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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

VARIAC MOTOR SPEED CONTROLS

INTRODUCTION

The Variac would appear to be an ideal component of a motor speed control, and much consideration has been given to the problem of developing a system employing it which would be suitable for general application. A study of the characteristics of various types of a-c motors operating on adjustable voltage has shown that, although series motors and straight repulsion motors are satisfactory with fans or with relatively constant loads, large changes of speed take place under varying load. A summary of the work on arrangements of this kind appeared in the *Experimenter* for February, 1944.

The Variac can be used also with a rectifier to supply adjustable armature voltage to a d-c shunt or compound motor, the field remaining fully excited over the speed range. This system can give a range of

Figure 1. View of a Type 1700-A Variac Speed Control installed on a bench lathe.

control of 15 to 1 or more. Use of this arrangement, however, has been limited, because it is considerably more complicated than the simple Variac control and, as usually constructed, leaves much to be desired in the way of regulation.

Recent development work on the Variac-rectifier system, however, has overcome many of the earlier limitations. As a result, the TYPE 1700-AL and TYPE 1700-AH Variac Speed Controls are now offered as compact single-unit controls having a maximum rating of ⅓ h.p. and with regulation characteristics entirely adequate for a large variety of applications. These controls, however, are not intended to replace the more complicated electronic controls for uses where very close regulation of speed with load is required.

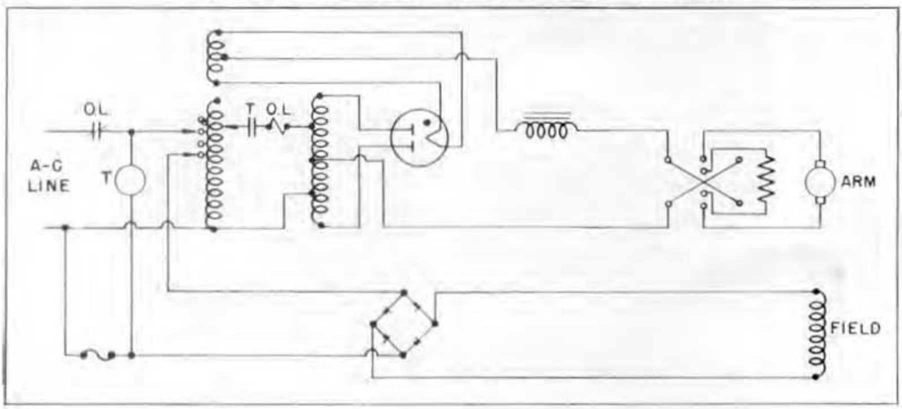
The external appearance of the new control is shown in Figure 1. Much of the design work was directed to achieving a compact construction which would permit the control to be placed beside a machine in the location of the usual push-button station. A manual start-stop-reverse switch is built into the control so that the need of a button station and separate box for the reversing contactors is eliminated. Only the control box and the motor are required for the complete system. This arrangement not only reduces the cost but also very much simplifies installation. Other important characteristics are the low ripple current in the armature circuit and the large overload capacity available for quick starting and reversing.

CIRCUIT DETAILS

The circuit is shown in Figure 2. The Variac supplies a full-wave xenon rectifier through a step-up autotransformer. A separate winding of a few turns on the Variac supplies filament power for the rectifier. The rectifier output goes through a choke and a three-position reversing switch to the motor armature. In the "off" position of the switch, a dynamic braking resistor is connected across the armature to stop the motor quickly. The coil of an overload breaker interrupting the input line is connected in the primary circuit of the autotransformer. The breaker serves also as the line switch.

A selenium rectifier bridge supplies the field current. Extra taps on the Variac permit boosting the input to the rectifier so that 230 volts dc can be obtained across the field from an a-c input voltage of the same value. Other taps can be used to reduce the field ex-

Figure 2. Circuit of the speed control unit. Industrial, rather than radio, symbols have been used for those elements that are peculiar to industrial equipment. Hence, the symbols T, T refer to the timing clock and its associated switch, and O.L. refers to the overload breaker.



citation and thus increase somewhat the maximum speed. To prevent damaging the rectifier tube, a timing clock delays application of plate voltage for 40 seconds after the filament is turned on. This delay unit recycles in less than a second and so protects the tube against interruptions of line voltage. It will not break the circuit on transient dips of voltage, however, and so prevents needless interruptions of service. The timing clock is connected beyond the field fuse so that armature power cannot be supplied unless this fuse is intact and in place.

