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AN ACCURATE, HIGH-SPEED, AUTOMATIC LINE-VOLTAGE REGULATOR

● **STABILITY OF A-C LINE VOLTAGE** is a primary requirement both in the laboratory concerned with precise measurement and in the industrial plant where processes must be precisely controlled. While manual control with a Variac[®] Autotransformer is adequate for many purposes, a completely automatic control system, which eliminates the need for an operator, is more satisfactory.

Most automatic regulators use vacuum tubes, saturating core devices, or mechanical systems as the regulating elements. For industrial and general laboratory use, the relatively high power rating required precludes the use of vacuum tubes. The magnetic type, using a saturable-core reactor as a series impedance, although fast-acting and eco-

nomical in small sizes, requires a restriction on load power factor and distorts the output waveform.

For many applications, the mechanical regulating system is, therefore, the most suitable. A Variac[®] adjustable autotransformer and an automatically controlled motor drive make an excellent regulator of this type. Although this regulator is inherently somewhat slower in response than the magnetic type, its speed is still adequate, it has high efficiency, it has no power-factor restrictions, and it adds no harmonic distortion to the input voltage.

The TYPE 1570-A Automatic Voltage Regulator is a high-speed mechanical regulator with $\pm 0.25\%$ accuracy and excellent transient response, combined

Figure 1. Panel view of the Type 1570-A Automatic Voltage Regulator.



<i>Also</i>	
I N T H I S I S S U E	
	<i>Page</i>
NEW VARIAC® AUTOTRANSFORMERS FOR 350- TO 1200-CYCLE SERVICE	6
SUMMER CLOSING.....	8

with 6KVA capacity, 98% efficiency, and no distortion or power-factor restrictions. Basically, this new regulator consists of a Variac autotransformer that adjusts the output voltage, a “buck-or-boost,” step-down transformer that effectively multiplies the power rating of the Variac, and a servomechanism that positions the Variac.

VOLTAGE ADJUSTING SYSTEM

The “buck-or-boost” circuit used as the means of control is shown at the left in the functional diagram of Figure 2. This circuit, which we have previously¹ recommended for manual line-voltage compensation, permits the control of high-power circuits with a low-power Variac, thus effectively multiplying the Variac rating.

The auxiliary transformer uses multiple windings to provide either a $\pm 10\%$ or $\pm 20\%$ correction range at 115 or 230 volts. The Variac autotransformer is a special ball-bearing model. Its Dura-

¹See operating instructions for Variac® Autotransformers.

trak contact surface provides a stable brush track capable of withstanding severe overloads, while the ball bearings minimize friction and give long life in a service demanding continual motion of the brush.

SERVOMECHANISM

A two-phase servo-motor operated by a control circuit positions the Variac so that the output voltage is held constant. The superior performance of this regulator is due in large part to the excellent design of the control circuit:

