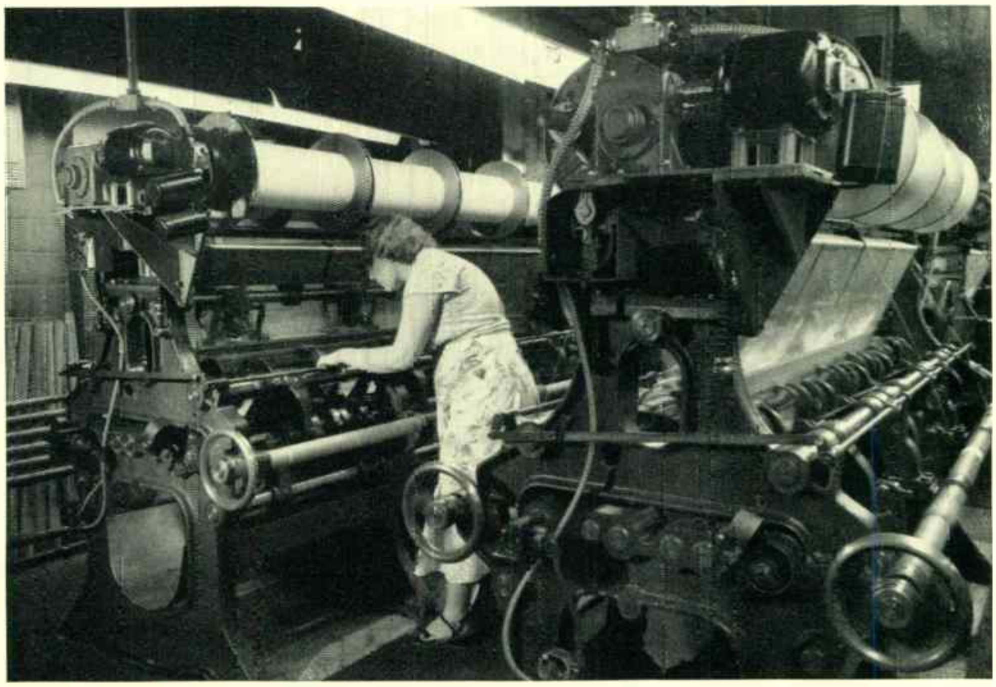
For those applications where there is no battery and it is not convenient for space or other reasons to provide one, the breaker can be equipped with a spring-powered closing mechanism. Use of a manually operated closing lever is not positive enough or fast enough in case the breaker is closed against a system fault. The hand-compressed spring provides ample energy for the task.

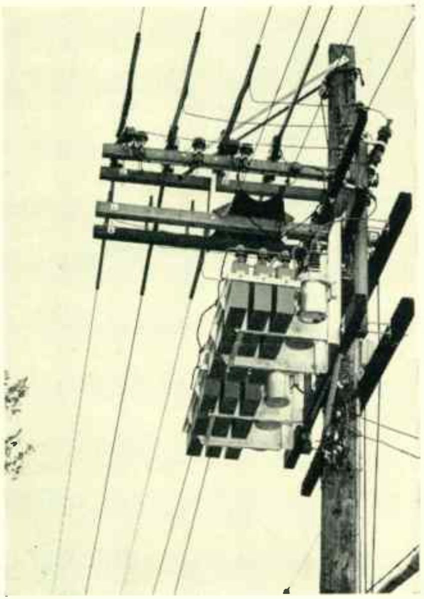
High-Speed Ironing of Photographic Paper

Glossy-finish photographic paper must have an extremely hard surface and be of extremely uniform quality. In the past this has meant high-pressure, low-speed supercalenders—running at about 200 feet per minute. Today there is being installed in an eastern mill a new supercalender with the output speed increased by about four times—but with the same quality maintained. The horsepower requirements are very large: 0.45 hp per inch of width per 100 feet per minute delivery speed. This compares with 0.214 for supercalenders used in finishing ordinary coated papers.

Electric Drive for Textile Beam Letoff

Electric motors and control are taking over, one by one, tasks in the production of fabrics. A recent one is that known as the beam letoff. In weaving or knitting, the yarn or thread must be paid out (let off) from the spools (beams) as it is called for by the weaving or knitting mechanism. Tension must be maintained constant but the rate at which the beams unwind is obviously variable with the amount of thread remaining. This chore has generally been done by mechanical devices, but these present problems of maintenance and variable friction. Various attempts have been made to do this electrically. A new one that is working out with excellent success involves an electronic device that controls a small capacitor motor driving the beam so that it runs in response to a sensitive tension-sensing bar over which the threads pass.