CONSTRUCTIONAL FEATURES

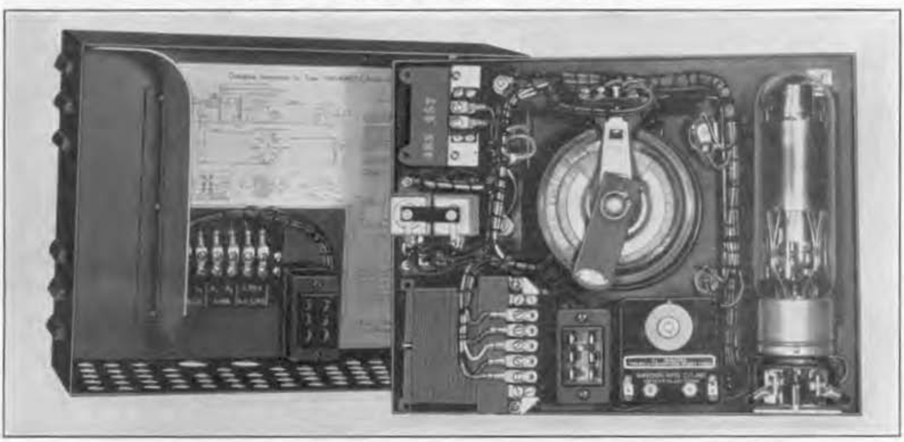
Several problems were encountered in making the entire control small enough to be placed beside a machine for direct control by the operator. An interior view of the control is shown in Figure 3. The box size is only 9 x 12 x 4½ inches so that little space is available between the components for assembly and wiring. This difficulty was overcome by mounting all components on the lid, permitting the wiring cable to be installed without interference from the sides of the box. This construction and the use of a plug and jack between the box and lid permits the box, also, to be permanently installed and the unit removed when desired for servicing without disturbing the installation wiring. Where several controls are in use, a spare can be kept and can be used to replace in a few seconds a unit needing attention.

Another design problem was to control the flow of heat from the rectifier tube, which is between 50 and 100 watts, so that overheating of the other components is prevented. To accomplish this, side louvers are provided and an aluminum baffle plate is placed between the tube and the remainder of the enclosure. The plate not only guides the heated air stream up to the louvers but also reflects back radiant heat from the tube. The Variac, transformer, and choke are mounted in close thermal contact with the lid, the outer surface of which provides considerable radiating area. The effectiveness of these measures is indicated by the fact that three hundred watts of armature power and forty watts of field power can be provided continuously by a unit of such small dimensions without overheating.

REGULATION CHARACTERISTICS

Probably the most important characteristic determining the field of application of an adjustable speed motor is

Figure 3. Interior view of the Variac Speed Control.



the speed regulation or change of speed which takes place when the load is varied. Close speed regulation in an adjustable speed motor is an expensive commodity, and it is wasteful to provide it for applications where it is not required. Information on the regulation of the TYPE 1700 Controls in comparison with that of a thyratron control and with the simpler controls should indicate the general fields of usefulness of each. Considerable saving in the cost of an installation can be made if the characteristics of the motor and control are properly matched to the regulation requirements of the load.

The TYPE 1700 Controls provide a quality of regulation which is very much better than that of the simple controls such as a Variac with an a-c commutator motor, although not so good as is obtainable with the fully compensated thyratron control. This is illustrated in Figure 4 which shows the speed as a function of load for different motor and control combinations, all adjusted to about one quarter of the maximum speed at full load.

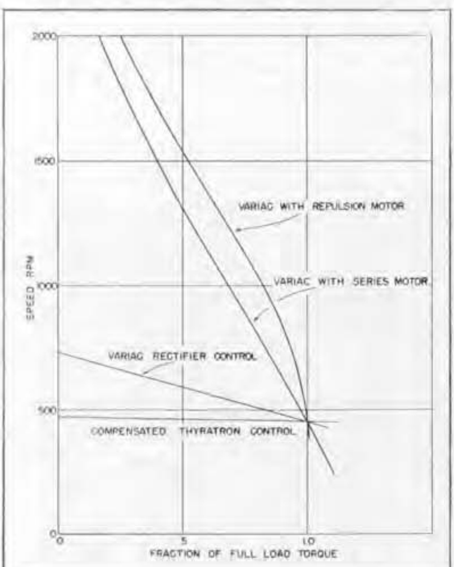


Figure 4. Comparison of the performance of various types of control systems adjusted for one-quarter maximum speed at full load.