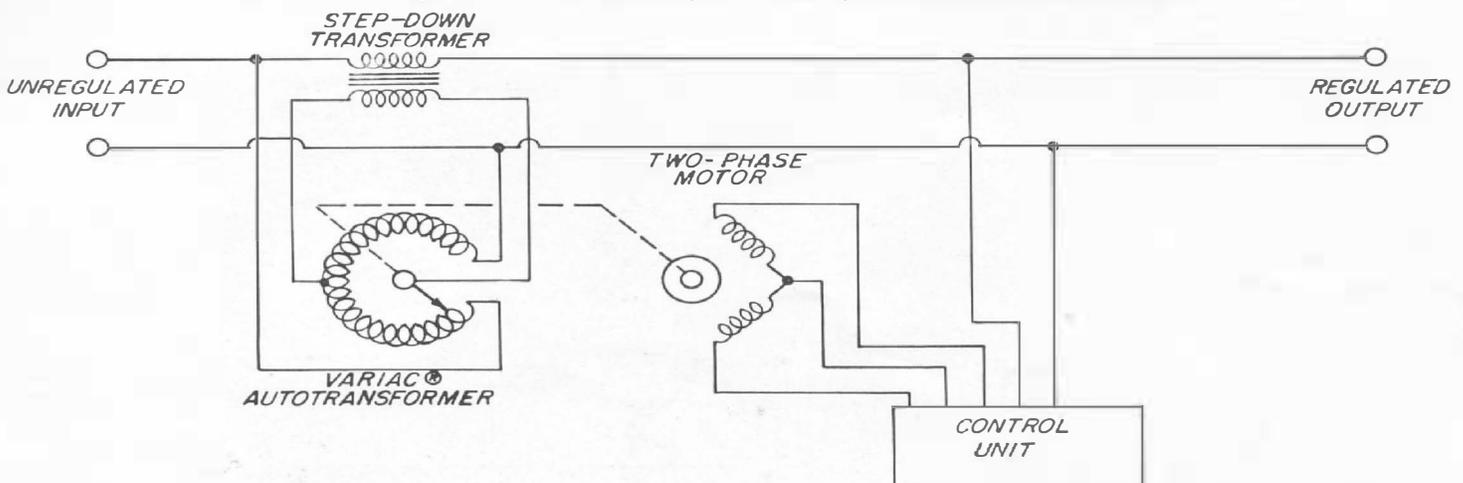
(1) The system utilizes a proportional-control servomechanism rather than the on-off type of control often used in this type of equipment. This yields better accuracy than would be obtained with relays.

(2) A low-inertia servo motor with dynamic braking gives good band width and resultant excellent transient response.

(3) No power amplifiers to supply the motor control windings are used. Motor power is obtained directly from the a-c line. The control unit controls the phase angle between the voltages applied to the two-phase armature and, thus, the rotation of the motor.

(4) Optimum design of the control unit utilizing appropriate lead and lag networks results in high response speed,

Figure 2. Functional diagram showing the buck-or-boost circuit.



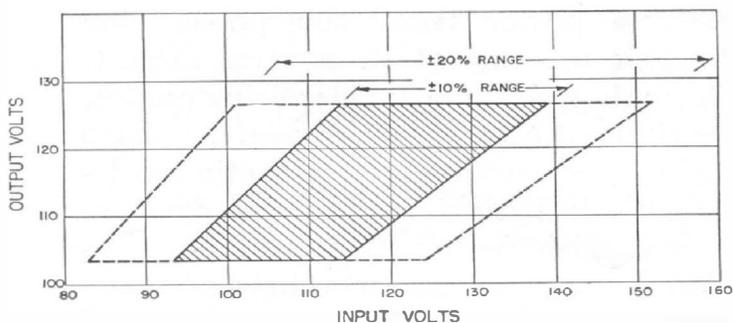


Figure 4. Range of operation for 115-volt models; for 230-volt models, multiply voltage scales by 2.

OPERATING CHARACTERISTICS

The excellent performance characteristics of the TYPE 1570-A Automatic Voltage Regulator — speed, accuracy, range, etc. — were mentioned briefly at the beginning of this article and are given in detail in the specifications at the end.

The range of operation is shown graphically in Figure 4 for 115-volt models. Multiplying both voltage scales by 2 gives the range for 230-volt models. It should be noted that when the range of control is doubled (from $\pm 10\%$ to $\pm 20\%$), the KVA rating is halved. A change of internal connections is necessary to change from one range to the other.

Response time, accuracy, and transient response are all interrelated. The response time for the $\pm 10\%$ range on the 115-volt model is 0.1 second per volt; for the $\pm 20\%$ range on the 230-volt model, it is 0.025 second per volt. Regardless of voltage rating or range connection, the time required for correction over any given fraction of the available range is constant. For the complete range, i.e., maximum positive correction

to maximum negative, the time is 2 seconds or less.