Automatic Capacitor Switching for Distribution Circuits

Most small capacitor installations on distribution circuits have been permanently connected to the line, because there was no suitable low-cost device that could be used to switch them. A new capacitor switch has changed this picture. The development of the type CSO-1 oil switch has made possible a compact, economical capacitor installation for distribution circuits, one that can be switched on and off of the line automatically in accordance with the need. The new switch is the key element in the open-type Autotrol capacitor equipment, a factory-assembled arrangement of capacitors and switches that can be mounted on pole tops or crossarms quickly and inexpensively.

The type CSO-1 is a single-pole, 15-kv, oil-filled switch. It is basically a type GRS sectionalizer which has been modified for use in switching capacitors. The current rating of the new switch varies from 34 to 200 amperes depending on the system voltage. Momentary rating is 6500 amperes (maximum rms current the switch will carry for one second or less).

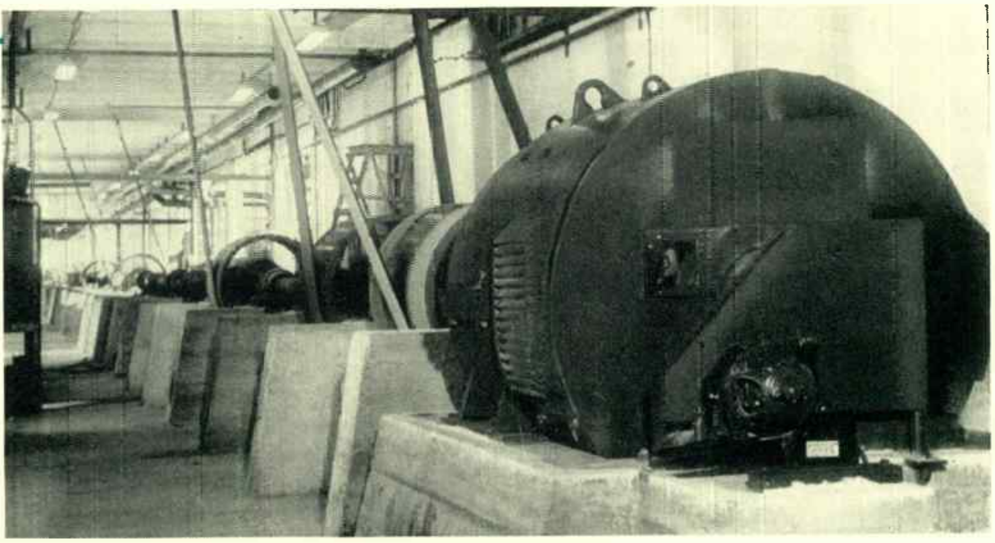
The new switch can be either manually or electrically operated. In the Autotrol equipment it is operated electrically to provide automatic switching. Since the equipment is intended for application on three-phase circuits, three switches are required. The opening and closing mechanisms are connected in parallel to insure simultaneous operation of all three.

The equipment is shipped as a complete unit, ready for installation on the pole crossarm. Only the control and three line connections to the switches are required to complete the installation. The control leads are brought into terminal blocks installed in weatherproof boxes mounted on the outside of the switch tanks.

These packaged capacitor banks are available in sizes from 45 to 300 kvar, for voltages from 2400 through 13 800 volts.

Single-Motor Paper Machine

A papermaking machine was installed in the plant of Enso Gutzeit, Osakeyhtio, Helsinki, Finland, last year driven by a single motor of 1250 hp. This is an extremely large if not larger than any previous single-motor drives. This machine produces kraft board in widths up to 18 feet 10 inches, and at speeds of between 200 and 2000 feet per minute, which is extremely fast for single-motor-driven paper machines. A 200-hp helper drive is used on the couch section.



Personality Profiles

G. E. Mathias comes by his writing talent naturally—his mother is a parttime professional writer. Otherwise, however, it's a case of "like mother, *unlike* son." Mathias does not particularly enjoy writing. And his approach to and choice of a career differs from his father's. His father left a promising career in mechanical engineering to farm in Colorado. Jerry, on the other hand, left the farm to become an electrical engineer.

Mathias stayed at Colorado A & M only until his junior year. He joined the Navy then and was assigned to V12 training at Colorado University. Next he studied radar at Princeton and MIT, before serving aboard a destroyer doing radar picket duty in the Pacific.

Mathias came to Westinghouse in 1946. He was just getting used to the Control Engineering Department at East Pittsburgh when it was moving time again. Motor Control Engineering was one of the groups that moved to Buffalo in 1949. Since then he has been designing controls for d-c hoisting equipment. Worked on the development of the d-c adjustable-varying-voltage crane-hoist control and the redesign of the d-c constant-potential controller system.

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For 25 years *W. C. Carl* has wrestled with the electrical problems presented by lifting and materials-handling equipment.

Carl obtained his engineering training at the University of Pittsburgh. He came to Westinghouse in 1924 with a backlog of varied experience gained with the Bell Telephone, Koppers, and Duquesne Light companies. Shortly after arriving at Westinghouse he was assigned to the materials-handling section, then being set up. Since then, his engineering talents have been devoted largely to materials handling equipment—including everything from electric shovels to movable traffic bridges and ore unloaders.

