centrifugal force these rings enlarge. They always stretch within their elastic limit, thus permitting the commutator to remain smooth as it increases uniformly in diameter.

Brush Holders Simplified. For about 15 years, medium- and larger-sized dc machines have used double brush holders for two reasons.

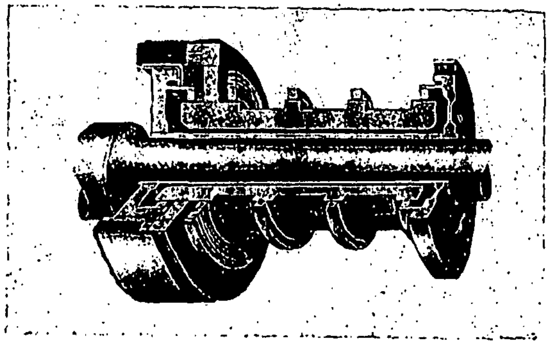
1. Two brushes, separated by a thin partition with individual-pressure fingers on each brush, reduce circulating current. This current, instead of simply flowing from one commutator bar across the face of the brush into the next bar, is forced to travel the full length of one brush through the shunt and back the length of the next brush.

2. Double brushes give better contact between brush and commutator surface. This is because inertia of brush is less and irregularities of the commutator surface do not necessarily lift both brushes. Individual fingers and springs permit separate brush wear.

Pilot Exciters. For many years, standard practice has used pilot exciters mounted on the shaft extension of the main exciter, photo on p 70, to furnish excitation for the main exciter. This eliminates the main-generator field rheostat with its losses and space requirements, and provides absolute stability of the main exciter when operated at any voltage the ac generator requires. Various methods of eliminating the pilot exciter have been tried, such as notching the poles of the main exciter. The weakness of these schemes is the possibility of instability when main exciter operates self-excited at low voltage.

The current per brush on pilot exciter is low—about 2½ amperes. It can be carried directly into the brush from the tip of the brush finger without difficulty. Brushes for the pilot exciter are standard but the shunts are cut off to within one inch of the brush as a means of removing a worn brush. Flexible shunts are used on the fingers, so spring and finger bearings do not carry current.

Separate Exciters. In the past, when motor generators or separate steam turbine-driven dc generators were used as exciters, they were open-type conventional machines. Recent improvements on motor-generator exciters consist of an oversized induction motor and a direct-coupled fly-wheel. This allows the exciter to ride through system disturbances where the motor receives its power from the main generator being served. The ac voltage can drop to 70% of normal value for a relatively long period, or to zero for 0.3 second without loss of stability. This provision



NEW-TYPE SHRINK RINGS are made so they expand as commutator increases in size because of temperature and centrifugal force; thus bars remain smooth

is ample for normal fault contingencies.

Electronic Exciters. Ignitron-type exciters have been supplied as a means of excitation for large-sized turbine-generators. When the ignitron receives its power from the generator it excites, special precautions are used against line disturbances. This is necessary because the dc-voltage output of the exciter bears a definite relation to the ac voltage. With some electronic exciters, a small separate ac generator coupled to the shaft of the turbine-generator supplies an independent source of exciter power.

Both of these types of excitation systems are more costly and take up considerably more space than the direct-connected exciter. The rectifier itself, however, can be anywhere in the station. Electronic units are subject to normal hazards of rectifier operation and are oversized so they can operate with part of the unit not normally functioning.

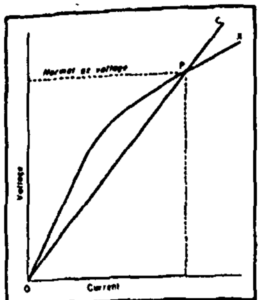
Rototrol Excitation. Rotating regulators, usually built to replace the conventional pilot exciter, constitute a recent improvement applicable to rotating exciters. Several schemes involving rototrols have been applied. In one type, the main exciter is a conventional unit and receives its full excitation from a rototrol pilot exciter. In a modified scheme the main exciter is conventional but has three shunt-field windings, diagram on facing page.

In this system, exciter shunt-field winding number 1 provides most of the main exciter-field excitation and receives its energy from the main exciter armature circuit in the usual manner. Field 3 is a small, separately excited shunt field, fed from the station battery or any other source of approximately constant dc voltage. This provides stability at low voltages during starting or any other time that the unit is under hand control.

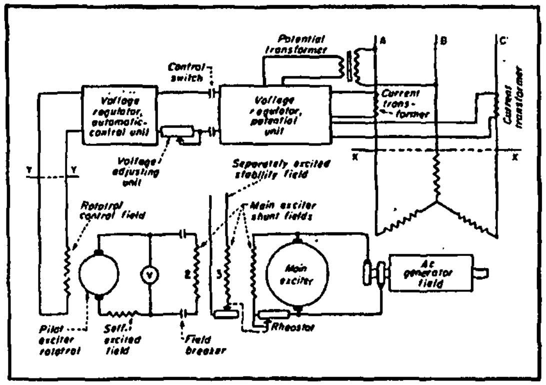
Rheostat arms in fields 1 and 3 are mechanically connected for motor or hand operation, as desired. As the arms turn, resistance is cut into one field circuit and out of the other. Also, the rheostat for the separately excited field 3 is built so at some point, about half voltage on the main exciter, the rheostat is open circuited and remains so as it is turned further in a direction to increase the voltage. This is done because field 3, the stability field, is not needed at higher exciting voltages. This reduces drain on the station battery. Shunt field 2 is excited from the rototrol pilot exciter. This scheme uses a "buck-boost" rototrol pilot exciter.