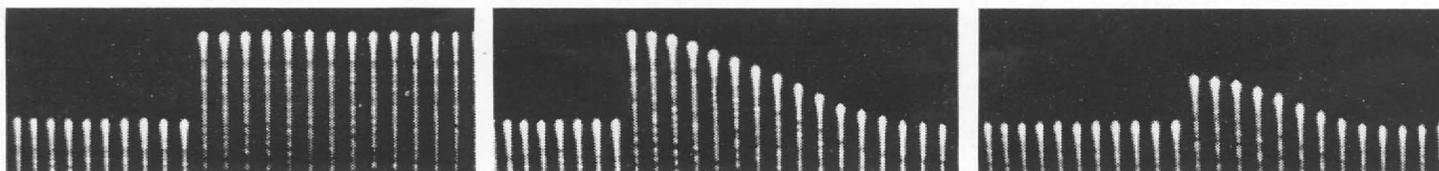
Accuracy is better by a factor of 2 on the narrower range. For either connection, accuracy can be increased slightly by adjustment of the gain control, if greater-than-normal overshoot can be tolerated. Normal adjustment is for negligible overshoot. When the degree of overshoot is thus increased, the total time required for the correction is unchanged.

As shown in Figure 1, there are but two panel controls — a switch to cut out the control unit and an output voltage adjustment accessible with a screwdriver. The gain control referred to above is behind the panel. The dial shown at the right of the panel is on the Variac shaft. Calibrated from -10 to $+10$, it indicates continuously the angular setting of the Variac and hence acts as a visual monitor to show how much of the range of control is being used at any instant. The calibration corresponds approximately to per cent of nominal line voltage for the $\pm 10\%$ range.

APPLICATIONS

The outstanding performance and large capacity of the TYPE 1570-A Automatic Voltage Regulator make it useful for a large number of applications. Models are available for both 115 and 230 volts, in three types of mounting: (1) metal cabinet with end frames for laboratory bench use; (2) metal cabinet with fittings for relay-rack mounting; and (3) metal box for mounting on wall or switchboard. The laboratory bench

Figure 5. The oscillograms below show traces of 60-cycle voltage sine-wave peaks illustrating the response speed of the Type 1570 Line Voltage Regulator. (a) Left, 2% change (step function) in voltage input to regulator; (b) center, voltage output of regulator as a result of 2% input voltage change shown in (a); (c) right, voltage output of regulator as the input voltage is changed 1%.





models, TYPES 1570-ALM,—AHM, are provided with standard 15-ampere line cords, so that the regulator plugs directly between line and load where the load current is small. In addition, for higher current applications, 50-ampere terminals are provided. The TYPES 1570-ALR, -AHR can be relay-rack mounted to regulate the supply to an entire rack or group of racks.

In our own plant we use the 115-volt wall-mounting model, TYPE 1570-ALW, with a fuse box and disconnect switch, to regulate one side of the balanced 230-volt line in the engineering laboratories. Thus each room is provided with half its 115-volt Pierceway outlets regulated and the other half unregulated. This installation is shown in Figure 6.

For the laboratory engaged in electrical and electronic measurements, regulated line voltage is an essential. In a measurement setup using a number of indicating instruments — meters and oscilloscopes — for measuring gain, power, waveform, etc., regulated a-c supply assures stable, repeatable indications. In the adjustment and calibration of bolometer bridges; in performance tests on rectifiers; in sensitive electro-medical instruments such as electrocardiographs and electroencephalographs, regulated line voltage facilitates accurate measurements. Light measurements with a-c lamps are particularly affected by supply-voltage variations; in photometry as well as in photographic work where color temperature is important, a line-voltage regulator finds many uses.

The TYPE 1570-A Automatic Voltage Regulator, owing to its high accuracy and speed of response, is particularly well suited to these applications in the field of precise measurement.