The upper curve is for a repulsion motor with a Variac. The next curve is for a similar arrangement using an a-c series motor. The two are essentially similar except that the repulsion motor "breaks down" or suddenly loses speed like an induction motor, but at a much lower fraction of synchronous speed. The series motor loses speed more or less uniformly as the torque is increased in the neighborhood of full load. For both motors at this setting the speed at one-quarter load is about four times the full-load speed and even a slight change in load results in a considerable change in speed. The improvement with the TYPE 1700 Control is shown in the third curve. The rise in speed when the torque is reduced to one-quarter of its full-load value is only 210 rpm or 47 per cent instead of 300 per cent or more noted for other arrangements. A curve for 5 per cent regulation, readily achieved with the compensated thyratron control, is shown for comparison.

The rise in speed in rpm between full load and no load is the same at all speed settings for the new control. This performance is not necessarily obtained with a system of this kind, because on light loads the back emf of the motor, which is proportional to the speed, tends to rise to the peak value of the rectified wave. Use of a properly designed choke will prevent the rise of voltage above the average value and greatly improve the regulation. Figure 5 shows regulation curves at various speed settings for the TYPE 1700-AH Control and shows by dashed lines for comparison the performance of a similar system without a choke. The marked improvement is apparent. Since the rpm rise in speed between full load and no load is the same at all settings, the percentage regulation is inversely proportional to the speed setting. Thus at the rated speed of 1750 rpm the regulation is only 16 per cent instead of the larger value corresponding to the reduced speed setting used in Figure 4.

MOTOR LOSSES AND EFFICIENCY

In comparison with a speed control of the thyratron type, the new control gives considerably reduced motor losses, because the a-c ripple in the armature circuit is very much less. This characteristic is partly due to the fact that the firing point is not delayed by grid action and partly due to use of the choke. Use of the diode rectifier in the new control makes it possible to obtain good filtering using only a small choke, while it is not usually feasible to attempt to filter the sharply peaked waveform of the thyratron rectifier circuit.

The net result is that the form factor of the armature current of the thyratron control at full load is about 1.55 at all speed settings[1], and for the Variac Rectifier Control varies between 1.16 at full speed to 1.02 at one-tenth of maximum speed. Curves of form factor as functions of load at various speeds are given in Figure 6.

Since it is the low-speed losses that usually limit the rating of an adjustable-speed motor, the result in practice is that no derating of the motor due to ripple is required with the new control.

[1] Raymond W. Moore, "Performance of D–C Motors Running on Thyratron Rectifiers," ELECTRICAL MANUFACTURING, Vol. 37, pp. 124-127, 210, 212, 214, March, 1946.

With the thyratron control the motor must be derated about one-third. For many applications employing the Variac control, it is a convenience as well as an economy not to have to use an oversize motor to take care of the ripple current in the armature circuit.

STARTING CURRENT AND OVERLOAD CAPACITY

The full-wave xenon rectifier is more compact and less expensive than a pair of thyratrons of equal rating, so that it is economically feasible to provide tube capacity in the Type 1700-AH Control almost five times the full-load armature current rating of the motor. The rectifier tube, in addition, has a three-second overload rating 50 per cent greater than its continuous-duty rating. This permits about seven times the full-load motor current for three seconds on starting or reversing, and the momentary initial surge of current may be even greater. The circuit breaker is of the inverse-time-delay type and its delay characteristics are approximately

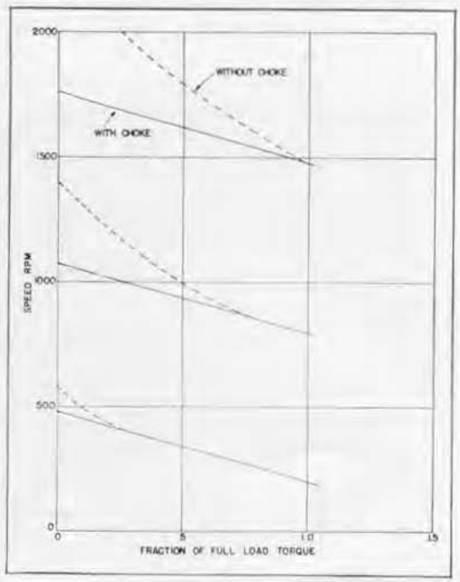


Figure 5. Regulation curves at various speeds for the Type 1700-AH Variac Speed Control. Dotted lines show performance of a similar system without choke.