In the early thirties he correlated the Westinghouse engineering activities on electrical equipment for coal- and ore-unloading docks at Toledo, Ohio. That installation marked the initial use of a-c power to drive Hulett ore unloaders.

Carl's introduction to lock and dam applications came in 1940 when he went to Panama to coordinate the Westinghouse activities there in connection with the widening of locks in the Canal. During his year in the Canal Zone, Carl gained a new appreciation of the need for better methods of protecting electrical equipment from moisture. His urging contributed to the subsequent improvement in moistureproof designs and materials for Westinghouse electrical apparatus. His experience in the damp atmosphere of the Canal Zone later proved to be of further value in his work on flood-control and reclamation projects. In this he has worked closely with the Corps of Engineers, the Bureau of Reclamation, TVA, and similar groups since 1942.

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W. R. Wickerham has, in some respects, been "up in the air" most of his adult life. His work: designing controls for a-c powered hoists and lifts. His hobbies: flying and astronomy.

Although Wickerham's principal engineering activity has been designing electrical controls for hoist equipment, his engineering accomplishments during the past 35 years cover the whole field of a-c motor control. Since starting with Westinghouse in 1917, he has received 20 patents for various a-c control devices. The most recent of these cover the reactor and the new Load-O-Matic a-c crane hoist controllers.

Like all pilots, Wickerham has a favorite story—about the time he got lost following the Ohio River. On a cloudy day several years ago, Wickerham learned that near Portsmouth, Ohio the Ohio River and a sine wave have much in common. Visibility was poor and our pilot-without-instruments wanted to find the Ohio River and then to follow it downstream—going south.

He found the river all right, but after proceeding south for some time, made a startling discovery: the river was flowing upstream! This conception eventually had to be abandoned in favor of the correct one: he was on the wrong leg of a bend—downstream was north! However, he arrived at his destination safely, but later than he had planned.

Wick has religiously avoided rivers with unusual bends ever since.

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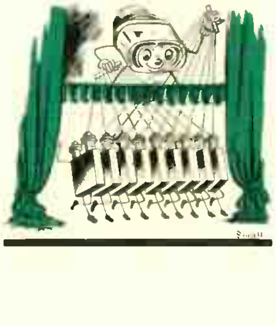
R. L. Tremaine and *W. H. Cuttino* present a combination of talents and experience that makes an article on the control of switched capacitors a natural for them to coauthor.

Tremaine, who was profiled on this page last September, is a Central Station Engineer in the Industry Engineering Department. Like other Central Station Engineers, he is basically a consulting engineer, assisting utilities in planning expansions and solving application problems. With his broad acquaintance with distribution problems, he can approach "Control of Switched Capacitors" from the point of view of the engineering of the entire distribution system.



Complementing Tremaine's general background are Cuttino's 20 years of specialized experience with the design of capacitors and capacitor controls, the last 15 devoted almost exclusively to switched-capacitor applications.

Cuttino came north from Clemson College in 1929. A strong inclination for construction work took him to Jones and Laughlin Steel Corporation, which was then building a new tube mill at Aliquippa, Pa. A year in construction proved to be all Bill cared for and at the urging of several of his former classmates who were then at the East Pittsburgh Works, he decided to come with Westinghouse.

During his first few years with Westinghouse, Cuttino worked on all phases of capacitor design, including capacitors, protective devices, and control. As capacitor applications were extended, he began to specialize in control devices and circuits. Since the late 30's Cuttino has been designing controls for switched capacitors. This remains his principal interest.

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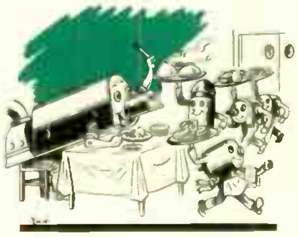
R. W. Ferguson is part of the Central Station Section of Industry Engineering. He works with utility engineers, helping them solve problems that require industry-wide experience.

Since last May, when he first appeared in the Westinghouse **Engineer**, Ferguson has been busy with several activities that indicate the variety of problems a Central Station Engineer is likely to meet. He has completed the final "clean-up" work involved in revising the "Electrical Transmission and Distribution Reference Book," a task which itself required extensive knowledge of many phases of power-system work. Just last fall he completed a year-long survey of powerhouse auxiliary practice in the United States. In the past year he also coauthored a paper on relaying of series capacitors.



The S. S. *United States* is big and fast. Over 51 000 gross tons, 990 feet long, it will be driven by four Westinghouse propulsion turbines at speeds in excess of 30 knots. Passenger capacity is 2000, plus a crew of 1000. If the need arises, she can be converted into a troop ship capable of transporting 14 000 men 10 000 miles without stopping for supplies. Her maiden voyage is scheduled for early July.