— M. C. HOLTJE

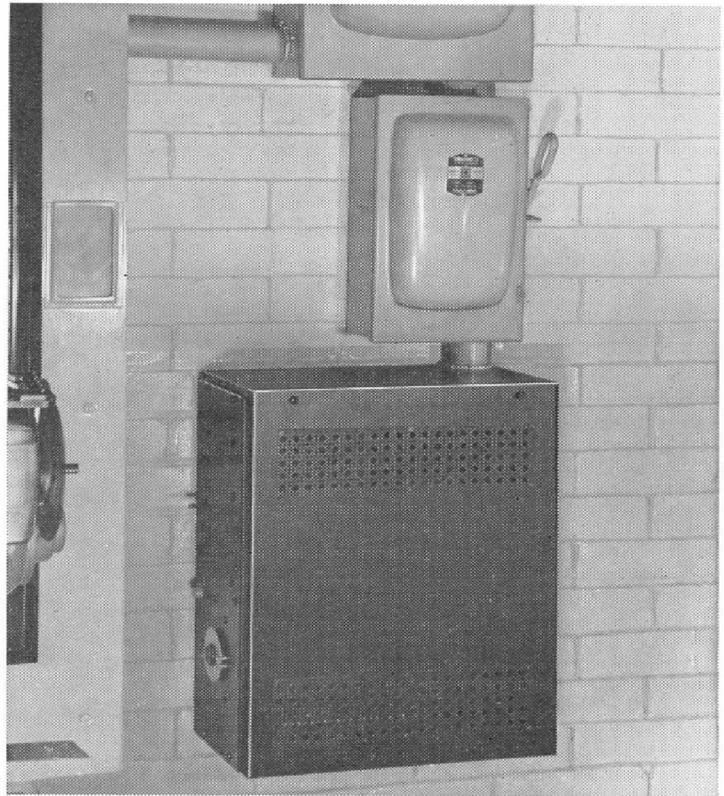


Figure 6. Wall-mounting model, Type 1570-ALW, as installed in the General Radio engineering laboratories.

SPECIFICATIONS

Output Voltage: Adjustable over a range of $\pm 10\%$ from a base value of 115 volts (for TYPE 1570-AL) or 230 volts (for TYPE 1570-AH) by means of a screw-driver adjustment on panel.

Input Voltage Range: The desired output voltage will be maintained if the input voltage does not vary by more than $\pm 10\%$ from this value of output voltage. A $\pm 20\%$ range connection is also available (see footnote below).

Output Voltage	115 Nominal Adjustable $\pm 10\%$		230 Nominal Adjustable $\pm 10\%$	
	90% to 110%	80% to 120%	90% to 110%	80% to 120%
Input voltage as a percentage of output voltage*				
Output current amperes	50	25	20	10
KVA	6	3	5	2.5
Accuracy in % of output voltage	0.25%	0.5%	0.25%	0.5%
Speed of Response volts per second†	10	20	20	40

*TYPES 1570-AL and 1570-AH can be connected for either $\pm 10\%$ or $\pm 20\%$ input voltage range. Instruments are shipped connected for $\pm 10\%$ range unless 20% range is specified on order.

†Slightly less for very small voltage corrections.



Waveform Distortion: No distortion. Output waveform same as input.

Waveform Error: The voltage sensing device responds to the average value of the rectified output voltage. Therefore, the average value of the output voltage is held constant, and a loaded d-c power supply operated from the output of the regulator will give constant output voltage regardless of the harmonic distortion present in the power line. The rms output voltage will also remain constant, regardless of the harmonic distortion present, as long as the phase and amplitude of these harmonics are constant. If the harmonic content changes, the rms value will change by an amount less than $\Delta R/n$, where ΔR is the change in the harmonic amplitude and n is the harmonic number.

Efficiency: 98%

Ambient Temperature: Full ratings apply up to 40°C.

Frequency: Standard models, 60 cycles. The instrument can be modified at the factory for operation at 50 cycles. There is a nominal charge for this modification, which must be made before shipment.

Power Consumption: No Load 35 watts
Full Load 100 watts

Mounting: Relay rack (-R model), table top (-M model), or wall (-W model).

Dimensions: (Width) 19 x (height) 7 x (depth) 12 $\frac{7}{8}$ inches, over-all; depth behind panel 11 $\frac{3}{4}$ inches, for -R and -M models; -W models, (width) 13 $\frac{1}{2}$ x (height) 19 $\frac{1}{2}$ x (depth) 8 $\frac{1}{4}$ inches, over-all, in position shown in Figure 6.

Net Weight: Relay-rack and table models, 56 $\frac{1}{2}$ pounds; wall model, 63 $\frac{1}{2}$ pounds.