matched to the overload rating of the rectifier tube, as shown in Figure 7. With this protection, advantage can be taken of the short-period overload capabilities of the tube without risking destruction in the event of a stall or the application of a load of excessive inertia. The Type 1700–AL Control for 115-volt operation, employing the same tube, has the same current rating at half the voltage so the overload and starting margin is reduced. Even in this case 350 per cent of full-load current, ample for ordinary work, is available for starting, and full protection is provided by the breaker.

The quick-starting feature of the control is frequently of great importance in production work. Many of the thyratron controls provide protection of the tubes by automatically limiting the starting current to 150 or 200 per cent of the full-load current. This is sometimes necessary in special cases for protection of the driven load, but for ordinary work the relatively slow start is a definite drawback. The Type 1700 Controls should prove their value in many applications where fast starting or reversing is desirable.

APPLICATIONS

Many fields of application of adjustable speed motors which have been assumed to require a control of close regulation can be served by the Type 1700 Controls. This is because the choice has hitherto been limited, essentially, to controls of either very good or very poor regulation. It has been found, with the new control, that even the speed rise of 100 per cent or more which takes place at the lower speed settings when the load is removed is not ordinarily objectionable. In work with small lathes or drill presses, for example, the operator merely turns up the control until the desired cutting speed is obtained under load. It is believed that work of this kind within the torque limits of a 1/3 h.p. motor will generally be found suitable for the Type 1700 Controls.

An application for which the new control seems ideally suited is to winding machines of various types. Here a wide range of operating speeds is desirable in addition to a gradual start under control of the operator. Considerable production time, also, can be saved if, after starting, the speed can be turned up to

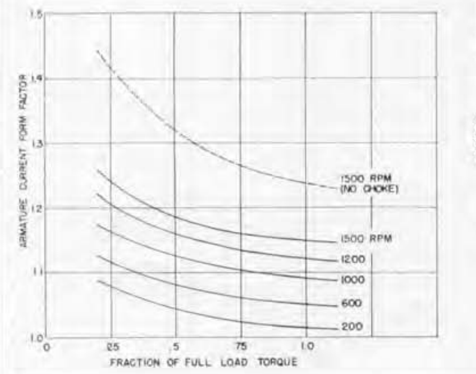


Figure 6. Form factor of armature current as a function of load at various speeds.

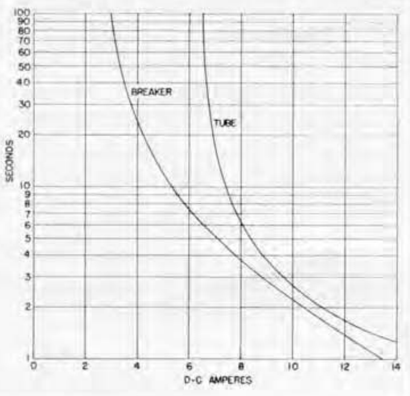


Figure 7. Overload characteristic of rectifier tube and delay characteristic of circuit breaker.

the maximum which is safe for a given set of winding conditions. Universal winding machines are generally supplied with adjustable speed motors of the brush-shifting type. These have characteristics similar to those of a repulsion motor operated with a Variac and, particularly at the lower-speed settings, are very sensitive to load, as shown in Figure 4. The speed tends to creep badly and even warm-up of the lubricating grease can cause the speed to double. In our own factory we have found that use of the TYPE 1700 Control gives a marked increase in the stability of operation of machines of this type with a corresponding increase in production efficiency.

Another application which should prove important is to processing of various kinds where the timing of an operation must be adjustable over a fairly wide range. Examples are blueprinting machines, photographic developing equipment, electroplating, etc. In work of this kind the load is nearly constant, and the motor will hold the set speed very closely. Slight changes of speed will occur with line voltage variations, but the speed changes less than in proportion to the voltage change. This is because in a shunt motor the change in field excitation partially compensates for the armature voltage variation.