In diagram, facing page, rheostat on the main exciter is adjusted to provide a base value of excitation for the ac generator. This can be set to maintain steady-state stability at any load desired on the ac generator. The pilot exciter operates so field 2 of the main exciter either adds to or subtracts from the excitation of field 1. This requires the pilot exciter to operate at positive or negative polarity and of a magnitude to produce the necessary excitation. A generator static voltage regulator and the "buck-boost" rototrol pilot exciter produce excitation of the correct polarity and magnitude to maintain the ac voltage in spite of changing loads.

This is better than using excitation for the main exciter from the rototrol



CURVE above, shows typical capacitor-reactance impedance that is used with a static voltage regulator



EXCITATION by buck-boost rototrol is shown in schematic diagram, right

pilot exciter because if anything happens to the pilot or any part of the voltage regulator, complete excitation is not lost, nor would continuity of load be disturbed. In this case, the main exciter, operating as a self-excited generator, provides excitation for the ac generator at some predetermined voltage, say, 75%. If such a failure occurs and the load is other than 75%, the generator continues to carry whatever load is placed on it within its capacity. But the power factor changes, since the ac generator is under- or over-excited depending on whether the load is more or less than the original setting. The equipment continues to function in this manner, even though a short circuit or open circuit develops in the pilot exciter output. This would not be true if fields 1 and 2 of the main exciter were combined, nor if the "buck-boost" rototrol pilot were connected in series with the circuit of self-excited field 1. If a failure does occur, the excitation system can be operated manually.

In the diagram above, only two fields are used on the rototrol pilot exciter; a self-energizing series field, and a control field that combines a differential shunt field and a pattern field. Its excitation is secured from the turbine-generator through a voltage-regulating potential unit and a voltage-regulating automatic-control unit. These two devices are adjustable, but have no moving parts in the sense of an ordinary voltage regulator of the contact-making or rheostatic type.

Voltage Regulation. The various component parts of the voltage-regulating potential unit and voltage-regulating automatic-control unit function as follows:

Current transformers are located on conductors *A* and *C* while a potential transformer is connected to conductors *A* and *B*. Current-transformer *A* supplies a filter reactor, whereas *C* is connected through a resistor to half of the same primary winding of the filter reactor. Output voltage of the two current transformers produced in the secondary winding of the filter reactor is combined with the voltage output of the secondary of the potential transformer to make the voltage regulator responsive to three phase-voltage conditions. Final ac output voltage is a measure of the voltage delivered by the ac turbine-generator, compensated for the load current being carried. This output voltage is fed through the two control switches and a voltage-adjusting resistor into two impedance circuits, one capacitive and the other reactive, each terminating in a rectifier.

The curve shows capacitor and reactor impedances for a static voltage regulator. The relation between the applied ac voltage and the current through a capacitor is a straight line *OPC*. Curve *OPX*, is nonlinear and shows relation of the ac applied voltage and the current in a saturated reactor. With the proper capacitance and reactance, these two curves intersect at *P*, as indicated. This point is chosen to correspond approximately to normal ac voltage on the turbine-generator. The voltage-adjusting resistance unit permits reasonable variations in this voltage, as desired by station operation.

The two rectifier units are connected in series through a mid-tapped resistor. The equipment is adjusted so these two dc output voltages are equal when the ac generator output is at normal voltage. Under this condition there is no voltage output at *YY*, in diagram above.

If ac-generator voltage drops, voltage applied to the capacitor and reactor is reduced so their delivered voltage changes in accordance with the curves above. This produces a different dc output voltage from each of the two rectifier units. When this occurs, the difference is the voltage that appears across points *YY* and is fed into the rototrol control field.

The polarity is such as to cause the "buck-boost" rototrol to increase its voltage, for a drop in the ac voltage. The pilot exciter thereupon increases its voltage and adds excitation into field 2 of the main exciter. This increases the excitation on the main exciter and, in turn, excitation of the ac machine, until its voltage is again brought back to normal. There is then no difference in the output from the two rectifiers and thus no voltage is produced at *YY* and the rototrol control field operates at zero excitation.

If the voltage of the ac generator increases, say, from a drop in load, the same action takes place, but of opposite polarity. Here, the polarity of the voltage from *YY* is reversed and, when delivered to the pilot rototrol control field, puts a voltage of opposite polarity on field 2 of the main exciter. This bucks its voltage downward and decreases the excitation on the main exciter and on the field of the ac machine, bringing ac

(Continued on page 134)