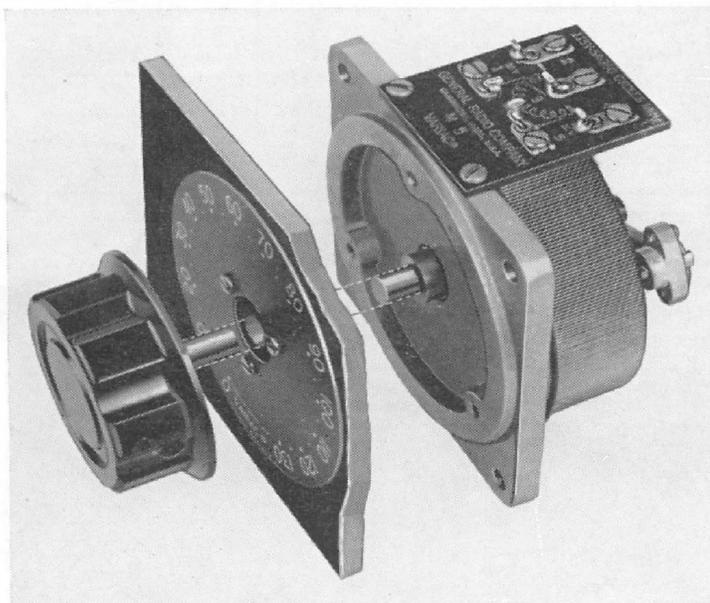
Type		Code Word	Price
1570-ALM	Line Voltage Regulator, 115 volts, table top model	CEDAR	\$470.00
1570-ALR	Line Voltage Regulator, 115 volts, relay rack model	CHARY	465.00
1570-ALW	Line Voltage Regulator, 115 volts, wall model . . .	CLOWN	465.00
1570-AHM	Line Voltage Regulator, 230 volts, table top model	CHALK	470.00
1570-AHR	Line Voltage Regulator, 230 volts, relay rack model	CURLY	465.00
1570-AHW	Line Voltage Regulator, 230 volts, wall model	CLOSE	465.00

Patent Applied For.
Delivery from stock as with most General Radio instruments.

NEW VARIAC® AUTOTRANSFORMERS FOR 350- TO 1200-CYCLE SERVICE

Increasing use of higher-frequency power in aeronautical and marine designs, with its consequent saving in bulk and weight of iron-cored electrical devices, calls for voltage-control apparatus designed with the particular requirements of these services in mind. Two new Variac® autotransformers, the

TYPE M-2, rated at 2 amperes, and the TYPE M-5, rated at 5 amperes, are designed specifically to meet these requirements. The M-5 Variac supplants the older TYPE 60-A. Smaller and lighter than their sixty-cycle counterparts, they have been "beefed-up" to withstand shock, vibration, and environmental tests under MIL-T-945A specifications. This "ruggedizing," while not of primary concern to the civilian user, does assure exceptional reliability under both ordinary and extraordinary service conditions. The use of a Duratrak² contact surface on all units is a still further guarantee of trouble-free operation.



²A New Standard of Reliability in Variable Autotransformers, Variac® with Duratrak — General Radio Experimenter, April, 1953.

Figure 1. View of the Type M-2 Variac® Autotransformer.



FEATURES

The TYPE M-2 and TYPE M-5 Variacs incorporate several new features that, we feel, constitute distinct improvements over previous designs.

The rectangular base, with its four corner holes, permits attachment of the Variac to walls and bulkheads without rear access, although the three tapped holes used in TYPES V-2 and V-5 Variacs are also provided. The base is also in better thermal contact with the coil, and with the panel, for improved conduction of heat from the unit to its environment. An additional design feature permits back-to-back mounting of two coils on a single base for further weight and space economy in ganged assemblies.

The radiators are counterbalanced to hold their setting under shock and vibration. This has formerly been a feature of larger Variacs only.

Winding taps are concealed to preclude the possibility of damage to taps, leads, and winding during handling and installation. End-taps are not self-leads, but are deliberately brought in a few turns from the end of the winding. This permits the brush to reach zero or maximum voltage without traversing the end turn, which, owing to its position, is usually somewhat less secure and mechanically stable than the other turns. It also avoids the possibility of the brush leaving the end of the winding at limit travel.