The limitations of the control must be kept in mind in order to apply it successfully. The intermediate quality of the regulation characteristics has already been discussed. Much machine work, including precision grinding, requires that speed be very closely maintained under fairly wide variations of load. For such applications, the control is clearly not suitable. Another limitation common to many adjustable-speed motors is that torque rather than horsepower must be kept within a limiting value over the speed range. If an adjustable speed motor replaces a fixed speed motor using several pulley ratios, the available horsepower instead of being the same at the various fixed speeds will be proportional to the speed. This is not as serious as it might appear because many types of load have a constant torque characteristic or a torque that decreases as the speed is reduced. The point should be borne in mind, however, in estimating the size of motor required for a given application. Because of the torque limitation, it is important to choose the pulley or transmission ratio so that the working speed range is near the upper limit of the control.

Figure 8. Panel view of the Type 1700-AH Variac Speed Control.

If the characteristics of the control and motor are properly matched to the load requirements, it is believed that a wide field of application will be found for the TYPE 1700 controls, and that the advantages of adjustable speed operation can be extended to many fields where the cost of other suitable systems is prohibitive.

— W. N. TUTTLE

SPECIFICATIONS

Ratings	*Type 1700-AL*	*Type 1700-AH*
Supply Frequency	50–60 c	50–60 c
A-C Input Voltage	105–125	210–250
D-C Output Armature Voltage	0–115	0–230
D-C Output Armature Current		
Continuous	2.6 a	1.35 a
30 Seconds	9.6 a	9.6 a
D-C Output Field Voltage	115, 105, 95, 78	230, 210, 190, 156
D-C Output Field Current	0.4 a	0.2 a

Speed Range: Motor rated speed down to zero at constant torque. Usual operating range 10:1 or 15:1.

Motor: Any d-c shunt or compound motor within the above ratings may be used with the control. A motor with a commutating pole is preferable because improved commutation is obtained over the speed range. We can supply motors as listed below.

A motor of ¼ h.p. rating can be operated continuously at about 20% overload by the TYPE 1700-AL Control and at about 25% overload by the TYPE 1700-AH Control. A motor of ⅓ h.p. rating can be used with either control for intermittent duty or for continuous duty when the armature current is within the limits given in the ratings.

Overload Protection: A time-delay magnetic circuit breaker protects the rectifier tube against excessive starting current but does not protect the other components or the motor against sustained overloads. For applications requiring continuous duty near full load, the armature current requirements should be checked with a meter.

Reversal and Dynamic Braking: A manually operated start-stop-reverse switch and a dynamic braking resistor are included in the control. Strong braking action is obtained in the stop position.

Mounting and Wiring: Holes are provided in the back of the box for mounting on a wall or bracket. Mounting must be vertical and must permit free access of air through the bottom of the cabinet. Two holes for BX or conduit wiring are located in the center of the bottom of the box.

Dimensions: Box, 9$\frac{5}{16}$ x 12⅜ x 4⅝ inches; dimensions over knobs and louvers, 9$\frac{5}{16}$ x 12¾ x 6 inches.

Net Weight: 31¼ pounds; G. E. motor 30 pounds.

Tube: One TYPE EL-6C supplied with the control.

Type		*Code Word*	*Price*
1700-AL	**Variac† Speed Control,** 115-v., 50-60 c.	ABASE	**$175.00**
1700-AH	**Variac† Speed Control,** 230-v., 50-60 c.	ABOVE	**175.00**
BC46AB29	**G. E. ⅓ h.p. Semi-enclosed, sleeve-bearing, compound-wound motor,** 1750 rpm, 115 v. dc, for use with TYPE 1700-AL	MOTOR*	**45.79**
BC46AB30	**G. E. ⅓ h.p. Semi-enclosed, sleeve-bearing, compound-wound motor,** 1750 rpm, 230 v. dc, for use with TYPE 1700-AH	MOTOR*	**47.59**
EL-6C	**Full-wave xenon rectifier tube** (Spare)		**15.70**

*To order speed control with motor, use compound code word, ABASEMOTOR or ABOVEMOTOR.

†Trademark registered in U.S.A. U.S. Patent No. 2,009,013.

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