"Angel-cake pan" coil cups are an-

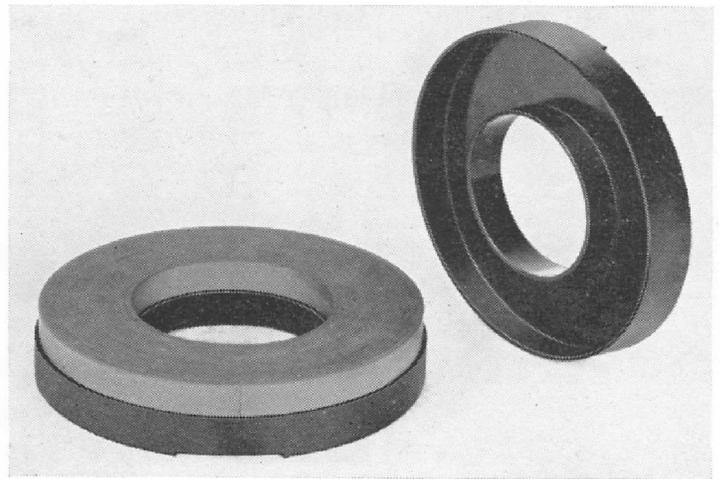


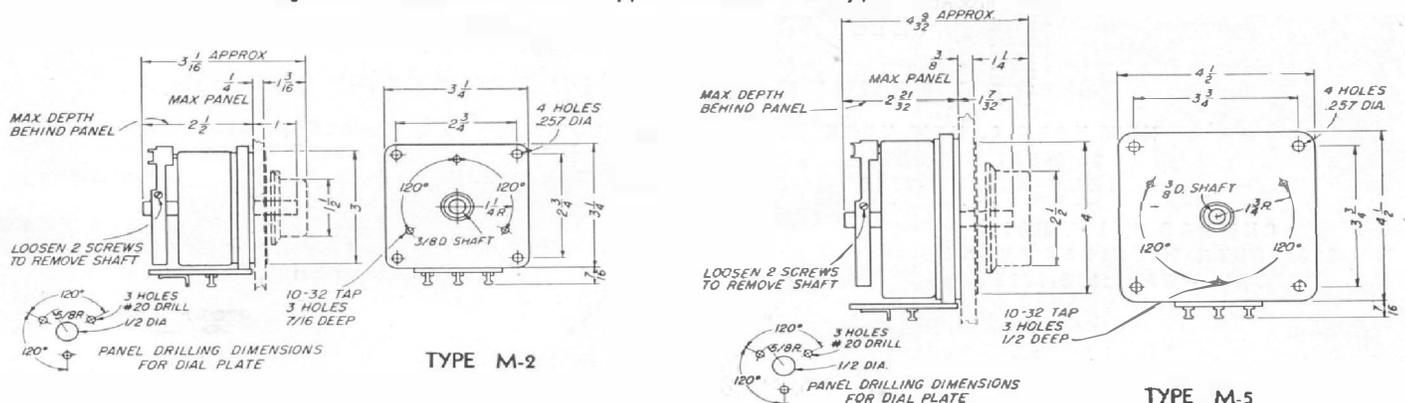
Figure 2. View of the coil cups which enclose the core and constitute the winding form.

other feature. These molded cups, shown in Figure 2, fit tightly over the core to form a rigid, firm support for the winding. First used in TYPES 200-B, V-2, and V-5 Variac autotransformers, these coil cups resist deformation of the brush track far more effectively than do flat end-plates, because of their channel section. Their use also eliminates the need for fiber or paper wrap-arounds on the cylindrical core surfaces, thus effectively up-grading insulation quality.

VOLTAGE RATINGS

The TYPES M-2 and M-5 Variacs are designed for 115-volt, 350- to 1200-cycle, input; 0-115 or 0-135 volt output, determined by connections. Two-gang assemblies (G2) may be used in 115 volt, 3-phase, open delta circuits, in two-phase circuits, or for the simultaneous control of two independent loads. Three-gang as-

Figure 3. Dimensions of the Type M-5 and the Type M-2 Variacs®.





semblies (G3) are particularly adapted for wye connection in 208-230 volt, three-phase service. This use of the wye connection is possible since the wye voltage of a 230-volt circuit is 133 volts, and M-2 and M-5 coils are wound for 135 volts.

LOW-VOLTAGE USE AT 60 CYCLES

The TYPE M-2 and M-5 Variacs are also applicable to low-voltage 50-60

cycle service. They have 37.5% of the core stack of comparable V-line Variacs and can thus be operated to 3/8 of V-line maximum voltage, 50 volts at 50 cycles. This suggests their use for the single-phase or polyphase control of intermediate-voltage rectifiers, etc., particularly where space and weight may be at a premium.

— GILBERT SMILEY

SPECIFICATIONS

Table with 6 columns: Specification, Type M-2, Type M-5, Specification, Type M-2, Type M-5. Rows include Line Frequency, Input Voltage, Output Voltage, Rated Output Current, Maximum Output Current, No-Load Loss, Number of Turns on Winding, D-C Resistance of Winding, Driving Torque, Net Weight, and Dimensions.

Table with 4 columns: Type, Description, Code Word, Price. Lists models M-2, M-2G2, M-2G3, M-5, M-5G2, M-5G3 with their respective descriptions, code words, and prices.

Patent applied for.

SUMMER CLOSING

During the weeks of July 26 and August 2, our Manufacturing Departments will be closed for vacation.

Our Sales, Engineering and Commercial Departments will be operating normally. Shipments of material in stock can be made promptly. Inquiries, including requests for technical

and sales information, will receive immediate attention.

Our Service Department requests that, because of absences in the manufacturing and repair groups, shipments of material be scheduled to reach us either well before or delayed until after the vacation period.

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accuracy, and excellent overshoot characteristics.

Figure 3 is an elementary circuit diagram of the control unit. The regulated output voltage is measured with an average-response full-wave rectifier to obtain a d-c voltage proportional to the a-c output voltage. The d-c value of this rectified voltage is obtained by providing a resistive load for the rectifiers and filtering the ripple voltage. The use of a full-wave rectifier separates the undesired ripple frequency as far as possible from the pass band of the regulator; and the ripple filter provides an infinite rejection at the 120-cycle ripple frequency, with negligible phase shift below 5 cps. The rectifiers are germanium junction diodes, which provide a high rectifier efficiency and thus minimize any effect of changes in rectifier characteristics.

This filtered voltage is compared with a standard voltage from a 5651-type voltage reference tube. The difference between these voltages is the error voltage and is used ultimately to reposition the Variac.

The amplified error voltage is applied in push-pull to a thyatron motor control circuit. The thyratrons are provided with a 60-cycle bias voltage at a 90° phase angle with respect to the a-c plate voltage. The amplified d-c error voltage superimposed on this a-c bias voltage smoothly changes the thyatron firing angle from near 0° to 180° .

A two-phase motor is supplied with

60-cycle power from the power line through the thyatron control circuit. Through variations in their firing angles, the thyratrons control the relative phase angle between the motor-winding voltages. Their distorted output voltages are filtered with resonant circuits and applied to the motor windings. As the thyatron firing angle changes from 0° to 180° , the angle between the motor voltages changes continuously from approximately $+90^\circ$ to -90° . At balance, full voltage is applied to both motor windings at a zero-degree phase angle. The resultant dynamic braking improves the transient response.

ACCURACY

The motor torque is proportional to the error voltage and any error voltage greater than that required to overcome frictional forces results in acceleration of the motor until this error voltage is substantially eliminated. A limit on the ultimate accuracy of control is imposed by the fact that the motor cannot reposition the Variac until its torque is greater than the small friction losses in the system. These have been reduced to the point where other factors, such as limitations in the accuracy of the voltage reference tube, the magnitude of the voltage steps from the Variac, and initial-electron-velocity effects in the input amplifier, would combine to prevent any substantial increase in accuracy from a further decrease in friction.

Figure 3. Elementary schematic diagram of the control circuits.

